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ORIGINAL RESEARCH

Composting paper and grass clippings with anaerobically treated palm oil mill effluent

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Abstract
Purpose The purpose of this study is to investigate the composting performance of anaerobically treated palm oil mill effluent (AnPOME) mixed with paper and grass clippings.
Methods Composting was conducted using a laboratory scale system for 40 days. Several parameters were determined: temperature, mass reduction, pH, electrical conductivity, colour, zeta potential, phytotoxicity and final compost nutrients.
Results The moisture content and compost mass were reduced by 24 and 18 %, respectively. Both final compost pH value and electrical conductivity were found to increase in value. Colour (measured as PtCo) was not suitable as a maturity indicator. The negative zeta potential values decreased from −12.25 to −21.80 mV. The phytotoxicity of the compost mixture was found to decrease in value during the process and the final nutrient value of the compost indicates its suitability as a soil conditioner.
Conclusions From this study, we conclude that the addition of paper and grass clippings can be a potential substrate to be composted with anaerobically treated palm oil mill effluent (AnPOME). The final compost produced is suitable for soil conditioner.

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Keywords Composting · Paper · Grass · Anaerobic palm oil mill effluent · Phytotoxicity

Introduction

The large volume of palm oil mill effluent (POME) in Malaysia contributes a major source of pollution (Bala et al. 2014) and it is difficult to handle in effluent treatment plants especially during the rainy season. It was reported that about 60 million tonnes of POME were generated from 421 palm oil mills in Malaysia in the year 2010 (Tabassum et al. 2015). Most of the POME is treated through a series of anaerobic ponds followed by aerobic ponds. However, black-dark-brown coloured effluent is generated from the anaerobic ponds which is difficult to biodegrade at the subsequent aerobic ponds (Zahrim et al. 2014). The anaerobically treated POME or AnPOME consists of particulates [0.32–0.39 % (w/w)] such as anaerobic microorganisms, bioflocs, and macrofibrils. The soluble fraction contains carbohydrates, pectin, lignin, tannin, humic and fulvic acid based substances, melanoidin and phenolic compounds (Zahrim 2014; Yaser et al. 2013).

There are several methods to treat AnPOME including membrane separation, advanced oxidation processes, ozonation, sonication, adsorption, ion exchange, coagulation/flocculation and biological treatment. Each treatment has their advantages and disadvantages (Zahrim 2014). Owing to the large volume of palm oil mill effluent, the treatment will be more efficient if the effluent loading rate can be reduced by recycling it as a substrate for the composting process and direct irrigation (Palaniappan 1993). Although, direct irrigation has the lowest operational cost, there is potential for leaching of nutrients into the soil over a long period of time, which could lead to an imbalance of nutrients for plant uptake (Palaniappan 1993). Composting is defined as an aerobic microbiological process that converts the organic substances of wastes into stabilized humus and less complex compounds (Xiao et al. 2009). The composting process is affected by many factors such as carbon to nitrogen ratio, moisture content, pH and aeration rate (Lim et al. 2016; Wu et al. 2014; Zahrim et al. 2015).

The issue of solid waste, such as paper and grass clippings is also becoming a challenging task for large metropolitan areas in most developing countries (Moh and Abd Manaf 2014). If this waste is not managed well, it will become a problem to the environment. Composting has been reported as a potential method for recycling paper and grass clippings (Ball et al. 2000; Francou et al. 2008; Juchelkova et al. 2015; Elouaqoudi et al. 2015). However, to the best of our knowledge, there is no published study on the composting of AnPOME mixed with paper and grass clippings, although these may offer complementary constituents e.g., in terms of nutrients and moisture content. Several studies have been conducted utilizing POME for composting with other materials e.g., (Zahrim et al. 2015). Recently, Hoe et al. (2016) evaluated the suitability of using POME-EFB compost as a carrier for nitrogen fixing bacteria (NFB) and phosphate solubilizing bacteria (PSB). In another study, Amira Dayana et al. (2011) showed the performance of *Trichoderma virens* as an activator for the conversion of empty fruit bunches (EFB) and palm oil mill effluent (POME) into compost. The authors reported that the N, P and K content of compost with *T. virens* increased significantly after maturation which was 1.304, 0.5034 and 0.645 %, respectively (Amira Dayana et al. 2011).

To obtain an efficient composting process, the influencing factors must be controlled and optimized. In this study, the AnPOME is utilized as a nutrient source and moisturizing agent for grass clippings–paper mixture. The performance of the process was evaluated based on temperature due to heat profiles, moisture content, mass reduction, pH level, electrical conductivity, colour, zeta potential and phytotoxicity.

Methods

A composting study was established at the Environmental Lab, Faculty of Engineering (FKJ), Universiti Malaysia Sabah which is located at Sabah, Malaysia. The study was conducted over a period of 40 days. A laboratory-scale composting system was used for this study (Figs. 1, 2). A plastic box with lid was used as the bioreactor with a dimension of 35.7 cm × 28.8 cm × 48 cm. The design of this bioreactor was inspired by our previous study (Yaser et al. 2007). From our perspective, the small bioreactor is easy to maintain i.e., less waste required and easy to control with low capital cost. The bioreactor was placed on two bricks and there were eight holes (1 cm diameter) at the bottom of the reactor to provide air into the reactor. A multipurpose tray was placed under the bioreactor so that cleanliness of the floor could be maintained. There were three holes (1 cm diameter) in the reactor lids and three holes (1 cm diameter) at the side of the reactor for inducing passive aeration. Two reactors were run simultaneously.

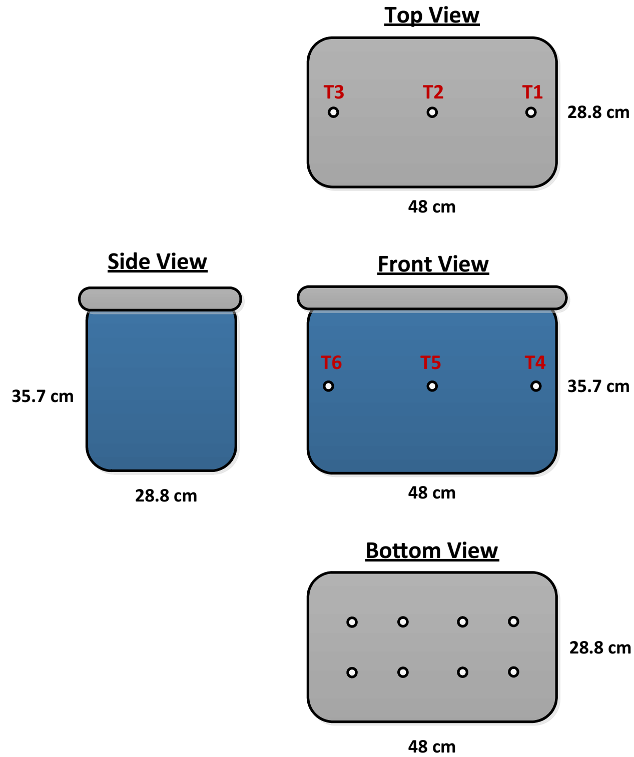

Fig. 1 Bioreactor design

Materials

About 2.4 kg of paper, 3.6 kg of grass, 1.8 kg of anaerobically treated palm oil mill effluent (AnPOME) and 1 kg of recycled compost were used as the experimental material in the composting process. These figures were obtained from the moisture balance analysis for the initial compost mixture. Paper used in the experiment was collected from the Faculty of Engineering (FKJ) office, University Malaysia Sabah and was shredded. Fresh grass was collected from house gardens in Kingfisher residential area. Recycled kitchen waste compost was supplied by a local house waste composter in Taman Indah Permai residential

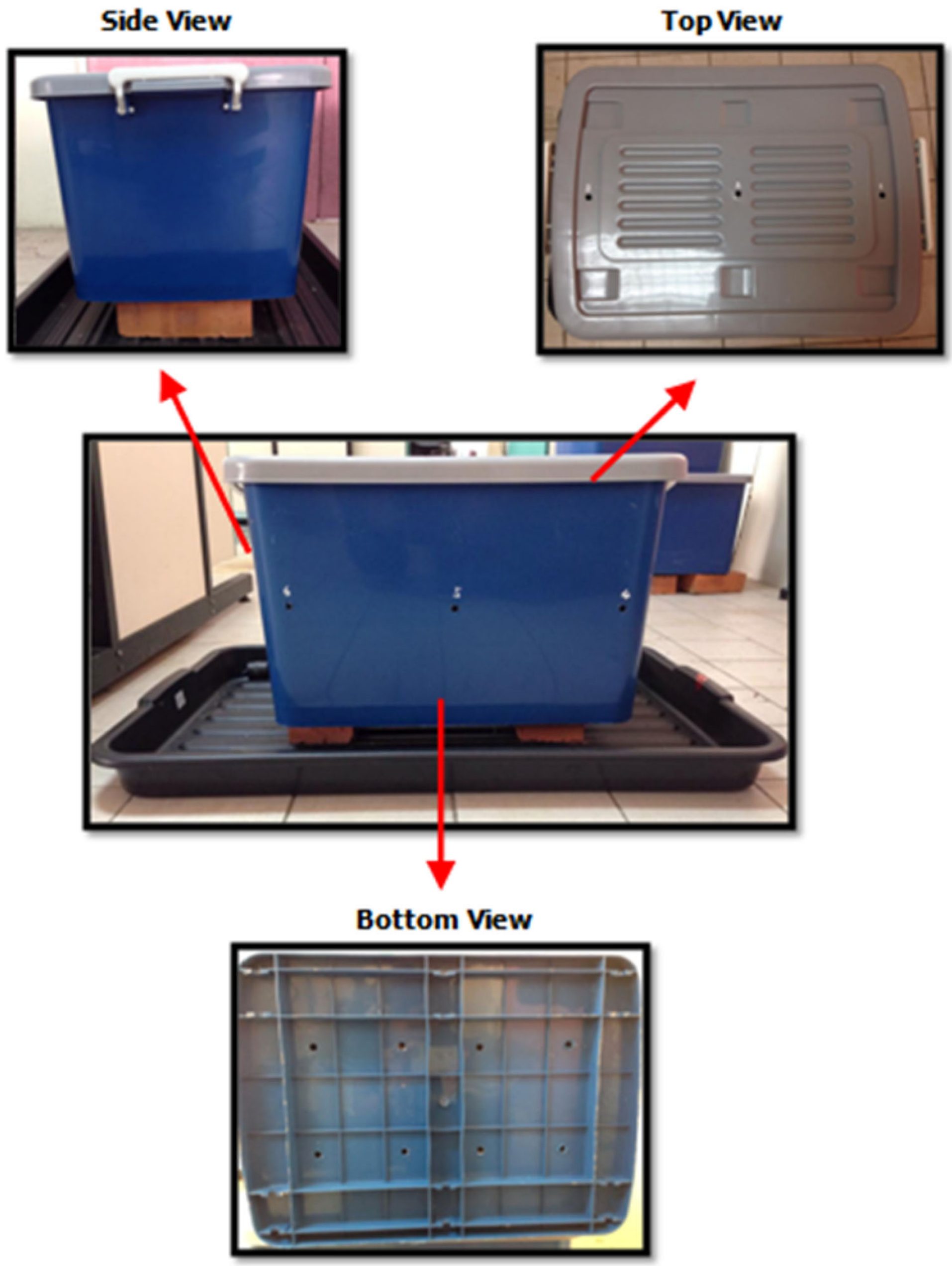

Fig. 2 Diagram of the bioreactor in laboratory-scale composting system

area to facilitate the composting process (Yaser et al. 2007). Normally, the kitchen compost has the following characteristics (Baishya et al. 2016): pH 07.6; N 0.198 %; P 0.212 %; K 0.399 %; Na 0.253 %; C/N 26. The AnPOME was collected from Sawit Kinabalu Kilang Lumadan, in Beaufort. AnPOME was used as a nutrient source and moisturizer for the composting process. The composting materials were manually mixed in the reactor to achieve better homogenization of material. Table 1 shows that the characteristics of the composting materials including moisture content, total organic carbon, total nitrogen, pH and electrical conductivity.

Sampling

The samples were taken from different places in the composting materials (top, middle, and bottom) after mixing. The analysis of the fresh samples was performed immediately after taking them out of the reactor; otherwise the sample would be covered by plastic and stored in the refrigerator. The collected samples that were not immediately analyzed from each time period were stored at −4 °C until required for analysis of moisture content, total organic carbon, total nitrogen, pH, electric conductivity and phytotoxicity. For the whole sampling procedure, the total

Table 1 Characteristics of the composting materials

Characteristics of materials	Moisture content (%)	Total organic carbon (%)	Total nitrogen (%)	pH	Electrical conductivity (dS m^{-1})
Paper	8	41.4, Siang and Zakaria (2006)	0.11, Siang and Zakaria (2006)	6.9	0.13
Grass	71.38	18.4, Traversa et al. (2014)	1.56, Traversa et al. (2014)	5.8	0.54
Anaerobic palm oil mill effluent	–	100[a], Zahrim et al. (2014)	200[b], Zahrim et al. (2014)	7.0	3.03

[a] Chemical oxygen demand (COD), mg/L

[b] Ammonia nitrogen, mg/L

mass of samples taken was less than 5 % of the total mass of the mixture.

Physicochemical analysis

Temperature of the compost and ambient temperature were measured daily over the period of 40 days. A digital thermometer was inserted into the six holes of the reactor to measure the temperature of compost [T1, T2, T3, T4, T5, and T6) at six different places (refer to Fig. 2)]. The ambient temperature was also determined using the digital thermometer and recorded.

20 g of sample was taken to measure the moisture content on days 0, 10, 20, 30 and 40. The moisture content of the mixture was determined by the dry oven method at 105 °C for 24 h (Petric et al. 2012). The initial mass and final mass of the mixture were recorded. The moisture content of the mixture was calculated by using the following formula:

$$\text{Moisture content }(\%) = \frac{\text{Initial mass} - \text{final mass}}{\text{Initial mass}} \times 100\,\%$$

The mass reduction was measured on days 0, 10, 20, 30 and 40. The mass reduction of each compost sample was calculated as the difference between the original mass and the mass at each sampling time, accounting for any removal from previous samplings. The pH and electric conductivity of the mixture were determined on days 0, 10, 20, 30 and 40. 10 g sample was added to 100 mL distilled water, mixed with magnetic stirrer for 20 min, allowed to stand for 24 h and then filtered. The solution was analyzed using a pH/conductivity meter (HI9811-5, Hanna Instrument Ltd.) (Yaser et al. 2007). Samples were taken on days 0, 10, 20, 30 and 40 to test the colour of the compost. 10 g sample was added to 100 mL distilled water, mixed with magnetic stirrer for 20 min, let stand for 24 h, and then filtered. The absorbance at $\lambda_{max} = 455$ nm was used to analyze colour of the solution with a HACH DR/2010 Spectrophotometer based on HACH DR/2010 Spectrophotometer Procedure Manual from HACH Company, USA, 1996–2000.

The zeta potential of the compost was determined on days 0, 10, 20, 30 and 40. 10 g sample was added to 100 mL distilled water, mixed with magnetic stirrer for 20 min, let stand for 24 h and then filtered. The solution was tested by using a Malvern-Zetasizer Nano Series model ZS machine to determine the zeta potential of the compost.

A germination test was used to evaluate the phytotoxicity of the compost on days 0, 20 and 40. The cabbage seeds (Brassica oleracea) were bought from Lian Lee Kimia Sdn. Bhd., Kota Kinabalu, Sabah. The cabbage seeds were soaked in distilled water for 24 h to determine the initial condition of the seeds. 10 g of fresh sample and 50 mL distilled water were mixed to make water-soluble extracts from the compost. Ten cabbage seeds were tested in 5 mL of water-soluble extracts of compost in petri dishes with a piece of filter paper in darkness at room temperature for 3 days. Another ten cabbage seeds were tested in 5 mL distilled water with a piece of filter paper as the control (El Fels et al. 2014). The number of germinated seeds was calculated and the growth of roots was recorded after 3 days. The percentage of relative seed germination (RSG), relative root growth (RRG) and germination index (GI) were calculated according to the following formula (Miaomiao et al. 2009):

$$\text{RSG }(\%) = \frac{\text{number of seeds germinated in sample extract}}{\text{number of seeds germinated in control}} \times 100$$

$$\text{RRG }(\%) = \frac{\text{root length in sample extract}}{\text{root length in control}} \times 100$$

$$\text{GI }(\%) = \frac{\text{RSG} \times \text{RRG}}{100}$$

Results and discussions

Temperature profiles

Figure 3 shows the changes in the compost temperature (T1, T2, T3, T4, T5, and T6) and ambient temperature over

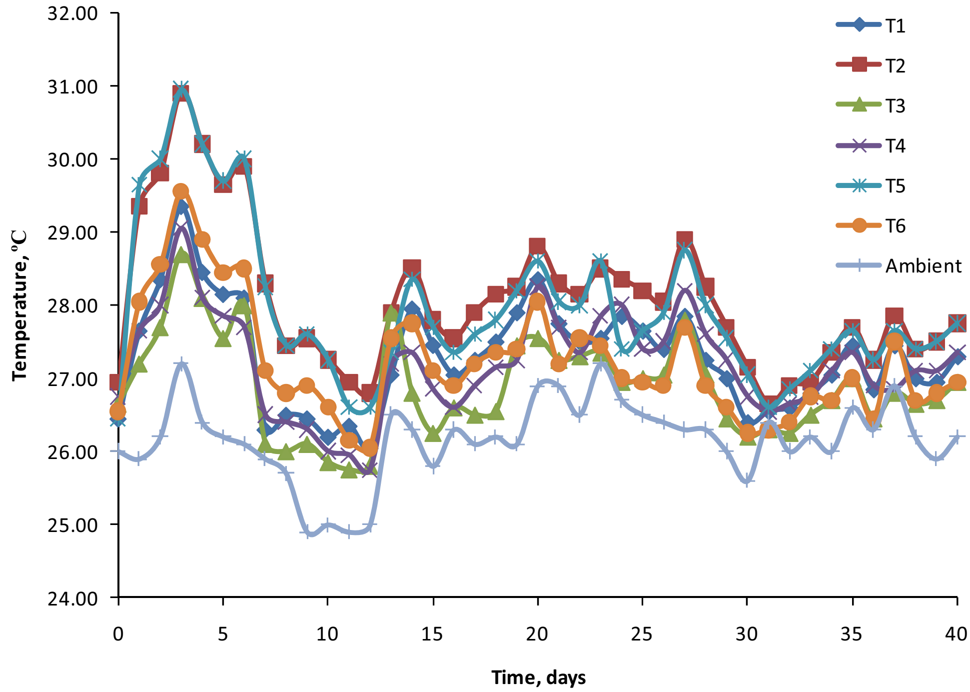

Fig. 3 Profiles of temperature during composting

the period of 40 days composting. The profiles of temperature correspond to the stages of composting, microbial activity and microbial group proliferation (Liu and Price 2011). The compost temperatures varied between 25.75 and 30.95 °C, and the ambient temperatures ranged from 24.90 to 27.2 °C. It can be seen that there is a similar pattern in the changes of compost temperature and ambient temperature. The compost temperatures (T2 and T4) showed higher temperature than the others. This might be because of less ventilation in the center of the reactor and thus more heat might be trapped that led to higher temperature. The rise in compost temperatures after the initial peak temperature is due to a renewed increase in the microbial activity (Atagana 2004). At the end of the composting process, the low temperature of the compost indicates that the microbial activity has become weaker.

The compost temperature (T4) reached the highest temperature of 30.95 °C on day 3. However, this temperature did not achieve the thermophilic temperature which is about 40–65 °C. Similar results have been reported by Lai et al. (2013), Holmqvist and Stenstrom (2002) and Paradelo et al. (2013). This is most probably due to lack of green waste (Lai et al. 2013; Paradelo et al. 2013) and the small size of reactor (Tang et al. 2007). In addition, it could be caused by the insufficient isolation of the composting material (Paradelo et al. 2013) and the high humidity in the reactor during composting (Lai et al. 2013). As a result, the heat might be easily dissipated during composting thus slowing down the decomposition of organic matter and the emission of nitrogenous products (Lai et al. 2013; Tang et al. 2007).

Moisture content

A moisture content of 50 % is the minimal requirement for composting (Liang et al. 2003). Figure 4 shows moisture content profiles for this study. As compared to other studies (Kalamdhad and Kazmi 2009; Villegas and Huilinir 2014; Kulcu and Yaldiz 2004), the trend of the moisture content is almost the same; that is, the moisture content decreased slowly as the composting proceeded. In the beginning, the moisture content of the paper–grass clipping–AnPOME compost was 70.35 % and the final compost moisture content obtained was 53.40 %. Rapid drop in moisture content, such as this, is due to high heat generation in composting that leads to higher water loss (Kulcu and Yaldiz 2004). In the interval of time: days 10–40, the moisture content of the compost increased to ~56 % due to the lower heat generation. Consequently, the condensed vapor that attached to the back of the reactor's lid fell back into the mixture (Unmar and Mohee 2008).

Mass reduction

Mass reduction determines the effectiveness of composting as a waste disposal technique (Tang et al. 2007). Figure 5 shows the mass profiles over the study period. In this study, the waste compost gave a mass reduction of 18.29 %; which is in the range of other studies (see Table 2). In general, a thermophilic process is believed to accelerate composting. However, based on a study by Arrigoni et al. (2015), a thermophilic process is not a guarantee for higher

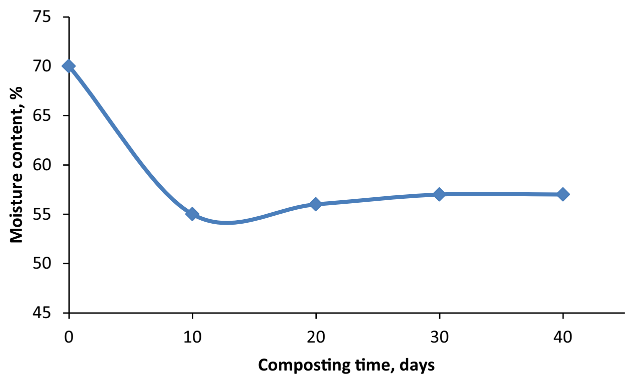

Fig. 4 Moisture content profiles

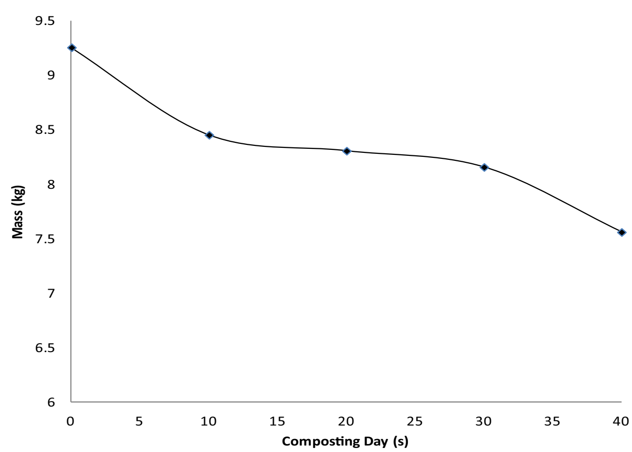

Fig. 5 The change in mass over composting days

mass reduction (see Table 2). The lower mass reductions might be due to the presence of lignin, which is relatively more degradable in aerobic environments but refractory in anaerobic ones (Komilis and Ham 2003). According to Loow et al. (2015), lignin acts as a protective barrier, impermeable and immune to attack from microorganisms and chemical degradation.

Profiles of pH and conductivity

Figure 6 shows pH and electric conductivity against the number of days during the composting process. According to theory, the increase in pH during the first stage of composting can be attributed to the production of ammonia associated with protein degradation in the samples and to the decomposition of organic acids (Liu et al. 2011), or bioconversion of organic nitrogen into free ammonia (Altieri et al. 2011). Based on this study, the pH obtained increased slightly from day 0 to day 40. The highest pH obtained during the composting was 7.4 and the lowest pH was 6.95. Based on this study, the trend was for the electrical conductivity to increase during composting. The increase in electrical conductivity is caused by the accumulation of mineral salts as a result of degradation of organic matter (Bustamante et al. 2012).

Colour

The maturity stage of the compost can be evaluated by the change of color. The change in color of the compost during the composting process reflects the aesthetic quality and potential acceptability of the final compost, which indicates the stabilization of the compost (Mbuligwe et al. 2002). The variation in the colour of compost during the composting period gives an indication of the degree of stabilization of the compost (Mbuligwe et al. 2002). The results showed that after 40 days the color of the compost darkened, which is an indication of stabilization. The changes in color during the composting process might be due to the presence of dissolved and particulate organic matter (Chatterjee et al. 2013). The dark-colored composts lead to higher light absorption and lower reflection rate of light (known as albedo). As a consequence, the dark colored compost will warm up faster due to the higher light absorption as compared to light-colored compost (Fischer and Glaser 2012). Figure 7 indicates the color changes

Table 2 Mass reduction in several composting processes

Substrate	Composting time	Highest temperature (°C)	Mass reduction (%)	References
Paper–grass clippings–AnPOME	40	31	18	This study
Paper–meat–vegetables	140	50–53	5.5–7.1	Arrigoni et al. (2015)
Garden waste	20	52	40–57	Colomer-Mendoza et al. (2012)
Domestic waste	40	70	78	Elango et al. (2009)
Kitchen waste	120	57	59–62	Karnchanawong and Suriyanon (2011)
Biodegradable plastic with green wastes	56	63.3	53.2	Unmar and Mohee (2008)

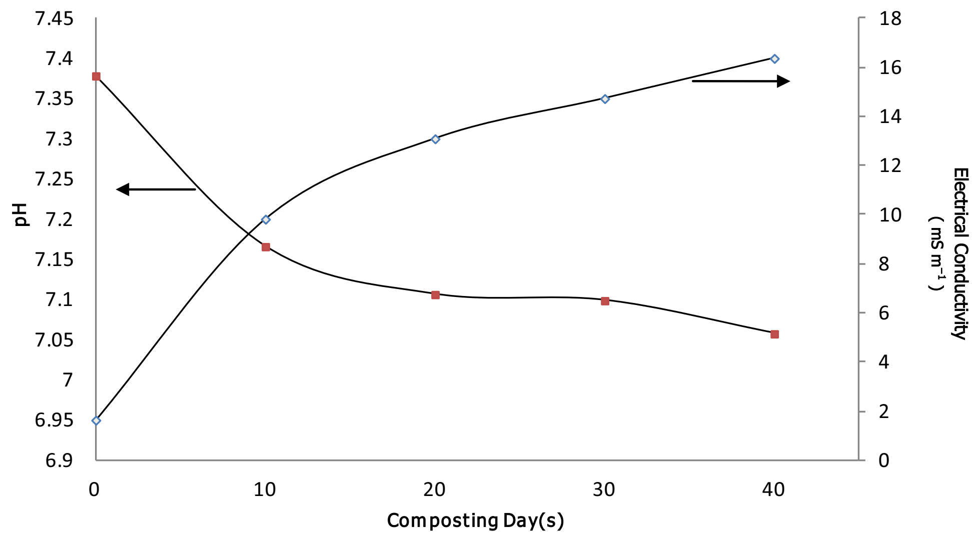

Fig. 6 Profile of pH and electrical conductivity (EC) during the composting process

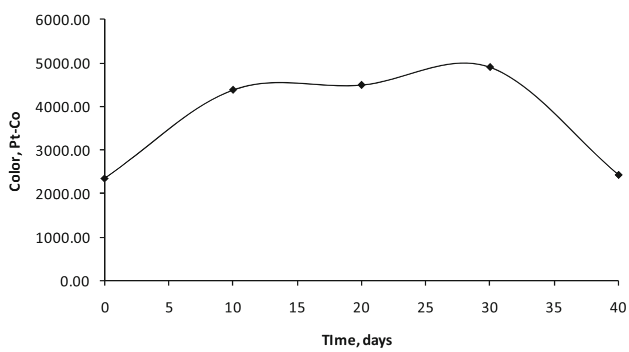

Fig. 7 Changes in color of the compost during composting

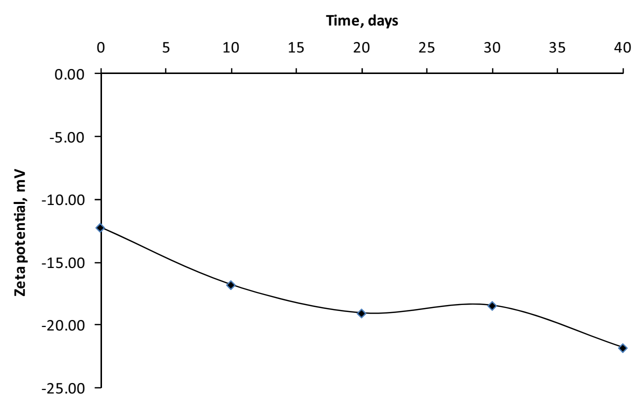

Fig. 8 Profiles of zeta potential during composting

during the 40 days of paper–grass clippings–AnPOME composting. With the increase of composting time, the color of compost gradually increased from initial color of 2353 Pt–Co to maximal 4903 Pt–Co on day 30 and then decreased to 2434 Pt–Co at the end of the composting process. However, colour is not suitable as maturity indicator in this study as there is no continuous increase in the colour of the compost as can be observed from the results in Fig. 7.

Zeta potential

The profiles of zeta potential over the composting period is shown in Fig. 8. Zeta potential can be expressed as the potential difference between the dispersion medium and the stationary layer of fluid attached to the dispersed particles. It indicates the electric potential variation of the residue surface during the decomposition period (Li et al. 2014). Surface charge (characterized as zeta potential) is often used to indicate the surface characteristics (Yan et al. 2015). In this study, the results revealed that negative values of zeta potential were obtained in the whole composting process. As composting progressed, the zeta-potential value of the compost decreased gradually from −12.25 to −19.05 mV in the first 20 days. It can be seen that there was a slight increase on day 30 with a zeta potential value of −18.05 mV. The lowest zeta potential value of −21.80 mV was observed on the last day of composting. As reported by Zahrim et al. (2014), although the POME is negatively charged from the beginning (i.e., in anaerobic ponds), the POME tends to be more negative in the following treatments i.e., in aerobic ponds, due to the degradation of organic matter.

Phytotoxicity

The germination index (GI) test is often used to evaluate the compost maturity and phytotoxicity of organic wastes (Miaomiao et al. 2009). Germination index can be indicative that low toxicity is affecting root growth while high toxicity can affect germination (He et al. 2009). The

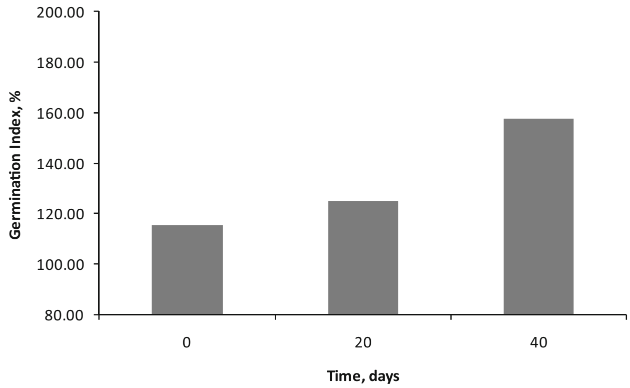

Fig. 9 Profiles of germination index during composting

Table 3 Physicochemical analysis of initial and final compost

Composition	Initial compost mixture	Final compost	Recommended value for ideal stand-alone substrate
C/*N* ratio	33.39	30.93	<20 (Jimenes and Garcia 1989; Yaser et al. 2007)
P_2O_5, %	ND	0.09	>0.5 (Nogueira et al. 1999; Yaser et al. 2007)
K_2O, %	ND	0.43	>1.5 (Nogueira et al. 1999; Yaser et al. 2007)
pH	7.36	7.2	5.5–6.5 (Poole et al. 1981; Yaser et al. 2007)
C, %	38.4	37.19	–
N, %	1.15	1.20	–
MgO, %	ND	0.20	–

ND not determined

variation of the germination index of the composting process using cabbage seeds (*Brassica oleracea*) is illustrated in Fig. 9. The results showed that the germination index of the compost had increased gradually with GI values of 115.66, 124.74 and 157.61 % on days 0, 20 and 40, respectively. The germination index increased with the age of composting, indicating the decomposition of toxic materials in the composting process (He et al. 2009). These results reflected that phytotoxicity of compost reduced during the composting process and the beneficial effects on *Brassica oleracea* (cabbage) were more noticeable. The reduction in phytotoxicity is most likely due to the reduction of the fatty substance and soluble phenol content, and also the changes in level of organic acids (Piotrowska-Cyplik et al. 2013). In this study, GI content of the compost had exceeded 80 % indicating phytotoxic-free and mature compost (Gao et al. 2010; Gopinathan and Thirumurthy 2012; Guo et al. 2012).

Final nutrients

Table 3 shows the nutrient data of the final compost in this study that was analyzed by PCM Prestige Central Management Sdn. Bhd. From Table 3, it can be seen that the pH of the compost is 7.2 which needs to be adjusted before it can be used as a substrate. The pH value obtained in this study is within the range of other findings i.e., pH 5.6–8.5 (Zahrim and Asis 2010). The compost nutrient content i.e., N, P, K and Mg (Table 3) is considered to be in the acceptable range and could help the farmers to reduce reliance on inorganic fertilizer and simultaneously improve the soil condition. Application of inorganic fertilizer is costly and could turn the soil more acidic. Also, excessive use of inorganic fertilizers without organic supplements not only deteriorates the physical and chemical properties of the soil but also pollutes the surrounding environment (Lim et al. 2015).

The *C*/*N* ratio in this study, i.e., 30.19, is higher than the recommended value for an ideal substrate. It should be noted that, the further stabilization occurred after application to the soil. It was reported that a *C*/*N* of approximately 20 is reported to be phytotoxic-free although the compost is considered as immature (Alam and Ainuddin 2007). A larger amount of grass clippings could be used in the composting to improve *C*/*N* ratio of compost by increasing the nitrogen content. The composting time is suggested to be increased so that greater mineralization of organic matter can be achieved.

Conclusions

In this study, a mixture of paper–grass clippings–AnPOME was decomposed for 40 days. The highest compost temperature (31 °C) was achieved on day 3 of the composting process. The pH value was increased slightly from 6.95 to 7.4. The electrical conductivity also increased. The moisture content was decreased slightly from 70.35 to 53.40 % while the compost mass reduction was 18.29 %. Since the trend of colour (measured as PtCo) is not consistent in this study, the colour is not suitable as a maturity indicator. The negative zeta potential values decreased from −12.25 to −21.80 mV due to organic degradation. The results show that phytotoxicity of compost reduced during the composting process as the germination index increased.

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