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Incorporation of Rice Husk Ash with Palm Oil Mill Wastes in Enhancing Physicochemical Properties of the Compost

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ABSTRACT

Rice husk ash (RHA), palm oil mill effluent (POME) sludge and decanter cake can be utilized together in compost production to minimize the environmental pollution. This study aims to evaluate the role of different composition of RHA in enhancing the physicochemical properties of palm oil-based compost. The composts were prepared by mixing different composition of RHA, in the range of 0% to 30%, with 1:1 (wt/wt) weight ratio of POME sludge and decanter cake. The moisture content, water holding capacity, pH, nitrogen (N), phosphorus (P), potassium (K), silica (Si) contents, and C:N ratio of raw materials were analyzed by using CHNS and WDXRF analyzers. The composting process was conducted in compost containers for 60 days, in which the temperature and pH of the composts were monitored daily. The finished composts were analyzed for physicochemical properties as same as raw materials. For physical properties of finished composts, RHA_{30} had the highest moisture content and water holding capacity which was 1.9 to 23.8% (wt/wt) and 4.2 to 26.8% higher compared to other finished composts, respectively. For chemical properties, the highest N and P contents were recorded by control compost. However, for K and Si content, the elements were found to be higher in RHA_{10} and RHA_{30}, respectively, compared to other finished composts. Overall, RHA, POME sludge and decanter cake combination in compost production can create a well-balanced condition for the compost to perform effectively as an organic fertilizer. The addition of 5% to 10% RHA in compost formulation made from palm oil mill wastes is suggested to achieve the desirable condition.

Keywords: Compost, decanter cake, POME sludge, rice husk ash

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INTRODUCTION

The demand of rice, which is one of the most crucial crop in the world, has triggered the expansion of rice processing industries in many countries including Malaysia, India, and China (Babaso & Sharanagouda, 2017). One of the valuable wastes produced by this industry is rice husk ash (RHA). RHA is the ashes produced through the burning process of rice husk. Although it is considered as a waste product, it can be exploited in agricultural industry as it has the ability to influence the hydro-physical properties of the soil and amend the acidity level as buttressed by Islabão et al. (2014). Other than that, RHA contains an enormous amount of silica components which can be as high as 89% (Badar & Qureshi, 2014). Silica plays a crucial role in retaining soil moisture content due to the presence of highly porous structure of this element (Phonphuak & Chindaprasirt, 2015).

Apart from rice processing industries, Malaysia is also leading towards palm oil industry, which can trigger the production of enormous amounts of wastes. Palm oil mill effluent (POME) is one of the wastes generated from palm oil mill. The effluent is generated from various processing units including sludge clarification, drain-off of hydrocyclone, and condensates sterilization (Akhbari et al., 2020). Approximately 0.50 to 0.75 tons of POME will be generated for every ton of FFB from the milling process (Wun et al., 2017). If the effluent is not treated accordingly, POME can cause a significant environmental pollution, especially water pollution, due to its characteristics that contain a very high level of biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Thus, POME undergoes several treatment process in the treatment ponds before being discharged into the river, whereby the process produces a sediment known as POME sludge (Khairuddin et al., 2017). POME sludge has been widely utilized as a fertilizer through compost making process to reduce its disposal to the environment. Khairuddin et al. (2016) had suggested that, POME sludge could be experimented on crops to prove its effectiveness as an organic fertilizer as this material contained several essential nutrients that were crucial for plant growth.

Other from POME sludge, decanter cake (DC) is another type of solid waste produced in palm oil mill industry. For every ton of palm fresh fruit bunch (FFB), approximately 0.035 tons of DC is produced (Sahad et al., 2014). The direct dumping of the waste has caused numerous hazards to the environment such as leaching, odor, water pollution, pests, and rodents as claimed by Embrandiri et al. (2012). However, as mentioned by Dewayanto et al. (2009), DC can be beneficially utilized as fertilizer as it contains a significant amount of nitrogen (N), potassium (K), and phosphorus (P).

As the abundance of those types of waste available in Malaysia, study related to utilization of those types of wastes into valuable and environmental friendly material is worth to be explored. Hence, as suggested by Anwar et al. (2015), the wastes from rice mill and palm oil mill industries can be converted into an environmentally friendly waste by utilizing them as an organic fertilizer through composting process. The compost produced through the process may promote the production of healthier plants. Other than that, the process is also practical and convenient. Moreover, composting process can be conducted with low operating and capital costs, and it is a great alternative to reduce landfill space.

Although there have been many studies that were conducted to prove the effectiveness of palm oil wastes in enhancing the physicochemical properties of compost, the incorporation of RHA with the palm oil mill wastes in compost production is worth to be explored. Previous research made by Theeba et al. (2012) had attempted to investigate the effect of RHA in combination with other organic substrates, such as chicken manure and rice bran. The authors had studied the addition of 4% and 6% of RHA to the compost and found that, 4% RHA could improve the moisture and nutrient content of the compost produced. Similar as Theeba et al. (2012), Frimpong-Manso et al. (2011) also discovered that, RHA could serve as an addition to composted sawdust, in which the composition was varied between 2% to 20% in their study. However, based on the authors, 2% RHA addition could enhance the growth nutrient content and growth of oyster mushroom. The findings obviously show that the best composition of RHA would vary when different compost raw materials were used.

Even so, based on Theeba et al. (2012) and Frimpong-Manso et al. (2011)'s study, the percentage of RHA utilized in the research is not varied broadly. There may be a tendency of the chosen percentage of RHA not being the best composition of RHA to be added as an additive to the compost in composting process. Therefore, this study attempted to vary the RHA composition in a broader range, which was between 0 to 30% of RHA composition. This is because; RHA could benefit the agricultural activity by enhancing the nutrients uptake by the plant due to the presence of high content of silica that can improve the crop production.

Moreover, the source of raw materials used in Theeba et al. (2012) and Frimpong-Manso et al. (2011) were different compared to the materials utilized in this work. This research had utilized the palm oil mill wastes as they contained high amount of N, P, and K, which were essential for the plant growth. Since the palm oil mill wastes were available in abundance in Malaysia, therefore it was worthwhile to investigate the potential of these wastes to be converted into compost materials. Thus, this research was aimed to evaluate the effectiveness of RHA addition at different composition in enhancing the physicochemical properties of palm oil-based compost. The physicochemical parameters of the raw materials and compost were measured in terms of pH, moisture content, water holding capacity, N, P, K, and Si contents.

MATERIALS AND METHODS

Sample Preparation

Rice husk ash (RHA) was purchased from a nursery in Kuantan, Pahang. Meanwhile, palm oil mill effluent (POME) sludge and decanter cake were collected from LKPP Lepar, Pekan, Pahang. All raw materials were stored at ambient temperature before ready to be used in experimental work.

Physicochemical Properties Analysis of Raw Material

RHA, POME sludge, and decanter cake were analyzed for physical and chemical properties, which includes the analysis of moisture content, water holding capacity, pH, and elemental contents. Three replicates of samples were prepared in the analysis for each physical and chemical property in order to obtain the mean and standard deviation of the data.

For pH analysis, 5 g of sample was taken and diluted in 50 mL of water and stirred by using magnetic stirrer. Then, the supernatant liquid was obtained from the mixture through filtration. The pH meter probe (METTLER TOLEDO S20 SevenEasy™) was inserted into the supernatant liquid and the reading was taken (Ramli et al., 2016).

For moisture content analysis, the sample was weighed to obtain the fresh weight. Then, the sample was dried at 105 ± 2°C for 5 h in an oven. The sample was then reweighed again to obtain the dry weight and moisture content was calculated based on standard test ASTM D4442-16.

Meanwhile, for the analysis of water holding capacity, 10 g of sample was mixed-well with 50 mL of distilled water and allowed to stand for 30 min. Then, the sample was transferred on filter paper in a funnel. The drop-off water was recorded every 30 min until the sample began to dry. The weight of wet sample in the filter was taken when the weight remain unchanged. The sample was dried in an oven for 48 h at 105°C ± 2°C and reweighed again. Standard test ASTM D2980-02 was referred to calculate the water holding capacity of the sample.

For chemical analysis, the sample was oven-dried for 24 h at 105°C ± 2°C and pulverized by using a grinder until a powder form was obtained. Standard test ASTM E1621 - 13 was used to determine the content of potassium (K), phosphorus (P), and silica (Si). Wavelength Dispersive X-ray Fluorescence (WDXRF) spectrometer instrument (model Axios^{mAX} made in Netherlands by PANalytical) was employed to determine the elements. Meanwhile, CHNS analyser (model vario MICRO cube made in Germany by Elementar) was utilized to detect the carbon (C) and nitrogen (N) contents.

Preparation of Rice Husk Ash

In this work, seven samples with different composition of RHA were prepared. The RHA composition was varied in the range of 0 to 30%. However the weight ratio of POME sludge to decanter cake was kept constant at ratio 1:1 (wt/wt) as referred to the previous work by Ramli et al. (2016). Other than that, the total weight of composting material was fixed at 5 kg. The variation of weight composition for material in the sample is presented in Table 1.

Table 1
Weight of material used in composting process

Treatments	Composition of RHA (%) added	Weight of RHA (kg)	Weight of POME sludge (kg)	Weight of decanter cake (kg)	Total weight (kg)
Control	0	0	2.50	2.50	5.00
RHA_5	5	0.25	2.375	2.375	5.00
RHA_{10}	10	0.50	2.25	2.25	5.00
RHA_{15}	15	0.75	2.125	2.125	5.00
RHA_{20}	20	1.00	2.00	2.00	5.00
RHA_{25}	25	1.25	1.875	1.875	5.00
RHA_{30}	30	1.50	1.75	1.75	5.00

Composting Process

The composting process was conducted at Universiti Malaysia Pahang based on the procedure stated in Ramli et al. (2019). The process was conducted in seven containers based on the composition as shown in Table 1. Each composition was developed with a total weight of 5 kg and placed inside containers with a size of 16 cm (H) x 30 cm (L) x 18 cm (W). For control treatment, the formulation was carried out without RHA component. The sample only contained main component of the compost, which were POME sludge and decanter cake, with weight ratio of 1:1 (wt/wt). Meanwhile, for RHA_5, RHA_{10}, RHA_{15}, RHA_{20}, RHA_{25}, and RHA_{30} treatments, the amount of RHA added to the palm oil mill wastes was based on the weight of materials as tabulated in Table 1. All materials were mixed together in the containers and the treatments were allowed to be decomposing for a period of 60 days. The pH and temperature of the composts were monitored daily for 60 days in the afternoon by using the 4 in 1 Soil Survey Instrument. In order to control the odor and aid the decomposition process, the composts were turned by using a pitch-fork once a week. Other than that, 200 mL of tap water was added to each container once a week to maintain moisture level at desired condition (40-60 %) (Zakarya et al., 2018). All samples were analyzed once the composting process was completed. For physical properties analysis, moisture content and water holding capacity were measured. Meanwhile, chemical properties analysis was performed to determine the N, P, K, and Si contents of finished compost. Both analyses were conducted based on the procedure as described in part ‘Physicochemical Properties Analysis of Raw Material’. All experiments were conducted by using a completely randomized design (CRD) with three replications of sample for each experiment.

Statistical Analysis

The data obtained was subjected to Analysis of Variance (ANOVA) using MINITAB®18 Statistical Software (Version 18.1, Minitab, Inc., State College, PA). Least significant difference (LSD) at significant level of $p \leq 0.05$ was performed to determine the significant difference among means.

RESULTS AND DISCUSSION

Physical Properties of Raw Materials

The data obtained for the physical properties analysis is tabulated in Table 2. Based on Table 2, the highest pH was recorded by RHA while the lowest was obtained by decanter cake. For moisture content, the highest percentage was achieved by decanter cake, with 70.59%, followed by POME sludge and RHA. Meanwhile, the analysis for water holding capacity had clearly shown that, RHA had the highest percentage, which was 83.61%, compared to POME sludge and decanter cake.

Based on Table 2, the pH of RHA was slightly alkaline, which is similar with the findings obtained by Islabão et al. (2014), Saranya et al. (2018), and Persaud et al. (2018). The alkaline condition of RHA is crucial to reduce the acidity of soil as buttressed by Okon et al. (2005). For POME sludge, the pH obtained for this material was close to neutral level. However, it still lies within an acceptable range between 6 to 9 as this material was directly retrieved from aerobic pond of palm oil mill (Akhbari et al., 2020). Meanwhile, the pH for decanter cake was acidic, which might be due to the release of humic acid caused by the material degradation as reported by Osman et al. (2019). The presence of humic acid could increase the concentration of hydrogen (H^+) ions which can be detected by pH analysis.

According to the results tabulated in Table 2, the percentage of moisture content obtained for POME sludge and decanter cake in this study was close to the results obtained by Khairuddin et al. (2016), Razak et al. (2012), and Sahad et al. (2014). Meanwhile, RHA contained as high as 59.17% of moisture content, which might be related to high specific surface area and highly porous structure of silica in its components that could absorb water efficiently (Phonphuak & Chindaprasirt, 2015). Other than that, the presence of high content of silica also influences the water holding capacity of this material. The presence of silica allows the material to retain more water due to the highly porous structure of the element that can increase the moisture content as well. Other than that, the water holding capacity for POME sludge and decanter cake were impressively high with 69.53% and 76.28%, respectively, which proved the significantly high moisture content obtained by these materials.

Chemical Properties of Raw Materials

The data obtained for carbon (C), nitrogen (N), potassium (K), phosphorus (P), and silica (Si) contents existed in the raw

Table 2
Physical properties of raw materials

Parameters	Materials (Mean ± SD)		
	Rice husk ash	POME sludge	Decanter cake
pH	8.70 ± 0.15	7.20 ± 0.10	4.43 ± 0.15
Moisture content (%)	59.17 ± 0.94	64.47 ± 0.85	70.59 ± 0.58
Water holding capacity (%)	83.61 ± 0.54	69.53 ± 0.64	76.28 ± 0.96

materials are presented in Table 3. Based on Table 3, the highest N, P, K contents were recorded by POME sludge while RHA obtained the highest Si content and C:N ratio compared to other materials.

Based on Table 3, POME sludge contained an appreciable amount of N, which was in agreement with Bala et al. (2014). The authors had claimed that POME sludge contained high amount of essential nutrients in its components such as N, P, and K. Since POME sludge is formed from the treatment of palm oil mill effluent (POME), it contains a considerably high amount of organic matter (Kamyab et al., 2018) which can act as a reservoir of nutrients for plants including N, P, and K. Meanwhile, for RHA, it only consists of a small amount of N as this material was widely utilized to enhance the availability of nutrient as buttressed by Islabão et al. (2014), and not as the main source of N.

For phosphorus (P), the high content of this element attained by POME sludge lies within the range of P content mentioned by Khairuddin et al. (2016) and Zaini et al. (2014) in their studies. For RHA, it achieved the lowest amount of P which proved the statement made by Dizaji et al. (2019). The authors stated in their work that, RHA only consisted a small amount of nutrient elements, which prevented them from being consumed for land usage and it was usually directly disposed.

Meanwhile, for potassium (K), this element was found to be higher in POME sludge compared to other materials, which was supported by the previous research by Nizar et al. (2018). However, for RHA, K content obtained for this material was the least compared to other raw materials. This is because the content of elements existing in RHA will vary based on temperature and time when the husk is burnt as claimed by Priyadharshini and Seran (2010).

For silica (Si) content, the highest content was recorded by RHA, which proved the role of RHA as the main source of Si (Rambo et al., 2011). The Si content in RHA may reach up to 95%. For POME sludge, although the Si content was the lowest compared to RHA and decanter cake, the value obtained in this study was almost similar to the Si content reported by Zaini et al. (2014).

Apart from that, RHA had the highest carbon to nitrogen (C:N) ratio, followed by decanter cake and POME sludge. According

Table 3
Chemical properties of raw materials

Parameters	Materials (Mean ± SD)		
	Rice husk ash	POME sludge	Decanter cake
N (%)	0.85 ± 0.07	4.17 ± 0.10	2.74 ± 0.06
P (%)	0.70 ± 0.93	3.71 ± 0.11	2.29 ± 0.89
K (%)	1.65 ± 0.11	5.00 ± 0.34	1.98 ± 0.20
Si (%)	69.28 ± 0.82	8.48 ± 0.35	20.26 ± 0.71
C/N	43.8 ± 0.64	6.74 ± 0.16	14.63 ± 0.30

to Misra et al. (2003), C:N ratio greater than 35 will trigger the microbial immobilization, prolong the composting period and limit the microorganisms' growth. Meanwhile, for POME sludge and decanter cake, the C:N ratio obtained for both materials were between 6 to 15, which were quite low. C:N ratio value in the range of 1 to 15 will result in rapid release of N into the soil for immediate crop use and enhance the mineralization process (Brust, 2019). In composting process, the available C:N ratio must be kept at a proper level to ensure the microorganisms remain active.

Temperature Profile of Compost

Temperature is considered as an important parameter that needs to be closely monitored as to ensure the completion of composting process. The temperature profile for all composts is illustrated in Figure 1.

As shown in Figure 1, the temperature of the composts began to increase from day 9 until day 18, which indicates the mesophilic stage of composting process. Mesophilic stage had a range of temperature between 20 to 45°C as stated by Misra et al. (2003). In this stage, RHA_{15} recorded the highest temperature which was more than 47°C, recorded on day 16. Meanwhile, control compost recorded the lowest temperature at this stage. Compost that contained an appropriate moisture content level may improve the consumption of oxygen by aerobic microorganisms that will enhance the microbial activity (Kim et al., 2016). As a result, more heat would be generated as the biodegradation process by

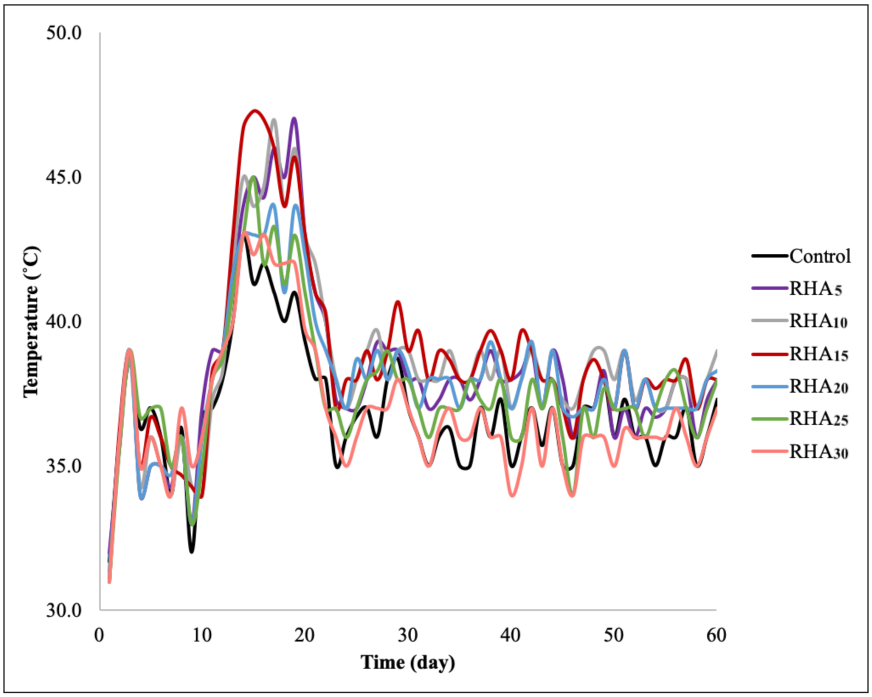

Figure 1. Temperature profile for a period of 60 days

the microorganisms was enhanced (Trisakti et al., 2018). However, excessive moisture content may reduce the microbial activity as the oxygen transport to the composting zone was greatly reduced (Makan et al., 2013). This scenario was proven by the composts with higher RHA composition that had a lower temperature level compared to RHA_{15}, although the moisture content of these composts were higher than RHA_{15}.

However, based on Figure 1, the temperature of all samples only fell within the mesophilic stage temperature, which was similar to the findings obtained by Hayawin et al. (2016) and Trisakti et al. (2018). The temperature obtained in this study was insufficient to enter the thermophilic stage. This occurrence was due to the minimal microbial activity that prevented the temperature to increase until the required level (Hayawin et al., 2016). Apart from that, the lower C/N ratio of POME sludge and decanter cake might also prevent the temperature to reach the temperature required to enter thermophilic stage since lower C/N ratio will result in lower compost temperature as mentioned by Neugebauer et al. (2017).

Starting from day 19 onwards, the temperature of the composts were gradually declined and fluctuated due to the deceleration of microbial activity. The curing stage was noted when the temperature of all samples remained close to the surrounding temperature that indicates the full consumption of residual substances by the microorganisms and the composts were already stabilized as stated by Lee (2016).

pH Profile of Compost

The data obtained for pH profile throughout 60 days of composting process is presented in Figure 2.

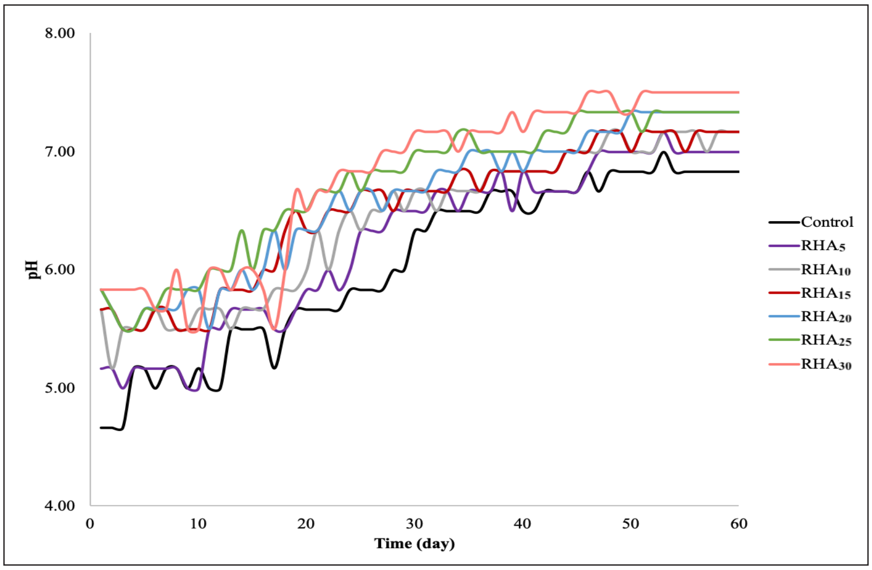

Figure 2. pH profile for a period of 60 days

According to Figure 2, the composts had recorded pH value in the range of 4.6 to 5.8, which was observed at day 1 until 10. The pH level of the samples was then increased from pH 5 to pH 7 between day 10 until 40, which was caused by the organic acids degradation (Hock et al., 2009) and the nitrogen (N) transformation into ammonium (NH_4^+) or ammonia (NH_3) via ammonification process (Irvan et al., 2019). In ammonification process, the NH_3 is be protonated and formed the NH_4^+ and hydroxide (OH^-), that eventually increase the alkalinity of the compost (Krause et al., 2018). This process is performed by the ammonifying bacteria.

At the beginning of composting process, control compost recorded the lowest level of pH, which was due to the properties of raw materials, POME sludge and decanter cake, which were slightly alkaline and acidic, respectively. Meanwhile, RHA_{30} recorded the highest pH level, which was due to the alkaline condition of RHA. Okon et al. (2005) had stated that, the presence of RHA was able to minimize the acidity level of composts, which was proven in this study. Other than that, alkaline condition is important in composting process to enhance the activity of microbes that can increase the rate of degradation as mentioned by Ameen et al. (2016).

Starting from day 26 onwards, the pH level of all composts gradually reached neutral level of pH 7. This level was reached when the organic acids existed in the compost was neutralized by the humic substances' buffering effects (Hock et al., 2009). Next, the pH level of all samples that contained RHA had exceeded the neutral level and became slightly alkaline starting from day 30 onwards. However, according to Jain et al. (2019), pH level of 7 to 8 can improve the organic matter decomposition by microorganisms. The completion of composting process could be noted from day 45 onwards when the pH of all composts was relatively stable. The final pH level achieved by all composts lies within an acceptable range of 6 to 8 for finished compost as mentioned by Sharma et al. (2017).

Physical Properties of Finished Compost

In this part, the results obtained for moisture content and water holding capacity were presented in Table 4. According to Table 4, RHA_{30} has recorded the highest percentage of moisture content, which was 1.9 to 23.8% higher compared to other samples. The

Table 4
Physical properties of finished composts

Parameters	Treatments (Mean ± SD)						
	Control	RHA_5	RHA_{10}	RHA_{15}	RHA_{20}	RHA_{25}	RHA_{30}
Moisture content (%)	47.37 ± 0.38^e	48.19 ± 0.36^e	53.21 ± 0.32^d	56.35 ± 0.40^c	57.50 ± 0.36^b	57.56 ± 0.42^{ab}	58.64 ± 0.56^a
Water holding capacity (%)	55.39 ± 0.85^e	57.21 ± 0.78^e	59.52 ± 0.82^d	64.02 ± 0.66^c	65.45 ± 0.70^{bc}	67.45 ± 0.68^b	70.26 ± 0.57^a

Note. Means in column with the same letters are not significantly different at $p \leq 0.05$

value obtained by RHA_{30} was significantly different from other treatments at $p \leq 0.05$, except for RHA_{25}. Besides, water holding capacity of RHA_{30} was also the highest with 4.2 to 26.8% higher than other finished composts and was significantly different compared to other treatments.

Based on the results presented in Table 4, RHA_{30} was found to depict the highest percentage of moisture content and water holding capacity. This is caused by the presence of high amount of silica present in RHA_{30} as linked to the data presented in Table 5. Previous research by Badar and Qureshi (2014) had claimed that, RHA could contain as high as 89% of silica in its components. The silica component contains a large specific surface area and highly porous structure (Phonphuak & Chindaprasirt, 2015). These special characteristics of silica allow it to retain high amount of liquid which can enhance the moisture content and water holding capacity of the material. Schaller et al. (2020) had also proven that, the amorphous structure of Si with high surface area had improved the water holding capacity of soil that would enhance the availability of water in soil. High availability of water can increase the nutrient uptake by plant via roots.

Apart from that, Kim et al. (2016) had suggested that, an ideal range of moisture content for a compost is between 40% to 60 %. This range was achieved by all finished composts in this study, although the percentage was lower compared to the percentage obtained by RHA_{30}. The microbial activity will be restricted if the moisture content is below 40% and decomposition of organic matter will be reduced if the percentage exceeds 60% (Kim et al., 2016).

Chemical Properties of Finished Compost

In this part, the data obtained for the chemical properties analysis of finished composts is presented in Table 5. Based on Table 5, the highest N content was recorded by control treatment, in which the difference was significant compared to other treatments at $p \leq 0.05$, except for RHA_5. Other than that, control and RHA_{10} treatments recorded the highest P and K contents, respectively,

Table 5
Chemical properties of finished composts

Parameters	Treatments (Mean ± SD)						
	Control	RHA_5	RHA_{10}	RHA_{15}	RHA_{20}	RHA_{25}	RHA_{30}
N (%)	3.31 ± 0.02^a	3.20 ± 0.04^a	2.97 ± 0.08^b	2.53 ± 0.07^c	2.29 ± 0.01^d	1.92 ± 0.05^e	1.73 ± 0.03^f
P (%)	0.87 ± 0.03^a	0.72 ± 0.02^b	0.67 ± 0.02^{bc}	0.59 ± 0.01^d	0.59 ± 0.01^d	0.61 ± 0.04^{cd}	0.67 ± 0.02^{bc}
K (%)	3.46 ± 0.04^b	3.41 ± 0.06^b	3.74 ± 0.07^a	2.81 ± 0.01^c	2.75 ± 0.06^c	2.28 ± 0.02^e	2.54 ± 0.03^d
Si (%)	18.32 ± 0.87^c	25.94 ± 0.91^b	28.12 ± 0.66^b	35.31 ± 0.98^a	35.40 ± 0.62^a	35.84 ± 0.98^a	36.00 ± 0.96^a

Note. Means in column with the same letters are not significantly different at p ≤ 0.05

which was significantly higher than other treatments. Meanwhile, the highest Si content was obtained by RHA_{30}. However, the Si content in RHA_{30} was not significantly different from the treatment of RHA_{15}, RHA_{20}, and RHA_{25}.

As presented in Table 5, control compost possessed the highest N and P contents as it contained the largest weight composition of POME sludge and decanter cake. These palm oil mill wastes were the main source of N and P, which contributed to the high percentage of these nutrients in control compost. The addition of RHA into the compost had diminished the N content as the weight composition of palm oil mill wastes was reduced. Moreover, the presence of RHA did not contribute in enhancing the N and P content of the composts as much as the palm oil mill wastes could do since this material only contained a small amount of N and P as linked to the findings tabulated in Table 3.

Apart from that, it was also expected that control compost would have the highest amount of K. However, the actual result was contradicted with the predicted result, in which RHA_{10} had the highest composition of this element compared to control. As K is highly soluble in water, this element can be easily leached which could lead to the reduction of this element inside the compost as buttressed by Mendes et al. (2016). Alfaro et al. (2017) had also claimed that, K could be lost through leaching since K was a mobile ion and the loss could be expected when the inputs of K exceeded the retention capacity of the soil. Therefore, the addition of RHA, which act as a nutrient binder, can minimize nutrient leaching. However, RHA_{15} until RHA_{30} shows slightly lower amount of K. This is due to the availability of K in the raw materials of RHA_{15} to RHA_{30} that were lower compared to control, RHA_5 and RHA_{10} since the weight proportion of palm oil mill wastes was decreased as shown in Table 1.

Meanwhile, for Si, this element was found in abundance in RHA_{30} as this formulated compost had the highest RHA composition compared to other composts. This finding was similar to the prior findings obtained by Hisham and Ramli (2019). The authors also found that, the addition of higher percentage of RHA could enhance the Si content in the compost.

Hence, based on the results obtained in this study, the utilization of RHA as a compost material could enhance the moisture content, water holding capacity and Si contents in the finished compost. The addition of RHA could potentially enhance the nutrient contents, which is N, P and K, in finished compost. This is well-correlated with the trend obtained by Hisham and Ramli (2019). However, the authors suggested that $RHA_{7.5}$ was the best option, which is slightly different to the current work since the source of raw materials obtained in both studies were different. The results tabulated in Table 3 clearly show that, the POME sludge and decanter cake were the main source of N, P, and K. The composition of the important nutrients would be higher when lower percentage of RHA was added to the compost material.

Thus, the addition of RHA in the range of 5% to 10% is recommended for compost production as they gave a balance condition of physicochemical properties.

CONCLUSIONS

The addition of RHA in composting process involving palm oil mill wastes has proven that this combination can improve the physical properties of finished compost. An appropriate pH, moisture content and water holding capacity are important to boost the plant's nutrient uptake. Based on the findings, the presence of RHA did not contribute significantly towards increasing the macronutrient contents of the finished compost. Even so, this material can slightly enhance the nutrient contents of the compost. The addition of 5% to 10% RHA to palm oil mill wastes in compost formulation is suggested to improve the moisture content, water holding capacity, and NPK contents of the finished compost. Hence, the reported results in this study can give more options to the farmers and manufacturers in formulating and producing the compost according to their needs. The composition of RHA should be reduced if high NPK content is aimed for the compost. Meanwhile, high RHA composition is recommended if the compost is aimed to maintain a high level of moisture content and water holding capacity. Thus, it is important to have an appropriate composition of NPK, water holding capacity and moisture content in the compost since these properties can beneficially help farmers to enhance their crops' growth.

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