COMPOSTING PROCESS BY USING PALM OIL MILL EFFLUENT (POME) AEROBIC SLUDGE, DECANTER CAKE AND RICE HUSK ASH

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ABSTRAK

Industri kilang kelapa sawit telah menyumbang kepada pencemaran yang signifikan terutamanya pencemaran sungai apabila mereka melepaskan efluen mereka seperti kumbahan POME dan kek dekanter ke dalam sungai. Untuk menyelesaikan masalah alam sekitar, sisa-sisa ini boleh digunakan sebagai baja melalui proses pengkomposan. Walau bagaimanapun, terdapat beberapa kelemahan yang mungkin berlaku dalam proses pengkomposan dari segi masa yang diperlukan dan kualiti kompos. Untuk memudahkan proses pengkomposan, adalah disarankan untuk menggunakan abu sekam padi sebagai bahan mentah tambahan kerana sifat fizikal dan kimianya. Objektif kerja ini adalah untuk mencirikan sifat fizikal dan kimia bahan mentah (enapcemar POME aerobik, kek dekanter, abu sekam padi), untuk memformulasikan baja kompos organic pada komposisi abu sekam padi yang berbeza, untuk menilai kesan pemanasan terhadap proses pengkomposan dan untuk membandingkan sifat fizikokimia kompos yang dirumuskan dengan produk komersial yang sedia ada. Dalam kerja ini, enapcemar POME aerobik dan kek dekanter dicampurkan dengan nisbah berat tetap (1:1) dengan penambahan jumlah abu sekam padi yang berbeza. Kemudian, proses pengkomposan dilakukan selama 50 hari dengan menggunakan tong kompos. Semasa proses pengkomposan, profil suhu dan pH kompos dipantau setiap hari. Setelah proses pengkomposan selesai, kompos yang matang dianalisis dari segi analisis unsur, pH, kandungan kelembapan dan kapasiti pegangan air. Keputusan menunjukkan bahawa komposisi abu sekam padi sebanyak 6.98% menunjukkan hasil yang signifikan dalam rumusan kompos kerana berjaya mengekalka kandungan kelembapan pada julat 50-60% dan julat 61-73% untuk kapasiti pegangan air. Pada akhir pengkomposan, sampel yang mengandungi 6.98% abu sekam padi memperoleh pH 6.44, nisbah C/N sebanyak 10.28 dan nisbah N-P-K sebanyak 3.3-8.1-9.7. Hasil daripada kajian ini digunakan untuk kajian yang seterusnya dengan menggunakan kaedah pemanasan paksa. Kaedah pemanasan paksa menghasilkan kompos yang mengandungi kelembapan dan kapasiti pegangan air yang rendah berbanding kaedah tong kompos. Walau bagaimanapun, kedua-dua kaedah tidak memberikan perbezaan ketara dari segi sifat kimia (makronutrien dan mikronutrien).

ABSTRACT

Palm oil mill industry had contributed to significant pollution especially river pollution when they discharged their effluents such as POME sludge and decanter cake into the rivers. To solve the environmental problem, these wastes can be utilized as fertilizer through composting process. However, there are some drawbacks in which possibly occur in composting process such as time consuming and the quality of compost. In order to facilitate the composting process, it was suggested to use rice husk ashes as additional raw materials due to its physical and chemical properties. The objectives of this work are to characterize the physical and chemical properties of raw materials (POME aerobic sludge, decanter cake, rice husk ash), to formulate the organic compost at different rice husk ash composition, to observe the heating effect towards the composting process and to compare the physicochemical properties of formulated compost with existing commercial product. In this work, POME aerobic sludge and decanter cake were mixed at constant weight ratio of (1:1) with addition of different amount of rice husk ashes. Then, the composting processes were carried out in 50 days by using compost bins. During the composting process, temperature and pH profile of compost were monitored daily. After composting process completed, the matured compost was analysed in terms of elemental analysis, pH, moisture content and water holding capacity. The result indicates that rice husk ash composition at 6.98% gives significant results in the compost formulation as the moisture content maintain within the range of 50-60% and range of 61-73% for water holding capacity. At the end of composting, sample with 6.98% rice husk ash obtain pH of 6.44, C/N ratio of 10.28 and N-P-K ratio of 3.3-8.1-9.7. The results obtain from this study were used for subsequent study by using forced heating composter. Forced heating composter produced compost with lower moisture content and water holding capacity compared to compost bin. However, composting by using both methods did not give significant difference in terms of chemical properties (macronutrients and micronutrients).

Key words: POME aerobic sludge, decanter cake, rice husk ash, composting

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

cm	Centimeters
g	Grams
ºC	Degree celcius

LIST OF ABBREVIATIONS

BOD	Biological Oxygen Demand
C	Carbon
CHNS	Carbon Hydrogen Nitrogen Sulphur
COD	Chemical Oxygen Demand
EFB	Empty fruit bunch
FFB	Fresh fruit bunch
K	Potassium
MC	Moisture content
N	Nitrogen
P	Phosphorus
PKC	Palm kernel cake
POME	Palm oil mill effluent
POMS	Palm oil mill sludge
RHA	Rice husk ash
Si	Silica
SSF	Solid-State Fermentation
TSS	Total Suspended Solid
VSS	Volatile Suspended Solid
WHC	Water holding capacity
XRF	X-Ray Fluorescence

CHAPTER 1

INTRODUCTION

1.1 Research Background

Malaysia is one of the top producers of palm oil and currently strengthening its palm oil production rate due to the increasing global demand for edible oil, biodiesel, and oleochemicals derived from palm oils. Malaysia was one of the world's largest producers of palm oil with a staggering 5.85 million hectares of oil palm plantations recorded in the year 2018 (Hanin et al., 2020). However, the palm oil industry in Malaysia had contributed to the significant pollution load into the rivers throughout the country as the palm oil industry continues to grow. According to Wahi et al. (2017), it has been estimated that about 44 million tonnes of POME was generated in Malaysia in the year 2008. Apart from that, rice husk ash is an abundant agricultural solid waste as a result of combustion or burning of rice husk (Abbas et al., 2017). Rice husk is considered a waste by-product, which required a lot of space and can cause environmental problems to dispose of it.

1.2 Problem Statement

Palm oil mill effluent (POME) sludge is wastewater generated mainly from sterilization and pressing of fruits in palm oil mills (Krishnan et al. 2016). POME sludge can cause serious land and aquatic pollution when discharged immediately into the environment. The application of untreated POME sludge on soil can alter its physicochemical properties and cause decrement in pH and increment in salinity (Iwuagwu & Ugwuanyi, 2014). Besides that, slow degradation of POME sludge in aerobic treatment from which it emits strong and bad odour is causing air pollution. Apart from POME aerobic sludge, decanter cake is the other type of solid waste generated from the milling process of crude palm oil. Similar to POME aerobic sludge, decanter cake can cause an environmental problem because there are remaining oil left that can be leached by rain and discharged into the nearby water source (Cherypiew & Suksaroj, 2014). Studies by Alkarimiah & Suja'(2020) and Ramli et al. (2016) have reported the potential of utilising these two-waste materials from the palm oil milling process, especially for composting purposes.

Another agricultural waste that can cause pollution is rice husk ash. Rice husk ash is a crop residue ash waste from the rice milling industry. It is produced after the burning process of rice husk for power generation. Due to its lightweight, rice husk ash can cause air pollution as it is easily carried by the wind. However, there are limited research has discussed on how the addition of any biochar during composting can help to improve the quality of the compost, especially in terms of physical and chemical properties. In this study, rice husk ash has been used as one of the raw materials since it is known for its ability to maintain the moisture level at the desired condition. Thus, it can promote the biodegradation process by the microbe in compost.

Composting is an efficient technology that converts organic residues into stable substances which can be handled, stored, transported, and applied to the field without adversely affecting the environment (Mohammad & Kabashi, 2015). Under ideal conditions, the composting process is being able to produce compost with a high percentage of macronutrients and micronutrients, which is beneficial for crop growth. Composting, which involves aerobic bacteria are strongly influenced by the oxygen level due to the turning process. Meanwhile, the oxygen level is related to the level of moisture content that exists in the compost. It was recommended by Liang et al. (2003) and Kim et al. (2016) that moisture content during the composting process should be in the range of 40-60%. Therefore, research related to the presence of rice husk ash during the composting process is worth exploring as to investigate whether the rice husk ash can be potentially added in order to keep the moisture level at the desired condition on the finished compost formulated in this study.

Generally, the addition of effective microbes is essential to assist and accelerate the composting process. In fact, most of the studies reported before used the seeding bacteria as the source of an effective microbe in compost formulation. In this case, the study focussed on the use of indigenous species of microbes, which originally exist from the raw material. It was reported by Baharuddin et al. (2010) that the addition of POME sludge into composting material could enhance microbial seeding as it contains high volatile suspended solids. This approach is conducted in order to reduce operation costs by discarding costs for buying an effective microbe for biodegradation during the composting process. As mention before the study attempt only to utilize “in-house” bacterial only exist in the material used for formulation.

Even though the composting process is no longer considered as new technologies in this era, but in some area, especially related to the operating condition need to explore more. There are many composter machines available in the market which claims that the compost product takes only two days to be readily produced by using force heating method. Therefore, this present research is conducted to investigate does the quality of the compost produce using the composter machine is comparable to the compost produced using conventional method and commercial compost available in the market.

1.3 Motivation

There are many studies reporting the use of POME aerobic sludge and decanter cake as fertilizer. However, few investigations have been carried out with regards to using rice husk ashes as additional materials to promote the composting process in the production of organic fertilizer. Study on the potential use of POME aerobic sludge, decanter cake and rice husk ash as an organic fertilizer is worthless if the characteristic of these materials were not determined in prior as to ensure POME aerobic sludge and decanter cake can take a ‘role’ as prominent ‘nutrient provider’ while rice husk ash as ‘nutrient binder’. For that reason, the characteristics of the raw materials involved in this study are important because it affected the physicochemical properties of fertilizer. In this research, the characteristics of POME aerobic sludge, decanter cake, and rice husk ash are investigated.

Apart from that, the study about rice husk ash composition towards the composting process is also limited. The rice husk ash is one of the activated carbons generated from biomass waste. It has an ability to retain moisture and avoid nutrient loss in soil, where it is widely used as soil amendment material. Studies by Saranya et al. (2018), Ogbe et al. (2015) and Rajor et al. (2014) reported the use of rice husk ash as a soil amendment to improve the physical, chemical and biological properties of soil but not as composting materials. Therefore, it is very interesting to know does the presence of rice husk ash during composting can improve the process or enhance the quality of the finished compost. Thus, in this work, the study is focused on the effect of rice husk ash on the composting process at different compositions.

Apart from raw material, the quality of the finished compost was also affected by the operating condition during the composting process. This research attempt to investigate whether the forced heating method (using composter machine) were severely affect the final properties of the finished compost compared to compost produced through the conventional method.

In order to validate the quality of formulated compost with commercial organic fertilizer available in the market, the study on the comparison between them was made. The formulated compost was compared with a commercial chicken manure fertilizer in terms of physicochemical properties to evaluate whether the compost produced in this study is comparable to the fertilizer available in the market. This will add value to the formulation of the compost made from a combination of POME aerobic sludge, decanter cake, and rice husk ash.

1.4 Research Objectives

a. To characterize the physical and chemical properties of raw materials, which consists of POME aerobic sludge, decanter cake, and rice husk ash.
b. To formulate the organic compost prepared at different rice husk ash composition and to observe the heating effect towards the composting process.
c. To evaluate and compare the physicochemical properties between formulated compost with commercial chicken manure fertilizer.

1.5 Scopes of Study

a. Physical properties such as temperature, moisture content, water holding capacity, and pH were determined. For chemical properties, the C/N ratio was determined by using CHNS analysis. Meanwhile, the micronutrient and macronutrient were determined by using X-ray Fluorescence (XRF) analysis.
b. Rice husk ash composition is varied in a range of 0 to 9.09%, where the weight ratio between POME sludge (from aerobic pond) and decanter cake (from decanter

machine at oil clarification process) is kept constant at 1:1 respectively. The composting process was carried out for 50 days.

c. The best composition of rice husk ash was chosen to undergo a composting process in a reactor equipped with a heater, and the physicochemical properties between the sample with and without heating are compared.

d. The physicochemical properties between formulated compost and commercial chicken manure fertilizer are compared using a similar method of analysis stated in (a).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter aims to review the raw materials and fundamental methods of composting. This chapter starts with the description of raw materials such as palm oil mill effluent sludge, decanter cake, and rice husk ash in terms of physical and chemical properties. Then, followed by the discussion on the methods available to produce organic fertilizer. Next, the literature related to the effect of some parameters towards the composting process was also discussed in this chapter. Apart from that, the literature also includes the effect of heating on the physicochemical properties of compost and some description about commercialize chicken manure fertilizer.

2.2 Palm Oil Mill Effluent (POME) Aerobic Sludge

During the process of producing crude palm oil in the palm oil mill, more than 70% by weight of the processed fresh fruit bunch (FFB) was left over as oil palm waste (Rupani & Singh, 2010). Empty fruit bunch (EFB), seed shells, and fibre from the mesocarp, palm oil mill sludge (POMS), leaves, trunk, palm oil mill effluent (POME), palm kernel cake (PKC), and decanter cake are the by-products produced after the extraction process of oil from fresh fruit bunch (FFB).

In the oil extraction process, POME is produced in the form of liquid waste. It was generated mainly from oil extraction, washing, and cleaning processes in the mill. A study was done by Mamimin et al. (2016) and Krishnan et al. (2016) have confirmed that the untreated POME is rich with chemical oxygen demand (COD) of about 15,000-100,000 mg/L, biochemical oxygen demand (BOD) of 25,000 mg/L, volatile suspended solids (VSS) of 21,100 mg/L, and total suspended solids (TSS) of 40,500 mg/L. POME is also acidic, with a pH of around 4.0-5.0 (Wun et al., 2017). In the palm oil mill industry, POME is known as one of the main causes of environmental pollution because it has high BOD, COD, and TSS. Thus, it cannot be discharged without treatment. Usually, open lagoon technology such as anaerobic and aerobic processes is used as the most convenient method to treat POME (Akhbari et al., 2019). Figure 2.1 shows the conventional method used to treat POME in the industry.

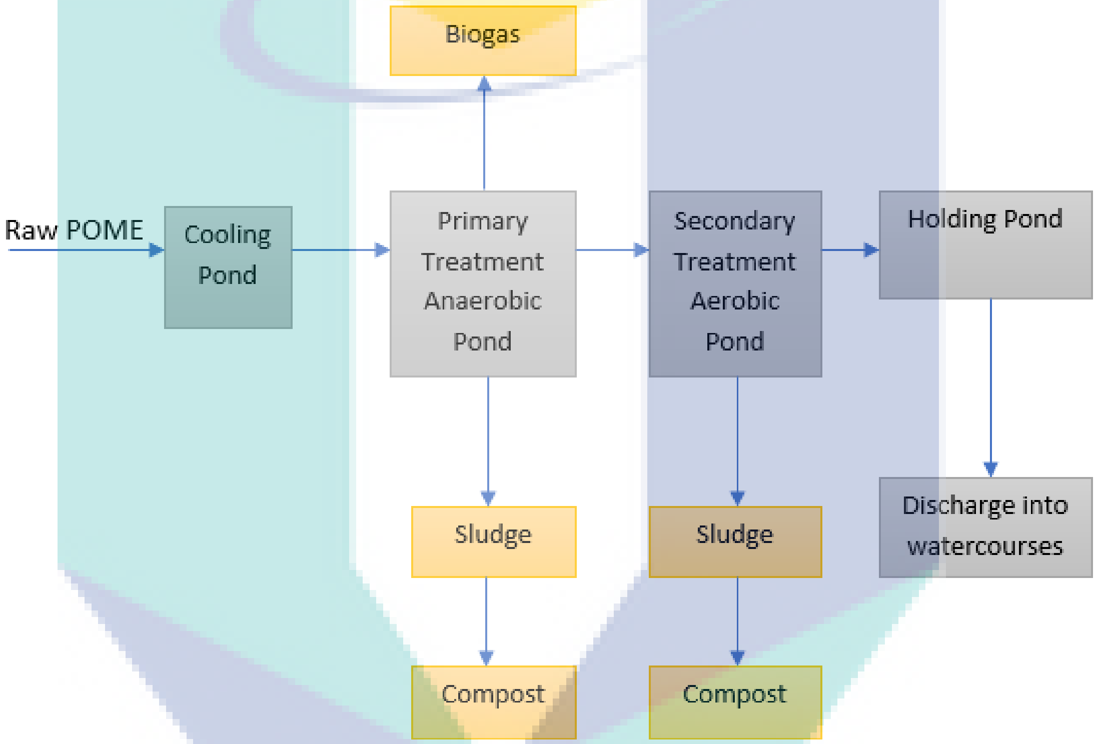

Figure 2.1 Conventional method process flow diagram for POME treatment

Source: Khadaroo et al. (2019)

Based on Figure 2.1, the raw POME enters the cooling pond in the form of sludge water to reduce its temperature. In the cooling pond, the solid crude palm oil arises on the surface and so that it is easy to collect before entering the anaerobic and aerobic lagoons. In anaerobic treatment, the degradation of organic waste releases methane, carbon dioxide, and hydrogen through the hydrolysis process, acidogenesis process, and methanogenesis process (Lim & Vadivelu, 2019). Meanwhile, in aerobic treatment, the microorganisms convert the organic waste carried over from anaerobic treatment into biomass (sludge) and carbon dioxide (Akhbari et al., 2019). According to Khadaroo et al. (2019), during aerobic treatment, the sprinklers were installed to provide enough and evenly distributed oxygen supply in the aeration systems. After aerobic treatment, the treated sludge was produced, and it was held for nine days in the holding pond before being discharged into the environment (Akhbari et al., 2019). POME sludge formed during the treatment can be utilized in many ways due to its physical and chemical properties. The applications of POME sludge are summarized in Figure 2.2.

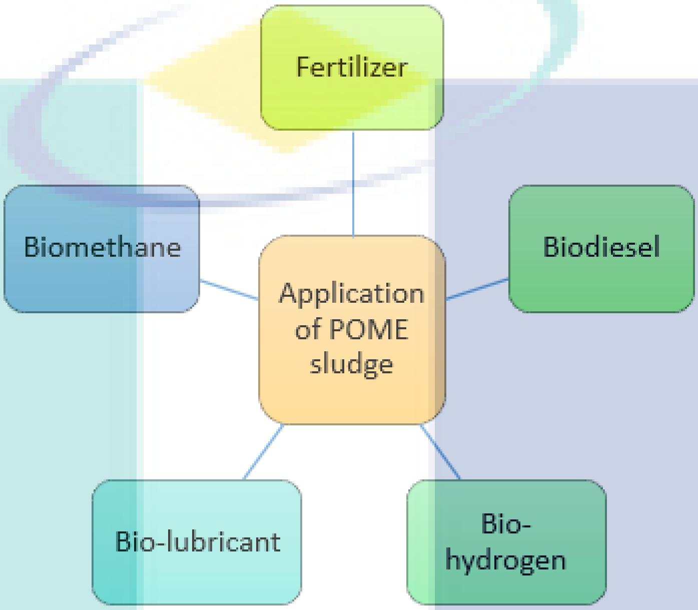

Figure 2.2 Applications of POME Sludge

Source: Krishnan et al. (2016), Baharuddin et al. (2010), Syaima et al. (2015), Norfadilah et al. (2016), Leela et al. (2018), Zainal et al. (2020)

As seen in Figure 2.2, POME sludge can be utilized into bio-methane (Zainal et al., 2020), bio-lubricant (Syaima et al., 2015), biodiesel (Leela et al., 2018), and bio-hydrogen (Norfadilah et al., 2016). However, this study is going to focus on the utilization of POME sludge from the aerobic pond which can be used for composting process to produce compost fertilizer. Composting is a cost-efficient way to treat the palm oil mill residues because it can recover valuable nutrients and generates a value-added product (Krishnan et al., 2016). Moreover, the addition of thickening POME aerobic sludge into compost material is able to enrich the composting materials with high nutrient and microbial sources (Baharuddin et al., 2010). The characteristics of POME aerobic sludge is tabulated in Table 2.1.

Table 2.1 Characteristics of POME aerobic sludge

Parameters	POME Aerobic Sludge
Moisture (%)	94.03 ± 2.3
pH	7.50 ± 0.5
C/N	8.30
N (%)	4.68 ± 0.5
P (%)	1.25 ± 0.1
K (%)	5.16 ± 2.2

*All the percentages are in dry weight.

Source: Baharuddin et al. (2010) and Alkarimiah & Suja'(2020)

From Table 2.1, the characteristics of POME aerobic sludge show that it has enough N, P, and K, which are required to produce quality compost. This is because POME aerobic sludge contains appreciable amounts of macronutrient and micronutrient, which are vital nutrient elements for plant growth (Baharuddin et al., 2010). However, POME aerobic sludge has a low C/N ratio, which indicates that it needs to be mixed with other material that contains a higher C/N ratio to reduce the loss of nitrogen as ammonia gas during composting (S. Zhou et al., 2019). In terms of pH, POME aerobic sludge was slightly alkaline, as reported by Baharuddin et al. (2010) and Alkarimiah & Suja' (2020).

2.3 Decanter Cake

Decanter cake is a solid waste produced when the crude palm oil is centrifuged for the purification process at the oil clarification process. During this process, the oil is the supernatant, and the sediment is the decanter cake (Maniam et al., 2013). Adam et al. (2014) and Akhbari et al. (2019) explained that decanter cake is increasingly produced throughout the country due to the installation of new decanter machines in the palm oil mill to recover the remaining oil from the underflow (sludge fraction) in the oil clarification process and to reduce the solid loading in the POME before being sent for further biological treatment using open lagoon treatment system. Due to the increasing amount of decanter cake every year, proper management of decanter cake should be considered to address the growing environmental concerns.

The production rate of decanter cake is about 4-5 wt% of fresh fruit bunch processed, and it is equivalent to around 3.6 million tonnes of decanter cake generated by Malaysian palm oil industries in 2012 (Dewayanto et al., 2014). According to Raeze et al. (2017), decanter cake contains water (about 76% on wet basis), residual oil (about 12% on dry basis) and nutrients, cellulose, lignin, and ash. Due to its characteristics, decanter cake can be used in various applications, as described by (Kanchanasuta & Pisutpaisal, 2017). The applications of decanter cake are summarized in Figure 2.3.

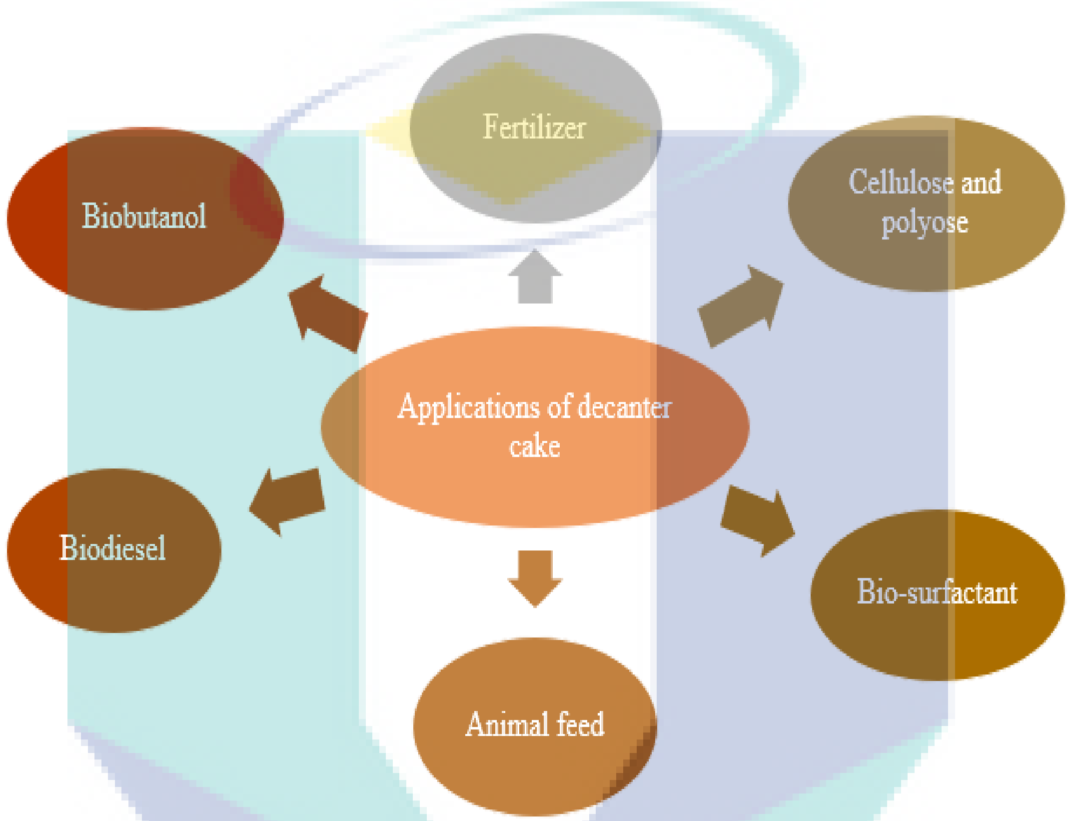

Figure 2.3 Applications of decanter cake

Source: Embrandiri et al. (2016)

Based on Figure 2.3, decanter cake can be utilized as fertilizer, biobutanol, animal feed, biodiesel, bio-surfactant, cellulose, and polyose. According to Embrandiri et al. (2016), decanter cake is suitable to be used as fertilizer because it is enriched with a potential source of nutrients which are necessary for plant growth. The characteristics of the decanter cake are shown in Table 2.2.

Table 2.2 Characteristics of decanter cake

Elements	wt%*
Nitrogen as N	2.38
Phosphorus as P_2O_5	0.39
Potassium as K_2O	2.39
Magnesium as MgO	0.80
Calcium as CaO	1.02
Silica	0.61

*Values expressed on a dry basis.

Source: Yahya et al. (2010)

From Table 2.2, decanter cake is rich with essential nutrients such as nitrogen, potassium, and calcium, which are important for plant growth. Research conducted by Nutongkaew et al. (2014) has reported that decanter cake is rich in nitrogen, potassium, and calcium, which can enhance the nutrient value of compost. It is believed that the addition of decanter cake to produce compost is yet another way of utilizing more of the waste from the oil palm mill, which ultimately could not only solve the present environmental problems but also enhance the economic benefits (Yahya et al., 2010). In order to make a comparison on the use of decanter cake as compost and soil amendments, studies by several researchers on the function of decanter cake in compost and soil amendments are shown in Table 2.3.

Table 2.3 Comparison on the application of decanter cake

Author	Raw materials	Findings
Yahya et al. (2010)	Empty Fruit Bunches (EFB), decanter cake	The use of decanter cake in the composting process is more preferred since the nutrient content is higher and able to enhance the faster production of matured compost.
Kananam et al. (2011)	Empty Fruit Bunches (EFB), decanter cake, chicken manure	Compost, which consists of decanter cake, has higher total nitrogen content compared to chicken manure-based compost.
Lim & Wu (2016)	Decanter cake, rice straw	Compost with the addition of decanter cake shows high nutrient recovery, especially for potassium and phosphorus compared to the control sample, which has no decanter cake.
Embrandiri et al. (2016)	Decanter cake	The mixture of decanter cake and soil could serve as a source of soil amendment for the cultivation of brinjal plants.

Based on Table 2.3, it was found that the use of decanter cake as the raw material for the composting process has the potential to increase the nutrient content of compost. Researches, Yahya et al. (2010), Kananam et al. (2011), and Lim & Wu (2016), have reported that nutrient content in compost is higher with the addition of decanter cake. Besides that, decanter cake is also suitable to be used as soil amendments for plant cultivation, as reported by Embrandiri et al. (2016).

2.4 Rice Husk Ash

Rice husk ash is an abundant agricultural solid waste from rice milling industry produced after the burning process of rice husk to generate steam for electricity supply (Prasara-a & Gheewala, 2016). It was estimated 55kg (25%) of rice husk ash produced from the burning of 220kg rice husk (Hossain et al., 2018). The abundant amount of rice husk ash produced can foster environmental problems because it does not biodegrade easily. In some cases, rice husk ash can lead to air pollution and water pollution due to its low density (Benassi et al., 2015). Proper management of rice husk ash is essential to promote sustainable development because large areas are required to dispose of the rice husk ash. Currently, there are several potential applications of rice husk ash which could help to avoid environmental pollution produced from the combustion of rice husk. The potential applications of rice husk ash are summarized in Figure 2.4.

According to Figure 2.4, there are many ways to utilize rice husk ash into value-added products. In civil engineering, rice husk ash was used as a cement binder used for construction applications, which increase the compressive strength of recycled aggregate concrete (Rattanachu et al., 2020). Jeer et al. (2018) also stated that rice husk ash contains a high source of silica, potassium, and high specific surface area which plays a vital role in stabilization of soil. Besides that, it can also be used as raw material for amorphous silica, biochar, catalysts, and biofertilizer production due to its characteristics as reported by Pode (2016) and Moayedi et al. (2019). The characteristics of rice husk ash are shown in Table 2.4.

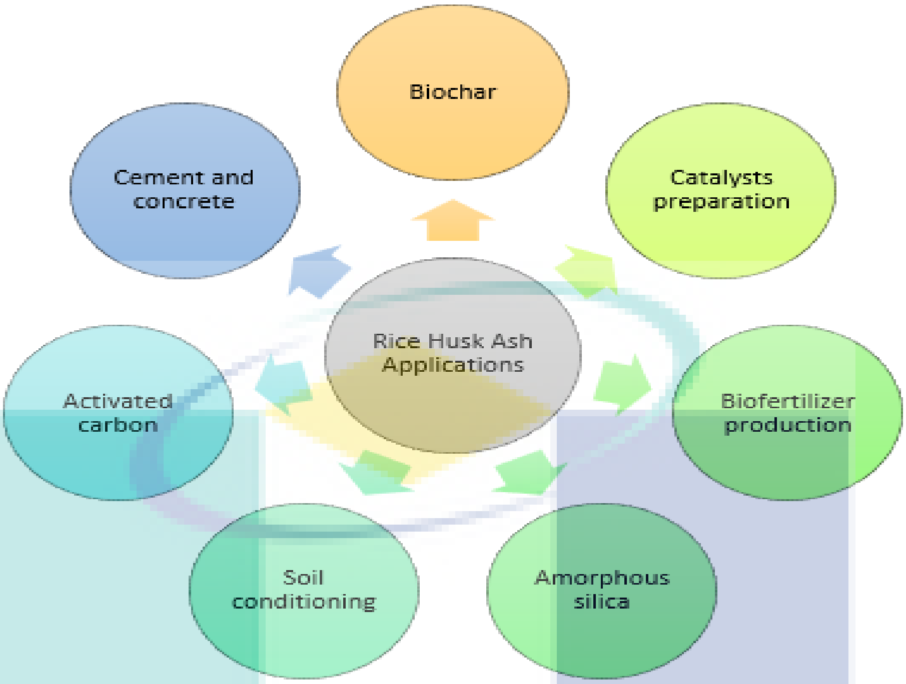

Figure 2.4 Applications of rice husk ash

Source: Pode (2016) and Moayedi et al. (2019)

Table 2.4 Characteristics of rice husk ash

Elements	**Weight (%)**
Silica as SiO_2	92.80
Potassium as K_2O	3.35
Aluminium as Al_2O_3	0.15
Calcium as CaO	0.70
Iron as Fe_2O_3	0.17
Magnesium as MgO	0.79
Phosphorus as P_2O_5	1.07
Sodium as Na_2O	0.08

Source: Sinyoung et al. (2017)

From Table 2.4, rice husk ashes mainly consist of more than 90% of silica and some metallic impurities such as iron (Fe), manganese (Mn), calcium (Ca), sodium (Na), potassium (K), and magnesium (Mg). According to Pode (2016), the addition of rice husk ash in composting could help to improve plant growth while helping to retain the nutrients in the soil. Several studies have been conducted by various researchers to investigate the functions of rice husk ash as compost and soil amendments. Those researches and their findings are shown in Table 2.5.

Table 2.5 Comparison on the application of rice husk ash

Authors	Composition of rice husk ash	Findings
Reza et al. (2014)	1 to 5%	The growth of plants applied with 5% of rice husk ash was significant.
Ogbe et al. (2015)	0 to 6%	6% of rice husk ash shows the best result with the biggest improvements in the physical and chemical properties of the soil.
Rajor et al. (2015)	0 to 15%	The proportions of 2.5% of the rice husk ash show the significant result which able to provide nutrition to crops as fertilizer.
Saranya et al. (2018)	0% to 20%	Maize growth was enhanced by the application of 10% rice husk ash.

Based on Table 2.5, most researchers investigated the use of rice husk ash as compost and soil amendments. It was found that 2.5-6.0% of rice husk ash composition was able to give the best performance. Studies by Reza et al. (2014) and Rajor et al. (2015) have found that the use of 5% and 2.5% rice husk ash on plants was able to provide essential nutrients for plant growth. Meanwhile, Ogbe et al. (2015) have reported the use of 6% rice husk ash as soil amendment was able to improve the physicochemical properties of soil. It was also reported by Saranya et al. (2018) that the application of rice husk ash at 10% composition has able to improve the growth of maize. Here, most of the researches only investigate the effect of rice husk ash towards plant growth without any validation and explanation related to chemical composition. However, this work is considering how does the chemical composition can interfere or influence the physicochemical properties of the final compost.

2.5 Methods Available to Produce Organic Fertilizer

In order to produce organic fertilizer, there are three methods that can potentially apply and reviewed in this work. This includes composting, vermicomposting, and solid-state fermentation. The description and comparison of each method available are discussed in the section below.

2.5.1 Composting

The composting method is used to produce organic fertilizer. It is considered as an aerobic, thermophilic, microorganism-mediated process where microorganism helps to decompose the organic matter into more stable compounds that are precursors of humic substances called compost (Sánchez et al., 2017). The process is carried out by mixing different organic wastes (agricultural waste and agro-industrial residues) to achieve optimum microbial growth.

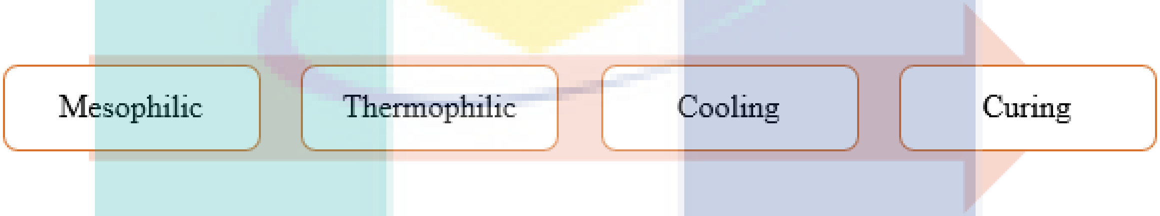

Figure 2.5 The concept of composting

According to Pergola et al. (2017), the compost can be applied to the soil as a soil amendment or as fertilizer in order to recover degraded soils with low production costs and lowering the negative impacts of agricultural activities by limiting the inputs of fertilizers. Composting offers several benefits such as enhanced soil fertility and soil health, which resulted in the increase of agricultural productivity, improved soil biodiversity, reduced ecological risks, and a better environment (Sarkar et al., 2016). If the composting process is carried out in the right condition, it can only take about 6 to 8 weeks for the process to complete (Angima et al., 2011). There are four main stages in the composting process method, and each stage is associated with particular groups of microorganisms (Oviasogie et al., 2013). The concept of composting is summarized in Figure 2.5, according to Oviasogie et al., (2013).

According to Figure 2.5, the composting process starts with the mesophilic phase. During this phase, the temperature of composting piles started to increase from ambient temperature to 40°C, where metabolization of carbohydrates, sugars, and proteins occur due to the presence of acid-producing bacteria such as *Lactobacillus spp.* and *Acetobacter spp.* (Yaser, 2019). At this stage, the mesophilic microorganisms bacteria such as *Pseudomonaceae*, *Erythrobacteraceae*, *Comamonadaceae*, *Enterobacteriaceae*, *Strepromycetaceae*, and *Caulobacteraceae* families grow at a temperature between 15°C to 35°C, where the breakdown of the organic matter is started (Sánchez et al., 2017).

The next stage is called the thermophilic stage, as shown in Figure 2.6. In this phase, high microbial activity caused an increase in the degradation process of organic matter. According to Partanen et al. (2010) and Sánchez et al. (2017), Gram-positive bacteria such as *Bacillus* spp. and Actinobacteria (mostly belong to *Thermoactinomycetacea*, *Themomonosporaceae*, and *Pseudonocardiaceae* families) became dominant in the thermophilic stage and generates exothermic reactions which caused an increase in the temperature to the range between 65°C to 85 °C. According to Insam et al. (2010), the thermophilic fungi grow at temperature up to 55°C. When the temperature in the pile increases, the heat generated during composting will destroy all the pathogenic bacteria in compost (Chandna et al., 2014).

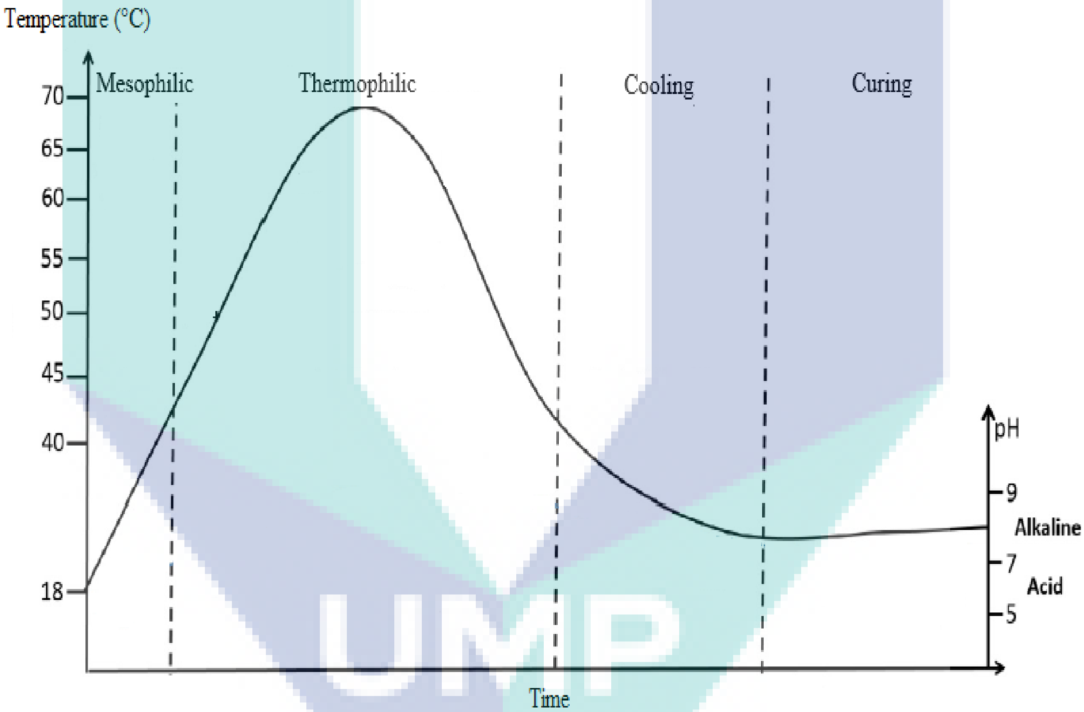

Figure 2.6 Temperature profile for average pile during composting

Source: Sánchez et al. (2017)

After the thermophilic phase, the cooling stage (second mesophilic phase) will take over in composting pile. At this stage, the activity of the thermophilic bacteria will decrease due to the exhaustion of substrates, and this condition caused the temperature to drop (Insam & de Bertoldi, 2007). According to Sánchez et al. (2017), when the temperature drops to the range between 35-15 °C, the energy sources depleted and resulted in the second colonization of compost by the mesophiles.

The curing phase is the final stage in the composting process. In curing stage, the majority of easily degradable substrates will leave behind some cellulose (lignin and humic substances) for mesophiles (fungi and actinomycetes) to act upon (Udoh et al., 2013). Besides that, residual ammonia also undergoes nitrification to nitrite and subsequently nitrate in the curing stage. At this condition, the C/N ratio tends to stabilize for any intended use of the end product as fertilizer or soil enhancer (Evans, 2014).

2.5.2 Vermicomposting

Another method to transform organic waste into fertilizer is through vermicomposting. Vermicomposting is a natural process of biochemical decomposition of organic waste through metabolic processing with the help of earthworms (vermiculture) and microorganisms. This process allows the bioconversion of organic waste into bio-fertilizer (Huang & Xia, 2018). However, the efficiency of the vermicomposting process is influenced by the C/N ratio, pH, moisture content, and the nature of organic waste, which are linked to the earthworms species used in the vermicomposting process (Lim et al., 2016).

Even though the microorganisms biochemically degrade the organic matter in vermicomposting, the earthworms act as the key driver of the process as it can promote aeration conditions, fragment the substrate, and increase the microbial activity (Hanc & Dreslova, 2016). The earthworms require suitable conditions (pH, temperature, and moisture) to convert organic waste into high nutritious value products under aerobic conditions (Alavi et al., 2017). After the vermicomposting process completed, the earthworms are removed from the vermicompost by using light, vertical, or sideways separation (Lim et al., 2016).

However, there are some drawbacks to the vermicomposting process in terms of time consumption and quality of compost produced. Unlike the composting method, the vermicomposting method involves only the mesophilic phase due to the presence of earthworms. According to Nigussie et al. (2016), composting is done at high temperatures (>45 °C), while vermicomposting is done at a lower temperature (<30 °C). Since the vermicomposting process is done at the mesophilic phase (low temperature), the waste might not be sanitized at low temperature, and the vermicompost could not meet the required level of pathogens in the organic fertilizer where only limited studies show that vermicomposting could reduce the pathogens in the organic waste (Lim et al., 2016).

Other than that, the earthworms used in the vermicomposting process can consume organic materials that have pH in the range of 5 to 8, moisture content between 40 to 55% and initial C/N ratio around 30 which limit the process since not all organic waste are suitable for vermicomposting (Lim et al., 2016). According to a research by Taeporamaysamai & Ratanatamskul (2016), municipal solid waste containing a lot of kitchen waste was not suitable to feed the earthworms because it was highly acidic in vermi bed which can affect the growth of the earthworms.

2.5.3 Solid-State Fermentation (SSF)

Nowadays, there are many research developments on various bioprocesses and products by using solid-state fermentation (SSF). SSF can be defined as a process in which microorganisms grow in an environment without free water, or with very low content of free water (Soccol et al., 2017). One of the applications of SSF is the production of organic fertilizer through anaerobic fermentation of solid waste. Research by Lim & Matu (2015) showed that the SSF method is suitable to produce effective and economical biofertilizers from the utilization of agro wastes, which could increase the yield of the crop. However, it is difficult to control the conditions during the SSF process, which leads to the restriction of large-scale industrialization of SSF for the production of high-quality fertilizer (Wang et al., 2014).

SSF is the process which is affected by various environmental factors such as water activity, moisture content, temperature, pH level, oxygen levels, and concentration (Lim & Matu, 2015). In SSF, bacteria and fungi require a different level of moisture content where fungi need lower moisture content around 40% to 60%, whereas bacteria need high moisture content around 60% to 85% (Yazid et al., 2017). Low moisture content will reduce the solubility of nutrients in the substrate, low degree of swelling, and high water tension while high moisture content can reduce the enzyme yield (Mrudula & Murugammal, 2011).

Besides that, temperature also plays a significant role in determining the success of SSF. According to Yazid et al. (2017), the temperature will increase when the oxygen is supplied and exchanged with carbon dioxide, and the heat will be generated by microorganisms in aerobic fermentation. However, the high temperature will have a negative effect on the growth of microorganisms and product formation (Pandey, 2003).

Furthermore, the diffusion of mass and heat in SSF also might be a problem since it depends on the aeration, which may differ based on the substrate types used. According to Yazid et al. (2017), appropriate aeration allows heat dissipation and regulation of the mass moisture content level on a small scale. However, in large scale, it can be a problem to remove the heat generated during the metabolic growth.

2.6 Methods Comparison

In this work, the best method is required to produce organic fertilizer, which can save time and cost. A comparison of each method is summarized in Table 2.6.

Table 2.6 Comparison of methods to produce fertilizer

Comparison	Composting	Vermicomposting	Solid-State Fermentation (SSF)
Maintenance	Low. No need to supply food.	High. Need to supply food for worms.	Low. No need to supply food.
Duration	Moderate. It takes about 42-56 days under optimum conditions (Lim et al., 2016).	Slow. Vermicomposting could take up to 50 days if done without pre-treatment (Bakar et al., 2012; Singh & Singh, 2014).	Fast. The maturation process was achieved at 37 fermentation days (L. Chen et al., 2011).
Pathogen Problems	It can kill the pathogen. Composting is essential as it inactivates some of the pathogenic microorganisms due to thermophilic temperatures (Malińska et al., 2017).	It cannot kill the pathogen. Vermicomposting cannot be conducted at sufficient temperatures to kill pathogens due to earthworms used which do not tolerate high temperatures or excessive amounts of ammonia (Matthews et al., 2014).	It cannot kill the pathogen. The optimum temperature is at 30°C (Kumari et al., 2012).

Based on Table 2.6, the maturation process for SSF only takes 37 fermentation days, which is a very fast process compared to the other processes. However, it was reported by Manan & Webb (2018) that it is burdensome to measure the biomass in SSF due to the problem in separating the microorganisms from the solid particles. Besides that, the SSF method has several operational limitations, such as difficulties in controlling the substrate moisture level and circumvent the heat build-up (Vitcosque et al., 2012).

Composting and vermicomposting are almost the same methods. The difference between these methods is the type of decomposer (organisms used to carry out the decomposition process) involved. In vermicomposting, earthworms act as the decomposer to convert organic materials into humus-like material known as vermicompost. Vermicomposting is a method that works at a temperature below 35˚C since most earthworm species require moderate temperatures from 10˚C to 35˚C (Zainal et al., 2013). Since the temperature is below 35˚C, the pathogens cannot be killed, and this may affect the plants' growth. Vermicomposting is a relatively slow process because it can take up to 50 days (with pre-treatment) and can take up a few months to finish the process (without pre-treatment) depends on the earthworms.

Meanwhile, in the composting method, aerobic microorganisms decompose the organic matter into nutrient which can be absorbed by the plant. Hence, the microorganisms generate heat that helps to convert organic waste to compost. As a result, the pathogen can be killed due to the temperature generated more than 40 °C. In fact, the composting process is faster compared to vermicomposting. Based on the comparison study conducted in Table 2.6, it can be concluded that composting is the best method to choose to produce organic fertilizer. For that reason, this method is chosen compared to another method based on aspects, as considered in Table 2.6. However, the efficiency of the method is strongly affected by the parameters involved in the composting process.

2.7 Parameters in Composting

There are six key parameters for composting process which is the temperature (Qian et al., 2016), moisture content (Kim et al., 2016), water holding capacity, pH (Sundberg et al., 2013), C/N ratio and aeration (Guo et al., 2012). Table 2.7 describes each parameter for the composting process.

Table 2.7 Description for each parameter in composting process

Parameters	Authors	Description
Temperature	Jain et al. (2019)	• The maximum temperature should be around 55-60 °C to eliminate pathogens that are harmful to humans and plants.
	Qian et al. (2016)	• Temperature is used to indicate the activities of microbes as well as the maturity of compost. • Temperature >40 °C for at least five consecutive days and >55 °C for more than three consecutive days which could eliminate pathogens and weed seeds in the compost. • The degradation of fats, cellulose, hemicellulose, lignin, and pathogens mainly occurs during the thermophilic phase. • During the curing phase, the remaining sugars, cellulose, and hemicellulose continue to degrade.
	Sarkar et al. (2016)	• The high temperature phase supports the growth of high microbial activity where biodegradation is maximized, and pathogenic microbes are killed.
Moisture content	Kim et al. (2016)	• Optimum moisture levels for various composting materials are based on water holding capacity concept.
	Zakarya et al. (2018)	• Optimum moisture content represents a trade-off between moisture requirements of microorganisms and their simultaneous need for adequate oxygen supply. • If the moisture content drops below 40%, the nutrients are no longer in an aqueous (watery) medium and not easily available to microorganisms which will cause the microbial activity to decrease and slows down the composting process. • If the moisture content exceeds more than 60%, anaerobic condition will occur, which will halt the ongoing composting process.

Table 2.7 Continued

Parameters	Author	Description
Water holding capacity	Li et al. (2016)	• Optimum moisture content was observed near the water holding capacity, which ranged from 60% to 80% on a wet basis.
	Kim et al. (2016)	• This refers to the amount of water held in composting materials that are available for microorganisms. • It is affected by organic matter content, texture, and structure of compost raw materials.
pH	Mohammed-Nour et al. (2019)	• High pH values in the starting material in association with high temperatures can cause a loss of nitrogen through the volatilization of ammonia. • All ammonia is present as ammonium ions at low pH due to the equilibrium of ammonium (NH_4^+) and ammonia (NH_3) when the protein is decomposed during the composting process.
	Sundberg et al. (2013)	• The initial low-pH phase during the composting can be handled by a combination of high aeration rates that provide oxygen and cooling.
	Liu et al. (2014)	• Nitrification of NH_4^+ released H^+ caused the pH of fertilizers to decrease.
	Jain et al. (2019)	• The activity of proteolytic bacteria and the high buffering capacity of bulking agents cause an increment in pH values during the composting process.
C/N ratio	Guo et al. (2012)	• The C/N ratio is one of the most important factors that influence the quality of compost. • Composting at a lower initial C/N ratio can increase the number of raw materials treated and can also increase the loss of nitrogen as ammonia gas. • Initial C/N ratios of 25-30 are considered as ideal for composting.
	Long et al. (2017)	• C/N ratio can be used to assess the maturity of compost as it indicates the digestion process through microbial activity.

Table 2.7 Continued

Parameters	Author	Description
Aeration	Alkoaik (2019)	• It has an indirect effect on temperature by speeding the rate of decomposition and the rate of heat production. • The temperature of compost and the stage of composting are affected by the air requirement, which can be controlled using the aeration system.
	Oliveira et al. (2018)	• Higher turning frequencies speed up the composting process and promote heat dissipation.

Based on Table 2.7, it can be summarized that the ideal composting process should have a temperature profile trend greater than 55 °C for at least three consecutive days to destroy the pathogen, as reported by Jain et al. (2019). Besides that, the moisture content should be monitored so that it will not drop below 40% to avoid dehydration in compost. This is because the moisture content influenced the microbial activity and degradation rate in the composting process, as reported by Zakarya et al. (2018). Moreover, as reported by Kim et al. (2016), the water holding capacity should be between 60-80% on a wet basis because it affects the structure and texture of compost. For pH, it depends on the properties of feedstock used and the ammonia volatilization process. However, at the end of the composting process, the pH usually around 6.0-8.0 (Ozores-hampton, 2017).

2.8 Macronutrients and Micronutrients

Macronutrients and micronutrients play multiple roles for plant growth and development. Macronutrients in the fertilizer are nitrogen (N), phosphorus (P), and potassium (K). Meanwhile, silica (Si) is categorized as micronutrients. These nutrients need to be supplied by organic fertilizer inadequate amount so that the plants can grow healthily and produce quality yield. Table 2.8 below described the roles of each nutrient.

Table 2.8 Roles macronutrients and micronutrients

Nutrients	Author	Findings
Nitrogen	Razaq et al. (2017)	• Important for plant productivity and growth. • Essential for plant morphology, net photosynthesis, and nutrient availability. • Affect the partitioning of biomass between the shoots and roots. • Nitrogen is required to increase the seedling biomass during the initial stage of plant growth.
	Song et al. (2019)	• Nitrogen can increase plant salinity tolerance, which later contributes to improved growth and grain yield due to higher photosynthetic efficiency.
Phosphorus	Heuer et al. (2017)	• Important for plant growth and development. • The deficiency of phosphorus in plants will limit the crop yield.
	Razaq et al. (2017)	• Phosphorus is important in lateral root morphology and root branching. • Phosphorus influences the development of root and availability of nutrients to the plants.
	Ajmera et al. (2019)	• Phosphorus is an essential element for the development of plants' root, shoot, and rhizosphere. • Lack of phosphorus will cause stunted growth and branching, weaker and thin stems, imperfect pollination, poor grain quality, and low yield.
Potassium	Hassan et al. (2017)	• Important for the development and growth of plants. • Affect the plants' survival under drought stress, which restricts the root growth.
	Hasanuzzaman et al. (2018)	• Photosynthetic carbon dioxide fixation and the transport of assimilates will reduce if K deficiencies occur. • Lack of potassium also will cause membrane and chlorophyll degradation in plants.

Table 2.8 Continued

Nutrients	Author	Findings
Silica	Luyckx et al. (2017)	• Useful to plants, especially under stress conditions. • Able to alleviates the toxic effects in plants caused by abiotic stresses such as drought, salt stress, and heavy metals. • Provide a physical barrier to protect the cell wall of plants.
	Agostinho et al. (2017)	• Enhance the resistance of plants against diseases. • Boost the plant photosynthesis, and growth. • Prevent lodging by alleviating the water.
	Mills-Ibibofori et al. (2019)	• Lack of Si will cause weaker structure of plants, more prone to growth abnormalities, and stunted development.

Based on Table 2.8, nitrogen, phosphorus, potassium, and silica are important for plant growth. Nitrogen is an important nutrient to plant because it plays a crucial role in photosynthesis and nutrient availability. Lack of nitrogen will lead to stunted growth and low productivity of plants as reported by Razaq et al. (2017) and Song et al. (2019). Besides that, studies by Heuer et al. (2017), Razaq et al. (2017), and Ajmera et al. (2019) have revealed that phosphorus is important for plant root systems. Poor root systems of the plants will restrict the root growth. Another important nutrient is potassium and silica. Both nutrients are important for the survival of plant under drought stress. Potassium can maintain cell membrane stability, which can help the plant to be resistant towards drought stress Hassan et al. (2017). Meanwhile, silica helps to alleviate water to prevent lodging (Agostinho et al., 2017).

2.9 Forced Heating Composter and Compost Bin

There are many types of conventional composting technology that had been practiced by industry to manage their waste. In-vessel composting, aerated static pile, and turned windrow composting are few types of conventional composting methods available (Lim et al., 2017). For in-vessel composting, the composting process is done in containers or vessels. The advantage of using this system is it required less land area. Besides that, the composting process is easily controlled when using in-vessel systems. Forced heating composter and compost bin are two types of composter which apply the in-vessel systems.

2.9.1 Forced Heating Composter

In a forced heating composter, the composting process takes place in a container that is equipped with mechanical turning for continuous turning and mixing. Figure 2.7 shows an example of a forced heating composter.

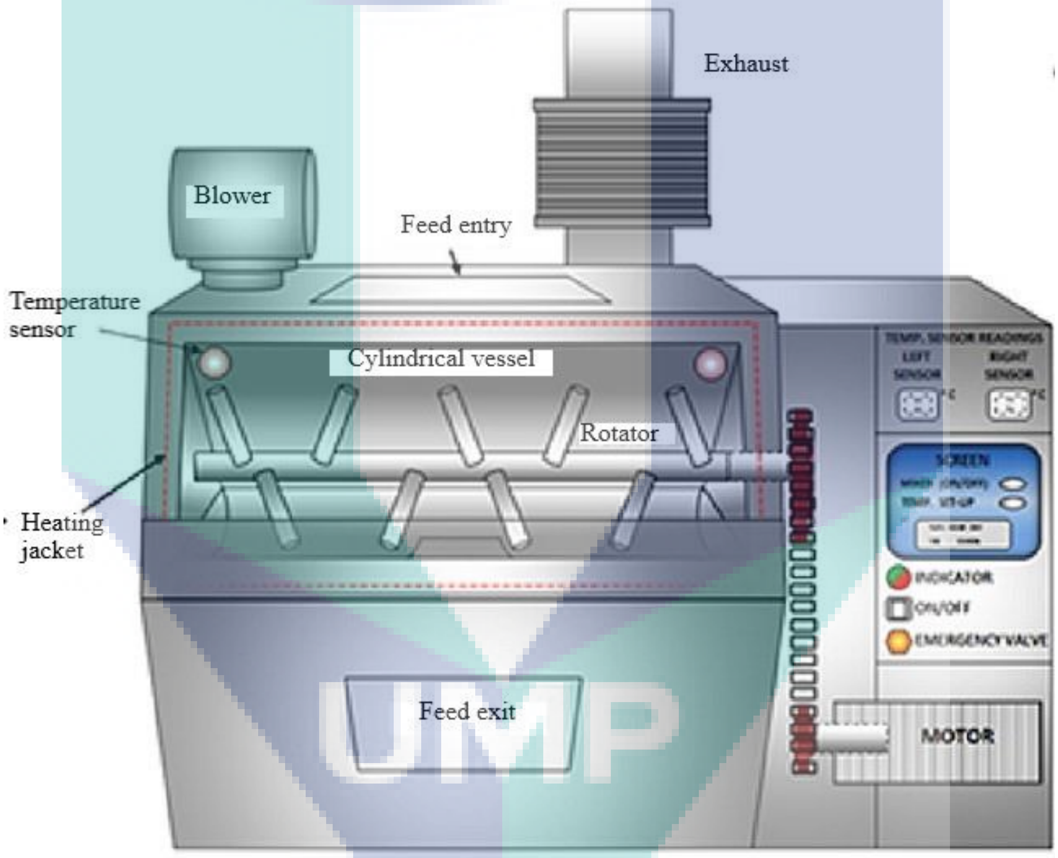

Figure 2.7 Forced heating composter
Source: Pandey et al. (2016)

According to Pandey et al. (2016), in the forced heating composter, continuous turning and mixing were provided together with external heating to achieve a temperature of 60 ºC during the composting process. Thus, it will shorten the time taken to produce mature compost by reducing the active phase of composting. The active phase of composting is the biological phase, where the process proceeds from the mesophilic phase until the curing phase (Alkoaik, 2019).

From Figure 2.7, an air blower is used in the composter to maintain the oxygen levels in the chamber. Meanwhile, the temperature inside the chamber is automatically controlled by using a heating jacket and temperature sensors. When the microorganism begins to degrade the organic matter, the heat generated will cause the temperature inside the chamber to change. Besides that, aeration by the ambient air blown inside the composter also affects the temperature inside the chamber (Malakahmad et al., 2017). According to Malakahmad et al. (2017), a rotator is used in the forced heating composter to agitate, aerate, and mixed the compost uniformly. This helps to produce uniform compost texture.

Even though the forced heating composter was able to complete the composting process in a short period, this system required high capital cost and skilled labour to maintain the composting process (Griineklee, 1998; Malakahmad et al. 2017). Besides that, the power consumption in operating the composter and maintenance are also high (Lim et al., 2017).

2.9.2 Compost Bin

In the compost bin, the composting process can be done in a container or box (Griineklee, 1998). Different from the forced heating composter, the heating process occurred naturally in the compost bin without using a temperature controller or heating jacket. The heating process for this system is done by microorganisms through the degradation of organic matter. The degradation of organic matter is controlled by the aeration rate. In this composter, the aeration is done manually to avoid overheating during the composting process. This is because overheating will kill the microorganisms in the compost (Raabe, 2018).

2.10 Characteristics of Ideal Finished Compost

In order to produce quality compost, there are several characteristics of ideal compost that should be considered. Those characteristics are described below.

2.10.1 Moisture Content

Soil nutrient release from organic matter and nutrient cycling processes were hugely affected by the moisture content of compost prior to planting. When the compost is incorporated into the soil, it will give a sustained release of available nutrients such as nitrogen, phosphorus, and potassium to plants. According to a study by Ngo & Cavagnaro (2018), the subsequent growth and nutrition of plants depend on the moisture content of compost. This is because the soil microbes require adequate moisture to help the release of nutrients from organic matter sources. As suggested by Sullivan et al. (2018), the ideal moisture content of the finished compost should be 40-60% for planting. This is because if the moisture content of compost above 60%, it will be difficult to spread and usually in the clumpy form. Meanwhile, for compost with moisture content below 40% are usually dusty.

2.10.2 Water Holding Capacity

Water holding of compost is important to retain the water and improve soil structure. According to Fulekar (2010), the water holding capacity of the finished compost will helps to increase the soil's moisture content for plant uptake and held the soil particles to prevent erosion when it was incorporated into the soil. It was reported by Gould (2015) that the ideal water holding capacity of finished compost should be 100% to prevent water stress for plant growth.

2.10.3 pH

The pH of compost is one of the key drivers which affected plant growth and its development when it is applied to the soil. According to a study by Ozores-hampton (2017), the pH range for finished compost should be around pH 6.0 to 7.5, but it is highly dependent on the type of raw material used, the composting process and the addition of amendments. It was reported by Gentili et al. (2018) that most of the micronutrients are more available to plants in slightly acidic soils rather than neutral-alkaline soils, which later will enhance plant growth. Plants such as broccoli, cabbage, lettuce, and spinach plant grow best in the pH ranged from 6.0 to 7.5 (Elzer-Peters, 2013).

2.10.4 N-P-K Ratio

The N-P-K ratio of finished compost depends on the type of raw material used in the composting process. According to Bean (2020), the N-P-K ratio of compost varies from 1.5-0.5-1.0 to 3.5-1.0-2.0. However, for compost made from green-waste biomass usually has the N-P-K ratio of 2.33-0.56-2.84 (Hanč et al., 2008).

2.10.5 C/N Ratio

The presence of carbon and nitrogen in compost affected the nitrogen content, which will be available for growing plants. As suggested by Misra et al. (2003), Angima et al. (2011), and Corral et al. (2019), the C/N ratio of finished compost should be in the range of 10.0-15.0.

2.11 Summary

This chapter has successfully reviewed the literature background of the study. The first until the third section discussed the raw materials. It can be concluded that POME aerobic sludge was chosen as one of the raw materials because it contains high nitrogen and other important nutrient contents. It is believed that the addition of aerobic POME sludge in the composting process is essential to sustain the microbial activity. Meanwhile, decanter cake is chosen as the raw material because it contains high moisture content, which can further accelerate the rate of the composting process. Apart from that, rice husk ash is chosen as the raw material since it contains a high content of silica which is important to retain nutrients in the compost. It is expected that the raw materials will complement each other in the composting process to produce quality compost. The fourth section discussed the method available to produce organic fertilizer. The fifth section compared the methods available. Meanwhile, the sixth section discussed the parameters involved in the composting process. The seventh section discussed the macronutrients and micronutrients in compost. The eighth section reviewed the types of aeration composting. Lastly, the ninth section explained the characteristics of the ideal finished compost.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discussed the works involved in this research. Basically, the work is divided into five parts in order to fulfil the objectives of this research. For the first part, the preparation and characterization of raw materials were carried out to study the physicochemical properties of the samples. The second part was continued by conducting the experimental study which set up for composting, including the fabrication of compost bin, and the variation of rice husk ash composition used in the work. Next, in order to ensure the quality of formulated compost, the samples were compared with commercial fertilizer based on physical and chemical properties. This was done by using a similar analytical procedure for characterizing the raw materials. Lastly, the heating effect on the compost physicochemical properties was studied by using forced heating composter. Figure 3.1 summarized the workflow involved in this study.

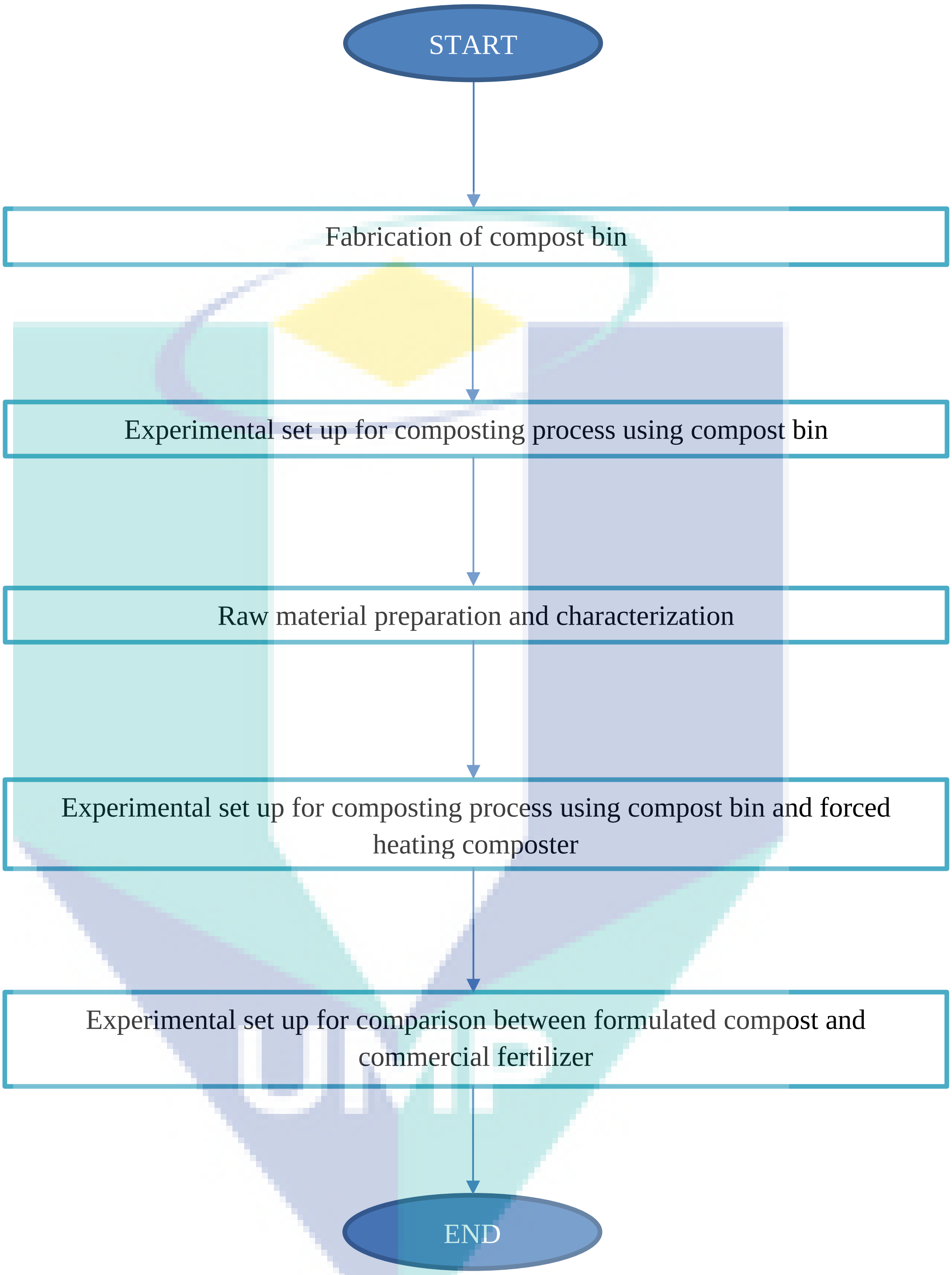

Figure 3.1 Workflow in this study

3.2 Fabrication of Compost Bins

The process of fabricating a compost bin is important in order to ensure the composting process takes place in the right condition. Several factors such as weight and volume of compost are considered before fabricating the bin. Figure 3.2 shows the schematic diagram for compost bin.

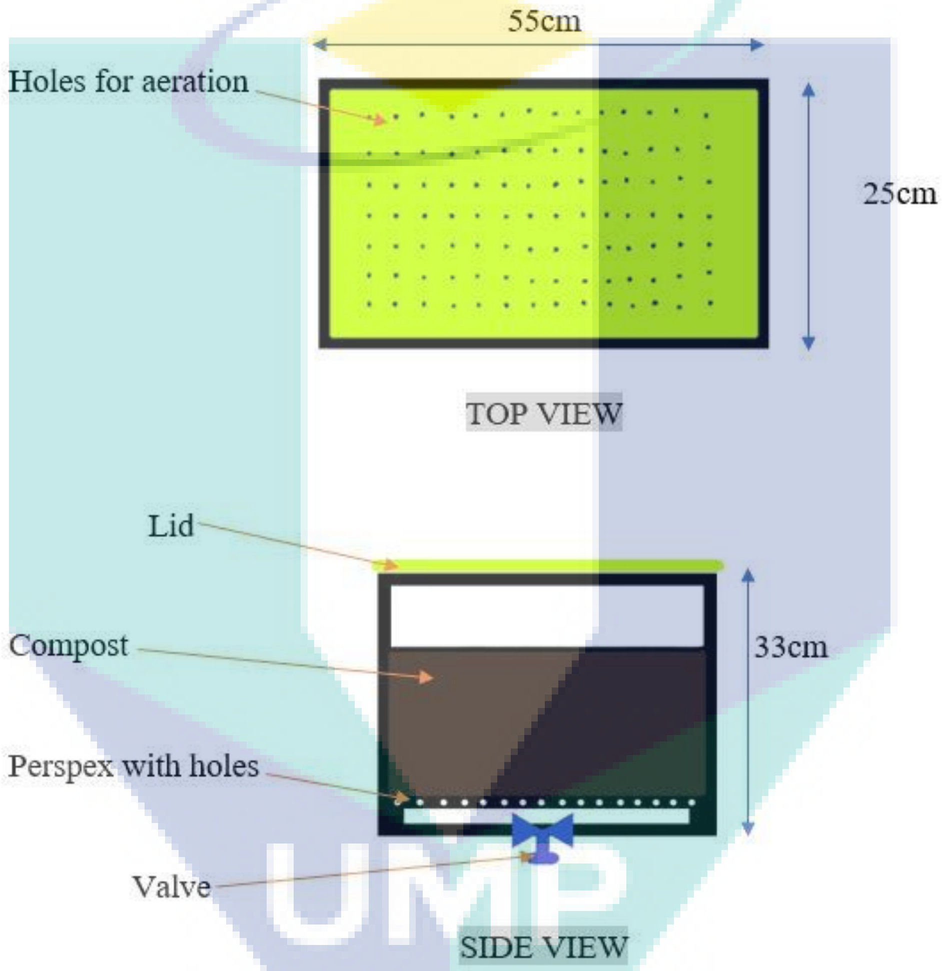

Figure 3.2 Schematic diagram for compost bin

From Figure 3.2, the compost bin was fabricated with 55cm length, 25cm breadth and 33cm height. At the beginning of composting process, almost 4/5 of volume in the compost bin was filled by compost. At the end of composting process, the compost volume was reduced to 2.5/5 of the bin volume. Inside the compost bin, Perspex were used and holes on the Perspex are made to release excessive water from compost which was formed during the condensation process. In order to avoid flooding in the compost bin, a valve was placed at the bottom of the bin. When flooding occurred, the valve is open to release the leachates to the environment. Besides that, holes with diameter 0.5cm on the top of the lid are made to ensure enough oxygen for the composting process. The holes on the lid makes the process of recording the temperature easier. The sampling point is kept at a constant point for each measurement (marked as Point A, Point B, Point C and Point D) as shown in Figure 3.3.

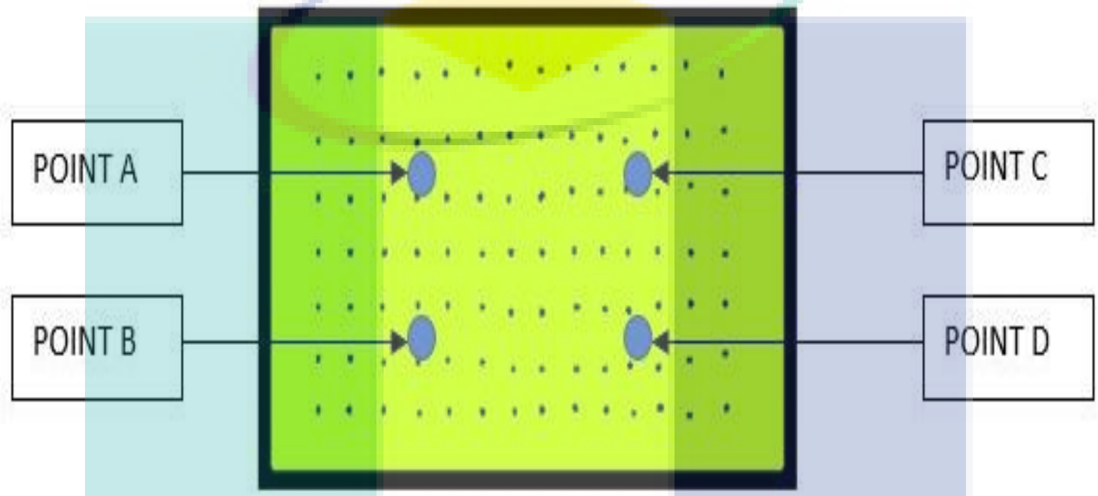

Figure 3.3 Sampling point for temperature measurement

3.3 Raw Material Preparation & Characterization

In this study, two main raw materials used which were POME aerobic sludge and decanter cake. POME aerobic sludge was obtained from the top layer of aerobic pond. Meanwhile, decanter cake was obtained from decanter machine at oil clarification section. Both samples were collected from LKPP Corporation Sdn. Bhd., Kuantan, Pahang, Malaysia. Meanwhile, the rice husk ashes were obtained from the rice-milling industry in Sungai Petani, Kedah, Malaysia. The sample preparation procedure is listed in Figure 3.4.

The characterization of POME aerobic sludge, decanter cake, and rice husk ash was done for pH, moisture content, water holding capacity, and elemental analysis. For each raw material, 500g fresh weight of the sample was measured. All samples undergo drying and grinding process before the analysis process. Figure 3.5 (a-c) shows the raw materials used in this work.

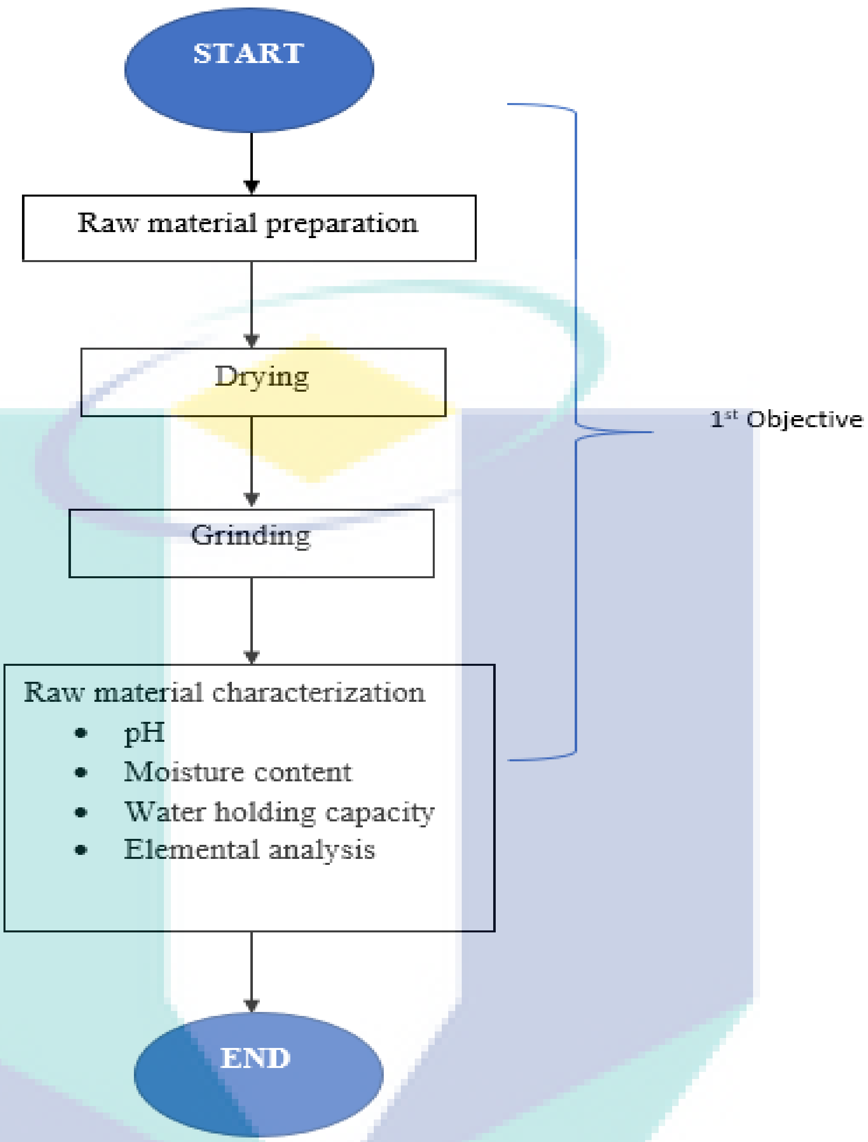

Figure 3.4 Steps for raw material characterization

(a) POME sludge (b) Decanter cake (c) Rice husk ash

Figure 3.5 Raw material used in the experiment

Before starting the composting experiment, all samples were analysed to determine the physical and chemical properties. For physical properties, parameter such as moisture content, water holding capacity, and pH was analysed. For chemical properties, the elemental composition of composts was analysed by using CHNS analysis to determine nitrogen and carbon content. Meanwhile, XRF analysis was used to determine phosphorus, potassium and silica content in the samples.

3.3.1 Moisture Content

For moisture content (MC) analysis, POME aerobic sludge, decanter cake, and rice husk ash were weighed (wet weight) before dried in an oven (Memmert UFE500) at 110˚C for 24 hours to reduce the moisture contained in the sample. Then, the samples were removed from the oven and reweighed again for 3 times. Equation 3.1 shows the formula to calculate the moisture content percentage stated in American Society for Testing and Materials in a publication (ASTM D4442-16, 2016)

$$MC(\%) = \frac{Final\ weight - Initial\ weight}{Initial\ weight} \times 100 \qquad 3.1$$

3.3.2 Water Holding Capacity

In order to measure the water holding capacity (WHC), 100ml water is applied to 100g of the sample in a pot and it was kept in a slanting position. When water drops stop from coming out, the sample was removed and weighed immediately. Afterward, the sample was dried at 105˚C for 48h in an oven (Memmert UFE500). After that, the samples were removed from an oven and reweighed again. Equation 3.2 shows the standard method by ASTM D2980-02 (2002) which are used to calculate the water holding capacity.

$$WHC(\%) = \frac{Total\ water\ in\ the\ wet\ soil}{Oven\ dry\ weight\ of\ total\ soil} \times 100 \qquad 3.2$$

3.3.3 pH

In pH measurement, 5g of samples were added to 50ml distilled water. The solution was then mixed by using magnetic stirrer for 20 minutes and filtered by using Whattman filter paper. After that, the supernatant layer was tested by using a pH meter (METTLER TOLEDO S20 SevenEasy) in an aqueous solution. According to standard method ASTM D1293-18 (2018), the probe was put in a beaker that contained the sample solution. The solution was then stirred at moderate speed. Once the sample was stable, the readings were recorded.

3.3.4 CHNS Analysis

The content of Carbon (C), Hydrogen (H), and Nitrogen (N) was analysed by using Elemental Analyzer (CHNS Analysis) model Elementar vario MACRO cube by using the standard method by ASTM D5373-08 (2008). The dry weight of the sample needed for the analysis procedure is 1 gram. The analysis for each sample was replicated three times.

3.3.5 X-Ray Fluorescence (XRF) Spectrometry Analysis

The X-ray fluorescence (XRF) spectrometry analyser PANalytical Axios MAX was used to analyse phosphorus, potassium and silica composition in the sample. This analyser was powered by 4kW of power. The analysis was done through calibration by using Omnian software which able to detect elemental composition in the sample (powder form) without specific standards. The dry weight of the sample needed for the analysis procedure is 1 gram. The analysis for each sample was replicated three times.

3.4 Experimental Set Up for Composting Process Using Compost Bin

As mentioned in Section 3.1, fabricated compost bin as shown in Figure 3.2 used for composting process in this work. The samples were mixed and placed in the compost bin by following the weight composition shown in Table 3.1. The composition of rice husk ash was varied for each sample in the range of 2.44% up to 9.09%. The control sample in this experiment only consists of the same amount of POME aerobic sludge and decanter cake which was the same as other samples. The ratio of POME aerobic sludge to decanter cake was chosen at 1:1 based on the research by Ramli et al. (2016) which suggested that ratio 1:1 promote better physical and chemical properties of compost.

Table 3.1 Composition of mixture in compost bins

Sample name	**POME Aerobic Sludge: Decanter cake**	**Percentage of rice husk ash added (%)**	**Amount of rice husk ash added into formulation (gram)**	**Total weight of samples in the compost bin (gram)**
Control	1:1	0.00	0	5000
RHA_a	1:1	2.44	125	5125
RHA_b	1:1	4.76	250	5250
RHA_c	1:1	6.98	375	5375
RHA_d	1:1	9.09	500	5500

The total weight for the control sample was 5000g. However, there was no rice husk ash were added inside the control sample. For sample RHA_a, it contains 125g of rice husk ash added to the aerated bin which gives a total weight of 5125g in the aerated bin. The same method was applied to RHA_b, RHA_c, and RHA_d which gives the total weight of 5250g, 5375g, and 5500g respectively. For each composition, the samples were replicated three times.

Once the samples were prepared according to the condition stated in Table 3.1, the samples were kept in the compost bin for composting process. During the process, the temperature was recorded by using digital temperature meter model ZD-07 manufactured by DANOPLUS. Meanwhile, Takemura soil pH meter was used to determine the pH for soil. The temperature and pH for all the samples and control were recorded daily. The initial temperature (day 0) was 27 ºC with pH around 4.5. Figure 3.6 and Figure 3.7 show the temperature meter and pH meter used in this work.

Figure 3.6	Temperature meter used in the experiment

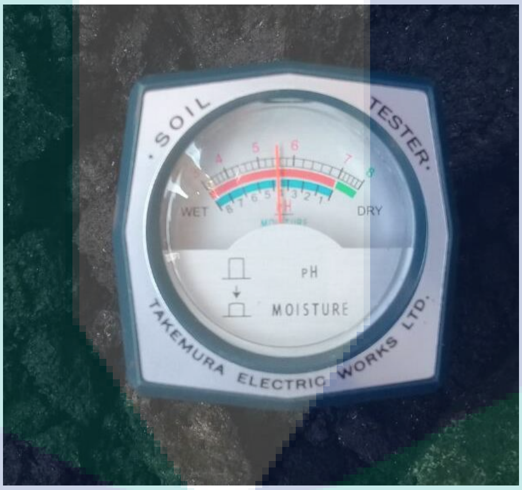

Figure 3.7	pH meter used in the experiment

The compost bin was placed in the open aerated space. Throughout the composting process, the samples were aerated manually twice a week by manual turning using a spade. Each compost bins were turned 20 times for each mixing. The turning process were carried out as to ensure the supplies of enough air which contain oxygen for digestion process of organic compound by the microbes. Once after the composting process was completed by observing the trend of pH and temperature of the compost, again the samples were analysed for pH, moisture content, water holding capacity, and elemental analysis by using the same method mentioned in Section 3.2. However, before the samples can be analysed it was dried and ground beforehand to ensure the sample are homogenized. Figure 3.8 summarized the workflow involved in the composting process to investigate the effect of rice husk ash.

3.5 Experimental Set Up for Composting Process Using Forced Heating Composter

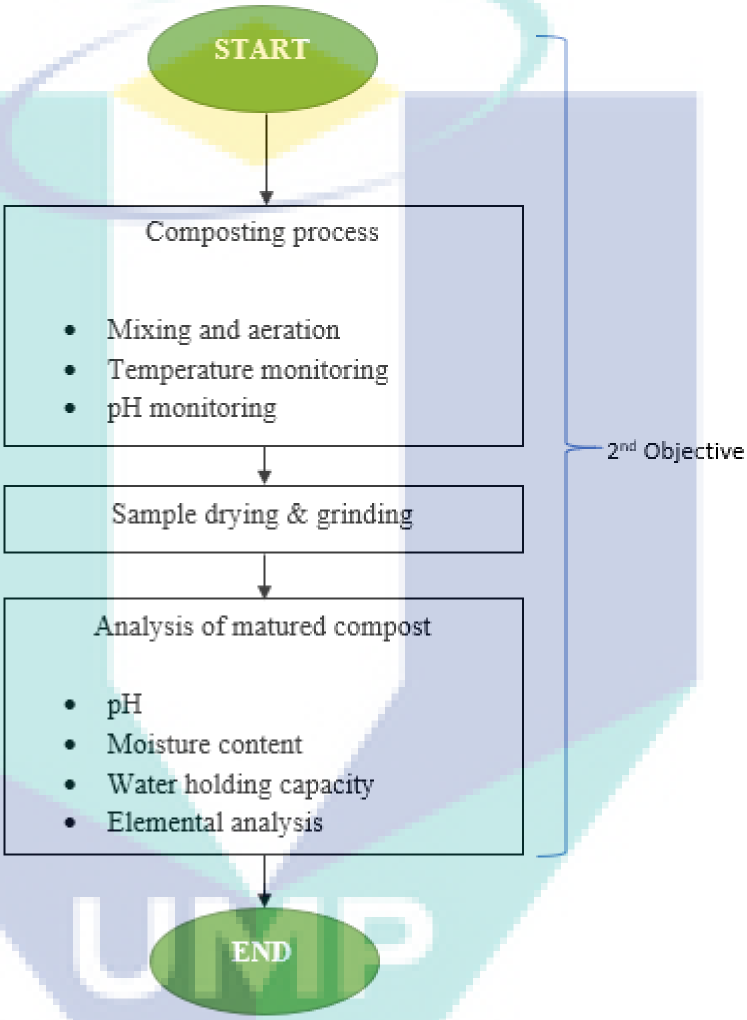

Figure 3.8 Workflow to determine the effect of rice husk ash composition

The best formulation from Section 3.3 was used to investigate the effect of heating on compost properties. In this section, the composting process was done in compost bin and forced heating composter to compare the heating effect by both types of composter. The forced heating composter is shown in Figure 3.9.

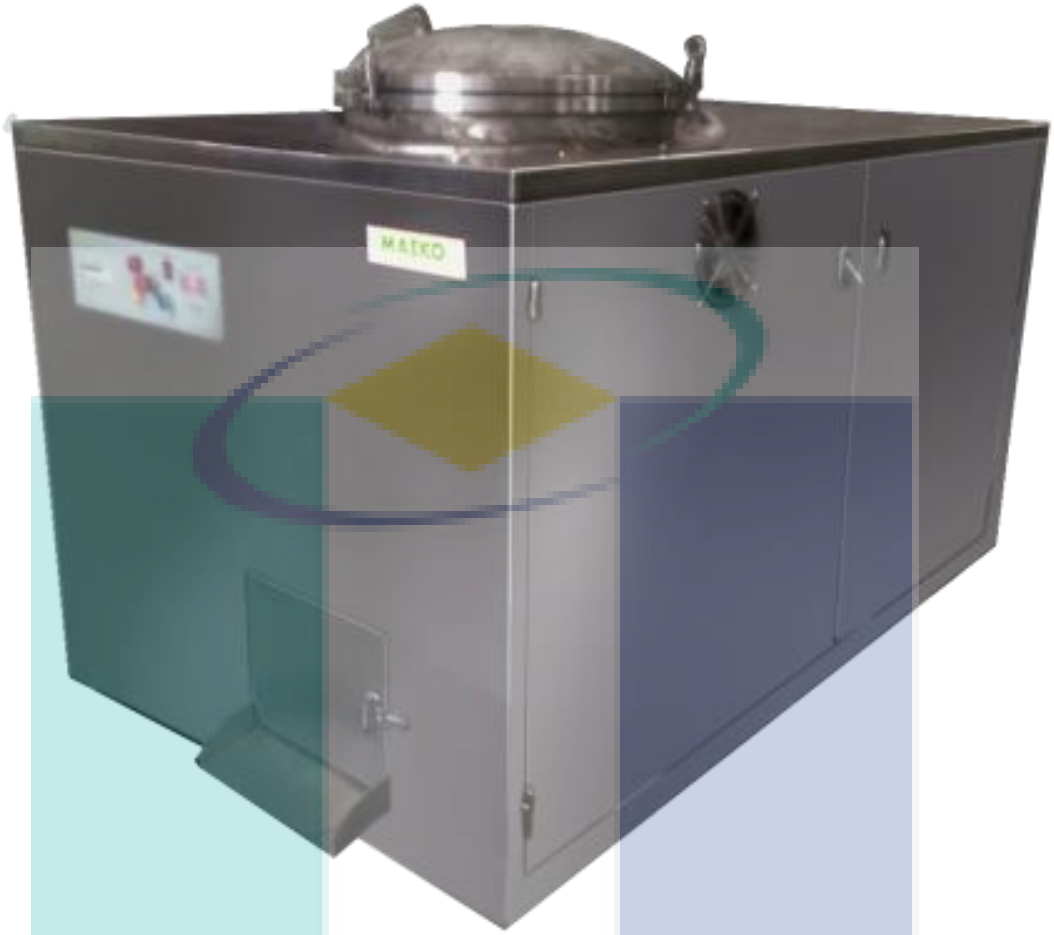

Figure 3.9 Forced heating composter used in the experiment

Figure 3.9 shows forced heating composter with model number CW 100 by MAEKO used for the experiment. This composter machine was made in Malaysia. The temperature of the composter was uniformly distributed and maintained at 60 °C. This model is a stand-alone unit with interactive touch panel control and built-in grinder or crusher system. This composter works at temperature within a range of 40-60 °C and able to process various types of raw materials such as bones, seashells, hard rinds, coconut husk, all types of fresh and cook waste. Figure 3.10 shows the schematic diagram of this composter.

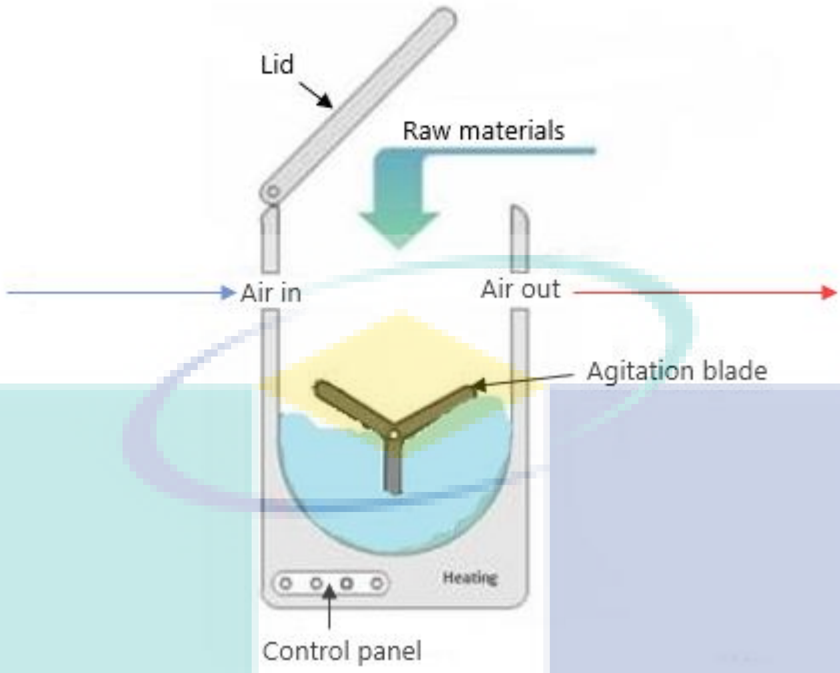

Figure 3.10 Schematic diagram for forced heating composter

Based on Figure 3.10, the forced heating composter was equipped with air flow system which was designed to increase the air flow for composting media. The air flow at of 0.005 m^3 min^{-1} was blown into the system. In order to maintain the system, the temperature controller sent a signal to the blower to remove excessive heat produced during the composting process. Meanwhile, the agitation blade turned the compost for the mixing process continuously.

The total weight used for raw materials in this work was 5.375 kg which contain 6.98% by weight of rice husk ash. For composting using forced heating composter, the process was completed in 48 hours due to continuous airflow and rotation which helps to shorten the active phase of composting. After the experiment done, the samples were dried and ground. Then, the samples were analysed for pH, moisture content, water-holding capacity and chemical properties by using the same method mentioned in Section 3.2. Meanwhile for composting by using compost bin, the same procedure as stated in Section 3.3 were repeated, in which it took 50 days to produce matured compost. Comparison in terms of physicochemical properties were made after the result was obtained. Work done in this section is summarized in Figure 3.11.

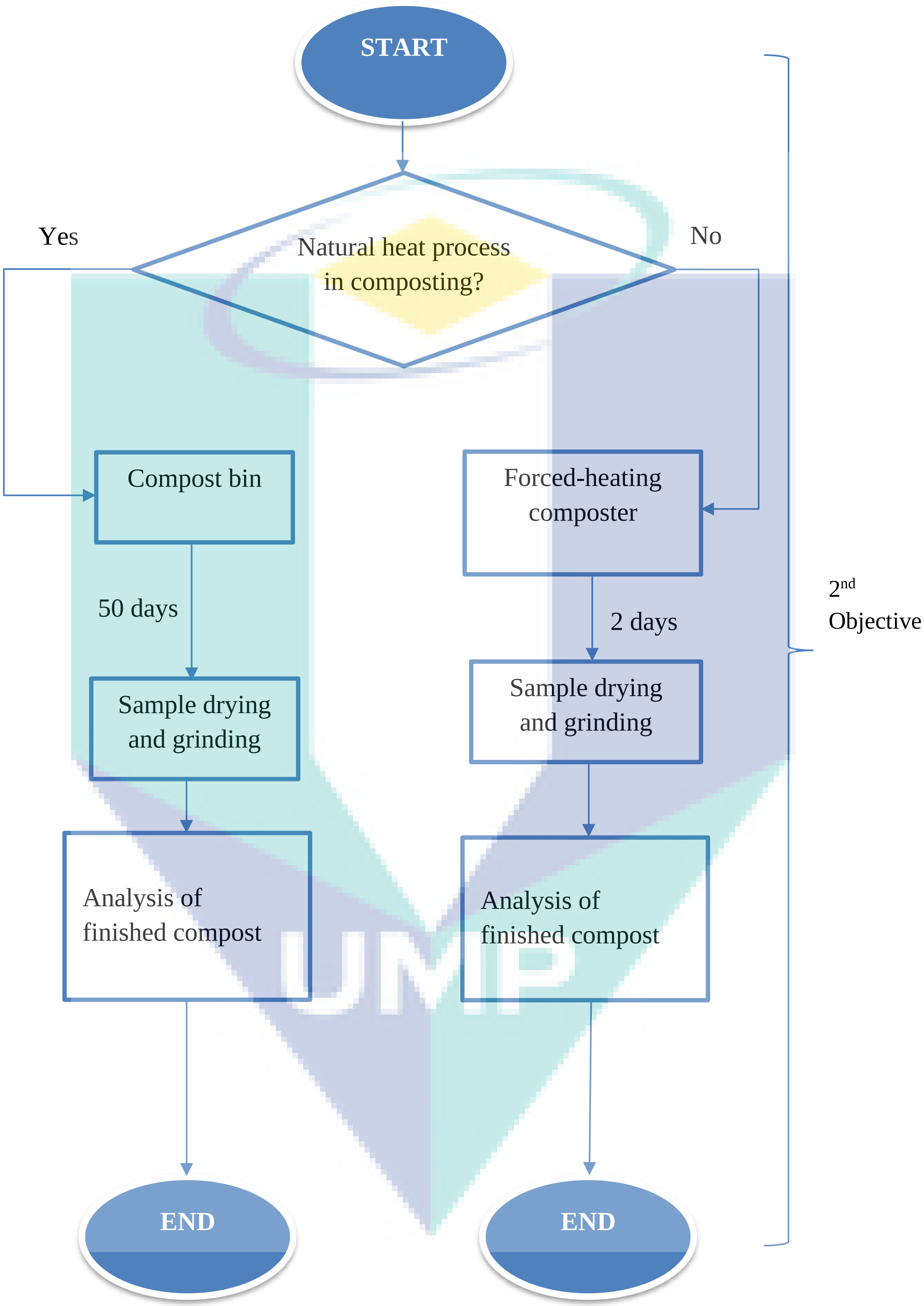

Figure 3.11 Workflow to investigate the effect of heating on compost properties

According to Figure 3.11, after the composting process complete for both composters, the samples were dried and ground. The samples were analysed by using methods mentioned in Section 3.2 for pH, moisture content, water holding capacity, and elemental composition.

3.6 Experimental Set Up for Physicochemical Properties Comparison Between Formulated Compost and Commercial Fertilizer

In order to determine the quality of formulated fertilizer, the formulated compost was compared with commercial chicken manure fertilizer in terms of physical and chemical properties. Steps to compare the formulated fertilizer with commercial chicken manure fertilizer is summarized in Figure 3.12 below.

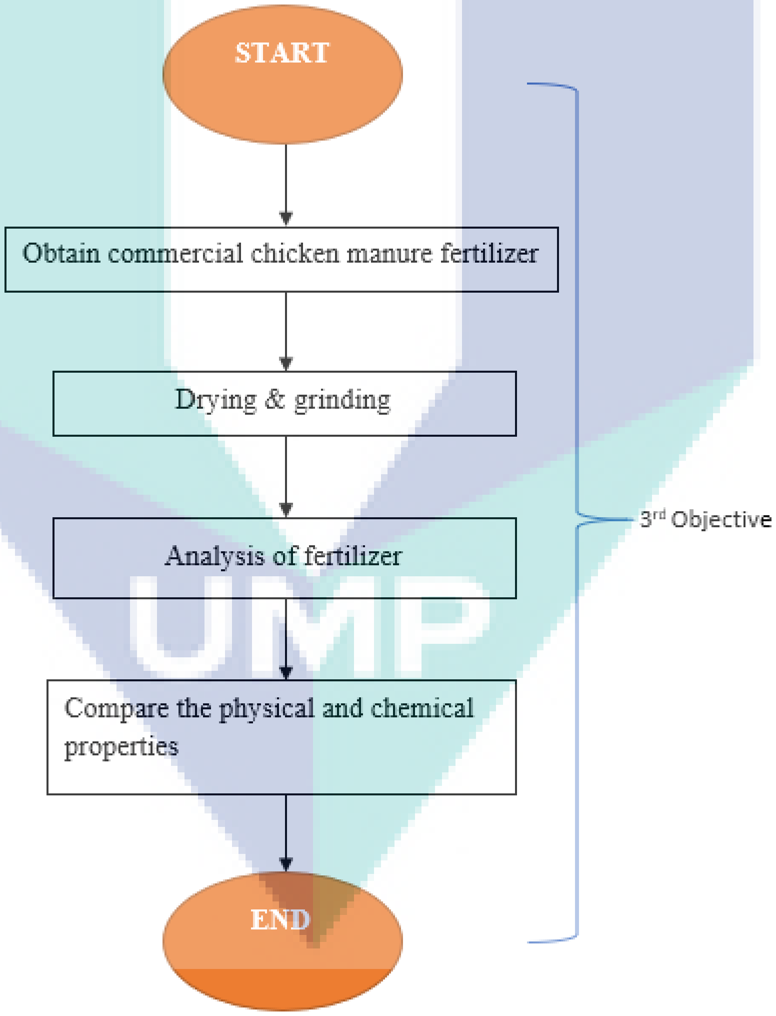

Figure 3.12 Steps to compare formulated fertilizer with commercial fertilizer

Based on Figure 3.12, 1000g of commercial chicken manure fertilizer manufactured by brand X were purchased for this study. It was chosen as benchmark in this study because this fertilizer is ideal for all plants (flower and vegetables) and has no chemical additives. The commercial chicken manure fertilizer was in pellet form. It was dried and ground before the analysis was made. Methods described in Section 3.2 was used to characterize the commercial fertilizer in terms of physicochemical properties. After the analysis completed, the physicochemical properties of commercial organic fertilizer were compared with formulated compost.

3.7 Summary

This chapter discusses in detail the fabrication of composting bin, raw material preparation, and characterization. Besides that, experimental set up for composting process using the compost bin was explained in this chapter. Apart from that, the method for comparison of the properties between forced heating composter and compost bin were described. set up for comparison between formulated compost with commercial chicken manure fertilizer were described. The procedure to validate the quality of formulated with the commercially available chicken manure fertilizer were also included.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter explains the findings related to the raw materials characterization and effect of varying rice husk ash composition during the composting process towards the properties of compost. Thus, the effect of heating on the compost properties was discussed in this chapter. The early part of this chapter outlined the physicochemical properties of raw materials analysis involved in the composting process. Section 4.2 elucidates the effect of rice husk ash on the composting process; in this section, the best formulation of composts was determined in terms of the temperature profile, pH profile, physical, and chemical properties. Section 4.3 gives an explanation on the effect of the heating process on the compost properties. The last part of this chapter presents the comparison study between formulated fertilizer and commercial fertilizer in terms of physical and chemical properties.

4.2 Physicochemical Properties of Raw Materials

This section reports the results obtained from the raw material analysis, which are categorized into two properties; physical and chemical. Physical and chemical properties of raw materials are important in the composting process as it influences the end-product properties. According to Kim et al. (2016), compost ingredients have their own unique characteristics that affect the compost properties. Besides that, physical and chemical compositions of the raw material affect the microbial activity in a certain organic waste (Cáceres, Malin´ska, & Marfà, 2018). The physical and chemical characteristics of raw materials for the composting process are presented in Table 4.1 and Figure 4.1, respectively.

Table 4.1 Physical properties of raw materials

Parameters	POME aerobic sludge	Decanter cake	Rice husk ash
Moisture content (%)	68.93 ± 0.02	79.06 ± 0.04	17.39 ± 0.02
Water holding capacity (%)	60.92 ± 0.03	70.12 ± 0.012	78.45 ± 0.01
pH	7.46 ± 0.02	5.10 ± 0.04	7.10 ± 0.02

High moisture content (> 40%) of raw materials is required to achieve an ideal condition for the composting process. As mentioned by Maheshwari (2014), the maximum temperature reached during the composting process is affected by the initial moisture content. As shown in Table 4.1, the highest moisture content for raw materials was recorded through the decanter cake with 79.06% of moisture content. Similarly, studies by Abdul Razak et al. (2012) and Sahad et al. (2014) reported comparable ranges of moisture content for decanter cake, which are 78.20 and 76.46%, respectively. According to Liang et al. (2003) and Kim et al. (2016), composting at a moisture content level between 40-60% is the most efficient to avoid dehydration and anaerobic condition. Therefore, decanter cake plays an important role in maintaining the required level of moisture content later in the composting process.

In contrast to decanter cake, rice husk ash gave a lower moisture content of 17.39% due to the burning process of rice husk, which eliminates the moisture content in rice husk ash during manufacturing processes. The removal of moisture content during the manufacturing process is important to ensure the rice husk ash (RHA) can be easily handled for logistic purposes. This is because the rice husk ash has a higher tendency to absorb moisture. This can be proven through the higher record of water holding capacity properties of the rice husk ash. According to the analysis results, the water-holding capacity of the rice husk ash is 78.45%. This is related well with the presence of silica in rice husk ash, as illustrated in Figure 4.1. Silica has played a vital role in water adsorption and avoid available nutrient from leaching. Studies conducted by Matichenkov & Bocharnikova (2001) and Schaller et al. (2020) reported that silicon-rich materials increased the water holding capacity of soil due to its high specific surface area to adsorb water. Therefore, high silica content (44.01%) in rice husk ash was beneficial to maintain an ideal range of water holding capacity (60-80%) for the composting process.

According to the results in Table 4.1, POME aerobic sludge and rice husk ash had almost neutral pH values, which are 7.46 and 7.10, respectively. On the contrary, decanter cake was acidic with a pH of 5.1, which might have been due to the acidic nature of decanter cake when freshly produced from the milling process. The obtained result is consistent with a previous study by Sahad et al. (2014), decanter cake was reported to contain a pH of 5.03. Since POME aerobic sludge and rice husk ash were almost neutral, it is necessary to include decanter cake as a raw material to complement each other. This is because most micronutrients are more available to plants in slightly acidic soils compared to neutral-alkaline soils (Gentili et al., 2018).

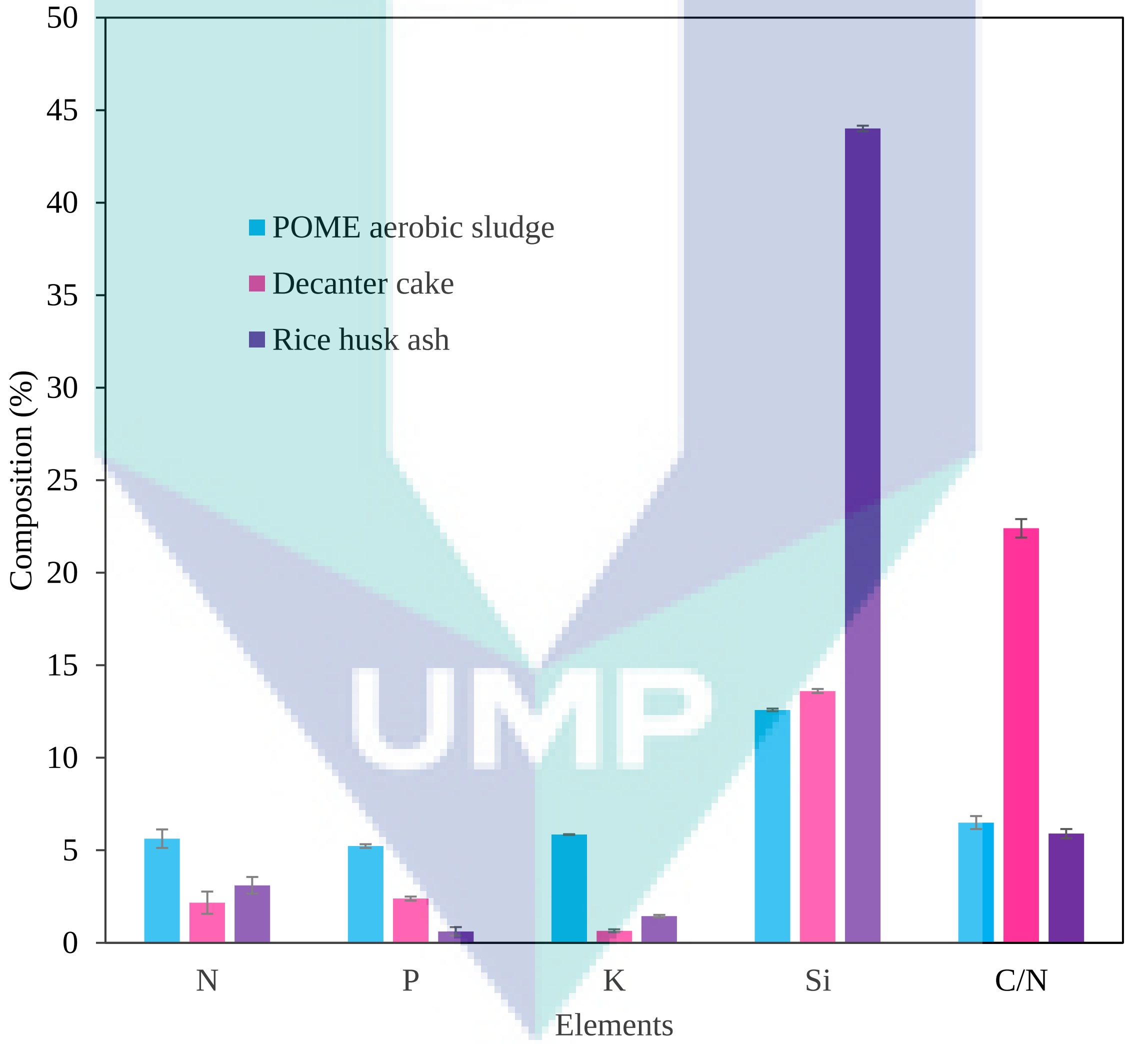

Figure 4.1 Chemical properties of raw materials

From Figure 4.1, POME aerobic sludge showed the highest amount of nitrogen (N), phosphorus (P), and potassium (K) that influence the N, P, K content of the end-product. This is because decanter cake and rice husk ash are lack of these macronutrients. Despite rice husk ash had a reduced N, P, K, it possessed the highest amount of silica (about 44.01%). A similar content of silica was reported by Bakar et al. (2016). Silica is an essential component for retaining important nutrients and minimizing the loss of nutrients. Many studies have reported that silica influences the nutrient accumulation and uptake of several macronutrients and micronutrients via binding to silicates (Greger et al., 2018; Sahebi et al., 2015).

Meanwhile, the decanter cake had the highest C/N ratio of 22.4. A study by Yahya et al. (2010) and Nutongkaew et al. (2014) reported similar ranges of C/N ratios for decanter cake (21.72 and 20.14, respectively). A study conducted by Zhou (2017) claimed that C/N ratio between 20-25 during the initial composting process was favourable for treating agricultural waste as it can reduce the nitrogen loss when there is an excess nitrogen per unit of degradable carbon. From the result, it showed that the combination of POME aerobic sludge, decanter cake, and rice husk ash is the best raw materials that can be used in the compost formulation.

4.3 Effect of Rice Husk Ash on Composting Process

The results generated from the composting process are divided into four parts, which are temperature profile, pH profile, physical, and chemical properties. It is crucial to analyse the temperature and pH profile as an indication of the stage that occurred during the composting process. Meanwhile, the best formulation for compost was determined through the physicochemical properties (moisture content, water holding capacity, and elemental analysis) of compost.

4.3.1 Temperature profile

The temperature profile is used to indicate the mesophilic phase, thermophilic phase, cooling phase, and curing phase. Besides that, the temperature is strongly related to moisture content and pH of compost. The first phase in the composting process is called the mesophilic phase. In this phase, the temperatures for all the samples will increase gradually to 40 ºC due to the microbial activity, which accelerates a decomposition process (Ramli et al., 2016).

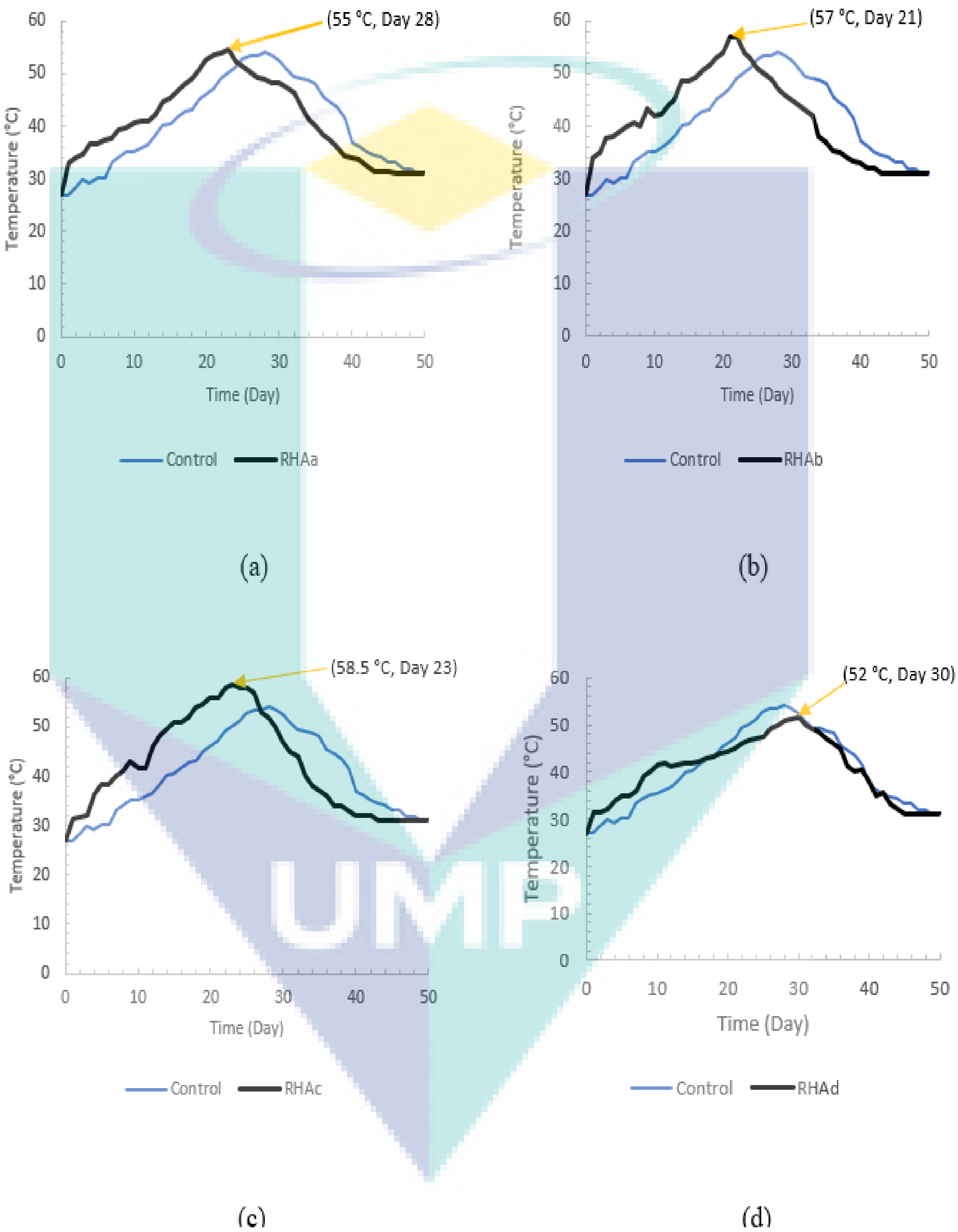

Figure 4.2 Temperature profile for composting process

According to Figure 4.2, Sample RHA_b managed to reach 40 ºC on day 6, followed by Sample RHA_c on day 7, Sample RHA_d on day 9, Sample RHA_a on day 10, and control sample on day 14^{th}. Then, the composting process proceeds until it reached the thermophilic phase, where the maximum temperature range was attained. This might be due to the heat released from the microbial activity, which enhances exothermic reactions in the composting pile (Sánchez et al., 2017). The maximum composting activity occurred during the thermophilic phase at the temperature range of 50-60 °C (Ramli et al., 2016). Based on the results shown in Figure 4.2, it has confirmed that the presence of rice husk ash has fastened the duration of the composting process. Based on Figure 4.2 (a)-(c), the duration taken by Sample RHA_a, Sample RHA_b, and Sample RHA_c to achieve maximum temperature is faster compared to the control sample. As mentioned in the methodology part, the control sample has no presence of rice husk ash. However, the temperature profile shows that the control sample managed to achieve a similar range of maximum temperatures. This is due to the same amount of POME aerobic sludge used in the formulation, which provides nitrogen sources and microbial seeding. According to Ahmad et al. (2011), nitrogen sources and microbial seeding from the POME aerobic sludge aid composting process.

As illustrated in Figure 4.2, the maximum temperature achieved by all samples were in the range between 52-58.5 °C. Overall, Sample RHA_d with the maximum percentage of rice husk ash (at 9.09%) showed the slowest rate as it requires 27 days to reach temperature 50 ºC. This correlated well with excessive moisture content (> 60%) observed in Sample RHA_d, which resulted in the partially anaerobic condition in the compost bin. It is known that the anaerobic condition can cause poor microbial activity. This is because the aerobic bacteria consist in the material requires adequate moisture content and temperature to complete the digestion process in converting the organic compound into nutrient content (Rogoff, 2014).

On the other hand, Sample RHA_c with 6.98% rice husk ash exhibited the fastest day in reaching a temperature above 50 ºC on day 15. Besides that, Sample RHAc showed the highest maximum temperature of 58.5 ºC on day 22. This might be due to the ideal moisture content level of 57.72% attained by Sample RHA_c, as presented in Table 4.3 (Section 4.2c). Nevertheless, the control sample that did not contain rice husk ash reflected the slowest trend in achieving 50 ºC compared to all the samples (except Sample

RHA$_d$). By comparing the results from Table 4.3 in Section 4.2 (c), partial dehydration was observed in the control sample because it obtained a moisture content level of 45.76%. In order to avoid dehydration during the composting process, the moisture content level must be in a range of 50-60% (Kim et al., 2016).

Once the maximum temperature was attained, the temperature of compost piles declined gradually and reached ambient temperature. This phase is called the cooling phase. Results reported in this study are consistent with previous studies by Zakarya et al. (2018) and Ramli et al. (2016) in which similar patterns of temperature profile were obtained. In the cooling phase, the temperature decreased until it reaches ambient temperature due to the exhaustion of substrates, which caused the microbial activity to decline (Insam & de Bertoldi, 2007). Besides that, a decrease in temperature might be caused by radiation that occurred in the composting process. Radiation occurred when the heat generated in the composting bin radiates out to cooler surrounding air through the holes made for airflow purposes (Alkoaik et al., 2019).

After the ambient temperature was achieved for at least 3 consecutive days, the composting process was considered complete. According to the results illustrated in Figure 4.2, Sample RHA$_b$ and Sample RHA$_c$ completed the composting process 3 days earlier compared to other samples. This might be due to the ideal range of moisture content level in Sample RHA$_b$ and Sample RHA$_c$. The composting process can be enhanced through temperature increment, where the temperature was influenced by moisture content (Liang et al., 2003). The composting process continued with the curing phase until day 50. According to Ramli et al. (2016), the chemical reaction continues to occur during the curing phase, resulted in more stability of the organic matter, which was highly beneficial for plant growth.

4.3.2 pH profile

Another factor that can affect the progress and maturity of compost is pH. In the composting process, when the mesophilic phase changed to the thermophilic phase, the pH of compost will be increased. In this study, the pH of the composts was recorded daily for 50 days, and the result is presented in Figure 4.3.

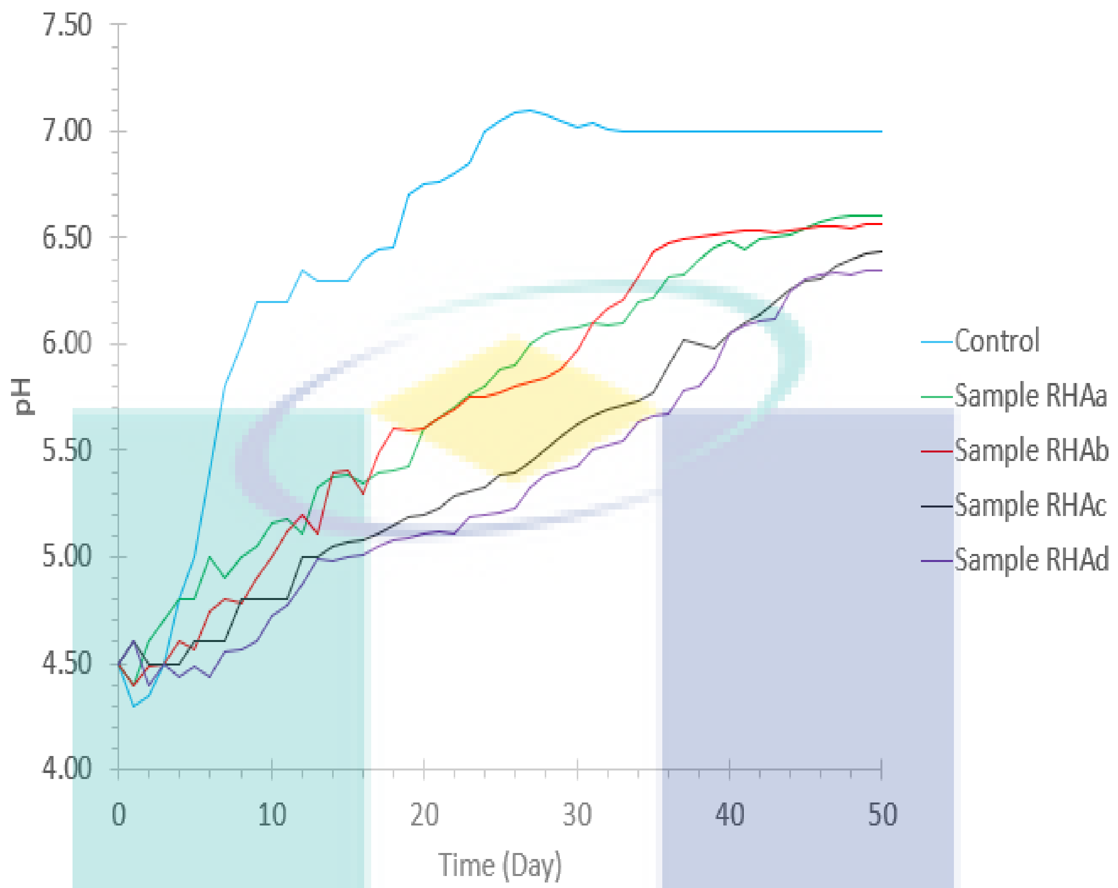

Figure 4.3 pH profile for composting process

Based on Figure 4.3, the pH of all samples increased until a constant pH value in the range of 6-7 was achieved. A study by Rihani et al. (2010) highlighted that the activity of proteolytic bacteria due to the degradation of organic matter caused an increment in pH values during the initial phase of composting. Nevertheless, as time increased, the pH values drop or stable due to ammonia volatilization and oxidation that caused a decrease in ammonia content in the sample. Moreover, Rihani et al. (2010) claimed that the release of humic substances, which act as a buffer, caused a decrease in pH values in composting.

After the composting process was completed, all the samples achieved pH in the range of 6.35-7.0. The result obtained in this study were in the range of targeted pH according to ideal compost properties reported by Ozores-hampton (2017). Generally, the pH range for finished compost should achieve within 6.0-8.0. However, it is highly dependent on the properties feedstock, composting process, and the addition of amendments (Ozores-hampton, 2017).

According to Figure 4.3, at the end of the composting process, the control sample depicts the highest pH value of 7.0. Meanwhile, Sample RHA_a, Sample RHA_b, Sample RHA_c, and Sample RHA_d have recorded a pH value of 6.60, 6.56, 6.44, and 6.35, respectively. A closer look at the data showed that the addition of rice husk ash prolongs the duration to achieve a stable pH trend. It can be seen in Figure 4.3 that as the amount of rice husk ash increased, the maximum pH value decreased, and the time increased. Samples with a higher presence of rice husk ash required a longer time to achieve constant pH. This might be due to the active surface on the rice husk ash, which can retain nutrient loss through leaching or ammonia volatilization (Ding et al., 2016). For that reason, the sample with a higher content of rice husk ash has recorded a lower value of maximum pH and longer time to achieve stable pH, as shown in Figure 4.3.

Table 4.2 Comparison on pH of compost

Author	**Feedstock**	**pH**
Present study	POME aerobic sludge, decanter cake, and rice husk ash	6.35-7.0
Zakarya et al. (2018)	Rice straw and food waste	4.9-8.3
Ramli et al. (2016)	POME sludge and decanter cake	6.7-7.0
Rashad et al. (2010)	Rice straw, soybean wastes, vinasse, rock phosphate, and microbial additives	6.5-7.0

Based on the data comparison presented in Table 4.2, it has shown that the pH of composts in the present study (6.35-7.0) agreed with other studies as reported by Zakarya et al. (2018), Ramli et al. (2016) and Rashad et al. (2010). A previous study by Malakahmad et al. (2017) confirmed that the soil pH of 6.0-8.0 is ideal and suitable for various types of vegetables. Therefore, this finding indicates that the pH of compost can be controlled by the addition of rice husk ash in order to obtain an ideal pH (6.0-8.0), which is suitable for plant growth.

4.3.3 Physical properties of matured compost

The physical properties of matured compost are important to determine the stage involved in the composting process. The results for physical properties are reported in Table 4.3.

Table 4.3 Physical properties of matured compost

Parameters	Control	Sample RHA_a	Sample RHA_b	Sample RHA_c	Sample RHA_d
Moisture content (%)	45.76 ± 2.88	52.57 ± 6.11	54.67 ± 1.09	57.72 ± 1.24	62.54 ± 5.99
Water holding capacity (%)	51.38 ± 1.12	61.35 ± 1.39	63.26 ± 2.34	69.86 ± 1.54	73.58 ± 2.66

Based on Table 4.3, the result highlights two important findings related to moisture content and water holding capacity of the finished compost. It is found that the moisture content is directly proportional to the water holding capacity. The addition of rice husk ash caused an increase in moisture content and water holding capacity. The data shows that all samples has moisture content in the range of 45-63%. However, the ideal moisture content for compost should be more than 40% to prevent dehydration in the composting process and below 60% to avoid the anaerobic condition (Kim et al., 2016; Zakarya et al., 2018). Thus, Sample RHA_d does not meet the requirement.

Sample RHA_d had the highest moisture content (62.54%), which exceeded the acceptable range for moisture content. This possibly caused by excess content of rice husk ash in the sample formulation, which can cause the anaerobic condition in compost. According to the study by Zhang et al. (2014), the morphological property of rice husk ash is a highly porous structure, and it has a relatively large surface area, which is necessary for high performance adsorption of water. Nonetheless, excessive moisture content (> 60%) will cause anaerobic conditions in the composting bin (Liang et al., 2003). As put forward by Alkoaik et al. (2020) and Kim et al. (2016), anaerobic conditions occur due to low levels of oxygen in the pore spaces of solid matrices as it was filled with the water. The excess water content in the composting process will limit the diffusion and restrict oxygen utilization by the microorganisms (Cáceres & Malin, 2018). This situation affected the temperature profile of Sample RHA_d, where the microorganisms were unable to generate more heat. Thus, this finding is directly in line well with the previous studies, as discussed in Section 4.2 (a). Table 4.4 shows the comparison of moisture content obtained in this study and prior studies.

Table 4.4 Comparison of moisture content

Author	Feedstock	Moisture content (%)
Present study	POME aerobic sludge, decanter cake, and rice husk ash	52.57-62.54
Zakarya et al. (2018)	Rice husk ash and food waste	40.0-59.0
Qian et al. (2016)	Dairy manure and rice straw	45.0-60.0
Ramli et al. (2016)	POME sludge and decanter cake	45.3-48.9
Baharuddin et al. (2010)	Empty fruit bunch and POME sludge	51.8-64.5
Yahya et al. (2010)	Empty fruit bunch and decanter cake	49.0-67.0

Based on the data comparison of moisture content shown from Table 4.4, the results for moisture content in the present study are consistent with the previous studies by Ramli et al. (2016), Baharuddin et al. (2010), and Yahya et al. (2010). A study by Ramli et al. (2016) used POME sludge and decanter cake as the raw materials for the compost, and they claimed that the moisture content falls within 45.3-48.9% for the compost. Meanwhile, the compost produced in this study successfully increased the moisture content in the range of 6.27-13.64% with the addition of rice husk ash. This result is in accordance with the previous study by Qian et al. (2016) and Zakarya et al. (2018), they reported that the moisture content falls within the range of 45-60% and 40-59% respectively, with the use of rice husk ash as raw materials. These results suggest that the addition of rice husk ash increased silica content in the sample, which helps to increase the moisture content of compost.

4.3.4 Chemical properties of matured compost

Chemical properties of compost are important parameters that determine the composition of elements in the compost. For the chemical properties of formulated compost, the results are shown in Figure 4.4.

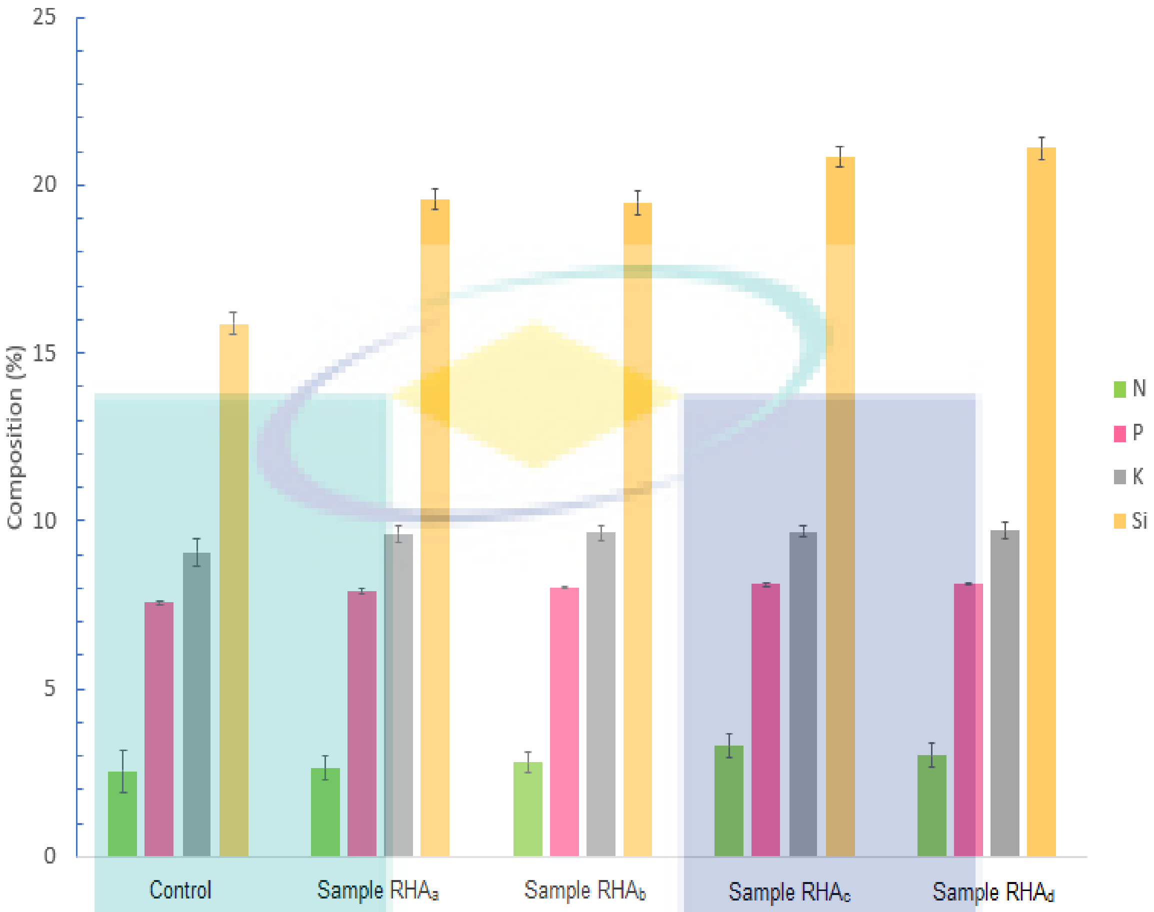

Figure 4.4 Elemental composition of compost

According to Figure 4.4, the result shows that the presence of rice husk ash seems not to have an impact on the nitrogen content in compost. Sample RHA_c had the highest amount of nitrogen (3.31%) compared to all the samples. However, Sample RHA_d had 0.38% lower nitrogen content compared to Sample RHA_c, even though it has the maximum percentage of rice husk ash. There are several possible explanations for this result, which are correlated with the results in Section 4.2 (a) and Section 4.2 (c). It was observed that partially anaerobic condition occurred in Sample RHA_d is due to excessive moisture content, which caused a slower trend of temperature increase during the thermophilic phase of the composting process. As proposed by Cáceres et al. (2018), the mineralization of nitrogen was affected by thermophilic temperature, which it favours the NH_4^+ formation. When the thermophilic temperature was interrupted due to high moisture content, the NH_4^+ formation will decrease (Koyama et al., 2018).

As seen in Figure 4.4, it is believed that the rice husk ash has an ability to increase phosphorus content in the samples by 0.33-0.67%. According to Gupta et al. (2014), the rice husk ash helped to enhance the nutrient availability in compost by increasing the surface adsorption of sites for phosphate. This might be due to the presence of a polar group, Si-O-Si, Si-H, and C=O on the surface of rice husk ash, which increases the cation exchange capacity (Mor et al., 2016). It was observed that increases in the amount of rice husk ash increased the phosphorus content proportionally. Thus, a control sample without rice husk ash showed the lowest amount of phosphorus (about 7.56%).

The application of rice husk ash in the composting process was seen to improve the amount of potassium by 0.55-0.74% in a compost. The control sample, which has no presence of rice husk ash, displayed the lowest amount of potassium (about 9.07%). In this case, the potassium was adsorbed by rice husk ash, which served as a sorption site through the ion exchange. A study by Hamzah et al. (2017) pointed out that the rice husk ash acted as a sorption site as it has a high cation exchange capacity. From the result demonstrated in Figure 4.4, a higher amount of rice husk ash in compost increased the cation exchange capacity. This pattern resulted in the increment of potassium adsorption through compost as Sample RHA_d with a maximum percentage of rice husk ash showed the highest potassium content (9.81%).

Furthermore, Sample RHA_d displayed the highest amount of silica (about 21.1%), as presented in Figure 4.4. This might be due to the high amount of rice husk ash added to the compost material. By comparing results from Figure 4.1, it was observed that the rice husk ash itself contained 41.01% of silica. The result suggested that samples containing rice husk ash showed 3.71-5.24% higher in silica content compared to the control sample. This finding is in accordance with the previous study by Anda et al. (2008), it was reported that the addition of composted rice husk significantly increased the amount of silica in soils. However, the small amount of silica in a control sample might be due to the silica content, which was initially from the POME aerobic sludge and decanter cake.

Table 4.5 N-P-K ratio and C/N ratio for compost

Parameters	**Control**	**Sample RHA_a**	**Sample RHA_b**	**Sample RHA_c**	**Sample RHA_d**
C/N	12.35	12.14	12.04	10.28	10.7
N-P-K	2.5-7.5-9.0	2.6-7.9-9.6	2.8-8.0-9.6	3.3-8.1-9.7	3.0-8.1-9.7

Generally, the optimum C/N ratio of finished compost ranges from 10 to 15, which represents the formation of humic acid that helps the plants to take up nutrient easily (Corral et al., 2019; Alkarimiah & Suja', 2020). However, the C/N ratio was affected by the maturity of the final compost, where the optimal C/N ratio varied based on the type of raw materials used in the composting process (Yan et al., 2015). From the result illustrated in Table 4.5, the C/N ratios of all compost were in the range of 10.28 to 12.35. It was observed that Sample RHA_c had the lowest C/N ratio due to the higher amount of nitrogen. A higher amount of nitrogen reduced the C/N ratio and sped up the composting process (Yahya et al., 2010). This finding is correlated to the result in Figure 4.2, which Sample RHA_c completed the composting process faster compared to other samples. Similar ranges of C/N ratio were reported by Erana et al. (2019) and Trisakti et al. (2017) to be 10.75-11.79 and 11.5-12.5, respectively.

According to Hanč et al. (2008), the best composition for organic fertilizer is 2.33-0.56-2.84 for compost based on green-waste biomass. However, N-P-K ratio of 3-6-3 is stated as standard N-P-K for commercialization of compost fertilizer suitable for fruits and organic vegetable plants (Kenso, 2017). From Table 4.5, Sample RHA_c and Sample RHA_d managed to achieve the required standard for commercial compost with a nitrogen composition of 3%. However, the content of phosphorus and potassium are excessive in both samples with P-K ratio of 8-9. For that reason, Sample RHA_c and Sample RHA_d also suitable to be categorized as 'general-purpose fertilizer' which are formulated for specific needs. For example, additional phosphorus can be used to prevent P deficiency on plant root development and additional potassium can be used increase fruit yield (Heuer et al., 2017; Razaq et al., 2017).

4.4 Heating Effect on Compost Properties

The aerobic composting process is recognized as the fastest way to produce high-quality compost where the organic wastes are stabilized and converted into a valuable product (Makan et al., 2013). In order to produce a stable and quality compost, the composting system was designed to provide an optimized condition for aerobic degradation of organic waste. In this section, the physicochemical properties of compost made by using compost bin and forced heating composter were analysed. The results obtained are presented in Figure 4.5 and Table 4.6.

Table 4.6 Physical properties of compost made by using compost bin and forced heating composter

Parameters	Compost bin	Forced heating composter
Time taken (day)	50	2
Moisture content (%)	57.72 ± 1.24	28.02 ± 2.13
Water holding capacity (%)	69.86 ± 1.53	41.98 ± 0.98
pH	6.44 ± 0.57	7.75 ± 0.23

From the result presented in Table 4.6, the forced heating compost managed to complete the composting process within 2 days. The process was quick compared to the compost bin due to the rotation system, which runs continuously to reduce the time taken for active phase in the composting process. Meanwhile, the compost bin requires at least 50 days to complete the composting process as the process naturally depends on the microorganism activity. This is consistent with findings by Alkoaik (2019), which also conducted research on composting using forced heating composter and compost bin. It was revealed that the compost made by using forced heating composter complete the composting process faster. This is due to the rapid degradation of organic matter and robust microbial activity in the forced heating composter (Qasim et al., 2018). In contrast, compost from the composting bin was still immature and active.

Table 4.6 compares the moisture content of both composts in which forced heating compost shows lower moisture content and water holding capacity compared to compost made by using a compost bin. It was found that high temperature (T > 60 ºC) in the forced heating composter led to the lower moisture content in compost due to water evaporation. A study by Malakahmad et al. (2017) reported that the heating process in a forced heating composter evaporates the water contained in the raw materials. Continuous mixing process equipped in the forced heating composter caused a higher evaporation rate compared to non-continuous mixing in compost bin (Won et al., 2018). The process of mixing and turning in the forced heating composter aided with a consistent temperature above 60 °C caused the reduction in the moisture content of the finished compost.

In terms of pH, compost produced using forced heating composter showed higher pH of 7.75, which is slightly alkaline. Gao et al. (2010), Pudełko (2014), and Yuan et al. (2016) conducted some studies on composting by using a forced heating composter, which has reported a similar range of pH values (7.20, 8.18 and 7.48, respectively). The pH value obtained was slightly alkaline due to the volatilization of ammonia during the nitrification process. The volatilization of ammonia and the release of H^+ from microbial nitrification process caused the pH of finished compost to stabilized in alkaline values since ammonia volatilization favours at alkaline pH (Gao et al., 2010; Febrisiantosa et al., 2018).

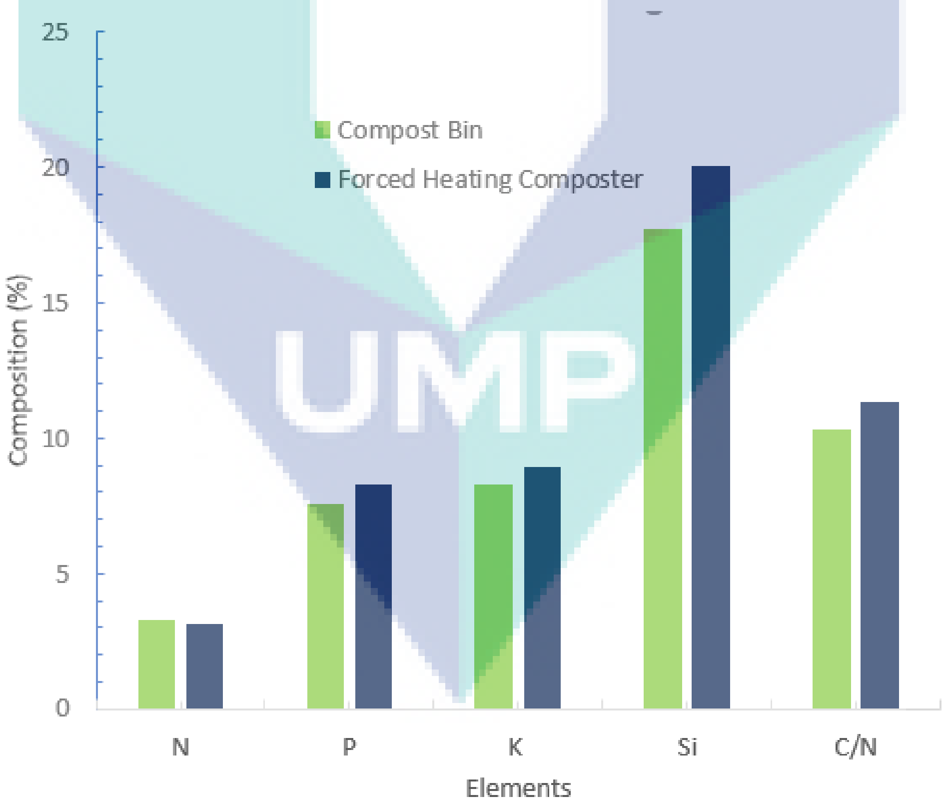

Figure 4.5 Elemental composition of compost made by using compost bin and forced heating composter

According to the results illustrated in Figure 4.5, the forced heating compost reflected a 0.13% reduction in nitrogen content compared to the compost made by using compost bin. The loss of nitrogen might be due to the high temperature generated in a composter. According to Mlangeni et al. (2013), the high temperature will increase the loss of nitrogen through volatilization of ammonia. Furthermore, higher nitrogen content in compost made by using a compost bin might be due to the longer time taken to complete the composting process. This is because when the compost age increased, the nitrogen content will increase as the compost will become more stable and mature (Al-bataina et al., 2016). This condition has caused a higher C/N ratio of compost made by using forced heating composter because the C/N ratio is inversely proportional to nitrogen content.

Even though compost made using compost bin recorded a higher content of nitrogen, but it had a lower content of phosphorus, potassium, and silica. There are several possible explanations for this result. It is very likely due to insufficient turning and mixing to increase the oxygen level in the compost material. A research by Zhou (2017) has reported that sufficient oxygen during composting produced higher microbial activities, which results in increased mineralization. However, excessive or lack of turning can cause the loss of total nutrients in the final product (Zhang et al., 2019). In this case, continuous turning or mixing by using a forced heating composter is more efficient compared to the compost bin in minimizing loss of phosphorus, potassium, and silica.

Another possible explanation for lower content of phosphorus, potassium and silica is due to the leaching that occurred during the composting when using compost bin. In the composting process, the degradation of raw materials released carbon dioxide and water vapour into the composting bin, which could increase the leaching losses (Carneiro et al., 2013). The compost bin was fabricated with a valve to prevent flooding during the condensation process. When there is water trapped in the bin, the water will be released to the environment through the valve. Thus, some nutrients might have leached off to together with the water trapped.

Overall, the compost bin can produce compost with high moisture content and water holding capacity. Meanwhile, a forced heating composter can potentially produce compost with slightly higher macronutrients and micronutrients compared to the compost bin. However, in terms of cost and knowledge, the compost bin is much preferred because it does not require high maintenance costs and skilled labour to control the composting process.

4.5 Comparison of Formulated Compost With Commercial Fertilizer

From Section 4.2, it was found that Sample RHA_c with 6.98% of rice husk ash gave the best performance in the composting process. This is because it took a shorter period to complete the composting process, optimum physical properties, and high macronutrients and micronutrients. In this section, the formulated compost Sample RHA_c was compared to a commercial organic fertilizer made from chicken manure. Chicken manure fertilizer was chosen to be compared with formulated compost because it is regarded as one the best organic fertilizer which contains macronutrients and micronutrients needed by plants (Arifin et al., 2006; Almaz et al., 2017). Both fertilizers were analysed in terms of physicochemical properties, and the comparison are presented in Figure 4.6 and Table 4.7.

Table 4.7 Physical properties comparison between formulated compost with commercial chicken manure fertilizer

Parameters	**Formulated compost**	**Commercial chicken manure fertilizer**
Moisture content (%)	57.72 ± 1.24	27.09 ± 1.06
Water holding capacity (%)	69.86 ± 1.54	40.58 ± 1.72
pH	6.44 ± 0.78	6.75 ± 0.67

Moisture content is a key factor that affected the subsequent growth and nutrition of plants via soil mineralisation (Ngo & Cavagnaro, 2018). Based on the result presented in Table 4.7, chicken manure fertilizer has 27.09% moisture content. A similar range of moisture content was reported by Singh et al. (2018) and Chen et al. (2015) for chicken manure compost, which was 28.26% and 29.93%, respectively. Low moisture content in chicken manure compost is very likely due to the addition of a bulking agent (sawdust) to prevent malodour and vector attraction (Dede & Ozer, 2018). Another possible reason is might be due to the drying process involved chicken manure fertilizer production in order to reduce volume for logistic purposes (Ozores-hampton, 2017). On the other hand, formulated compost has 30.63% higher moisture content compared to chicken manure fertilizer. This is because the rice husk ash content helps to retain the water in the organic fertilizer and no drying process involved in formulated compost.

Another key factor that affects plant growth is water-holding capacity. The soil acts as the storage medium for water to stay in the spaces between the soil particles until the plants absorb it for growth. Studies by Williams et al. (2016) and Chadha et al. (2019) verified that the growth of plants was associated with a water-holding capacity of the soil. Based on Table 4.7, the formulated compost had 29.28% higher water holding capacity compared to chicken manure fertilizer. This result could be attributed to the presence of rice husk ash in the formulated compost because rice husk ash has high silica contents. According to Schaller et al. (2020), higher water-holding capacity was observed when silica contents in soil increased. The high porosity of silica enhanced the adsorption of water.

Instead of moisture content and water holding capacity, pH of fertilizer also plays a vital role in the growth of plants. According to Karim et al. (2007), optimum pH was necessary for plant cell growth and tissue development. This might be because the nutrient uptake and enzymatic activities in plants are affected by pH. From the results shown in Table 4.7, formulated compost and chicken manure fertilizer were in a similar range of pH (slightly acidic). It was reported by Goulding (2016) that fertilizers with slightly acidic pH were suitable for the growth of plants such as kale, maize, wheat, turnips, and barley.

Overall, the formulated compost had a higher amount of phosphorus and silica compared to the chicken manure fertilizer. Based on the result presented in Figure 4.6, formulated compost reflected 1.91% higher phosphorus and 13.38% higher silica compared to the chicken manure fertilizer. The high content of phosphorus in formulated compost is associated with the presence of silica from rice husk ash. A study by Mayumi et al. (2016) reported that silicate increases the availability of phosphate in soil via cation exchange of phosphate from adsorption sites.

The phosphorus availability is essential for the root development of plants as it influences the lateral root morphology and root branching (Razaq et al., 2017). The deficiency of phosphorus can limit the crop yield as the growth of the plant will be stunted (Heuer et al., 2017; Hue & Fox, 2010). On the other hand, the presence of silica in organic fertilizer is beneficial to plant growth as it alleviates the toxic effects due to abiotic stresses such as drought, heavy metals, and salt stress. Studies by Luyckx et al. (2017) and Emamverdian et al. (2018) reported that silica helps in improving the plant resistance towards abiotic stresses by reducing the adverse effects of heavy metal toxicity. It was done through stimulation of antioxidant enzyme activity, complexation and compartmentalization of silicon with metal ions (Emamverdian et al., 2018).

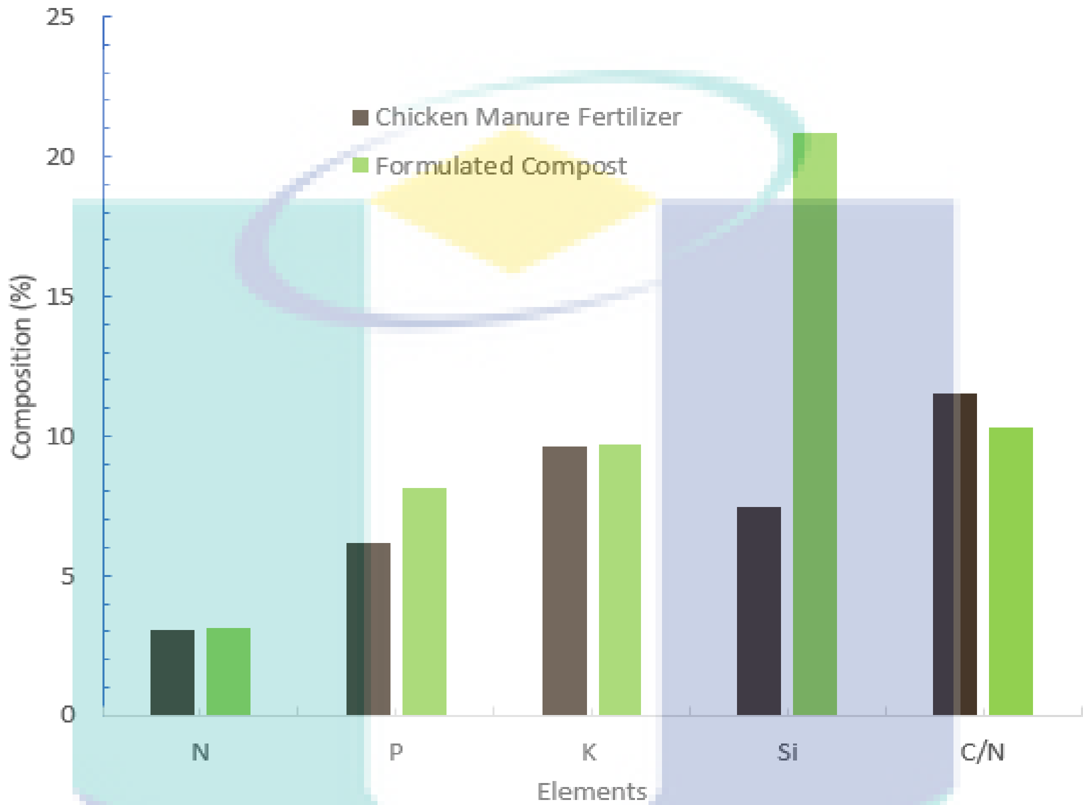

Figure 4.6 Comparison of chemical properties between formulated compost and chicken manure fertilizer

Other than phosphorus and silica, the formulated compost had a slightly higher amount of potassium and nitrogen compared to the chicken manure fertilizer, as shown in Figure 4.6. Even though the difference was not significant, those elements are essential for plant development and growth. Potassium is required for resisting drought stress like silica. When the amount of potassium is low, the drought stress can restrict the growth of roots (Hassan et al., 2017). As for nitrogen, it is crucial for plant's productivity and growth because it can affect the partitioning of biomass between the shoots and roots of a plant (Razaq et al., 2017).

From Figure 4.6, low nitrogen content in chicken manure fertilizer reflected a higher C/N ratio compared to the formulated compost. However, the difference is just about 1.23, which is not significant since the C/N ratio for both types of samples is still within the acceptable range between 10-15 (Trisakti et al., 2017). This is because the C/N ratio is influenced by bulking agents added into the compost to control the moisture content. The primary function of the bulking agent is to adjust the C/N ratio and control the water content of the waste to be composted (Jain et al., 2019; Sun et al., 2014). It is possible that the bulking agent (sawdust) added into the chicken manure during composting has slightly lower nitrogen content compared to rice husk ash, which reflected a higher C/N ratio compared to the formulated organic fertilizer.

CHAPTER 5

CONCLUSION

5.1 Conclusion

The significance of this study is the effect of rice husk ash on the composting process and a focus on producing quality organic fertilizer. Based on the analysis of raw materials, POME aerobic sludge contains higher macronutrients (nitrogen, phosphorus, potassium) compared to other raw materials. Meanwhile, the decanter cake plays an important role in achieving the appropriate range of pH and C/N ratio. Although the rice husk ash has a low content of macronutrients, however, the silica content micronutrients) in rice husk ash is the highest compared to other types of raw materials. This contributed to better physical properties of compost in terms of moisture content and water-holding capacity. Therefore, POME aerobic sludge, decanter cake, and rice husk ash can complement one another in terms of physical and chemical properties for the composting process.

Based on the composting experiment, it can be concluded that the composting process showed the best condition when the rice husk ash composition was 6.98%. The data showed that Sample RHA_c was able to fasten the composting period by 7 days compared to a control sample that did not contain rice husk ash. Besides that, the Sample RHA_c reflected optimum physical properties (pH, moisture content, and water-holding capacity). In terms of chemical properties, Sample RHA_c showed higher macronutrients and micronutrients compared to other samples. Moreover, it comprised the highest nitrogen content (3.31%), which is essential for plant growth. With the NPK ratio of 3.3-8.1-9.7, Sample RHA_c managed to achieve standard nitrogen composition for compost fertilizer. Whereas for phosphorus and potassium composition of Sample RHA_c can be used as 'general-purpose fertilizer'.

Furthermore, this study has revealed that composting by using forced heating composter and compost bin has significant difference in terms of physical properties (moisture content, water-holding capacity, and pH) of compost produced. It was observed that compost produced by using forced heating composter was too dry and contained lower water-holding capacity due to continuous turning and mixing at high temperatures. This condition has led to a higher evaporation rate compared to composting by using a compost bin. In addition, both composting methods did not give a significant difference in terms of chemical properties (macronutrients and micronutrients). Composting by using compost bin produced slightly higher nitrogen content with lower content of phosphorus, potassium, and silica compared to the forced heating composter. In general, composting by using compost bin is more preferred to produce compost with enough moisture content and water-holding capacity suitable for agricultural purposes.

Low moisture content was recorded by commercial chicken manure fertilizer compared to formulated compost due to the addition of a bulking agent (sawdust) in commercial fertilizer during the manufacturing process. Besides that, formulated compost showed higher water-holding capacity compared to commercial chicken manure fertilizer because it contains high silica content (contributed by rice husk ash), which increases the water adsorption. It was also observed that high silica content in formulated compost promotes higher phosphate content in compost due to ion exchange from adsorption sites. In conclusion, the addition of rice husk ash into compost formulation helps to improve the physical and chemical properties of compost, making the formulated compost are comparable to commercial chicken manure fertilizer.

5.2 Recommendations

Despite all the results achieved, there are several limitations in this study that can be improved for future research. It is recommended that further research should be undertaken in the following areas:

a. A field test is suggested to evaluate the effect of compost on plant growth. Properties such as the height of plants, count of leaves and fruits, the area of leaves, and colour of the leaves should be studied;

b. The biological properties such as colony counts method can also be used to verify the quality of the compost such as bacteria population and fungus population;

c. The moisture content and humidity are suggested to be recorded daily. This is due to unstable weather caused by monsoon season in Malaysia, which will affect moisture content and humidity inside the aerated bin. Thus, it will affect the microbial activity in the compost;

d. Maturity index should be added as one of the parameters to evaluate the maturity of compost. This can be done through Solvita Compost Maturity Index. This test helps to indicate carbon dioxide rate and the presence of free ammonia during the composting process;

e. Holding time or initial conditions should be measured to determine whether the composting process has taken place or not. This can be done by taking samples on day 2nd and analyse the physicochemical properties of compost, especially for compost made by using compost bin and forced heating composter.

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APPENDICES

APPENDIX A

Table 1 Chemical properties of raw materials

	POME sludge	Decanter cake	Rice husk ash
Nitrogen (%)	5.63 ± 0.50	2.17 ± 0.6	3.11 ± 0.45
Phosphorus (%)	5.23 ± 0.10	2.39 ± 0.11	0.62 ± 0.23
Potassium (%)	5.85 ± 0.02	0.65 ± 0.08	1.44 ± 0.07
Carbon (%)	36.58 ± 0.04	48.58 ± 0.10	18.59 ± 0.06
Silica (%)	12.59 ± 0.07	13.61 ± 0.11	44.01 ± 0.15
Iron (%)	16.58 ± 0.12	6.09 ± 0.10	0.104 ± 0.08
Manganese (%)	0.43 ± 0.03	0.12 ± 0.12	0.085 ± 0.25
Magnesium (%)	1.11 ± 0.08	1.65 ± 0.15	0.44 ± 0.23
Calcium (%)	0.09 ± 0.35	8.79 ± 0.5	0.85 ± 0.25
C/N	6.5	22.4	5.9

Table 2 Temperature of composts for 50 days

Day	Control	Sample RHA_a	Sample RHA_b	Sample RHA_c	Sample RHA_d
0	27	27	27	27	27
1	27	33.1667	34	31.3333	31.3333
2	28.33333	34	35	31.6667	31.3333
3	30	34.6667	37.6667	32	32.2
4	29.33333	36.6667	38	36.3333	34
5	30.33333	36.6667	38.8333	38.3333	35
6	30.33333	37.5	40	38.3333	35
7	33.33333	37.6667	40.6667	40	36
8	34.33333	39.3333	40	40.8333	39
9	35.16667	39.5	43.3333	43	40
10	35.33333	40.6667	42	41.6667	41.3333
11	36	40.8333	42.1667	41.6667	41.8333
12	36.66667	41	44	46	41

Table 2 Continued

Day	**Control**	**Sample RHA$_a$**	**Sample RHA$_b$**	**Sample RHA$_c$**	**Sample RHA$_d$**
13	38.16667	42.3333	45	48.3333	41.5
14	40	44.6667	48.5	49.5	42
15	40.33333	45.3333	48.6667	51	42
16	41.66667	46.5	49.3333	51	42.333
17	42.66667	48	50.6667	52	43
18	43	49	51.6667	54	43.333
19	45	50.6667	53	54.6667	44
20	46.16667	52.6667	54	56	44.333
21	47.16667	53.6667	57	56	45
22	49.16667	53.8333	57	58.5	46
23	50.16667	54.6667	54	58.5	46.7
24	51.16667	52.3333	53	58	47
25	52.66667	51.3333	51	58	47.33
26	53.33333	50.3333	50	57	49
27	53.33333	49.3333	49	53	50
28	54.16667	49	47	52	51
29	53.33333	48.3333	46	50	51.333
30	52.33333	48.3333	45	47	51.67
31	50.66667	47.3333	44	45	50
32	49.33333	46.3333	43	44	49
33	49.16667	43.6667	42	40	48.5
34	48.66667	41.3333	38	38	47
35	48.16667	40	37	37	46
36	45.33333	38.3333	35.5	36	45
37	44.33333	37.3333	35	34	41
38	43.33333	36	34	34	40
39	41.33333	34.3333	33.5	33	40.33
40	37	34	33	32	38
41	36.16667	33.6667	32	32	35

Table 2 Continued

Day	**Control**	**Sample RHA$_a$**	**Sample RHA$_b$**	**Sample RHA$_c$**	**Sample RHA$_d$**
42	35.16667	32.3333	32	32	35.5
43	34.66667	31.3333	31	31	33
44	34.33333	31.3333	31	31	32
45	33.33333	31.3333	31	31	31
46	33.16667	31	31	31	31
47	32	31	31	31	31
48	32	31	31	31	31
49	31	31	31	31	31
50	31	31	31	31	31

Table 3 pH of composts for 50 days

Day	**Control**	**Sample RHA$_a$**	**Sample RHA$_b$**	**Sample RHA$_c$**	**Sample RHA$_d$**
0	4.50	4.50	4.50	4.50	4.50
1	4.30	4.40	4.40	4.60	4.60
2	4.35	4.60	4.49	4.50	4.40
3	4.50	4.70	4.50	4.50	4.50
4	4.80	4.80	4.60	4.50	4.44
5	5.00	4.80	4.56	4.60	4.49
6	5.40	5.00	4.74	4.60	4.44
7	5.80	4.90	4.80	4.60	4.55
8	6.00	5.00	4.78	4.80	4.56
9	6.20	5.05	4.90	4.80	4.60
10	6.20	5.16	5.00	4.80	4.72
11	6.20	5.18	5.12	4.80	4.77
12	6.35	5.11	5.20	5.00	4.87
13	6.30	5.33	5.11	5.00	4.99
14	6.30	5.38	5.40	5.05	4.98

Table 3 Continued

Day	Control	Sample RHA_a	Sample RHA_b	Sample RHA_c	Sample RHA_d
15	6.30	5.39	5.41	5.07	5.00
16	6.40	5.35	5.30	5.08	5.01
17	6.45	5.40	5.49	5.11	5.05
18	6.46	5.41	5.60	5.15	5.08
19	6.70	5.43	5.59	5.19	5.09
20	6.75	5.60	5.60	5.20	5.11
21	6.76	5.65	5.65	5.23	5.12
22	6.80	5.70	5.69	5.29	5.11
23	6.85	5.76	5.75	5.31	5.19
24	7.00	5.80	5.75	5.33	5.20
25	7.05	5.88	5.77	5.39	5.21
26	7.09	5.90	5.80	5.40	5.23
27	7.10	6.00	5.82	5.45	5.33
28	7.08	6.05	5.84	5.50	5.39
29	7.05	6.07	5.88	5.56	5.41
30	7.02	6.08	5.97	5.62	5.43
31	7.04	6.10	6.10	5.66	5.50
32	7.01	6.09	6.17	5.69	5.52
33	7.00	6.10	6.21	5.71	5.54
34	7.00	6.20	6.32	5.73	5.63
35	7.00	6.22	6.44	5.78	5.66
36	7.00	6.32	6.47	5.90	5.67
37	7.00	6.33	6.49	6.02	5.78
38	7.00	6.40	6.50	6.00	5.80
39	7.00	6.46	6.51	5.98	5.89
40	7.00	6.48	6.52	6.05	6.05
41	7.00	6.45	6.53	6.10	6.09
42	7.00	6.49	6.53	6.14	6.11
43	7.00	6.50	6.52	6.20	6.12

Table 3 Continued

Day	Control	Sample RHA$_a$	Sample RHA$_b$	Sample RHA$_c$	Sample RHA$_d$
44	7.00	6.51	6.53	6.26	6.25
45	7.00	6.54	6.54	6.30	6.31
46	7.00	6.57	6.55	6.31	6.33
47	7.00	6.59	6.55	6.37	6.34
48	7.00	6.60	6.54	6.40	6.33
49	7.00	6.60	6.56	6.43	6.35
50	7.00	6.60	6.56	6.44	6.35

Table 4 Elemental composition for formulated compost

Elements	Control	Sample $RHA_{2.5}$	Sample $RHA_{5.0}$	Sample $RHA_{7.5}$	Sample $RHA_{10.0}$
Nitrogen (%)	2.56 ± 0.64	2.64 ± 0.36	2.81 ± 0.30	3.31 ± 0.38	2.93 ± 0.36
Phosphorus (%)	7.56 ± 0.05	7.89 ± 0.08	8.03 ± 0.03	8.11 ± 0.07	8.23 ± 0.05
Potassium (%)	9.07 ± 0.42	9.62 ± 0.23	9.64 ± 0.24	9.68 ± 0.16	9.81 ± 0.25
Carbon (%)	31.61 ± 0.87	32.05 ± 1.03	33.85 ± 1.07	34.02 ± 1.07	32.45 ± 1.08
Silica (%)	15.86 ± 0.33	19.57 ± 0.31	19.47 ± 0.35	20.82 ± 0.31	21.1 ± 0.32
Iron (%)	16.73 ± 0.71	17.38 ± 0.81	17.41 ± 0.12	17.86 ± 0.13	17.95 ± 0.17
Manganese (%)	0.44 ± 0.01	0.46 ± 0.005	0.47 ± 0.013	0.48 ± 0.02	0.48 ± 0.015
Magnesium (%)	1.18 ± 0.03	1.18 ± 0.02	1.19 ± 0.02	1.19 ± 0.02	1.20 ± 0.02
Calcium (%)	6.99 ± 0.35	7.03 ± 0.10	7.13 ± 0.03	7.24 ± 0.27	7.37 ± 0.09
C/N	12.35	12.14	12.05	10.3	10.7

Table 5 Elemental composition of compost made using compost bin and forced heating composter

Element composition	Compost Bin	Forced heating composter
Nitrogen (%)	3.27 ± 0.13	3.14 ± 0.15
Phosphorus (%)	7.54 ± 0.07	8.26 ± 0.017
Potassium (%)	8.32 ± 0.16	8.95 ± 0.11
Carbon (%)	33.67 ± 0.45	35.37 ± 0.49
Silica (%)	17.74 ± 0.56	20.04 ± 0.04
Iron (%)	10.34 ± 0.13	12.95 ± 0.04
Manganese (%)	0.44 ± 0.02	0.47 ± 0.03
Magnesium (%)	1.15 ± 0.02	1.17 ± 0.03
Calcium (%)	7.44 ± 0.16	7.98 ± 0.04
C/N	10.3	11.3

APPENDIX B

LIST OF PUBLICATIONS

1. Ramli, N. H., Badrul Hisham, N. E., Mohd Said, F., & Mariyappan, T. (2016). The Effect of Weight Ratio on The Physiochemical Properties of Compost From Palm Oil Mill Effluent (POME) Sludge and Decanter Cake. *Australian Journal of Basic and Applied Sciences*, *10*(17), 34–39.

2. Badrul Hisham, N.E. & Ramli, N.H. (2019). Effect of Rice Husk Ash on the Physicochemical Properties of Compost. *Indonesian Journal of Chemistry*, *19*(4), 967-974.