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Composting of food waste in passive aerated bioreactor with turning mode

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Abstract. Almost 45% of municipal solid waste in Malaysia consist of food waste. Composting is one of the sustainable ways to manage food waste compared to incineration and landfilling. This paper investigates the physicochemical and phytotoxicity characteristics during food waste composting in passive aerated bioreactor assisted with compost turning. The initial compost mixture consists of 124 kg of food waste mixed with 62 kg of dry leaves. The composting process was conducted for 40 days, and physicochemical characteristics i.e., temperature, moisture content, total organic carbon, pH and conductivity were monitored. Seed germination test was conducted with cabbage seeds (Brassica oleracea). The highest temperature and final moisture content obtained were 42 °C and 78%, respectively. The seed germination index value was 127%, indicating that the compost is suitable for plant growth.

1. Introduction

Food waste disposal worldwide, including in Malaysia is getting more challenging due to land shortage for landfilling. Malaysia generates about 38,000 tonnes of waste per day and around 17,000 tonnes is food waste [1]. Owing to the high moisture content of food waste, the incineration process is expensive [2]. In addition to that, dioxins and greenhouse gases may release during the process [3, 4]. Besides incineration, composting could be an alternative for food waste disposal. Composting is an aerobic microbiological process where organic waste is converted into compost, a humus-like structure. Various bulking agents have been used to enhance the degradation process with minimum odor generation, such as sawdust [5] and mushroom waste [6]. Nevertheless, the awareness among the community on sustainable food waste disposal is still lacking.

Higher learning institutions should play a vital role in their local community for sustainable food waste processing via composting. At Kean University, Mu *et al.* [7] composting food waste in an in-vessel composter. Their finding stated that the compost produced can be used to grow vegetables and able to generate profit from the activities. Recently, Saalah *et al.* [8] successfully produced compost from food waste collected at the Universiti Malaysia Sabah cafeteria. The initial compost mixture contains 1:1 (dry leaves:food waste) in a passive aerated bioreactor with turning mode. In this study, a similar process will be carried out with a different ratio of food waste-dry leaves i.e., 1:2 (dry leaves: food waste) to increase the final compost nutrients content.

The composting process can be conducted in passive (natural) or forced aeration mode. Bhave and Kulkarni [9] found that the quality of compost concerning Germination Index (GI), root length index and NPK value was better in an active aerated reactor compared to passive aerated reactor. Similarly, Sánchez *et al.* [10] also stated that composting process using forced aerated reduces methane and nitrous oxide emission. However, in another study, Varma *et al.* [11] found that passive aeration was better than force aeration in water hyacinth composting. Zahrim *et al.* [12] investigated composting of anaerobically treated palm oil mill effluent, leaves, and pre-digested papers using a passive aerated reactor. The authors found that the highest temperature achieved was 43 °C, 66% overall mass reduction, the organic degradation was 72% and the moisture content, total organic carbon and carbon to nitrogen (C/N) ratio decreased during the composting process. Karnchanawong and Nissaikla [13] have successfully carried out food waste and dry leaves composting using a passive aerated bin. In another study, Zahrim *et al.* [14] also applied passive aeration for co-composting of empty fruit bunches (EFB) and palm oil mill effluent (POME). With proper passive aeration arrangements, composting of paper and grass clippings with anaerobically treated palm oil mill effluent (AnPOME) can produce acceptable quality compost that is suitable for soil conditioner Zahrim *et al.* [15]. Thus, this study aims to investigate the physicochemical and phytotoxicity characteristics during food waste composting in passive aerated bioreactor assisted with compost turning.

2. Material and methods

2.1. Feedstocks
The feedstocks for the composting process consist of food waste and dry leaves with a ratio of 1:2 (dry leaves: food waste). Food waste was collected from the Faculty of Engineering cafeteria and dry leaves were gathered around the Faculty of Engineering area. The food waste in this study consisted of leftover cooked rice, noodle, vegetable, chicken, meat, fish and fruit peelings. Both food waste and dry leaves were segregated from not compostable materials such as plastic before feeding it into the composter.

2.2. Composting reactor
The composting process was carried out using Active Zone-Yield composter (AZY) located at the Faculty of Engineering, University Malaysia Sabah. The AZY composter consists of three-compartment which are A, B and C, as shown in figure 1. Compartment A and B are where the turning process was carried out and food waste degradation occurred. Compartment C is the storage of yield. The design of the front and the back view of the composter are shown in figure 2 and figure 3, respectively. Each compartment has 15 PVC pipe holes at the back wall with a diameter of 2.6 cm and 10 cm length to maintained natural air convection.

Figure 1. Active Zone-Yield composter.

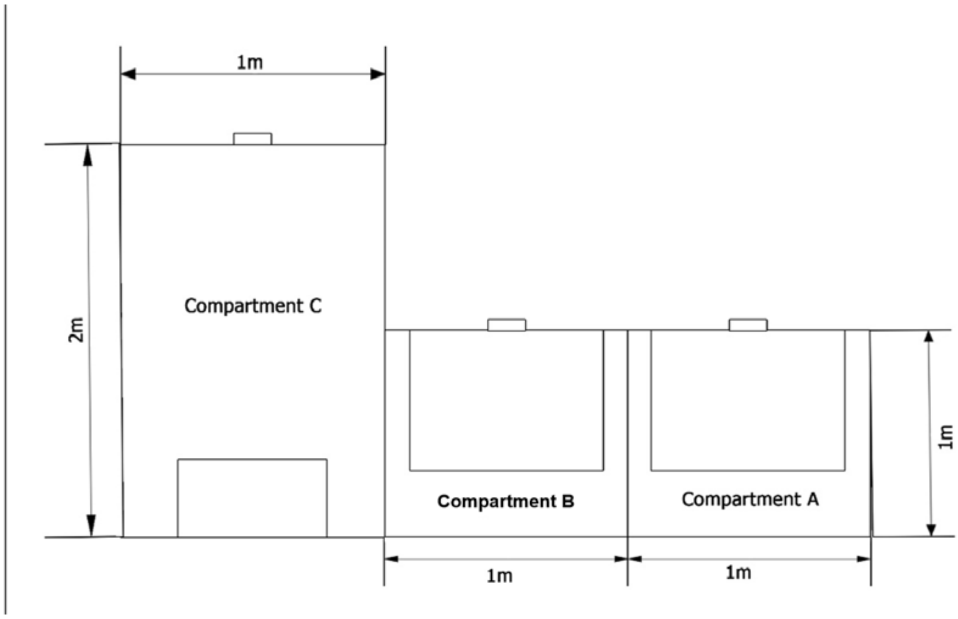

Figure 2. Front view of Active Zone-Yield composter.

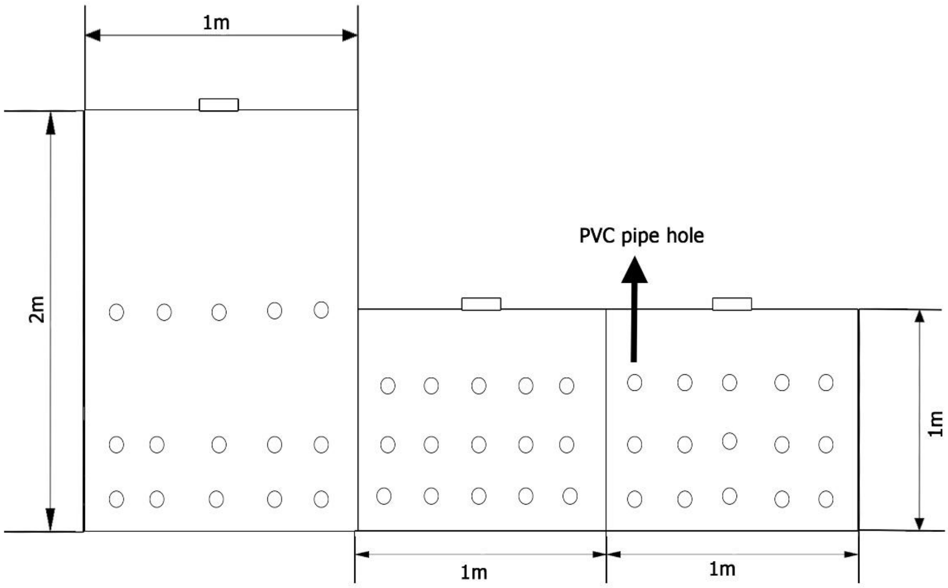

Figure 3. Back view of Active Zone-Yield composter.

2.3. Composting experiment

The composter was filled with food waste and dry leaves up to 90% of the volume and it was considered day 0. Around 62 kg of dry leaves and 124 kg of food waste were properly mixed (1:2 by weight). The composting process was carried out for 40 days. The turning process was carried out once a week on days 3, 11, 20, 25, and 38.

2.4. Analytical measurements

Laboratory analyses included moisture content measurements, total organic carbon (TOC), temperature, volume, pH and conductivity. About 0.4 kg of the compost was collected from five different places. The sample was dried at 103 °C in an incubator (Binder) for 24 hours; the weight loss was taken as the moisture content. The percentage of moisture content was calculated using equation (1). The oven-dried samples were further heated using a high temperature furnace (Thermolyne 46100) at 550 °C for 4 hours. The TOC was calculated using the equation (2) [16]:

$$Moisture\ content\ (\%) = \frac{weight\ of\ wet\ sample - weight\ of\ dried\ sample}{weight\ of\ wet\ sample} \tag{1}$$

$$TOC\ (\%) = \frac{100 - ash\ (\%)}{1.8} \tag{2}$$

The temperature was recorded every day at 12:30 pm. There are four data for temperature, including ambient temperature T0, upper-level T1, middle-level T2, and bottom level T3. For measuring pH and conductivity of compost, 5 g sample of the compost was added to 50 mL of distilled water. The mixture was mixed using a magnetic stirrer for 20 minutes and left for 24 hours. After the mixture was filtered, the pH and conductivity were measured using a pH/EC/TSD/°C portable meter (Hanna Hi 9811-5).

The germination test was performed three days in the dark cupboard with 10 cabbage seeds *(Brassica oleracea).* The seed was placed on a filter paper and soaked in petri dish filled with 5 mL of compost extract [16]. The germination test was repeated with another three replicates for compost extract and distilled water as a control. The seed germination percentage and root length of the cabbage seeds in the extract were determined. The following equation (3), equation (4), and equation (5) were used to calculate the percentage of the relative seed germination (RSG), relative root growth (RRG), and germination index (GI), respectively [15, 17].

$$RSG\ (\%) = \frac{number\ of\ seeds\ germinated\ in\ sample\ extract}{number\ of\ seeds\ germinated\ in\ control}\ x\ 100 \tag{3}$$

$$RRG\ (\%) = \frac{root\ length\ in\ sample\ extract}{root\ length\ in\ control}\ x\ 100 \tag{4}$$

$$GI\ (\%) = \frac{RSG\ x\ RRG}{100} \tag{5}$$

3. Results and discussion

3.1. Temperature

Figure 4 illustrated the changes in ambient and compost temperature. Temperature is the critical factor influencing composting efficiency, compost quality, and microbial activity [18]. The temperature variation during composting in this study went through three typical degradation phases which are mesophilic, thermophilic, and curing. The ambient temperature ranged from 28 °C to 35 °C throughout the composting period. Initially, the temperature was 31 °C, which in the mesophilic phase. The temperature increased quickly at the beginning of the composting process and reached the thermophilic phase (>40°C) on day 13 due to heat accumulation from microbial respiration. The temperature in the compost mixture is maintained above 40 °C for only three days might be due to an increase in moisture content that enhances the cooling effect. From day 23 onwards, the temperature decreased rapidly to the ambient temperature (30 ± 3 °C). The temperature started to drop due to the loss of readily biodegradable substances and reduced microorganism activities [19]. After that, the composting was in the curing phase, where the stabilization of product occurred.

Every time the turning (day 3, 11, 20, 25, 38) was carried out, the temperature shows some increment. This was because it loosens the organic compost material and the aeration was improved [20]. Hence, the organic matter and microorganisms could be reallocated, and as a result, it will increase the temperature [19].

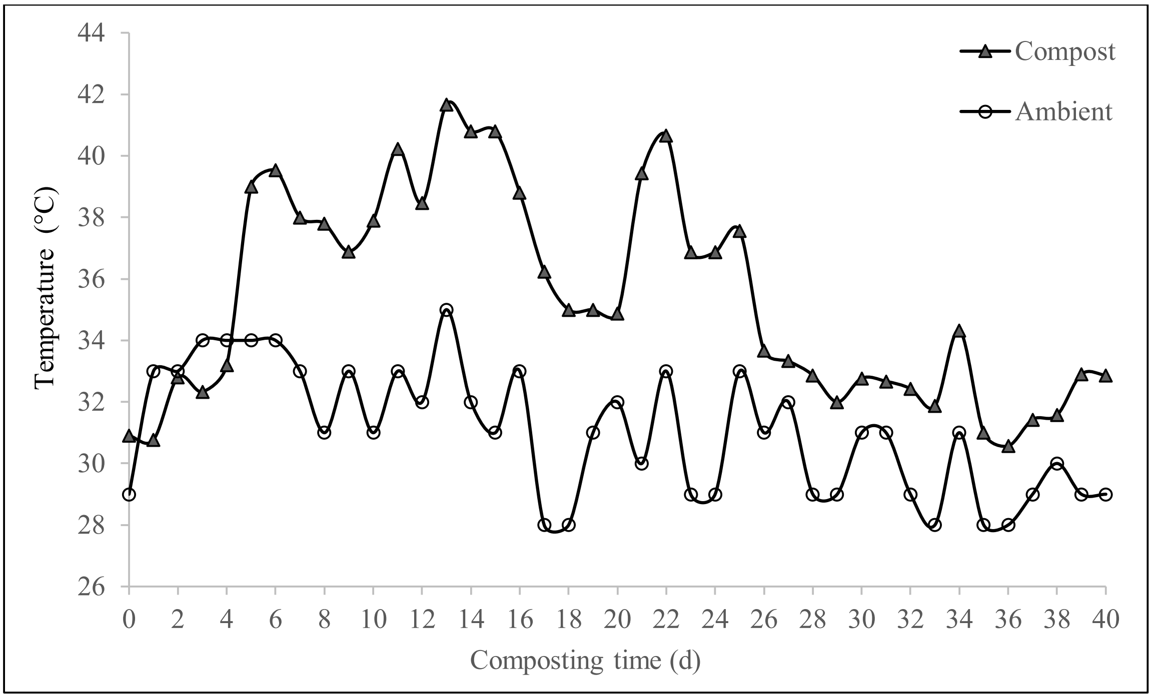

Figure 4. Compost and ambient temperature during composting.

3.2. pH and conductivity

The pH and the conductivity profile during composting are shown in figure 5. The initial pH was 3.2. The pH was low during the initial phase of composting due to the presence of organic acid in food waste [21]. As composting proceeds, the pH increases rapidly up to 7.5 in the first week. The increase in pH was potentially related with releasing of NH_3 [21]. According to Jain and Kalamdhad [22], the optimum pH range for composting is 7-8.

Compost conductivity indicates the salinity of the compost mixture matrix and it can be a limiting factor for seed germination and plant growth [5, 23]. Figure 5 showed that the initial electrical conductivity (EC) was 350 µS/cm and it gradually increased to 900 µS/cm. The increase in conductivity attributed to the released of soluble components, such as ammonium, volatile fatty acids, phosphate and potassium during decomposition and mineralization of organic substances [5, 20, 24]. Then it started to be maintained where the final EC is 870 µS/cm. Wang *et al.* [25] reported a similar result that the EC increased rapidly at the initial stage of the composting process. Table 1 shows the optimum range of EC for certain crops. According to ASCP Guidelines 2001, the conductivity in this study was at an acceptable level (<2500 µS/cm) for plant growth [26].

Table 1. Optimum range of electrical conductivity for certain crops.

Crops	Electrical Conductivity (µS/cm)	References
Cabbage	1800	[27]
Carrot	1000	
Lettuce	1300	
Spinach	2000	
Tomato	2500	

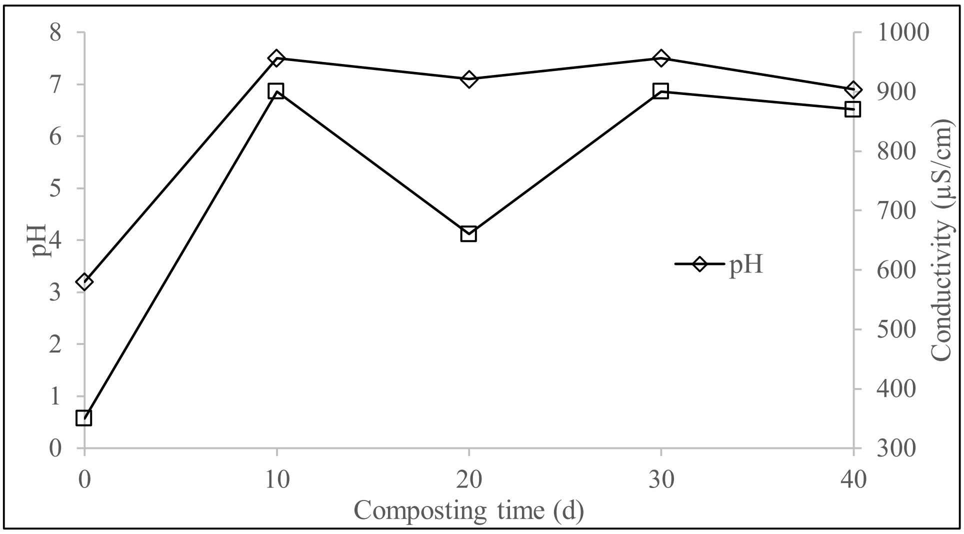

Figure 5. Profile of pH and conductivity of compost.

3.3. Moisture content and total organic carbon

The profile of moisture content (MC) and total organic carbon (TOC) during the composting process is shown in figure 6. Based on the figure, the initial MC of the compost was found to be 57%. Compared to other studies, this study has shown an increment trend in MC. The MC was decreased during composting of municipal solid waste [28], and a study by [29] also demonstrated a decreasing pattern in MC for food waste composting. However, in this study, at the end of the experiment, the MC value was 78% due to water production during degradation and the weak effect of vaporisation. The MC affects the temperature of the compost and the composting process [21, 30]. If the compost has a low value of MC, it can cause dehydration and premature compost. Simultaneously, an excess of MC will restrict the airflow and the composting process will become anaerobic [31] and thus lower the compost mixture temperature. The result indicates that the composting process had maintained the process since the acceptable range of moisture content as the recommended MC for composting process is 50-70% [30]. The initial TOC content is 48%, and it declined to 35% on day 40 of the composting process. The decreasing of TOC may attribute to the continuous degradation of organic matter [19]. TOC minimum value of 16% was recommended by the Government of India [32]. The TOC content in this study was slightly higher than the FCO standard. Nevertheless, high TOC value (40%) has been reported in a study on food waste composting in a passive aerated reactor [9].

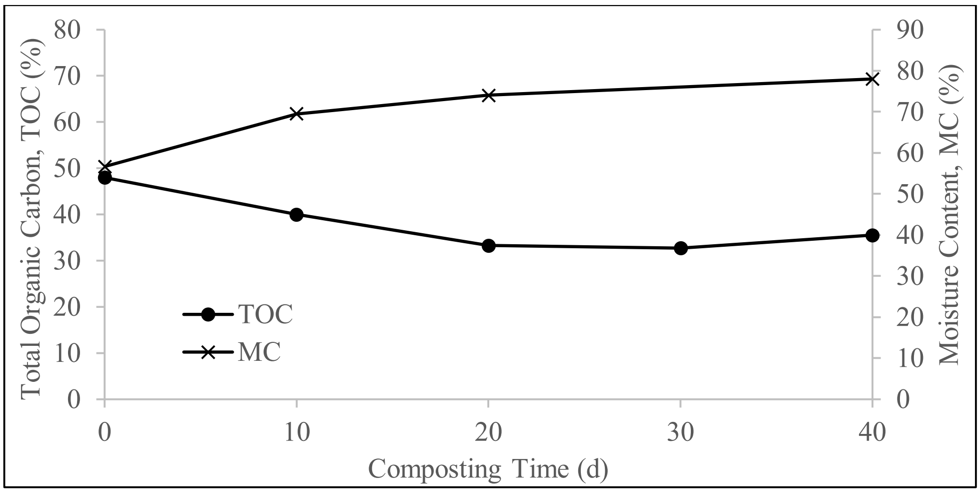

Figure 6. Profile of moisture content and total organic carbon during composting.

3.4. Germination index

Figure 7 and figure 8 illustrate the variation of GI during the composting process. The GI at day 0 was 66%. Bhave and Kulkarni [9] using wheat seed and Lee *et al.* [33] using cabbage seed for GI test also reported low initial GI value in their study on food waste composting, which were 45% and 21%, respectively. The NH_4^+-N and volatile fatty acids were released in high concentration during the initial of composting causing a low GI value [34]. At the end of the experiment, the GI value was 127%. The increase in the GI value shows that the decomposition of toxic and/or inhibitory substances [19]. The maturity and stability of compost are vital issues for land application as it can affect plant growth and the soil environment.

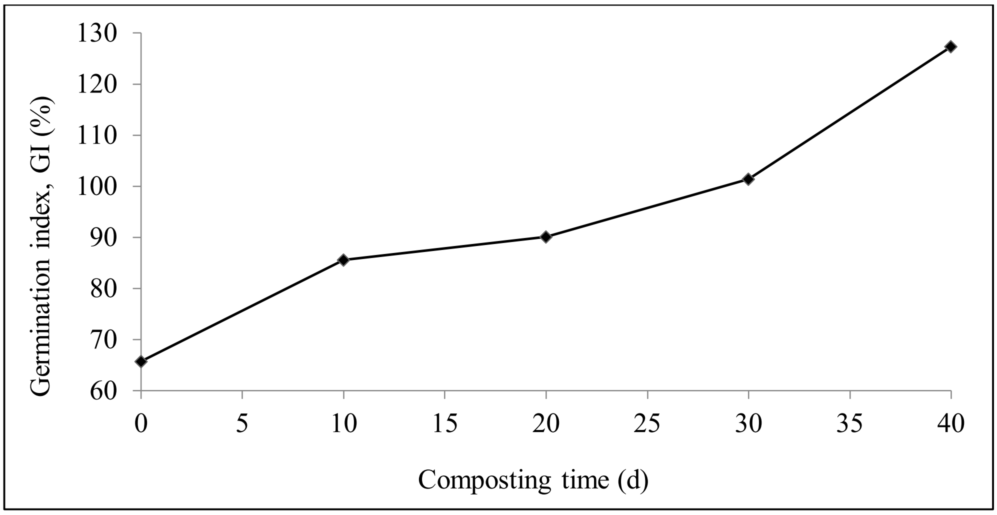

Figure 7. Germination index profile during composting process.

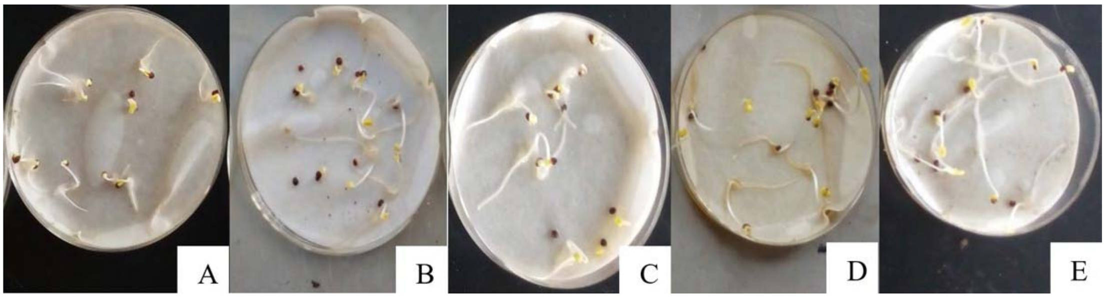

Figure 8. Profile of seed germination index during composting: (A) 0 day; (B) 10 days; (C) 20 days; (D) 30 days; (E) 40 days.

Previous studies stated that a GI value of more than 80% indicates the compost is mature and phytotoxic-free [5, 23, 35]. In this study, mature compost was found can be produced within 10 days. Based on compost maturity standards in the US, the germination index 80 – 90% are considered mature [36]. Table 2 shows the comparison of composting duration, GI and nutrients contents for passive aeration composting.

N, P, and K are important nutrients for the plant growth. The root growth and plant metabolism affected by the phosphorus content, while potassium acts as a regulator of the water content of the plant cell and is important for proteins and carbohydrate production [37]. The N, P, and K for this study were 2.50%, 0.003% and 0.0053%, respectively. Van Fan *et al.* [38] stated that the recommended range for compost is N ≥ 1%, P: 0.6 - 1.7% and K:0.4 - 1.11%. From table 2, the value of most of the studies was within the recommended range. It should be noted that the value of P and K in this study was lower. This might be due to the lower initial compost P and K than other studies. The initial value of both P and K were 0.001% and much lower than other studies where P: 0.61% K: 0.61 [9], P: 0.29% K: 1.19 [20] and P: 3.26% K: 0.92% [39]. Jamaludin *et al.* [40] reported a low value of N, P, and K in food

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waste, coconut fiber, salt, and breadfruit peels composting. In their study the N, P, and K value increase from 0.008%, 0.0002% and 0.013% to 0.224%, 0.001% and 0.069%, respectively. Gautam *et al.* [41] and Pathak *et al.* [42] also reported low values of N, P and K in municipal solid waste (mainly kitchen waste, vegetable waste, fruit waste) composting.

Table 2. Comparison of type of aeration, composting duration, germination index (GI) and nutrients for food waste composting.

Feedstocks	Aeration	Composting duration (days)	Germination Index, GI (%)	Nutrients (%)	References
Food waste, dry leaves	Passive with turning	40	127	N: 2.50 P: 0.003 K: 0.005	This study
Food waste	Passive aeration	110	71	N: 0.90 P: 0.91 K: 0.72	[9]
Food waste, dry leaves, rice bran	Passive with turning	56	402	N: 2.1 P: 0.4 K: 1.37	[37]
Food waste, garden and yard waste	Passive aeration	82	25	N: NA P: NA K: NA	[43]
Food waste, garden waste	Passive with turning	60	85	N: NA P: 0.15 K: 0.65	[29]
Food waste, coconut fiber, salt and breadfruit peels	Passive with turning	140	NA	N: 0.22 P: 0.001 K: 0.07	[40]
Food waste, dry leaves	Passive aeration	184	139	N: 2.52 P: 0.87 K: 2.26	[13]
Kitchen waste	Passive with turning	135	NA	N: 1.17 P: 0.04 K: 0.38	[42]
Kitchen waste, vegetable waste, fruit waste	Passive with turning	90	NA	N: 0.05 P: 0.003 K: 0.34	[41]
Pineapple leaves, chicken manure slurry	Passive with turning	57	84	N: 2.31 P: 0.47 K: 2.67	[20]
Vegetable waste, cow manure, sawdust, dry leaves	Passive with turning	20	NA	N: 3.01 P: 3.27 K: 1.70	[39]
Vegetable waste, cow dung, saw dust	Passive with turning	30	110	N: 2.40 P: NA K: NA	[44]
Vegetable waste, yard waste	Passive with turning	105	>100	N: 2.04 P: 0.18 K: 0.11	[45]

*NA: not available

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3.5. Other chemical properties

Table 3 shows the C/N ratio and nutrients content at the end of composting. The C/N ratio in this study was ~9. The quality and maturity of the compost can also be assessed using the C/N ratio and the C/N ratio less than 20 was reported as matured compost [30]. The nutrients (Ca, Mg, Na, Fe, Al, C, and H) in this study were lower compared to others study and the standard range. The availability of the nutrients depends on the feedstock composition of the compost. The magnesium (Mg) in compost will protect the plants from different scarcity. In contrast, the metabolism of plants and the chlorophyll will be helped by sodium (Na) in compost [46].

Table 3. Carbon to nitrogen ratio and nutrients content in compost.

References	[42]	[47]	[31]	[48]	[29]	Standard range [49]	This Study
Feedstock	Kitchen waste	Food waste, yard waste	Food waste, wood chips	Food waste, leaves, grass clipping	Food waste, green waste		Food waste, dry leaves
C/N	21.75	23.0	20.00	11.7	12.1	10.00 – 15.00	9.14
Ca (%)	NA	0.02	1.47	3.6 4	0.87	1.50 – 3.50	0.008
Mg (%)	NA	0.005	0.4	0.30	0.12	0.25 - 0.70	0.001
Na (%)	2.80	NA	1.97	0.23	0.45	< 0.60	0.003
Fe (%)	0.12	NA	NA	0.22	0.015	NA	0.001
Al (%)	NA	NA	NA	0.00003	0.003	NA	0.001
C (%)	NA	0.004	NA	34.1	NA	NA	22.85
H (%)	NA	NA	NA	NA	NA	NA	4.12

*NA: not available

4. Conclusions

This study evaluated the performance of food waste composting in a passive aerated bioreactor with food waste to dry leaves ratio of 2:1. The temperature reached above 40 °C on day 13 of composting. At the end of the composting process, the pH and conductivity were 6.9 and 870 µS/cm, respectively. TOC reduction of 26% was observed and the final value of moisture content was 78%. The final compost was matured within 10 days, with a GI value of more than 90 % on day 40 indicating very mature compost. The N, P and K value were 2.5%, 0.003% and 0.005%, respectively. Based on the result reported in this study, it is best to conclude that the compost produced is suitable for plant growth.

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