

In-vessel co-composting of yard waste and food waste: an approach for sustainable waste management in Cameron Highlands, Malaysia

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Received: 28 December 2016 / Accepted: 19 April 2017 / Published online: 25 April 2017
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Abstract

Purpose Huge amount of yard waste is produced in cities with excessive agricultural activities like Cameron Highlands, Malaysia where most of the time the yard waste is being managed poorly and big portion of it ends in dump sites. Therefore, this study aims to evaluate the applicability of converting yard waste generated in Cameron Highlands Malaysia into high-quality and fast compost via in-vessel method.

Methods In-vessel composting technique was applied for speedy biotransformation of yard waste. Addition of food waste, effective microorganisms (EM) and Shimamoto Enzyme[®] (SE) were investigated for improvement of compost quality. Four compositions of feedstock with different yard waste (YW) and food waste (FW) ratios were tested. The compositions were 70%YW + 30%FW, 80%YW + 20%FW, 90%YW + 10%FW and 100%YW. Physicochemical properties of compost including pH, moisture content and C/N ratio were monitored throughout the experiment. Furthermore, quality of compost and its potential for direct application after production were evaluated based on germination index (GI) and nutrient content (NPK).

Results The compost samples had pH ranging from 7 to 9 and moisture content of 15.45–32.13%. Initial C/N ratio of all feedstock was decreased throughout the composting process by more than 50%. Seed germination test showed that only 70%YW + 30%FW feedstock produced immature compost with GI < 80%. The highest GI of 130% was

obtained when FW represented in 10% of the feedstock with addition of EM. Average concentrations of nitrogen, phosphorus and potassium were 1.73, 1.21 and 1.66% in case of EM additive and 1.47, 0.56 and 1.74% in case of SE additive.

Conclusion Application of in-vessel composting can improve solid waste management in Cameron Highlands, Malaysia and yield a high-demand product. The approach used in this study can be a good practice for the societies have difficulties in managing their yard waste.

Keywords Aerobic composting · Compost quality · Municipal solid waste · Effective microorganisms

Introduction

Landfilling has been the most adopted option for disposing of growing quantities of municipal solid waste (MSW) in Malaysia as it is the cheapest disposal option (Agamuthu 2013). Besides 114 non-operational landfills, the Malaysian ministry of Housing and Local Government is responsible for other 176 in-operation landfills (Fazeli et al. 2016). Out of the currently operating landfills, only 14 have been classified as sanitary landfills whereas the remaining are unsanitary (Noor et al. 2013). Many illegal dumpsites have been used in Malaysia for disposing of the waste (Malakahmad et al. 2013). Statistics show that more than 90% of collected comingled solid waste in Malaysia is disposed of in unsanitary landfills (Badgie et al. 2012; Johari et al. 2014). Nevertheless, organic fractions of MSW such as yard waste can be transformed into useful products through biological conversion technologies such as composting (Parthan et al. 2012; Rajaie and Tavakoly 2016). Yard waste and food waste collectively represented nearly 50% of waste stream in Malaysia (Dinie et al. 2013;

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Periathamby et al. 2009). However, composting of organic wastes has been practiced in Malaysia for only 1% of solid waste from 2000 to 2006 and it is projected to increase to 8% by 2020 (Johari et al. 2014). Mansor et al. (2015) stated that ample quantities of yard waste get generated in Malaysia from areas that have high agriculture activities such as Cameron Highlands. Cameron Highlands is the largest vegetable, flower and tea supplier in Malaysia (Aminu et al. 2015). While considerable portion of generated waste in Cameron Highlands is disposed of in unsanitary dumpsite near Tanah Rata, organic MSW including yard wastes can be converted into useful products via biological transformation methods.

Composting, as a biological waste transformation technique, can be defined as decomposition and stabilization of organic matters, commonly in the presence of oxygen, for production of stable and free-of-pathogen final product that can be beneficially applied to land (Haug 1993) for soil amendment (Ch'ng et al. 2013; Mhindu et al. 2013; Pandey et al. 2016). Generation of renewable energy (Irvine et al. 2010), saving lands by increasing lifetime of landfills (Hoorweg et al. 1999) and reduction of transportation costs (Larney et al. 2006; Mandal et al. 2014) are reported as other benefits of composting. Moreover, less amount of landfill gases (LFG) and leachate would be generated when organic materials are composted rather than landfilled (Lou and Nair 2009; Sudharsan Varma and Kalamdhad 2014).

Composting of organic MSW can be done using different methods such as windrow, aerated static pile, and in-vessel techniques. Selection of composting methods can be considered in respect to factors such as capital and operating costs, land availability, operational complexity and potential of nuisance problems. Although more expensive compared to other methods, in-vessel composting is more controlled, needs smaller spaces and resulted in less bothers than other techniques (Cekmecelioglu et al. 2005). In-vessel composting technique allows the highest degree of temperature control. In addition, it can be used to shorten the time needed for production of compost drastically (An et al. 2012). In Malaysia, in-vessel composting also has been successfully implemented for industrial wastes (Razali et al. 2012; Zahrim et al. 2016). Therefore, in this study composting of yard waste generated in Cameron Highlands was conducted using an in-vessel composter. Quality of compost was assessed via measurement of germination index and nutrient values.

Methodology

Feedstock materials

Yard waste (YW) was gathered from a plant nursery in Cameron Highlands, Malaysia. It was then shredded using

mechanical shredder into smaller sizes with 4–5 cm maximum length. Shredding of organic waste into small sizes prior to composting results in faster stabilization (Tognetti et al. 2007). Food waste (FW) was collected from a nearby restaurant and comprised rice, chicken, potatoes, sausages, cooked spaghetti and green vegetables. The initial pH values of YW and FW were 6.17 ± 0.2 and 4.68 ± 0.2 , respectively. Even though the optimum pH range for composting is 5.5–8, raw feedstock having a pH value within the range of 3–11 can also be composted (Pichtel 2005). YW used in this study had low initial moisture content of $35.63 \pm 0.4\%$ while FW recorded moisture content of $58.24 \pm 0.4\%$. Optimum initial moisture content of raw feedstock ranges between 50 and 60% (Kalamdhad and Kazmi 2009). The analyses showed that YW and FW contained $17.17 \pm 0.5\%$ and $31.77 \pm 0.5\%$ of carbon, and $0.28 \pm 0.2\%$ and $3.43 \pm 0.2\%$ of nitrogen. The C/N ratios of YW and FW were 61.32 ± 0.3 and 9.26 ± 0.2 , respectively. Initial carbon to nitrogen ratios between 25 and 50 are optimum for aerobic composting (Kumar et al. 2010; Zhu 2007). High C/N ratio causes slow growth of microorganisms and consequently organic decomposition will be slow (Maheshwari 2014). On the other hand, low C/N ratio contributes to odor problems due to formation of ammonia or nitrous oxides. Blending of YW and FW can provide a near optimum C/N ratio.

In-vessel composter

An in-vessel actual-size rotary drum composter (COMPOSTECH CT200) with the dimensions $l: 2.0 \times w: 1.1 \times h: 1.3 \text{ m}^3$ was used in this study. Proper rotation in these kinds of composting machines is an efficient technique which produces uniform end product due to good agitation, aeration and mixing of the compost (Rich and Bharti 2015). The composter was able to handle 200 kg of waste at maximum. It was equipped with three rotary blades for mixing of materials and an air blower to maintain enough oxygen levels inside the chamber. Away from ambient temperatures which were 30 and 23 °C on average for day time and night time, respectively, the temperature inside the composter was automatically controlled at 56 ± 4 °C using heating functions and sensors equipped in the composter. The temperature inside the composter changed mainly due to heat generation as a result of degradation of organic matters by microorganisms and because of ambient air blown inside the composter for aeration purposes (Arslan Topal et al. 2016). Greatest thermophilic activity would be observed during composting process when the temperature ranges between 52 and 60 °C (Kalamdhad and Kazmi 2009; Mohee and Mudhoo 2005).

Table 1 Combinations of yard waste (YW), food waste (FW) and additives in samples

Compost proportion	Weight of material (kg)		
	YW	FW	Additives
Effective microorganisms (EM)			
100%YW	12.0	0	8.0
90%YW + 10%FW	10.8	1.2	8.0
80%YW + 20%FW	9.6	2.4	8.0
70%YW + 30%FW	8.4	3.6	8.0
Shimamoto Enzyme [®] (SE)			
100%YW	20.0	0	1.0
90%YW + 10%FW	18.0	2.0	1.0
80%YW + 20%FW	16.0	4.0	1.0
70%YW + 30%FW	14.0	6.0	1.0

Composting process

Four different compositions of feedstock with different YW + FW mixtures were examined (Table 1). Addition of food waste was driven by the fact that at specific C/N ratios for initiating composting, digester operating characteristics and end performance metrics can be improved (Brown and Li 2013). The compositions were (1) 100%YW, (2) 90%YW + 10%FW, (3) 80%YW + 20%FW, and (4) 70%YW + 30%FW. Each composition was composted twice using different additives. 8.0 kg of Effective Microorganisms (EM) and 1.0 kg of Shimamoto Enzyme[®] (SE) were used in each trial. EM and SE were added to the compost in values recommended by their manufacturing companies to improve and facilitate composting process. Compost additives increase the macro- and micronutrient content and result in more nitrogen (N), phosphorus (P) and potassium (K) nutrient content (NPK) (Jusoh et al. 2013). All prepared feedstock were composted in batches inside the composter for 24 h. Subsequently, approximately 7 kg of the product of each batch was unloaded from the composter and processed further for curing purposes. The curing process lasted for 35 days. The remaining amounts of the product (approximately 13 kg) were left inside the composter and recycled in the next batch.

Compost quality control

Existence of toxic substances is one of the common problems in immature composts (Itävaara et al. 2002). Therefore, phytotoxicity test is an important investigation to check the quality of compost before its application in different crops. In this study, compost extract was prepared initially with 200 mL of distilled water and 20 g of compost. The compost–water mixture was then stirred for 6 h and centrifuged at 8000 rpm for 20 min (Gariglio et al.

2002; Mitelut and Popa 2011). Seed germination was tested for 20 radish seeds in Petri dishes (El Fels et al. 2014). Seeds were soaked with 5 mL of compost extract and left for 5 days in darkness at 22 ± 3 °C. Then, they were preserved in distilled water overnight before germination test. A blank sample filled with distilled water was used as control. At the end of the experiment, the germination index (GI) was obtained based on the following equations explained by Zucchini et al. (1981).

Relative seed germination (%)

$$= \frac{\text{No. of seeds germinated in compost extract}}{\text{No. of seeds germinates in control}} \times 100\%, \quad (1)$$

Relative root growth (%)

$$= \frac{\text{Mean root length in compost extract (mm)}}{\text{Mean root length in control (mm)}} \times 100\%, \quad (2)$$

Germination index GI (%)

$$= \frac{\text{Relative seed germination} \times \text{relative root growth}}{100}. \quad (3)$$

Besides the seed germination test, the NPK content of produced compost was also determined. Total Kjeldahl nitrogen (TKN) test was used for nitrogen content determination using BUCHI Distillation Unit K-314. As for phosphorus and potassium content, collected samples were first digested using dry digestion method. Then, 1 g of dry solid sample was placed in a 10-mL crucible and heated at 550 °C in a muffle furnace for 5 h. Afterwards, total phosphorus and total potassium were determined using PhosVer[®]3 ascorbic acid and atomic absorption spectroscopy (AAS), respectively, and the results were compared with available standards. In addition, and for benchmarking purpose, quality of samples was compared with a compost produced in windrow system using similar yard waste applied in this study. Nitrogen, phosphorous and potassium content of the compost produced in windrow system were 0.77 ± 0.2 , 0.92 ± 0.1 and 1.58 ± 0.1 , respectively.

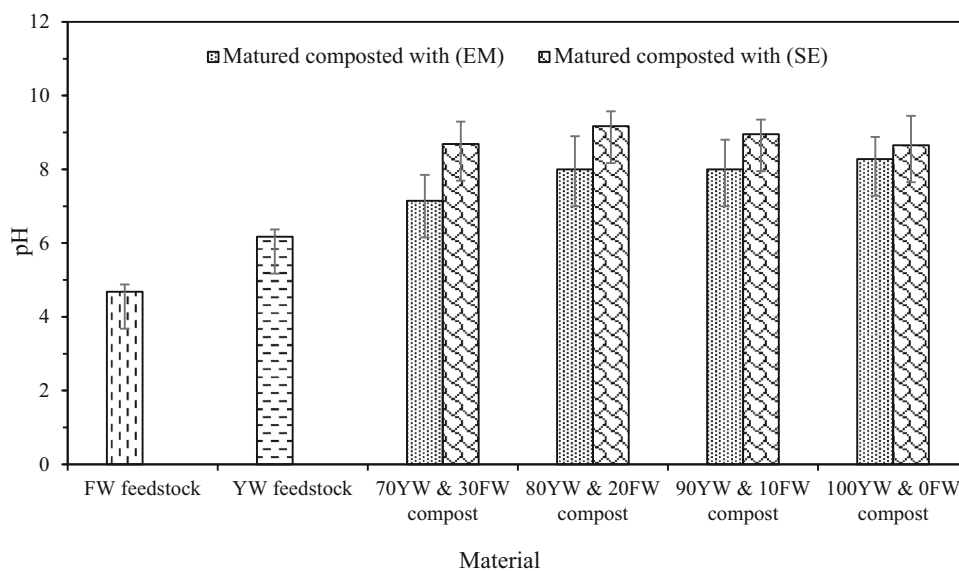
Results and discussion

Composting process

Figure 1 shows initial pH of FW and YW feedstock and final pH of four matured compost compositions. pH varied from 7.01 to 9.17 in investigated compositions. Mature compost usually has a pH range of 6–8 (Cooperband 2002). In compost samples with EM additives, pH values



Fig. 1 pH levels of FW and YW feedstock and matured compost samples collected after curing with application of EM and SE additives



decreased and reached an optimum range. However, samples with SE additives had pH higher than optimum range. Effective microorganisms produce organic acids and cause reduction of pH (El-Shafei et al. 2008). High pH values of compost with SE additive could be due to consumption of produced organic acids at the beginning of the process and their conversion to ammonia (Sundberg 2005). Reduction of final pH value of compost can be achieved using different ways, e.g., addition of elemental sulfur (Roig et al. 2004). It was also found that addition of FW could slightly reduce pH of samples. Effect of food waste in lowering pH values was also confirmed by Saad et al. (2013).

Figure 2 shows moisture content values of raw FW and YW feedstock and of composts produced from different compositions of YW and FW. Samples recorded moisture contents ranging from 15.4 to 32.1% which were lower than the optimum levels. Moisture content should be in the range between 50 and 60% during the composting process (Tchobanoglous et al. 1993). Low initial moisture content of YW is believed to be the reason for having low final moisture content in compost samples. Application of yard waste for reducing compost pile moisture due to its high consumption of moisture content has been reported (Rihani et al. 2010). In addition, water contained in the feedstock is consumed during decomposition of organics and consequently the moisture content decreases over time. Therefore, adding enough water into the feedstock prior to composting to maintain an acceptable percentage of moisture content could improve the final moisture content of the compost samples.

C/N ratio of compost ranged from 20 to 27 after 1 day of feedstock processing inside the composter (Fig. 3). Obtained C/N ratios indicated that composting process succeeded in decreasing initial C/N ratio of the feedstock in

large percentage. For instance, initial C/N ratio of the 100%YW feedstock was reduced around 56 and 65%, respectively, in case of EM and SE additives' application. Similar reduction percentages in initial C/N ratio were reported by other researchers (Jusoh et al. 2013; Makan and Mountadar 2012; Tumuhairwe et al. 2009). Organic carbon gets converted to CO₂ during composting process and, with minimal nitrogen loss the C/N ratio of compost will eventually decrease (Rasapoor et al. 2016). C/N ratio of finished compost is desired to be close to 10/1. Curing process can reduce further the C/N ratio of compost and resulted in a proper ratio (Shaffer 2010).

Compost quality

Figure 4 shows germinated radish seeds in control and in sample of composts with EM and SE additives. Results of seed germination test are shown in Fig. 5. All samples, except sample of 70%YW + 30%FW with EM additive, could produce satisfactory germination indexes.

Minimum acceptable germination index (GI) of mature compost for different seeds types have been investigated previously. Riffaldi et al. (1986) studied GI of garden cress and reported that compost is certainly not phytotoxic to plants when GI is more than 80%. Similar to garden cress seeds, germination indexes of at least 80% in radish seeds (Mitelut and Popa 2011) and cucumber seeds (Sangamithirai et al. 2015) indicated production of compost which is not phytotoxic. Investigated compost samples in this study recorded germination index higher than those achieved by Kumar et al. (2010) during co-composting of green waste and food waste at low C/N ratio using an in-vessel lab-scale reactor. Generally, the phytotoxicity effect is most likely due to the presence of fatty substance,

Fig. 2 Moisture content of FW and YW feedstock and matured compost samples collected after curing with application of EM and SE additives

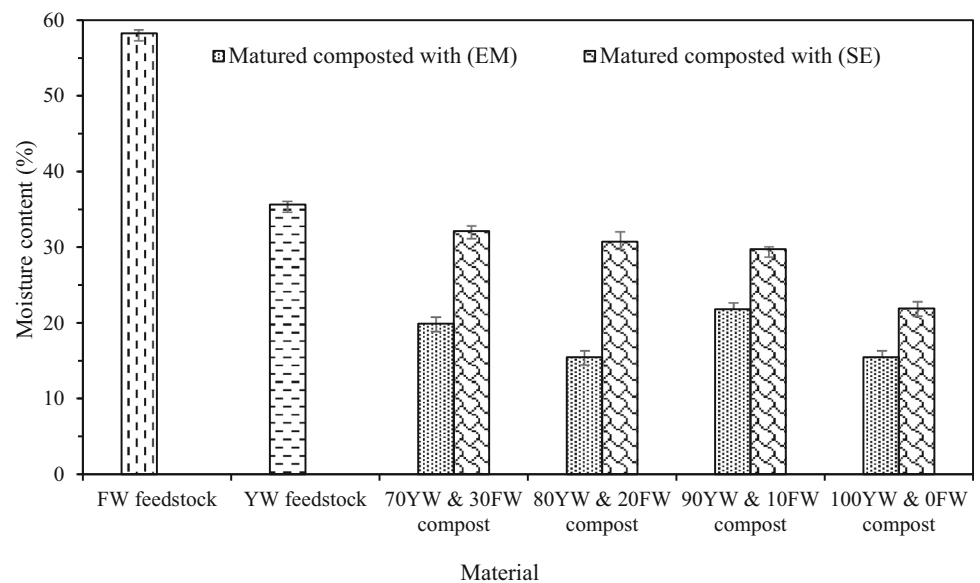
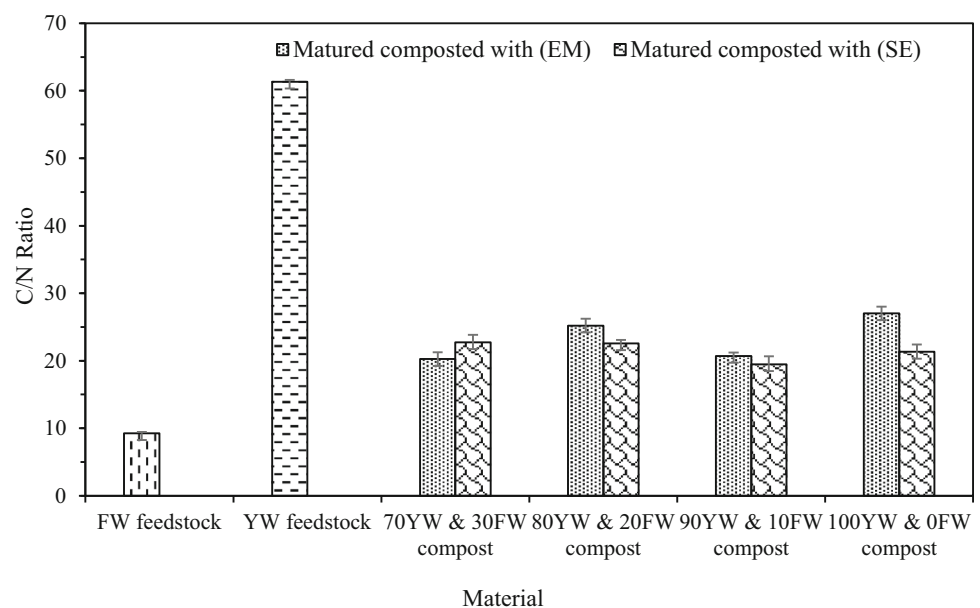


Fig. 3 C/N ratio of FW and YW feedstock and matured compost samples collected after curing with application of EM and SE additives



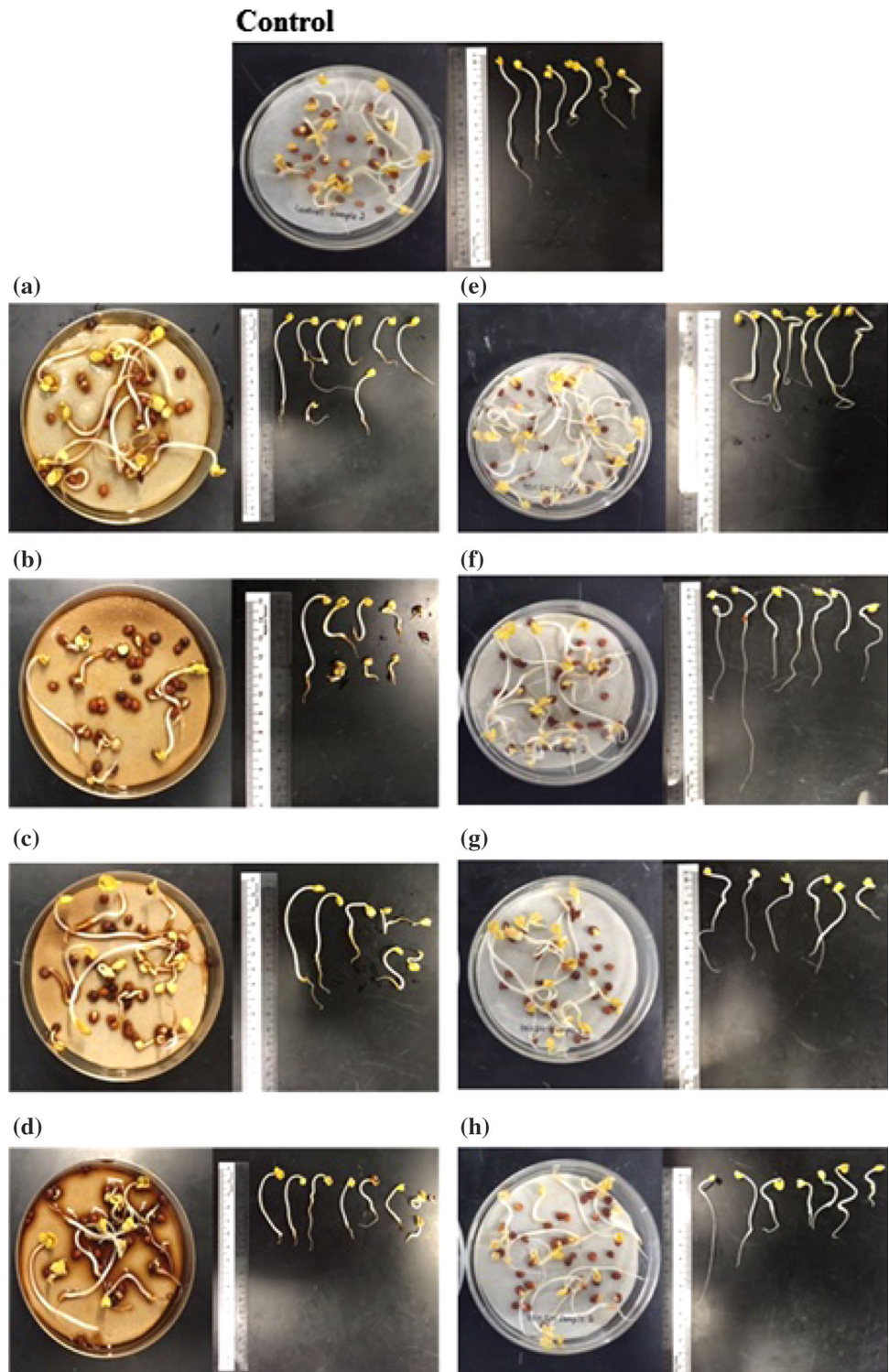
soluble phenol content as well as organic (Zahrim et al. 2016; Piotrowska-Cyplik et al. 2013).

Figure 6 shows NPK contents of produced compost with EM and SE additives. Nitrogen (N), phosphorus (P) and potassium (K) are among the most demanding nutrients by plants (Maathuis 2009).

Nitrogen mainly gives the plants dark green color and strong growth (Bojović and Marković 2009; Gastal and Lemaire 2002) while phosphorous (P) primarily results in healthy growth of roots and enhances crop quality (Ristvey et al. 2007). Enough potassium (K) content enhances plants' resistance against drought and diseases (Malvi 2011). Hence, NPK content of compost, as a benchmark for

compost quality, should be sufficient for plant growth (Rihani et al. 2010). All feedstock produced composts with acceptable levels of NPK. Good quality compost should have 0.4–3.5% nitrogen, 0.3–3.5% phosphorus and 0.5–1.8% potassium (Jaafarzadeh Haghghi Fard et al. 2015; Sadeghi et al. 2015). Addition of EM resulted in production of compost with higher percentages of nitrogen and phosphorus compared to SE. With addition of EM, feedstock with 10% FW recorded the best NPK value. Percentages of phosphorus and potassium decreased as FW percentage in the feedstock increased. In composts with SE additive, supplement of FW has no effect on phosphorus and potassium contents and almost similar percentages of P

Fig. 4 Seed germination test of control and compost produced using the 100%YW, 90%YW + 10%FW, 80%YW + 20%FW and 70%YW + 30%FW feedstock in case of EM (a–d) and SE (e–h) additives



and K were recorded in all compost samples. Nitrogen content, however, varied based on FW percentages. When compared with the compost produced using windrow method, with NPK values of $0.77\% \pm 0.2$, $0.92\% \pm 0.1$ and $1.58\% \pm 0.1$, composts produced in this study had better NPK content.

Conclusion

In-vessel co-composting of yard waste and food waste generated in Cameron Highlands, Malaysia was investigated with addition of effective microorganisms (EM) and Shimamoto Enzyme[®] (SE) in an actual-size composter.

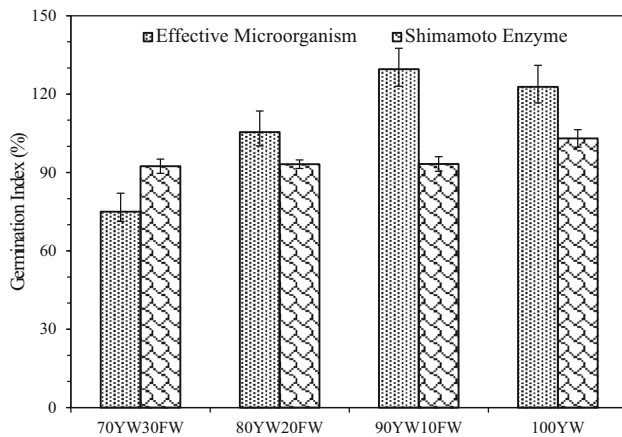


Fig. 5 Germination index results of produced compost with application of EM and SE additives

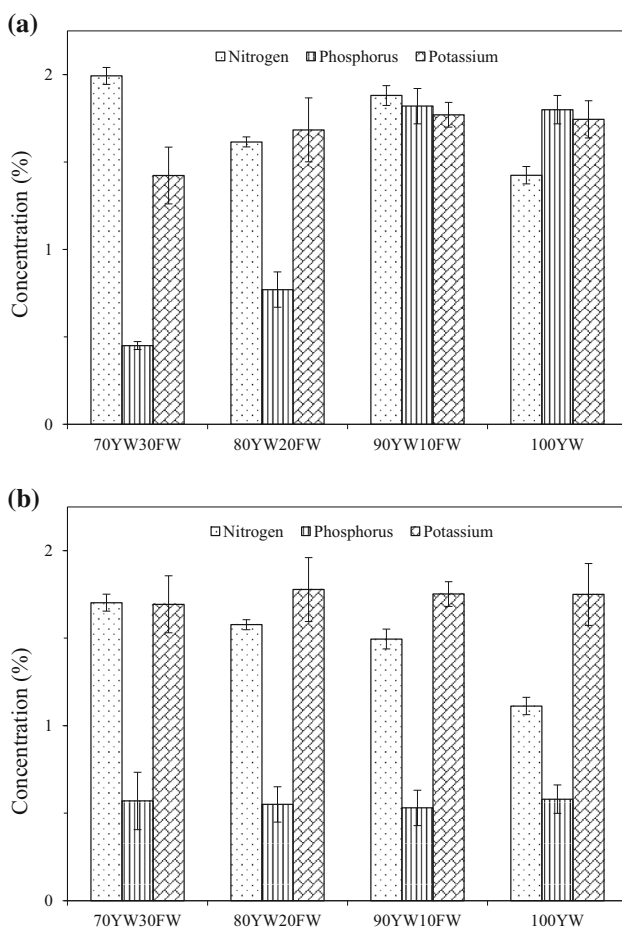


Fig. 6 NPK content of different compost compositions in case of **a** EM and **b** SE additives

Acceptable reduction of pH and C/N ratio was observed, specifically with the addition of effective microorganisms to the feedstock. All samples had insufficient moisture contents due to high percentage of yard waste in feedstock. Maturity tests of germination index and NPK value

indicated better quality of compost with EM additives compared to those with SE additive. Composts produced in this study have shown superior quality compared to the one produced in windrow method. Biological transformation of yard waste instead of its landfilling is not only a promising solution to overcome growing problems of solid waste management, but also reduces air and water pollution. In-vessel composting of yard waste instead of its windrow or aerated pile composting in Cameron Highlands, where the lands are in great demand, is an environmentally friendly and sustainable approach for solid waste management.

Acknowledgements This study was supported by the Ministry of Higher Education, Malaysia (MOHE) under classification of MyRA Grant scheme (0153AB-J13). Authors are thankful to Mr. Zaaba Mohammad and Mr. Ali Boualili for their kind assistance in this research. Cooperation from Mr. Leong Hua Qian and Magnificent Associated Nurseries Sdn Bhd for providing yard waste is highly appreciated.

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