Pertanika J. Trop. Agric. Sc. 42 (4): 1391 - 1403 (2019)

TROPICAL AGRICULTURAL SCIENCE

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

The Role of Wood Vinegar in Enhancing the Microbial Activity and Physicochemical Properties of Palm Oil-Based Compost

Nor Hanuni Ramli*, Nur Eliza Badrul Hisham, Farhan Mohd Said, Nur Ezyan Badrul Hisham and Olusegun Abayomi Olalere

Faculty of Chemical & Process Engineering Technology, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang Kuantan, Pahang, Malaysia

ABSTRACT

This paper presents an experimental study of the effect of wood vinegar at different concentrations on the biological and physicochemical properties of the composts by using the solution with the ratio of wood vinegar to distilled water in the range of 1:100 to 1:500 (v/v). The composting process was conducted by in-vessel composting method within 60 days where temperature and pH were recorded daily. The composts were then analyzed on the microbe counts, pH, moisture content, water holding capacity, and nutrient contents. XRF and CHNS analyzers were used to measure the NPK content exist before and after composting process. This research attempted to investigate the effect of wood vinegar concentration towards physiochemical and biological properties of the composts. The results showed that lower concentration of wood vinegar could potentially enhance microbial activity which could accelerate the composting process. However, in terms of physical properties, sample 1:400 (v/v) had recorded the highest reading for water holding capacity and moisture content which were about 2 to 19 % (ml/100g) and 1 to 27 % (w/w) higher than other samples, respectively. Therefore, it can be concluded that sample 1:400 (v/v) shows the best condition where it has

ARTICLE INFO

Article history:
Received: 7 May 2019
Accepted: 24 September 2019
Published: 13 November 2019

E-mail addresses:
drhanuni@ump.edu.my (Nor Hanuni Ramli)
elizahisham21@gmail.com (Nur Eliza Badrul Hisham)
farhan@ump.edu.my (Farhan Mohd Said)
ezyanhisham@yahoo.com (Nur Ezyan Badrul Hisham)
olabayor@gmail.com (Olusegun Abayomi Olalere)
* Corresponding author

ISSN: 1511-3701
e-ISSN: 2231-8542

achieved well-balanced condition between physicochemical and biological properties.

Keywords: Compost, microbe growth, wood vinegar

INTRODUCTION

Fertilizer plays a major role in agriculture sector. Both organic and inorganic (chemical) fertilizers are widely used in all countries, including Malaysia. The continuous use of chemical fertilizers poses a tremendous risk to the soil and environment. The need of having a new alternative to replace the use of chemical fertilizers has urged the research enthusiasts to discover a new way of benefiting the organic waste. Nowadays, organic farming has become more popular compared to the farming that involves the utilization of chemical fertilizers as it is inexpensive and can be the source of plant nutrients (Yap, 2012).

In Malaysia, palm oil production is currently the most significant agricultural export for the country and has increased due to global demand (Otieno et al., 2016). The increase in the palm oil production has caused pollution to the environment where enormous amounts of palm oil mill effluent (POME) sludge is generated and can be regarded as pollutant and waste material (Kanakaraju et al., 2016). POME sludge is a bio-waste generated from palm oil mills during the processing of the palm fruit for palm oil production (Obi, 2015). According to Rupani et al. (2010), POME sludge has pH of 8.4 with moisture content of 85.0 %. Besides that, POME sludge also contains 3.6 % nitrogen, 0.9 % phosphorus and 2.1 % potassium. Other than that, palm oil mill also produces decanter cake (DC) as waste. DC generates about 4-5 % from the total weight of fresh fruit bunch (FFB) (Dewayanto et al., 2015). DC accounts for 28.5% of the fresh fruit bunch (FFB) and it can be applied as an amendment to soil for the growth of the plant (Embrandiri et al., 2016). DC also has high moisture content, high biodegradability and nutrient-rich contents (Sahad et al., 2014). Research by Yahya et al. (2010) had reported that DC contained about 2.38 % nitrogen, 0.39 % phosphorus and 2.39 % potassium. Meanwhile, rice husk (RH) is an abundant agricultural solid waste which is the result of rice-milling process (Lin et al., 2012). The burning process of RH to generate electricity has produced rice husk ash (RHA). The ash contains 87-97 % silica that makes it a valuable material for agricultural application (Kumar et al., 2012). In agriculture activities, one of the alternatives to reduce the dependence on the use of chemical pesticides and inorganic fertilizers is wood vinegar. Wood vinegar or pyroligneous acid is a kind of crude reddish-brown liquid which is produced from distillation of biomass during pyrolysis process (Zhai et al., 2015). Basically wood vinegar contains acetic acid (34.4 %) propanoic acid (2%) and methanol (5.2 %) as reported by Payamara (2011). In agriculture, wood vinegar is used to promote rooting and germination of seed (Zhai et al., 2015). If applied to the soil in high concentrations, wood vinegar inhibits eelworms and soil diseases. However, in lower concentrations, it increases the quantity of useful microbes (Kishimoto & Tsuyoshi, 2015).

To overcome the excessive production of POME, the wastes from the palm oil industry can be utilized as organic fertilizer. Although many research has been conducted using POME sludge and DC, there is still lack of data about the effect of these wastes on the composting process. Rice husk and wood vinegar are claimed to be very beneficial to the plant and compost. Thus, the aim of this research is to study the effect of wood vinegar concentrations on biological and physicochemical properties of the composts. The properties include microbe counts, pH, moisture content, water holding capacity, and N, P, K values.

MATERIALS AND METHODS

Sample Preparation

The palm oil mill sludge and decanter cake were collected at FELDA Neram, Terengganu, Malaysia, and the rice husk ash was obtained from Salloma Nursery, Pahang, Malaysia. The wood vinegar was supplied in-kind by ACGE Company, Singapore.

Raw Material Analysis

In order to analyze the raw material, the samples were dried and ground to 0.08 mm before it was tested for physical and chemical properties. For physical properties, samples were analyzed in terms of moisture content, water holding capacity and pH. In order to analyze the moisture content, the samples were weighed before dried in an oven at 105 ± 2°C for 5 h. Then, the samples were taken out from oven and be weighed again. Standard test ASTM D4442-16 was used to calculate the moisture content of sample.

For water holding capacity, the samples were saturated with water by mixing 10 g of sample with 50 mL of water. The weight of the samples with dropped off water were recorded at 30 min intervals until the sample began to dry. After that, the samples were dried at 105°C for 48 h in an over and were weighed again. The water holding capacity was calculated based on standard test ASTM D2980-02. Apart from that, pH of samples was determined by using Takemura DM15 soil pH meter. The pH meter was inserted into the compost and the reading of pH was taken. Meanwhile for chemical properties, analysis of CHNS and XRF were used. For XRF analysis, standard test ASTM E1621 was used to detect the percentage of phosphorus and potassium. The WDXRF X-ray fluorescence spectrometer instrument, model Axios^{mAX} made in Netherlands by PANalytical was used in the investigation. Meanwhile for CHNS analysis, standard test ASTM D5291 was used to detect percentage of nitrogen.

Effect of Wood Vinegar Concentration on the Growth of Microbe

The wood vinegar was diluted in distilled water. The ratio of wood vinegar to distilled water that were prepared are 1:100, 1:200, 1:300, 1:400 and 1:500 (v/v), in which that, 1 mL of wood vinegar was added into the distilled water of 100 mL, 200 mL, 300 mL, 400 mL and 500 mL for dilution process. The best concentration of wood vinegar in compost mixture towards the microbe growth was chosen based on the highest microbe count (CFU) on nutrient agar after 3 to 5 days of incubation period. Each of the colored dots appeared on the surface of nutrient agar were counted regardless of size and color intensity ("Microbiological examination – Total colony number SCAN-CM 60:02 SCAN-P 81:02", 2002).

Effect of Wood Vinegar on Composting Process

The wood vinegar concentration in the range of 1:100 to 1:500 (v/v) were added to the compost mixture consist of palm oil mill effluent (POME) sludge, decanter cake (DC) and rice husk ash (RHA) with the weight of the compost mixtures was 5 kg. Meanwhile, the mass composition for POME, DC and RHA were based on the previous research reported by Ramli et al. (2016). The process of composting was carried out by using in-vessel composting in a size of 16 cm (H) x 30 cm (L) x 18 cm (W). In order to ensure the samples, reach maturation stage, the temperature and pH of the compost were recorded and monitored daily for 60 days. The composts were turned once a week by using a spade to aid the decomposition process. Apart from that, 200 mL of water was added to the compost once a week in order to maintain the moisture content within the range of 40 to 65 % as suggested by Woods End Research Laboratory (WERL) (2005) and Zakarya et al. (2018). Once the composting process was completed, the samples were then analyzed for physicochemical properties. For this property, the same analysis procedure described in raw material analysis was repeated.

RESULTS AND DISCUSSION

Effect of Wood Vinegar on Microbe Count

The total number of microbes was counted using the colony counts technique. Figure 1 shows the result that was obtained from the experiment. For this experiment, it was expected that the dilution of wood vinegar at ratio 1:300 to 1:500 (v/v) would significantly give a higher count of total microbes (Rui et al., 2014). Based on Figure 1, it shows that the mixture of 1:500 (v/v) of wood vinegar to the sample of POME sludge and rice husk gave the highest colony count with the value of 1.1×10^{18} CFU/mL, while the control sample with absence of wood vinegar solution, only gave the colony counts of 4×10^{17} CFU/mL.

According to Kishimoto and Tsuyoshi (2015), in high concentrations, the wood vinegar is applicable to inhibit the soil diseases. While, at low concentrations, the wood vinegar can be used to improve the quantity of useful microbes. This is because, at high concentrations, the high acidity and the presence of germicidal ingredients such as phenol and methanol in wood vinegar tend to kill the microbes which are weak in acid. However, at low concentration, the population of microbes is significantly increased which is due to the effect of acetic

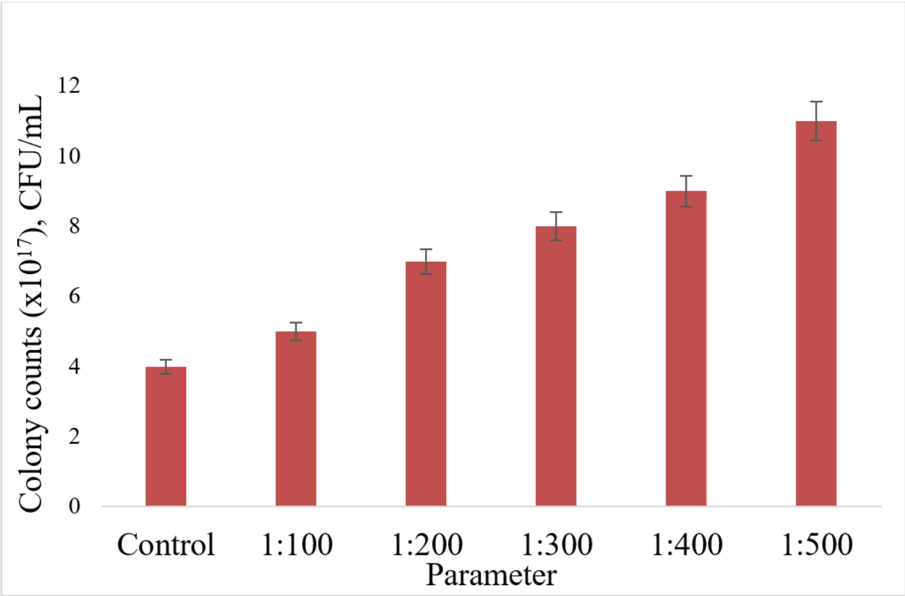

Figure 1. Colony counts of microbes

acids exist in wood vinegar. A substance named as acetyl coenzyme is produced from the presence of acetic acids. The acetyl coenzyme will be further converted into various substances that can facilitate the plants and microbes' growth. However, at a very low concentration of acetic acid, the effect on the growth of microbe would be insignificant as stated by Rui et al. (2014) in their research. Thus, the wood vinegar at 600 fold dilution gave lower microbe count compared to 300 fold and 500 fold dilution of wood vinegar. Therefore, the best concentration of wood vinegar should not be prepared greater than 500 fold dilution to avoid insignificant effect of acetic acid towards the growth of the microbe (Benzon et al., 2015).

Temperature Profile of Compost

The temperature is an important parameter to determine the success of composting process. The heat produced by the compost is a by-product of the microbial breakdown of organic material. In this experimental study, the composts were synthesized using the mixture of palm oil mill effluent (POME) sludge, decanter cake, rice husk and the solutions at different concentrations of wood vinegar. The temperature profile of the compost throughout composting period of 60 days is illustrated in Figure 2.

Based on Figure 2, the temperature of the composts started to rise from day 10 until the temperature reached more than 40 °C. This stage is known as mesophilic stage. The stage when the temperature is maintained at temperature between 41°C to 77°C is known as thermophilic stage of composting. However, for these composts, the temperature obtained by the composts was not high enough to maintain the thermophilic stage. Some of the composts might not be able to enter this stage. This might be due to the size of plastic container that was too small and leads to the heat loss to the surrounding (Misra et al., 2003). Hence, other external factors such as weather, humidity of surrounding area and thickness of container might also promote the heat loss and caused the compost unable to achieve the temperature above 41°C. However, at this stage the composts still managed to maintain the maximum temperature repeatedly for about 6 days before the temperature dropped to ambient temperature. The similar pattern of temperature profile was also reported by Trisakti et al. (2018). The next stage would be the curing stage. Figure 2 shows the curing stage was between day 40 to day 60, whereby the temperature of compost was slowly dropped to the ambient temperature. At this stage, there is no longer rise in temperature as the compost is already stabilized and the residual substances are fully consumed (Lee, 2016).

According to Sarkar and Chourasia (2017), vigorous microbial activity and rapid degradation of organic matter may increase the compost temperature. From Figure 2, the highest temperature was achieved by sample 1:400 (v/v). However, for the microbe counts, the highest value was obtained by sample 1:500 (v/v) as shown in Figure 1. This contradiction might be due to the insufficient aeration of sample 1:400 (v/v) as manual turning was done on the composts. Previous research by Zhi-Qiang et al. (2017) indicated that the lacked of aeration on the compost had led to the increase of compost temperature, which similarly happened in this case.

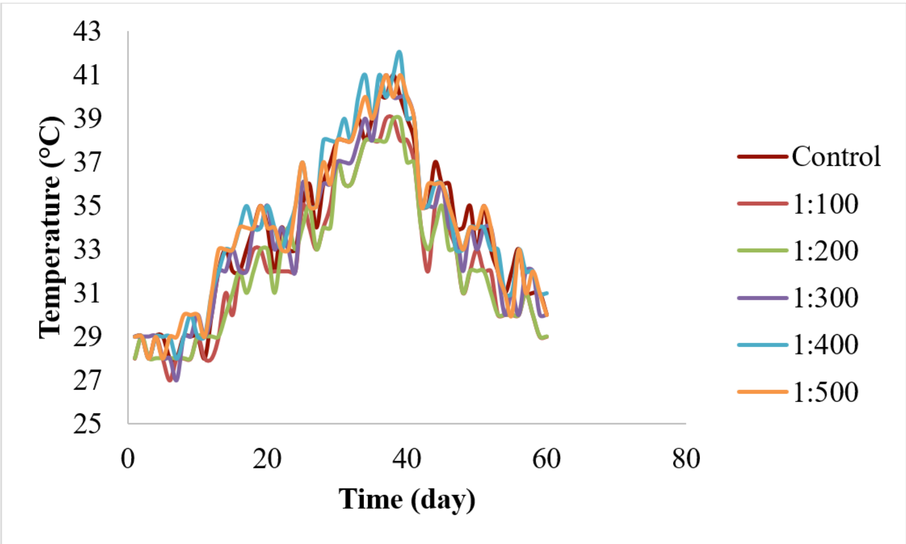

Figure 2. Temperature profile of the compost throughout composting period of 60 days

pH Profile of Compost

The pH of the composts was monitored daily for 60 days. The pH profile for the composting process is presented in Figure 3. Based on the figure, it shows that, at the beginning of the composting process, the pH of the composts was in the range of 3.5 to 5, which was acidic. The lowest pH was recorded by sample 1:100. Later, the pH of the composts was gradually increased on day 15th of composting process and eventually reached the neutral level of 7. Until the 60th day of composting period, the pH profile for all composts tended to be closer to neutral level, which indicated the maturity of the composts.

Based on Figure 3, pH of the composts was acidic at the beginning of the composting process due to the effect of organic acids in raw materials and the presence of acetic acid in wood vinegar. The lowest pH was recorded by sample 1:100 which was likely caused by the presence of high amount of acetic acid as the sample 1:100 contained the highest concentration of wood vinegar. As the time increased, the pH of composts was gradually increased caused by rapid metabolic degradation of organic acid contained inside the composts (Hock et al., 2009). Apart from that, the increase of pH also occurred due to the transformation of nitrogen (N) into ammonia (NH_3) or ammonium (NH_4^+) through ammonification process (Trisakti et al., 2018). At the end of the composting process, the pH of all composts were close to neutral in which the organic acids contained inside the composts were neutralized due to the buffering nature of humic substances (Hock et al., 2009).

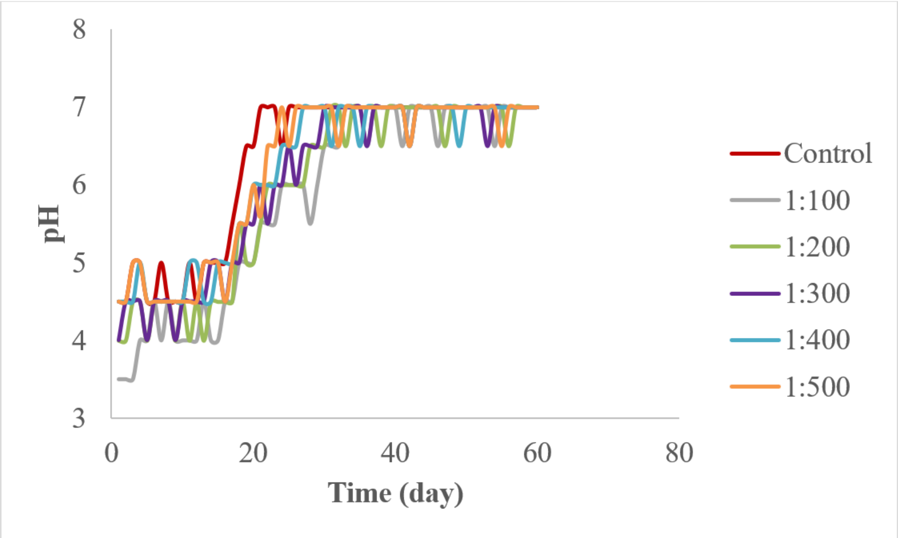

Figure 3. pH profile of the compost throughout composting period of 60 days

Chemical Properties of Compost

The chemical properties of the composts were investigated using XRF and CHNS analysis. By using XRF analysis, the composition of major components which are the phosphorus (P) and potassium (K) contained in each parameter were determined while CHNS analysis was used to determine the composition of nitrogen (N) inside the compost samples. The N, P, K composition in each sample are tabulated in Table 1. For the composition of N and K, it shows that the ratio of 1:500 (v/v) was slightly higher with the value of 8.82 % and 10.70 %, respectively, compared to the other parameters. Meanwhile, for the composition of P, the composts with the ratio of 1:400 and 1:500 (v/v) were slightly higher compared to the other samples with the value of 8.26 %. The lowest N, P, K values were recorded by the control with the value of 5.72 %, 7.75 % and 9.59 %, respectively.

According to Mungkunkamchao et al. (2013), only small amount of N, P, K is contained in wood vinegar. However, the effect of wood vinegar in promoting the growth of root for the plants has enhanced the nutrients intake by the plants and thus, promoting the growth of the plants (Hagner et al., 2013). Previous research by Jeong et al. (2015) also found that the application of wood vinegar had enhanced the N, P, K content in soil. Although it was not significantly increased, it showed that there was a possibility of the N, P, K content would be increased if wood vinegar was added to the compost, compared to the control that did not contain any wood vinegar. The increased of N, P, K content was due to the presence of beneficial microbes inside the composts. The results obtained in Table 1 correlated well with the results of microbial counts in Figure 1 whereby it showed that, as the concentration

Table 1
N, P and K composition of the samples

Materials	Sample	Elements		
		N (%)	P (%)	K (%)
Raw Materials	POME Sludge	5.63	5.23	5.85
	Decanter Cake	2.17	2.39	0.62
	Rice Husk Ash	3.11	0.65	1.44
Compost	Control	5.72	7.75	9.59
	1 to 100	5.93	8.18	10.53
	1 to 200	6.64	8.15	10.63
	1 to 300	7.35	8.17	10.41
	1 to 400	7.61	8.26	10.49
	1 to 500	8.82	8.26	10.70

of wood vinegar decreased from 1:100 to 1:500 (v/v), the microbe count and the N, P, K contents were also increased.

The beneficial microbes play a significant role in boosting the nutrients content, especially the N, P, K, in the composts which are useful for the plant growth (Singh et al., 2017). According to Rashid et al. (2016), the microbes are able to enhance the nutrient availability in the soil through the decomposition of organic matter, N fixation, and P and K mobilization. These nutrients will be converted to the preferred nutrients form for plants, which is in ionic species, such as ammonium, nitrate and phosphate (Jacoby et al., 2017) and potassium ion (Kant et al., 2006).

The presence of nitrogen is beneficial for the plants as it imparts dark-green color in plants, promotes leaves, stem and other vegetative part's growth and development, and also stimulates the root growth. For vegetables, the presence of nitrogen can promote the early growth, improve fruit quality and enhance the leafy vegetables growth (Leghari et al., 2016).

Other than that, the presence of phosphorus is advantageous to plant. According to Razaq et al. (2017), for plant growth, phosphorus is considered as primary nutrient and it is needed by the plants to sustain optimum plant production and quality. Other than that, phosphorus also plays an important role in root branching and lateral root morphology. The combination of nitrogen and phosphorus improves the root surface area, the length of root and root-shoot mass.

According to Prajapati and Modi (2012), potassium has the ability to increase crop yield and improves the quality of the plants. It is also needed by the plant for growth process. The presence of potassium can improve the physical quality, disease resistance and shelf-life of fruits and vegetables.

Physical Properties of Compost

In this section, the physical properties of compost that were measured are pH, moisture content (%), and water holding capacity (mL/100g). The results are tabulated in Table 2.

The pH value of compost is important for the soil as the compost can assist the soil to reach the suitable pH to promote the plant growth. From the data tabulated in Table 2, it shows that the pH for the composts, which were the control and the composts that contained wood vinegar by the ratio 1:100 to 1:500 (v/v), had reached the neutral pH level of 7 after 60 days of composting. The ideal pH of compost should be between the level of pH 6.0 to 7.5, where it should be neutral or slightly acidic (WERL, 2005).

For moisture content of the composts, the value was maintained between 50 to 65 %. The results showed that the compost of 1:400 (v/v) contained a higher value of moisture content with 64.53 % (w/w), which was 1 to 27 % higher than other composts. Meanwhile, the lowest moisture content was recorded by the control with 50.59 % (w/w) of moisture content. Moreover, the result also showed that the compost sample of 1:500 (v/v) had a lower moisture content

Table 2
Physical properties of compost

Materials	Sample	pH	Moisture content (%)	Water holding capacity (ml/100g)
Raw Material	POME sludge	5.5	68.93	60.92
	Decanter cake	5.8	79.06	70.12
	Rice husk ash	6.8	81.20	88.95
	Wood vinegar	2.57	-	-
	Control	7	50.59	68.15
	1:100	7	55.30	71.99
Compost	1:200	7	57.84	75.10
	1:300	7	63.56	79.91
	1:400	7	64.53	81.45
	1:500	7	58.25	77.23

compared to 1:300 (v/v) and 1:400 (v/v). The moisture content of compost sample is directly related to the decomposition process. In this process, the microorganisms will transform the organic materials into carbon dioxide (CO_2), water (H_2O) and other compounds (Gómez et al., 2006). Although the compost of ratio 1:500 (v/v) has the highest count of microbes, the organic materials inside the compost might not be sufficient to the amount of microbes contained in the compost. Thus, it will further reduce the decomposition of organic materials inside the compost and affecting the water produced through the process. In this case, as the production of water by the microbes through decomposition process was reduced, the moisture content of the compost might reduce as well. However, the moisture content of all composts still lies within the recommended range. According to Zakarya et al. (2018), the ideal moisture content that should be possessed by the composts would be in the range of 40 to 60 %. However, for a compost mix, it will require as much as 65 % (w/w) of moisture content to be ideally moistened (WERL, 2005).

For the water holding capacity, Table 2 shows that the water holding capacity in the formulated compost with wood vinegar at ratio 1:400 (v/v) was 2 to 19 % higher than other composts with the value of 81.45 mL/100g of sample. The lowest water holding capacity was recorded by the control with 68.15 mL/100g of sample. The water holding capacity and moisture content was correlated to each other. Thus, the soil with high water holding capacity is expected to maintain a high moisture content as well (Blažka & Fischer, 2014).

CONCLUSION

The mixture of 1:500 (v/v) of wood vinegar with the sample of POME sludge and rice husk gave the highest colony count with the value of 1.1×10^{18} CFU/mL. The result indicates that the low concentration of wood vinegar promotes the growth of microbes. Besides, the results for chemical properties had shown that the formulated compost of 1:500 (v/v) obtained the highest percentage of nitrogen (N), phosphorus (P) and potassium (K). Other than that, the results for physical properties indicated that the pH of all composts had achieved the neutral level. For percentage of moisture content and water holding capacity, the formulated compost of ratio 1:400 showed the highest value compared to other formulated composts. Even though the formulated compost of 1:500 (v/v) had shown the highest colony count and N, P, K value, the formulated compost of 1:400 (v/v) had shown to give a better performance in terms of physical properties (pH, moisture content, water holding capacity). Therefore, it can be concluded that sample 1:400 (v/v) shows the best condition as it has a well-balanced condition between physical, chemical and biological properties.

ACKNOWLEDGEMENTS

This research work is supported by Universiti Malaysia Pahang under research grant RDU160380.

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