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RESEARCH ARTICLE

Takakura composting method for food wastes from small and medium industries with indigenous compost

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Abstract

The current work aimed to study the physical, chemical and biological properties of food wastes generated from small and medium industries by using Takakura composting methods. Composting method was referred as indigenous compost (IC) and commercial compost (CC) reactors. The reactors were operated at 44 °C, pH (6 to 8.5) and 40 to 55 % of moisture for 22 weeks in closed environment using a carpet around the basket to avoid external disturbance. The results revealed that the total Kjeldahl nitrogen (TKN), total phosphorus (TP) and potassium (K) in the IC reactors were 6300, 10.57 and 726.07 ppm, respectively, while 8400, 15.45 and 727.81 ppm, respectively, in the CC reactors. Moreover, both IC and CC has Cd^{2+}, Cr^{2+}, Cu^{2+}, Pb^{2+}, Ni^{2+} and Zn^{2+} concentrations within the compost legislation standard (CLS). The findings of this study indicated that the composting method could be used as an alternative food waste management in small and medium industry and the Takakura composting method is suitable for food waste composting.

Keywords Food waste · Compost · Decomposition · Fermentation · Malaysia

Introduction

Among several constitutes of the municipal solid waste (MSW), food wastes represent as the major components and comprise 44.5% of the overall waste in Malaysia (Saipul et al. 2017). Currently, Malaysia is facing numerous issues in solid waste management due to lack of funds and expertise to carry out sufficient and efficient waste treatment methods (Moh and Manaf 2017). Landfills and open dumping are the most common disposal methods in Malaysia, and this practice is associated with adverse impacts on the environment and human health (Rakib et al. 2014). Moreover, the main concern lies in the organic wastes such as food wastes which are highly degradable and produces acids and creates toxic leachates. These leachates seep into groundwater and contribute to groundwater pollution (Chua et al. 2011). According to Aja and Al-Kayiem (2014), solid wastes generated by Malaysian are high in food waste, followed by plastic, paper materials and others waste components (metal, wood, glass). Food waste comprises about 60% of municipal solid waste (Abdul Hamid et al. 2012) which is generated from many sources such as households, manufacturing industry, food services, wholesale and retail. The characteristic of waste from small and medium industry involve carbohydrates, proteins, fats, cellulose and lignin. Carbohydrates are more easily decomposed compared to lignin, which is more resistant to decomposition. Microorganism activity requires carbon as an energy source and nitrogen to build proteins.

Composting method is a sustainable alternative for managing and recycling organic solid waste due to the high activity of the microorganism which contributes effectively in the biodegradation process (Pagans et al. 2006). Masirin et al. (2008) revealed that the composting solid waste could reduce the quantity of solid waste. In addition, Saheri et al. (2009) contended that the composting of organic material diverted from landfills prevents the production of methane and leachates in landfills. Therefore, a composting method could be the most feasible and natural process for food waste disposal. Composting process generates heat and moisture leading to

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decompose of food wastes. One of the most common composting methods is Takakura composting method (TCM) which has been invented by Mr. Koji Takakura (Bobeck 2010), which is characterized as easy to implement with organic matter from either food waste or garden waste, and decomposition of food waste occurs within 2 weeks in order to compost and reduces waste disposal in landfills (Cogger 2017). It involves several steps, including preparation of the fermented liquid and decomposing medium. The first stage involves the preparation of the fermentation liquid which can be either sugar or salt solution. The next step is the preparation of the decomposing medium which requires a ratio of 2:1 (soil and rice husk, 4 kg:2 kg). Lastly, to produce compost, the fermented decomposing medium (a mixture of fermentation liquid and decomposing medium) is transferred into a composting basket or container at a high rate of 60 %, while food waste is placed and planted to a depth of 5 cm from the surface (Mat Saad et al. 2014).

The composting process should be done under controlled conditions in terms of moisture, temperature and aeration. Fathi et al. (2014), and Lakhdar et al. (2009), reported that the decomposition of organic matter by microorganisms is affected by physico-chemical characteristics as well as the C/N ratio and pH value, which enhance the microbial activity.

The composting method is conducted and in compliance according to specific compost legislation standard (CLS). For instance, Table 1 shows the symptoms and desirable limits according to the standards recommended by Amlinger et al. (2004).

The availability and sustainability of the fermentation liquid and composting medium with effective microorganisms (EM) are important to achieve high efficiency of the composting process. Therefore, in many of the cases, the commercial fermentation liquid with EM is not effective in the composting process due to the differences in the environmental conditions which play a vital role in the composition process. One of the best methods to ensure high efficiency of the composting process is by preparing the right composting medium ratio and by inducing it with the fermentation liquid prepared by using local ingredients that enhance the growth of the native microorganism presented. This process, called bio-augmentations and has exhibited high efficiency in treating several types of the wastewater (Al-Gheethi et al. 2016). In this study, the indigenous compost (IC) consisted of soil and coconut fibre (2:1 kg, respectively) as the decomposing medium along with banana peel as the main ingredient for the fermentation liquid. As a comparison, the IC was compared with commercial composts (CC) which consisted of a combination of soil and rice husk (2:1 kg, respectively) as the decomposing medium along with fermented soybeans as the main ingredient for the fermentation liquid. The food wastes generated from the small and medium industries were fully utilized as the main ingredient for the fermentation liquid of IC and also act as the food wastes that were being decomposed by using both compost prepared in this study. This emphasizes the novelty of the current work. The efficiency of the composting processes was evaluated based on total Kjeldahl nitrogen (TKN), total phosphorus (TP), total organic carbon (TOC) and potassium (K) as well as heavy metal concentrations and bacterial load of the final composite products in comparison to compost legislation standard (CLS).

Materials and methods

Food wastes sampling and composts

The food waste samples (101.82 kg) for composting purposes were collected from Makanan Ringan Mas Industry (MRMi) at Parit Kuari Darat, which is a small to medium scale food

Table 1. Symptoms and permissible limit of trace elements

Trace element	Symptoms	Permissible limit (mg/kg)
Cadmium	• Chlorosis • Growth inhibition • Browning of root tips	6.7
Chromium	• Causes severe damage to cell membranes	4.0
Copper	• Reduces the root growth	2.2
Lead	• Irregular radial thickening in pea roots • Cell walls of the endodermis • Lignification of cortical parenchyma	4.0
Nickel	• Chlorosis • Necrosis in different plant species	3.0
Zinc	• Leaves become discoloured • Plant growth is stunted	4.0
Arsenic	• Reduces fruit yield • Decreases fresh leaf weight	2.5

Source: Amlinger et al. (2004)

industry that focuses on food production such as wood chips and coconut candy. The food waste produced by MRMi includes grated coconut, tamarind husks, banana peel and tapioca peel. The samples were included processed food waste such as wood chips and coconut candy with 14 % and 10%, respectively. On the other hand, raw food waste includes banana peel with 26%, followed by tapioca peel, coconut husk and breadfruit peel at 25%, 17% and 8%, respectively. The processed food waste was collected in a plastic bag, while raw food waste was collected in a gunny bag. The collected samples were transferred immediately to the laboratory and subjected to the physical and chemical analysis within 24 h.

Preparation of composite

The indigenous compost (IC) used soil with coconut fibre as the decomposing medium (SCF) and banana peel as the fermentation liquid (BFL). In contrast, the CC was consisted of soil and rice husk as the decomposing medium (SRH) and fermented soybeans as the fermentation liquid (SFL). The fermentation liquid for each compost was prepared according to Mat Saad et al. (2014). In brief, BFL was prepared using 250 g of salt in 3 L of water and 250 g of banana peel. During the fermentation process, the bottle caps were opened once a day to remove the gas trapped inside the bottle. BFL left for 5 days to allow the fermenting microbes to grow and then mixed with the decomposing medium (JICA 2014). On the other hand, SFL was prepared with 250 g of brown sugar in 3 L of water, and fermented soybeans were used to induce growth of the aerobic microorganism.

As shown in Fig. 1, the decomposing medium IC consisted of soil and coconut fibre at a ratio of 2 kg:1 kg, respectively, adopted from Tripetchkul et al. 2012, while in CC, the soil with rice husks were used as the decomposing medium at a ratio of 2 kg:1 kg as conducted by Abushammala et al. 2015. The components of the SCF and SRH were mixed until it became a homogeneous mixture. The fermentation liquids were mixed into the soil mixture slowly to ensure that it was well mixed and until the medium could be squeezed by hand. A fixed weight (3 kg) of each IC and CC was composted with a volume of 19’× 12’ × 12’. Therefore, the total amount of IC and CC in eight reactors was 24 kg. All the reactors were incubated for 7 days before the utilization in the decomposing process (Tripetchkul et al. 2012).

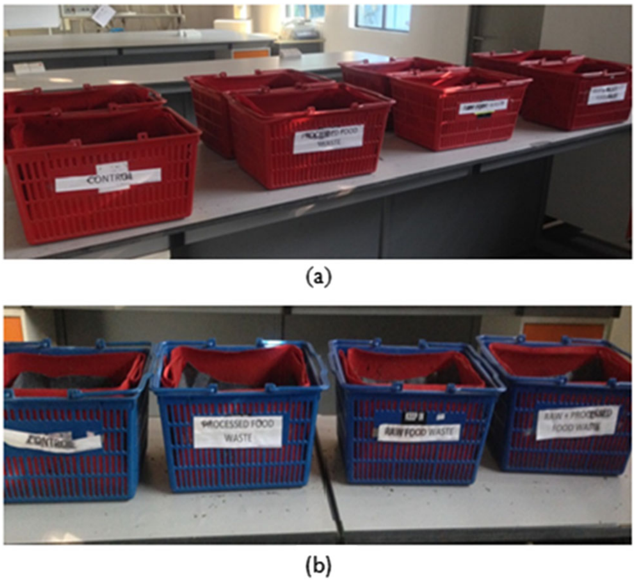


Fig. 1. **a** Reactors for IC and **b** reactors for CC

Composting reactor

A basket was used as the container for the reactors in this study. All eight compost reactors were used: four reactors for IC (A1, B1, C1 and D1) and another four reactors for CC (A2, B2, C2 and D2 for CC). A1 and A2 reactors were used as control sample, B1 and B2 were used for processing food waste, C1 and C2 were used for raw food waste and finally D1 and D2 were used for a combination of processed and raw food waste. After the preparation of the compost (IC and CC compost), the food waste collected from MRMi was placed in the reactors. One reactor was used as a control, while the other three reactors contained different types of food waste as shown in Table 2. The classification of food waste was conducted according to the study by Ganakumar et al. (2014). The proposed quantity (500 g) of food waste was left for 2 days, and a carpet was placed around the basket to avoid external disturbance. In addition, the compost basket was closed to avoid any unpleasant smells caused by the lack of air movement and to prevent flies, worms and pests.

Physical and chemical characteristics of IC, CC medium and final compost

The physical and chemical properties of IC, CC medium and final compost were investigated during the composting process, including temperature, pH, moisture content, bacterial concentrations, total Kjeldahl nitrogen (TKN), total phosphorus (TP), potassium (K), total organic carbon (TOC) and heavy metal concentration (Table 3).

Determination of nitrogen was conducted by Kjeldahl method, while Westco Smartchem 200 Discrete Analyser (Westco, USA) was used for determining TP. On the other hand, Perkin Elmer Analyst 300 Atomic Absorption Spectrometer (Agilent, USA) was used to determine the K, and heavy metal ions were determined by using Perkin Elmer Sciex Elan 6100 Inductively Coupled Plasma Mass Spectrometer (ICP/MS, Agilent, USA).

Table 2. Reactors with different types of food waste

Reactor	Classification of food waste	Types of food waste	Weight of waste
A1, A2	Control	None	0 g
B1, B2	Processed food waste	Coconut candy + wood chips	500 g
C1, C2	Raw food waste	Banana peel + tapioca peel + grated coconut	500 g
D1, D2	Processed food waste + raw food waste	Coconut candy + chips + tapioca peel + banana peel + grated coconut	500 g

Bacteria Count

The bacterial growth in the fermentation liquid was determined by culture-based method using spread plate method with standard serial dilution according to APHA (2005). The samples collected after 5 days of the fermentation process were subjected for the serial dilution (10^{-1} to 10^{-6}); a fixed volume (0.1 mL) of each dilution was spread on nutrient agar medium using a disinfected hockey stick to distribute the solution that had been pipetted over the plate agar surface. The culture plates were incubated at 37°C for 24 h; the colony counter was used to enumerate the plates with the colonies in the range from 30 to 300 colonies. The final concentrations were expressed as CFU mL^{-1} (Shymala and Belagali 2012).

$$\mathrm{CFU/mL} = \text{Colonies numbers on NA medium} \times \frac{1}{\text{Dilution factor}}$$

Statistical analysis

The collected data were subjected to one-way analysis of variances with three replicates. The differences between the numerical results were compared using LSD test (ANOVA). Analysis of variance (ANOVA) was performed in order to determine the significance of the differences between the results. The differences were considered significant at $p < 0.05$ (95% of the confidence level) based on the SD. The data were analysed using a Statistic program (IBM SPSS for windows, version 20, New York, USA).

Table 3. Test set up of study parameters for Takakura composting method

Test Name	Frequency	Duration
Temperature	Once a day	20 weeks
pH	Once in 2 weeks	20 weeks
Moisture content		
Bacteria count		
Total Kjeldahl nitrogen (TKN)		
Total phosphorus (TP)		
Potassium (K)		
Total organic carbon (TOC)		
Heavy metal		

Results and discussion

Composition and classification of food waste

The study results show that the amount of raw food waste represented the largest amount of food waste being produced from MRMi (Fig. 2). The largest waste category was banana peel, representing approximately 26% of the total amount of food waste generated, followed by tapioca peel, grated coconut and wood chips at 25%, 17% and 14%, respectively. The main production of the investigated industry is processed food of which variety of wood chips are produced. Hence, the amount of fruit peel generated was quite high. These findings are consistent with previous studies which revealed that the fruit peel waste, which is highly perishable, is a problem for the processing industry (Chikku 2014). Furthermore, Deng et al. (2012) also reported that the amount of fruit peel in waste is increasing and is one of the main sources of organic waste in municipal solid waste (MSW).

Bacterial load in the fermentation liquid

The concentrations of bacterial cells in BFL and SFL are illustrated in Table 4. It was noted that BFL having high load compares to SFL (1×10^4 vs. 6.4×10^3 CFU/mL^{-1}). These differences might be related to the composition of each fermentation liquid which might induce or inhibit the bacterial growth. This finding is consistent with Hassen et al. (2001) who suggested that a different medium and solution can be used to enhance bacteria population before using in the decomposing process.

Decomposing medium analysis

Five types of decomposing medium were suggested, namely, rice husks, wood chips, grated coconut, sugar cane bagasse

(a) Composition (%) of the classification of food waste

(b) Composition (%) of the processed food

(c) Composition (%) of the raw food

Fig. 2. **a** Composition (%) of the classification of food waste. **b** Composition (%) of the processed food. **c** Composition (%) of the raw food

and coconut fibre (Table 5, Batham et al. 2013). In this study, wood chips have the highest carbon-nitrogen ratio (C:TKN) of 2136:1. It is also easily available in the study area. However, wood chips are not very effective as a composting medium for food waste. This is because the high C/TKN value can protract the composting process due to low water absorption. However, according to Batham et al. (2013), wood chips are useful for composting wet materials such as pig manure. On the other hand, coconut fibre, sugar cane bagasse and grated coconut recorded C/TKN ratios of 577:1, 563:1 and 319:1, respectively. Grated coconut was found to be the best decomposing medium for IC as it has a lower C/TKN ratio. Sugarcane bagasse was found to be the second best option. Therefore, a combination of grated coconut and sugar cane bagasse might be useful to achieve an ideal C/TKN ratio. Unfortunately, insufficient grated coconut and sugar cane bagasse were generated for this study. Therefore, coconut fibre was chosen as the decomposing medium. According to Raghavarao et al. (2008), coconut fibre is very effective for holding water during the composting process. Moisture content affects microbial activity, compost temperature and rate of decomposition. Thus, coconut fibre was deemed to be a suitable decomposing medium. On the other hand, rice husks were chosen as the decomposing medium for the CC. Rice husks are commonly used in studies on compost medium as conducted by Mat Saad et al. (2014) and Jusoh et al. (2013). It is also widely available.

Physical, chemical and biological parameters of IC and CC

During the composting process, heat is an important factor which promotes microbial activity and degrades organic matter (Luangwilai et al. 2011). Figure 3 shows the temperature profile of two types of compost, and throughout the composting period, the temperature increased slowly at the beginning of the composting process but then increased to more than 40°C in week 12 for both types of compost. The temperature was maintained at this level for approximately 14

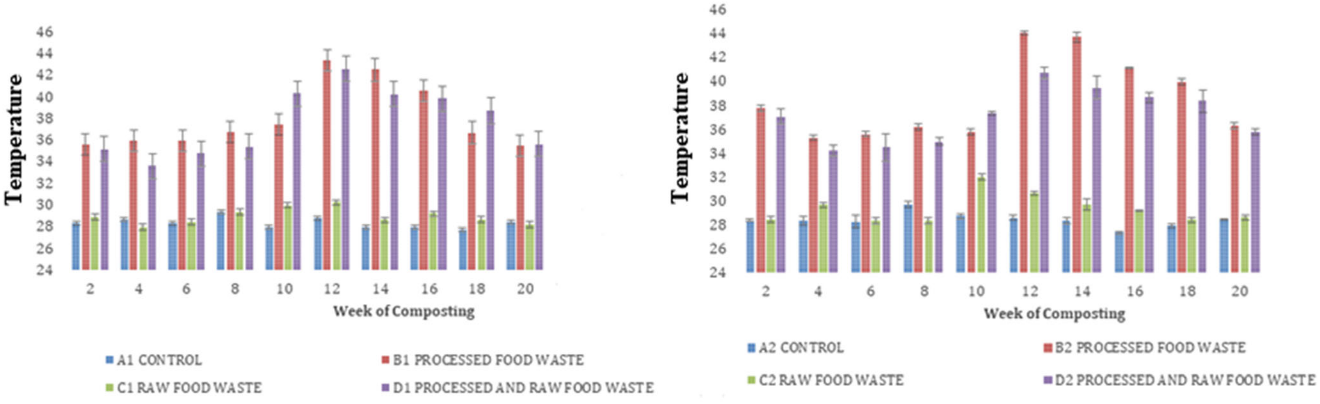
Table 4. Total bacteria per mL for both types of fermentation liquid

Fermentation liquid	CFU/mL
Banana peel liquid (BFL)	1×10^4
Fermented soybean liquid (SFL)	6.4×10^3

Table 5. Various types of decomposing medium and C/TKN ratio

Decomposing medium	C/TKN ratio
Wood chips	2136:1
Coconut fibre	577:1
Sugarcane bagasse	563:1
Rice husk	325:1
Grated coconut	319:1

Source: Batham et al. (2013)



(a) Changes in temperature in IC compost **(b) Changes in temerature in CC compost**

Fig. 3. **a** Changes in temperature in IC compost. **b** Changes in temperature in CC compost

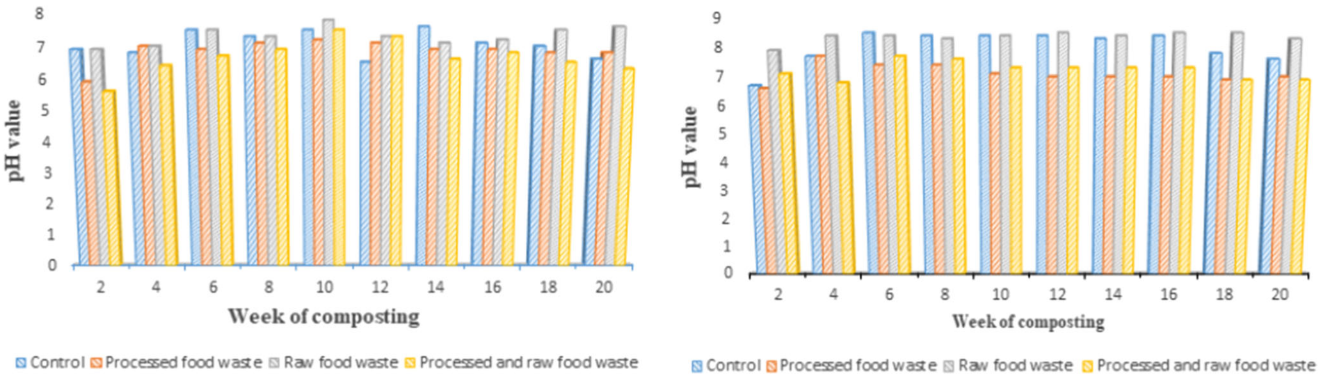
days (2 weeks) in reactor B1, reactor B2, reactor D1 and reactor D2 before slowly declining to 36°C at the end of the composting process. The results show that these reactors reach thermophilic temperatures, but the temperature slowly decreases afterwards. In this study, the changes in temperature are due to the different food wastes placed in the reactor. These results are supported by Pagans et al. (2006) who found a combination of organic compounds that contain protein, fats and a large amount of organic nitrogen, which are easily degradable that will affect the changes in the temperature. Venglovsky et al. (2005) revealed that the maximum microbial activity during the composting process takes place at temperatures between 35 and 40 °C.

The moisture content profile for IC and CC are illustrated in Table 6. The results found that the moisture content in the reactors was kept between 40 and 55%. During the composting process, the reactor has breathable pores and lined with carpet to avoid any unpleasant smells caused by the lack of air movement and to prevent flies, worms and pests. It was also kept untouched except for taking measurement and mixing every day to maintain aerobic condition in the system. However, the moisture content of both composts slowly decreased during week 12 during high temperature (thermophilic phase) because of the heat produced by the absorption of moisture content in food waste towards the end of the composting process in week 20. Moisture is fundamental in maintaining microbial activity throughout the composting period to achieve a stable end-product (Ishak et al. 2014). A good composting process requires optimum moisture content between 45 and 65 % (Gautam et al. 2010). Shymala and Belagali (2012) found that the moisture content decreases during the composting period due to the degradation of waste and the heat generated by microbial activity.

The pH value indicates the acidity or alkalinity of the compost which affects the growth of the microorganisms. Figure 4 shows that there is no significant difference observed in pH record. A similar trend was recorded by Ameen et al. (2016). The difference in the pH value could be due to the type of decomposing medium and the type of food waste placed in each reactor. These findings are consistent with Chowdhury

Table 6. Moisture content of study and commercial compost (%)

Week	IC				CC			
	Reactor A1	Reactor B1	Reactor C1	Reactor D1	Reactor A2	Reactor B2	Reactor C2	Reactor D2
2	40±0	40±0.58	50±0.58	50±0.58	40±0.58	40±0.6	60±2.0	50±0.60
4	40±0.58	55±1.53	50±2.00	60±0.58	40±0.58	45±2.5	50±1.50	55±2.50
6	45±2.00	55±2.52	50±0	55±2.52	45±2.08	55±2.00	55±2.10	55±2.00
8	40±0.58	55±3.06	55±0.58	50±0.58	45±2.00	55±2.50	50±2.50	55±0.60
10	40±0.58	50±2.00	50±0.58	45±1.53	40±0.58	50±2.00	55±3.00	50±2.00
12	45±2.00	45±2.52	55±2.52	45±0.58	40±0.58	40±0.60	55±3.10	40±0.60
14	45±2.00	40±0	50±2.52	45±0	40±0.58	41±0.60	50±2.50	45±1.50
16	40±0	40±0	50±1.53	40±0	40±0	40±0	50±0.60	45±0.60
18	40±0.58	40±0.58	50±0	40±0.58	40±0.58	41±0.60	55±2.50	45±2.50
20	40±0.58	40±0	40±0	40±0.58	40±0.58	40±0.60	55±1.50	40±0.60



(a) Changes of pH in IC

(b) Changes of pH in CC

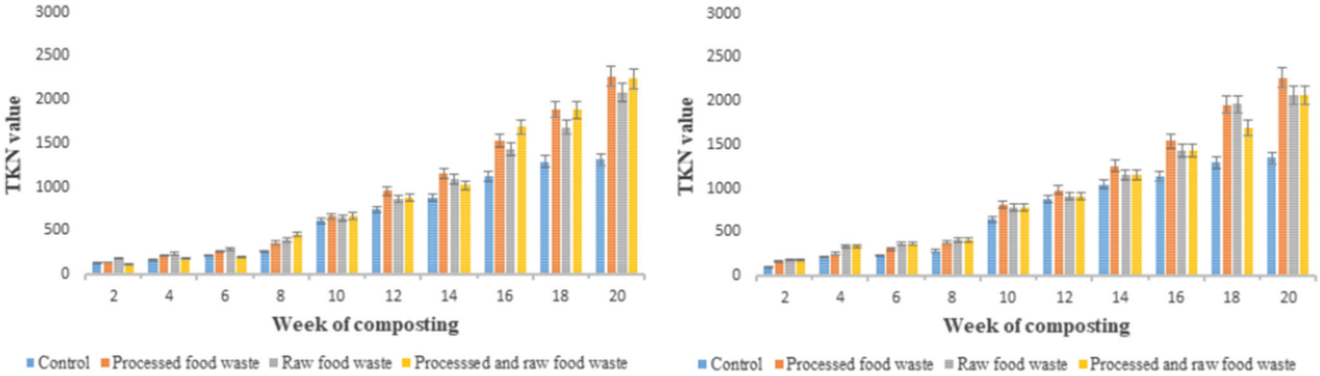
Fig. 4. **a** Changes of pH in IC. **b** Changes of pH in CC

and Bari (2014) findings who stated that the decomposition of organic matter by microorganisms produces acids, carbon dioxide and heat. Many researchers have emphasized on the importance of pH where the acceptable pH range of microorganisms and bacteria is generally 6 to 7.5 (Gómez-Brandón et al. 2008; Boulter et al. 2000). In this study, reactors B1, B2, D1 and D2 recorded a suitable pH ranging between 6.4 and 7.5 throughout the decomposition process.

The concentrations of TKN for both composts in this study gradually increased at the end of the composting process as shown in Fig. 5. In a comparison to previous studies, the concentration of nitrogen in this study is quite low. Pathak et al. (2012) also studied municipal solid waste compost and found that it provided less available nitrogen. However, the concentration of TKN obtained in this study was higher than the concentrations obtained by Gautam et al. (2010) which were between 300 and 700 ppm after the composting process of municipal solid waste. According to Civeira (2010), low of nitrogen concentration is due to ammonia volatilization and temperature during the composting process. Therefore, based on the results, the reactors containing processed food waste (reactors B1, B2) and the reactors containing processed and raw food waste (reactors D1, D2) were chosen due highest concentration value.

The TOC concentrations in this study declined slightly for both composts as shown in Fig. 6. A reduction in TOC values was most likely due to microbial activity in each reactor. Jusoh et al. (2013) indicated that microorganisms use carbon as a source of energy and transform it into CO_2 (carbon dioxide) during the composting process. Throughout this study, the microorganisms decomposed all the carbon found in organic matter to CO_2 under aerobic conditions. In addition, the decomposing mediums in this study, namely, coconut fibre (SCF) and rice husks (SRH) have a high carbon content that enhances microbial activity. Based on the results, it can be indicated that decomposition occurs in each reactor for both types of compost.

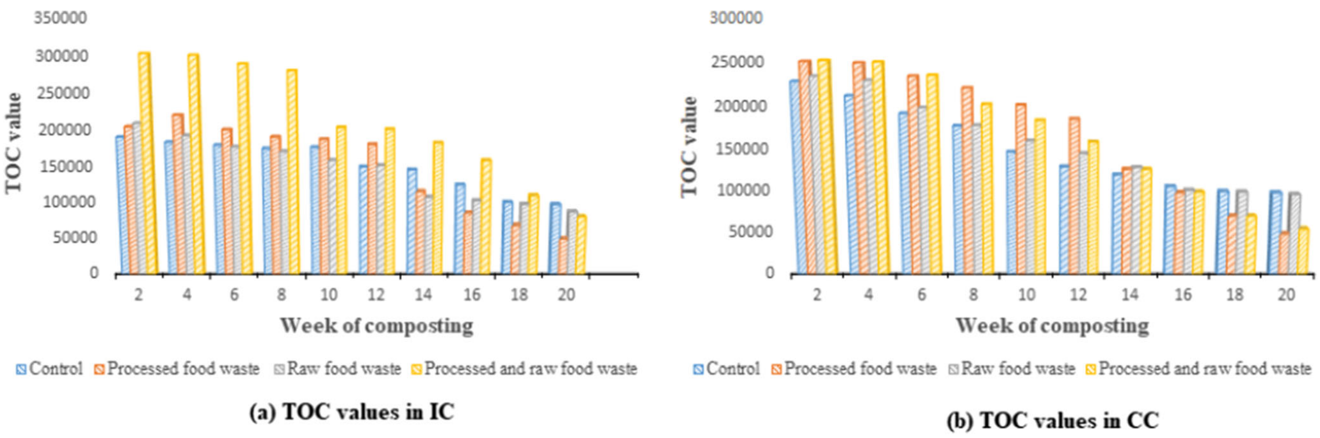
Table 7 shows the changes in the C/TKN ratio during the composting period for IC and CC, respectively. In this study, the C/TKN ratios were 21.49:1 in reactor B1, 46.26:1 in reactor C1 and 24.80:1 in reactor D1 for the IC. Meanwhile, the C/TKN ratios for the CC were 22.07:1 for reactor B2, 41.33:1 for reactor C2 and 36.03:1 for reactor D2 (Fig. 7). Reactor B1 was observed to have a higher C/TKN ratio reduction compared to reactor B2 at the end of the 20-week composting period. Therefore, the decrease in the C/N ratio of the compost indicates that the increase in nitrogen concentration is due to the degradation of organic carbon content (Ogunwande et al.



(a) TKN values in IC

(b) TKN values in CC

Fig. 5. **a** TKN values in IC. **b** TKN values in CC



(a) TOC values in IC

(b) TOC values in CC

Fig. 6. **a** TOC values in IC. **b** TOC values in CC

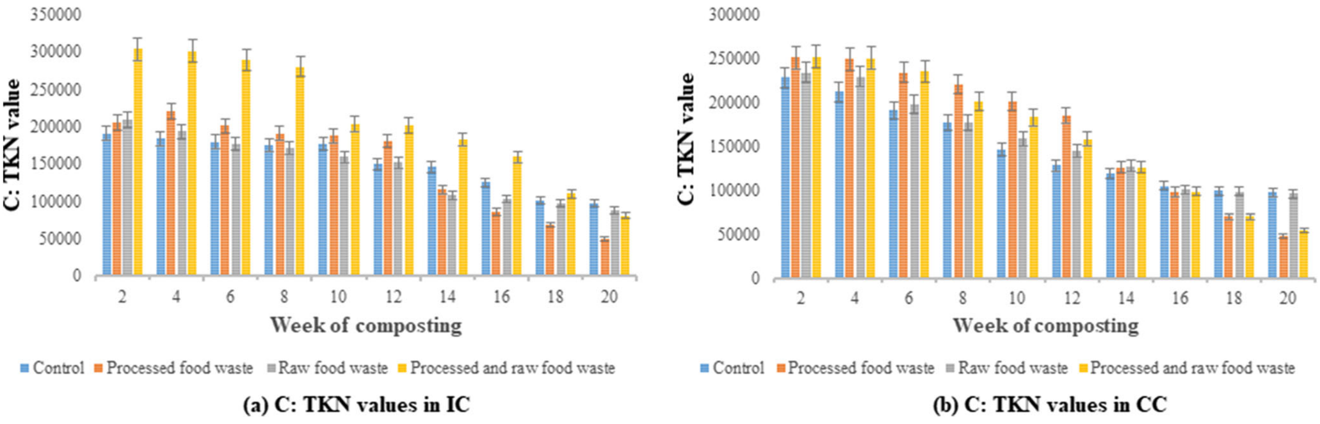
Table 7. Nutrient content in matured research compost and commercial compost

Compost sample	Nutrient	Control	Processed food waste	Raw food waste	Processed and raw food waste	Source	
						a	b
M.IC	TKN (ppm)	1300±0	6300±0	4900±0	5600±0	5700	1230
M.CC		1100±0	8400±0	5400±0	6400±0		
M.IC	P (ppm)	4.97±0.15	10.57±0.92	11.19±2.82	17.40±6.76	3400	6010
M.CC		4.90±0.17	15.45±2.80	12.23±1.91	11.23±1.95		
M.IC	K (ppm)	318.83±11.19	726.07±41.80	622.56±14.73	644.41±0.45	1210	1970
M.CC		391.33±2.79	727.81±42.84	647.51±17.80	725.85±60.65		

Values are mean ± SD; *M.IC* matured indigenous compost, *M.CC* matured commercial compost

2008). Reactor B1 is considered the best reactor due to the release of carbon dioxide (CO_2) by active microorganisms and this is supported by more declined of TOC in this reactor. This result is consistent with the rule of thumb for producing a good compost. According to Jusoh et al. (2013), a C/N ratio of less than 20 indicates a good degree of maturity. Meanwhile, Ahmed et al. (2007) contended that an optimizing C/N ratio for compost should be between 25:1 and 30:1.

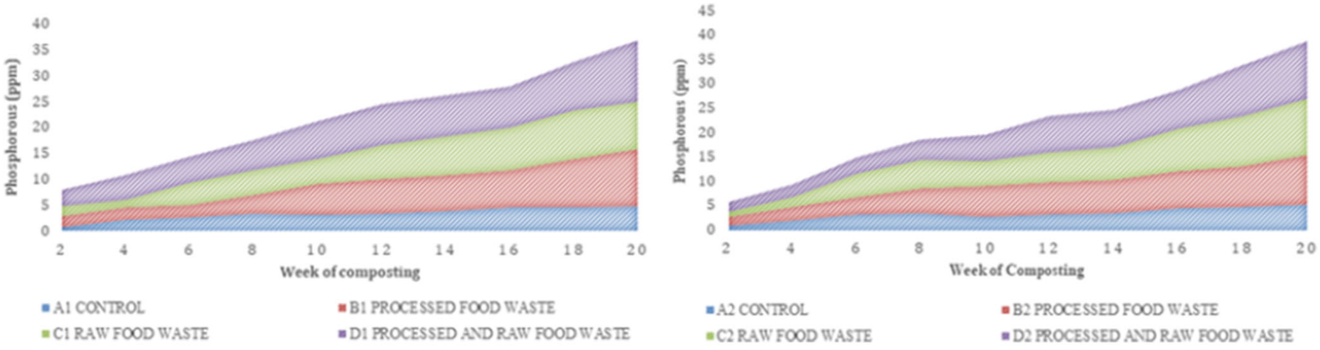
As shown in Fig. 8, phosphorus (P) content increased as decomposition progressed for IC and CC. The highest P concentration was recorded by the reactor containing processed and raw food waste for both types of compost, namely, 11.418 ppm for reactor D1 and 11.62 ppm for reactor D2. The difference in the concentration of P may be due to the type of food waste that is able to enhance the mineralization of organic matter under composting



(a) C: TKN values in IC

(b) C: TKN values in CC

Fig. 7. **a** C/TKN values in IC. **b** C/TKN values in CC



(a) Phosphorus values in IC compost **(b) Phosphorus values in CC compost**

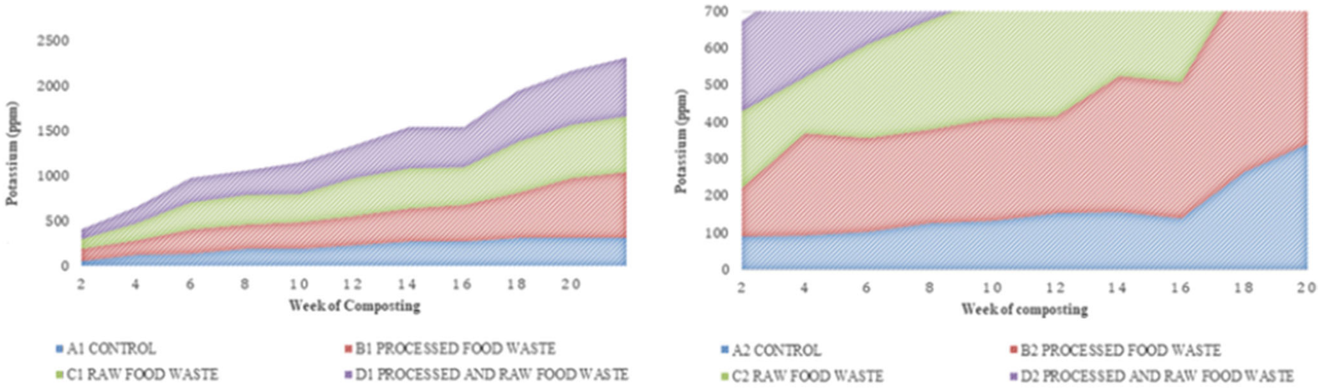
Fig. 8. **a** Phosphorus values in IC compost. **b** Phosphorus values in CC compost

conditions. On the other hand, the lowest P content of 9.257 ppm was recorded in reactor C1 which consisted of raw food waste. This was due to the leaching and slow decomposition processes. This is supported by Chaudhry et al. (2013) who stated that the lowest P content could be attributed to the leaching of mineralized P by excessive water from the heap and slow decomposition in the reactor.

Figure 9 shows that the potassium (K) concentration in both composts increased with composting time under aerobic conditions. The K concentration for the IC was found to be between 105 to 582.21 ppm in reactor C1 (raw food waste). On the other hand, the K concentration for the CC ranged from 130.15 in reactor B2 (processed food waste) to 516.00 ppm in reactor C2 (raw food waste). The K content was higher at the end of the decomposition period for reactor B1 (666.95 ppm for IC) and reactor D2 (645.55 ppm for CC). Coconut fibre and rice husks can absorb and maintain moisture content as the degradation of organic matter is enhanced by the activity of microorganisms. This has been reported by several researchers. According to Shymala and Belagali (2012) and Jusoh et al. (2013), the decomposing medium influences the increase in K due to characteristics that allow the absorption of moisture content as well as the maintenance of structural integrity and porosity. On the other hand, Haiba et al. (2014) found that microbial activity enhances the availability of K. In general, no significant values were recorded for both IC and CC. However, reactor B1 was observed to have achieved the highest K value of 666.95 ppm.

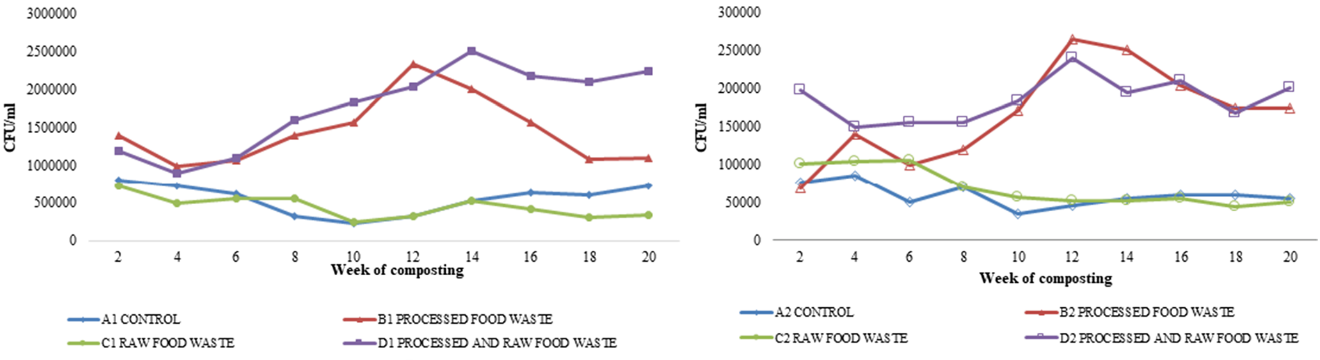
The heavy metals such as cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), zinc (Zn) and arsenic (As) concentrations were measured in all the reactors. The availability of heavy metal concentrations in compost needs to be measured because high concentrations could negatively affect soil, plants, aquatic life and human health. Table 8 represents the heavy metal content in IC and CC. However, according to the heavy metal analysis mentioned above, the heavy metal concentrations recorded for both IC and CC value were similar. The concentration of heavy metals in the analysed composts samples complied with the specified standards (CSL, ANNEX 2). In addition, IC and CC have the potential to be used as soil fertilizers as the heavy metal concentrations were below toxic levels.

The results obtained show that the total bacterial count increased gradually and reached its peak after 12 weeks before decreasing by the end of the composting period (140 days/22 weeks) (Fig. 10). Active microbial



(a) Potassium values in IC compost **(b) Potassium values in CC compost**

Fig. 9. **a** Potassium values in IC compost. **b** Potassium values in CC compost



(a) Colony forming unit (CFU/mL) in IC

(b) Colony forming unit (CFU/mL) in CC

Fig. 10. **a** Colony-forming unit (CFU/mL) in IC. **b** Colony-forming unit (CFU/mL) in CC

populations were present in the reactors processing the food waste (reactor B1) for both types of compost, namely, 2.34 × 10^6 CFU/mL^{-1} in IC and 2.6 × 10^6 CFU/mL^{-1} in the CC. The appearance of bacteria shows that the organic matter had degraded aerobically under thermophilic conditions. However, in the reactor containing raw food waste, the microbial growth was low. This reactor did not actively produce bacteria communities, and the daily temperature reading was low compared to the other reactors. According to Pathak et al. (2012), the microbial population is active and grows during the thermophilic phase (40 to 60 °C) because of the presence of organic matter as a food source. This contributes to the increase in temperature and the production of carbon dioxide, water vapour and humus as a result of microorganism growth. The activity of a microbial population depends on the type of organic compounds present as these are sources of carbon and energy. The decrease in microbial population at the end of the composting process coincides with the cooling phase. Generally, there was a higher presence of bacteria in the IC compared to the CC, especially in reactor D1 which consists of processed food waste and raw food waste. The activity of microorganisms produces heat and carbon dioxide, which helps hasten the composting process.

Conclusion

The results of the current work concluded that IC in B1 consisted of wood chips and coconut candy represents the best composting composition as it yielded 6300 ppm, 10.57 ppm and 726.07 ppm of TKN, P and K, respectively. In comparison CC in B2 yielded 8400 ppm, 15.45 ppm and 727.81 ppm of TKN, P and K, respectively. In addition, both IC and CC recorded low concentrations of cadmium, chromium, copper, lead, nickel, zinc and arsenic. To conclude, overall the IC is comparable to the CC. In addition, from the result of this study, it is expected the compost prepared could be a stable product and acceptable as compost fertilizer for native plantings. As a conclusion, this composting method can be used as alternative food waste management by small and medium industry.

Table 8. Concentration of heavy metal in final compost (week 20) with compost standard

Reactor/ parameter	IC (ppm)				CC (ppm)				CLS (ppm)
	A1	B1	C1	D1	A2	B2	C2	D2	
Cd	0.0031	0.0034	0.0034	0.0041	0.0022	0.0033	0.0033	0.0042	6.7
Cr	0.19	0.15	0.09	0.31	0.26	0.16	0.05	0.20	4
Cu	0.18	0.21	0.21	0.24	0.12	0.25	0.30	0.31	2.2
Pb	0.12	0.14	0.13	0.15	0.24	0.17	0.12	0.18	70
Ni	0.13	0.13	0.08	0.18	0.18	0.15	0.10	0.19	3
Zn	1.30	1.46	1.70	1.42	0.93	1.34	1.96	1.89	4
As	0.10	0.15	0.18	0.21	0.18	0.14	0.14	0.17	2.5

Source: compost legislation standard (CLS), ANNEX 2

Author contribution AAK and NWBA contributed to the study conception and design. Material preparation, data collection and analysis were performed by SAAA, AAK and NWBA. Interpretation of the data was made by SAAA, AAK and AA. The first draft of the manuscript was written by SAAA, AAK and AA, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability Most data generated or analysed during this study are included in this article. Anyway, further datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate Not applicable

Consent for publication Not applicable

Competing interests The authors declare no competing interests.

References

Abdul Hamid A, Ahmad A, Ibrahim MH, Nik Abdul Rahman NN (2012) Food waste management in Malaysia- current situation and future management options. J Sci Ind Res 2(1):36–39

Abushammala MF, Basri NEA, Zain SM, Saad NFM, Zainudin NA (2015) Green biological transformation of food and yard waste. J Teknol 73(1):21–26

Ahmed M, Idris A, Omer SS (2007) Behavior and fate of heavy metals in the composting of industrial tannery sludge. Malaysian J Anal Sci 11(2):340–350

Aja OC, Al-Kayiem HH (2014) Review of municipal solid waste management options in Malaysia, with an emphasis on sustainable waste-to-energy options. J Mater Cycles Waste Manag 16(4):693–710

Al-Gheethi AA, Mohamed RMSR, Efaq AN, Norli I, Abd Halid A, Amir HK, Kadir Ab MO (2016) Bioaugmentation process of secondary effluents for reduction of pathogens, heavy metals and antibiotics. J Water Health 14(5):780–795

Ameen A, Ahmad J, Raza S (2016) Effect of pH and moisture content on composting of municipal solid waste. Int J Sci Res 6(5):35–37

Amlinger F, Pollak M., Favoino E (2004) Compost standard and legislation. ANNEX 2. Heavy Metals and Organic Compounds from Wastes Used as Organic Fertilisers

APHA (2005) Standard Methods for the Examination of Water and Wastewater, 21st edn. American Public Health Association/ American Water Works Association/Water Environment Federation, Washington DC

Batham M, Gupta R, Tiwari A (2013) Implementation of bulking agents in composting: a review. J Bioremediat Biodegrad

Bobeck M (2010) Organic household waste in developing countries: an overview of environmental and health consequences and appropriate decentralized technologies and strategies for sustainable management

Boulter JI, Boland GJ, Trevors JT (2000) Compost: a study of the development process and end-product potential for suppression of turfgrass disease. World J Microbiol Biotechnol 16(2):115–134

Chaudhry A, Naeem M, Jilani G, Razzaq A, Zhang D, Azeem M, Ahmed M (2013) Influence of composting and poultry litter storage methods on mineralization and nutrient dynamics. J Anim Plant Sci 23(2):500–506

Chikku M (2014) Antimicrobial evaluation of jams made from indigenous fruit peels. Int J Curr Adv Res 2(1):202–207

Chowdhury AKM, Bari M (2014) Composting of agro-industrial wastes.

Chua K, Sahid EJM, Leong Y (2011) Sustainable municipal solid waste management and GHGs abatement in Malaysia ST-4. Green & Energy Management 4(2):1–8

Civeira G (2010) Influence of municipal solid waste compost on soil properties and plant reestablishment in peri-urban environments. Agricultura técnica 70(3):446–453

Cogger C (2017) Backyard composting: home garden series. Washington State University Extension Publication. EBI784E, United State

Deng GF, Shen C, Xu XR, Kuang RD, Guo YJ, Zeng LS, Gao LL, Lin X, Xie JF, Xia EQ (2012) Potential of fruit wastes as natural resources of bioactive compounds. Int J Mol Sci 13(7):8308–8323

Fathi H, Zangane A, Fathi H, Moradi H, Lahiji AA (2014) Municipal solid waste characterization and it is assessment for potential compost production: a case study in Zanjan City, Iran. AJAF 2(2):39–44

Ganakumar S, Murugappan A, Monson CC, Gopalakrishnan R (2014) Rotary drum composting of urban solid food wastes generated in commercial and residential complexes. Int J Advert 2(8):466–476

Gautam S, Bundela P, Pandey A, Awasthi M, Sarsaiya S (2010) Composting of municipal solid waste of Jabalpur City. Glob Environ Res 4(1):43–46

Gómez-Brandón M, Lazcano C, Domínguez J (2008) The evaluation of stability and maturity during the composting of cattle manure. Chemosphere 70(3):436–444

Haiba E, Ivask M, Olle L, Peda J, Kuu A, Kutti S, Nei L (2014) Transformation of nutrients and organic matter in vermicomposting of sewage sludge and kitchen wastes. J Agric Sci 6(2):114

Hassen A, Belguith K, Jedidi N, Cherif A, Cherif M, Boudabous A (2001) Microbial characterization during composting of municipal solid waste. Bioresour Technol 80(3):217–225

Ishak NF, Ahmad AL, Ismail S (2014) Feasibility of anaerobic co-composting empty fruit bunch with activated sludge from palm oil mill wastes for soil conditioner. J Phys Sci 25(1):77

JICA. Japan International Cooperation Agency. (2014) Environmental Management. Takakura Composting Method. Retrieve from https://www.jica.go.jp/english/our_work/thematic_issues/management/study_takakura.html.

Jusoh MLC, Manaf LA, Latiff PA (2013) Composting of rice straw with effective microorganisms (EM) and its influence on compost quality

Lakhdar A, Rabhi M, Ghnaya T, Montemurro F, Jedidi N, Abdelly C (2009) Effectiveness of compost use in salt-affected soil. J Hazard Mater 171(1):29–37

Luangwilai T, Sidhu H, Nelson M, Chen XD (2011) Modelling the effects of moisture content in compost piles.

Masirin M, Idrus M, Ridzuan MB, Mustapha S (2008) An overview of landfill management and technologies: a Malaysian case study at Ampar Tenang. Proceedings 1st National Seminar on Environment, Development & Sustainability: Biological, Economical and Social Aspects, 157-165

Mat Saad NF, Baharin N, Md Zain S (2014) Windrow composting of yard wastes and food waste. AJBAS 8(9):64–68

Moh Y, Manaf L (2017) Solid waste management transformation and future challenges of source separation and recycling practice in Malaysia. Resour Conserv Recycl 116:1–14

Ogunwande G, Osunade J, Ogunjimi L (2008) Effects of carbon to nitrogen ratio and turning frequency on composting of chicken litter in turned-windrow piles. CIGR Journal, Agricultural Engineering International

Pagans E, Barrena R, Font X, Sánchez A (2006) Ammonia emissions from the composting of different organic wastes, dependency on process temperature. Chemosphere 62(9):1534–1542

Pathak A, Singh M, Kumara V, Arya S, Trivedi A (2012) Assessment of physico-chemical properties and microbial community during composting of municipal solid waste (Viz. KItchen waste) at Jhansi City, UP (India). Res Sci Technol 4(4):87–95

Raghavarao K, Raghavendra S, Rastogi N (2008) Potential of coconut dietary fiber. Indian Coconut Journal 6:2–7

Rakib MA, Rahman MA, Akter MS, Ali M, Huda ME, Bhuiyan MA (2014) An emerging city: solid waste generation and recycling approach. Int J Environ Sci 2(3):74–84

Saheri S, Mir MA, Basri NEA, Begum RA, Mahmood NZ (2009) Solid waste management by considering composting potential in Malaysia toward a green country. Int J Humanit Soc Sci 4(1):48–55

Saipul NIL, Rahman MSA, Wing ACK, Jaganathan S, Maimun NHA, Yusoff NSM, Mohammed AH (2017) Parties and their roles in solid waste separation at the source: an example from Malaysia's award-winning residential area. Tourism 2(6):10–21

Shymala DC, Belagali SL (2012) Studies on variations in physico-chemical and biological characteristics at different maturity stages of municipal solid waste compost. Int J Environ Sci 2(4):1984–1997

Tripetchkul S, Pundee K, Koonsrisuk S, Akeprathumchai S (2012) Co-composting of coir pith and cow manure: initial carbon and nitrogen ratio (C:N) vs physico-chemical changes. Int J Recycl Org Waste Agric 1(1):1–8

Venglovsky J, Sasakova N, Vargova M, Pacajova Z, Placha I, Petrovsky M, Harichova D (2005) Evolution of temperature and chemical parameters during composting of the pig slurry solid fraction amended with natural zeolite. Bioresour Technol 96(2):181–189