Effect of Pretreatments on Compost Production from Shredded Oil Palm Empty Fruit Bunch with Palm Oil Mill Effluent Anaerobic Sludge and Chicken Manure

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Rapid co-composting of lignocellulosic oil palm empty fruit bunch (OPEFB) and palm oil mill effluent (POME) is a cost-effective and sustainable way to eliminate biomass residues. In this study, suitable pre-treatments and co-substrates for an accelerated composting treatment process were investigated. A steam pre-treatment was performed prior to composting. The composting mixtures were placed in plastic drums under a roofed area. They were regularly turned for aeration and measured for temperature, oxygen, moisture content, bulk density, carbon to nitrogen (C/N) ratio, and fiber tensile strength. C/N ratio is the main parameter measured as a maturity indicator for the compost. The compost temperature was above 60 °C during the thermophilic phase after the steam pre-treatment, based on the heat produced by the microbes. Steam-treated OPEFB and untreated OPEFB co-composted with chicken manure achieved the same maximum temperature of 62 °C and C/N ratios of 8.76 and 9.58, respectively. Steam pretreatment did not have significant effect when the treated OPEFB was co-composted with POME anaerobic sludge due to insufficient steam pressure at 40 psi and 140 °C. Steam-treated OPEFB and untreated OPEFB co-composted with POME anaerobic sludge achieved 54 °C and 60 °C, respectively, while the C/N ratios were 12.41 and 10.14, respectively.

Keywords: Steam; Pre-treatment; Palm oil mill effluent; Oil palm empty fruit bunch; Co-composting

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INTRODUCTION

Oil palm is widely planted in Malaysia because this crop has many valuable materials that are processed into food and non-food products, such as palm oil, margarine, soap, and other oleo chemical products. According to the Malaysian Palm Oil Board (MPOB), in 2017, Malaysia had a total of 449 fresh fruit bunch (FFB) palm oil mills and a vast oil palm plantation area, consisting of 5 million hectares of mature oil palms and 0.7 million hectares of immature oil palms. However, high palm oil production also generates abundant biomass resources such as oil palm empty fruit bunch (OPEFB) and palm oil mill effluent (POME). Malaysia alone produces about 40 million tons of oil palm biomass annually, including 280,000 tons OPEFB (Turunawarasua *et al.* 2013). POME is expected to increase from 60 metric tons in 2012 to 70 to 110 metric tons in 2020 (Melssen 2013).

OPEFB contains certain macronutrients and micronutrients that are required for plant growth. In the past, OPEFB were incinerated to produce bunch ash, which is rich in potash, for application as soil fertilizers. However, the Malaysia Department of

Environment has discouraged this activity due to the pollution problem and replaced it with mulching in oil palm plantations (MPOB 2014). Fresh OPEFB represents more than 20% of the FFB weight (Ma *et al.* 1993), and it is composed of cellulose (45 to 50%) and approximately equal amounts of hemicellulose (25 to 35%) and lignin (20.5%) (Deraman 1993). OPEFB, a lignocellulosic material, is difficult to degrade because the lignin and hemicellulose content protect the cellulose from being attacked by enzymes, thus slowing the decomposition process.

Palm oil production requires a considerable amount of water, leading to the generation of large volumes of POME. More than 500 kg (around 0.5 m^3) of POME are discharged during the processing of 1 metric ton of FFB (Ma *et al.* 1996). Therefore, more than 20 metric tons of OPEFB and 50 m^3 of POME are generated from a mill after processing 100 metric tons of FFB (the average capacity in the mill). POME is brownish, thick, containing 95 to 96% water, 0.6 to 0.7% oil, and 4 to 5% total solids, and it has a pH range from 3 to 7. Due to the presence of relatively high total solids in POME, this waste has been utilized into valuable products such as feedstock and organic fertilizer. Moreover, microorganisms in POME are critical to nutrient recycling in ecosystems because they can act as decomposers.

Application of manure supplies the appropriate nutrients; improves soil structure, water holding capacity, porosity, bulk density, moisture retention; increases microbial population; and preserves the crop quality (Agbede and Adekiya 2011). It may consist of an accumulation of chicken manure and feathers found in a broiler house. Effective Microbes (EM) is a suite of microorganisms that include photosynthetic bacteria, yeasts, fungi, and actinomycetes (Shaheen *et al.* 2017). The release of nutrients from organic wastes (mineralization) is a slow process and carried out by numerous enzymes and a wide range of microorganisms (Zaman *et al.* 1999); therefore, co-application of organic wastes with EM has been shown to facilitate release of nutrients such as N and P (Ahmad *et al.* 2012; Lack *et al.* 2013).

The increasing prices for fertilizer are due to the rising global demand and market fluctuations. It is also strongly related to low food production. In the future, increases in food production will have to occur on less available arable land, which can only be accomplished by the use of fertilizer to intensify the production (Roberts 2013). Compost or organic fertilizer, which is environmentally friendly because it consists of organic wastes, can effectively enhance crop growth and promote soil fertility. It is most recommended to substitute for chemical fertilizers, which are harmful to the environment because they leach underneath the ground and cause groundwater contamination. In addition, applying chemical fertilizers causes the soil to become acidic, which is not suitable for crop planting.

Bioconversion of OPEFB has many benefits because it can reduce the adverse impacts of the current inefficient disposal treatment, such as incineration, boiler fuel, and mulching. Besides, OPEFB has also been used for bio crude production *via* hydrothermal liquefaction, gasification, and so on. The conventional mulching of OPEFB requires high transportation and labor cost because of its large volume and weight compared to the compost. Therefore, composting of OPEFB is the most economical and effective way to replace the mulching in the oil palm plantation. Current conventional composting method without pre-treatment took months or years to reach maturation. Pretreatments can help to accelerate the decomposition by modifying the lignin and hemicellulose content in OPEFB. Most palm oil mills apply physical pre-treatment by shredding the OPEFB to increase the surface area available for microbial attack. However, this method consumes a lot of energy and time, and the nutrient loss is high. Other pretreatments such as chemical, physical, and biological pre-treatments, have also been studied. The chemical pretreatments have been widely used for fermentable sugar production. In this study, a combination of physical and chemical steam pretreatment was applied to the OPEFB to accelerate the structure degradation by solubilizing and removing the hemicelluloses component (Bahrin *et al.* 2012).

EXPERIMENTAL

Materials

This research was conducted under a roof area on a cement base in Faculty of Engineering, University Putra Malaysia. High density polyethylene (HDPE) plastic drums with 60-L capacity (0.9 m height and 0.5 m diameter) were placed at the composting site. Approximately 100 kg of shredded OPEFB and 100 liters of POME anaerobic sludge were obtained from Seri Ulu Langat Palm Oil Mill in Selangor, Malaysia. The shredded OPEFB was chosen instead of non-shredded OPEFB because the composting method by using plastic drums has limited area. Therefore, small sized OPEFB fibers are more suitable to be used. The weight of chicken manure collected from Poultry Unit, Department of Animal Science, UPM, Serdang was about 30 kg. The effective microbes (EM) solution manufactured by EMRO Malaysia Sdn. Bhd was obtained from a local plant fertilizer shop.

Methods

Steam pre-treatments

A pilot-scale sterilizer at the Faculty of Food Science and Technology, UPM, Serdang was used to treat the shredded OPEFB fibers with steam before co-composting with chicken manure, POME anaerobic sludge, and EM solution. The shredded OPEFB fibers were placed in the wheeled cage until its maximum capacity and put in a large horizontal vessel (1.5 m length and 0.5 m diameter) for the batch sterilization process. Then, steam was injected into the sterilizer until the pressure reached 40 psi (the temperature of about 140 °C) for 90 min as commonly practiced at palm oil mills. After the steam pre-treatment was finished, the shredded OPEFB fibers were removed from the cage to reduce the heat. Then, the fibers were brought to the laboratory in the Faculty of Engineering, UPM for the composting experiment.

Composting

Generally, there are 10 compost treatments, which consist of either steam treated or non-treated shredded OPEFB co-composted with either chicken manure or POME anaerobic sludge, or EM solution in the plastic drums for 80 days. Total composting time was 80 days based on the composting process performed by previous researchers (Baharuddin *et al.* 2009). The composting time is uniform for all compost treatments as the important factor is the final C/N ratio. Several parameters were controlled to ensure high quality and fast compost production such as moisture content, carbon-nitrogen (C/N) ratio, nutrients, and temperature (Ekinchi *et al.* 2004; Liang *et al.* 2003). A portable temperature and oxygen defector manufactured by Demista Instrument USA (Model M2006, USA) was employed for the measurement of the temperature and the oxygen content of compost materials. To maintain the compost moisture content, POME anaerobic sludge was added into the compost every three days until the moisture content achieved the range between 60 to 80%. Compost turning for aeration was conducted one to three times a week for sufficient oxygen supply by rolling the plastic drums on the ground several meters for 10 minutes at a constant speed. The turning process was performed after watering the compost to ensure that the moisture is spread uniformly. The ratio of POME anaerobic sludge added to the compost was 1:1 (Baharuddin *et al.* 2009), while the ratio of chicken manure to OPEFB was a 1:3 ratio (Thambirajah *et al.* 1993). The ratio of OPEFB with EM is 1:1000. Before mixing with OPEFB, the EM was diluted with water with a ratio of 1:1000.

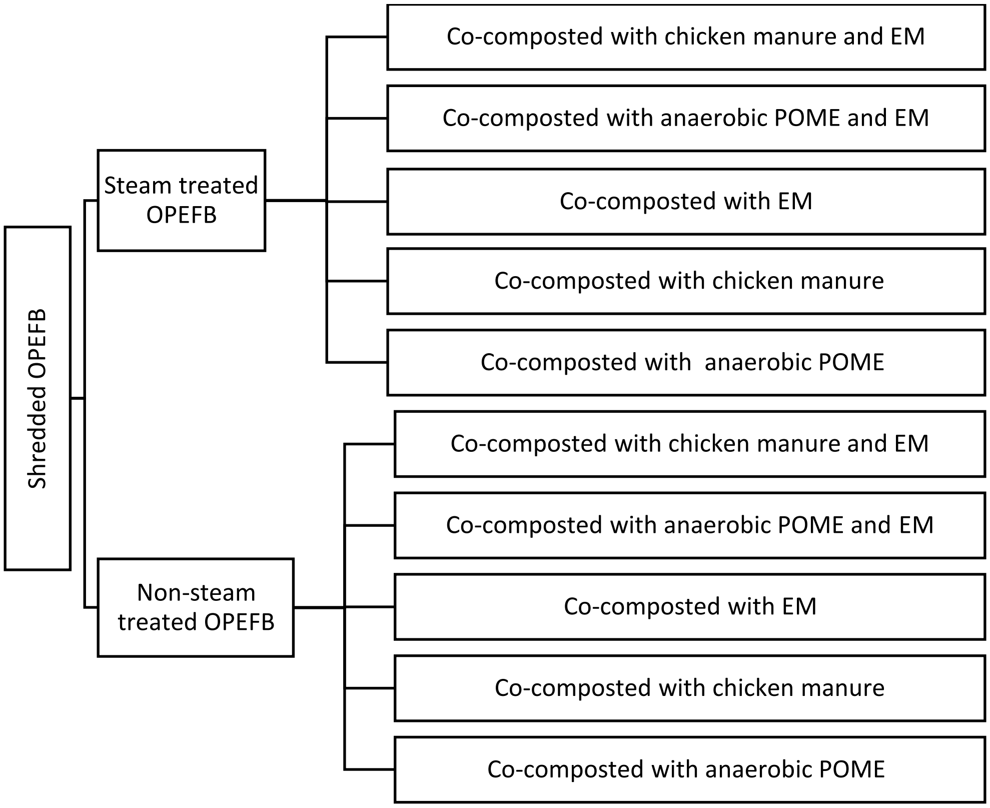

Fig. 1. Compost treatments

RESULTS AND DISCUSSION

Macroscopic Observation

The fibers released a caramel smell after the steam treatment. The bottom part of the OPEFB fibers also became wet because liquid portions, including condensates, were released and became stagnant during the process. The fibers changed from yellow to dark brown color after the steam treatment (Fig. 2). Sun *et al.* (1999) reported that brownish products after the steam pre-treatment were the result of carbohydrate degradation at high steam temperatures. The fibers were easily loosened compared with the non-steam treated fibers. Usually, the fibers are strongly attached to the bunch stalk. However, the heat causes physicochemical changes as it penetrates into the fibers, stalk, and other parts of the bunch.

Fig. 2. OPEFB before (left) and OPEFB after the steam pretreatment (right)

Effects of Treatment in Compost Temperature

Temperature is an important indicator for the microbial activity in the compost, as certain temperature levels determine the activity of the microbes. The temperature of the compost was measured at three different locations, which were the top, middle, and bottom of the compost heap. The temperature measurements taken were converted to average values and transformed into a graph of the temperature distribution of each composting treatment. Graph trends were studied to see the fluctuation of the parameters during the composting period, while the mean effect is the basic consideration to choose the most significant compost treatment.

Initially, the temperature was normal, but after a few days, the temperature became very high (Fig. 3). The sudden high temperature during the initial day of composting indicated that the microbes were actively consuming the organic materials. Gradually, the temperature decreased until it was similar with the ambient temperature, as the available organic materials decreased. In the last stage, the temperature decreased back to normal, which indicates that the activity was slowing down and the compost was approaching maturity. Generally, the compost treatments reached a thermophilic phase on the 2nd day of composting and gradually decreased to a mesophilic phase, which was below 45 °C on the 6th day of composting. Then, the compost reached a maturing phase after 38 days of composting.

The steam-treated OPEFB co-composted with chicken manure and EM solution, steam treated OPEFB co-composted with chicken manure, and non-steam treated OPEFB co-composted with chicken manure treatments showed the highest peak temperature of 62 °C (Fig. 3a). These values indicate an optimum condition because a temperature of approximately 50 °C is essential to maximize biodegradation, but a temperature of 60 °C reduces the microbial activity (Zahrim *et al.* 2015). However, temperature above 55 °C did not affect the microbial population's activity. Instead, the temperature could kill pathogens and sanitize the compost (Gea *et al.* 2005). Maximum temperature of 55 to 65 °C is necessary to kill the pathogens, but temperature 45 to 55 °C must be maintained for maximum biodegradation (Stentiford 1996). The steam pre-treatment yielded a high significant effect on the compost temperature when co-composted with chicken manure. The treatment of steam treated OPEFB co-composted with chicken manure and EM solution was able to maintain the highest temperature until the 38th day of composting.

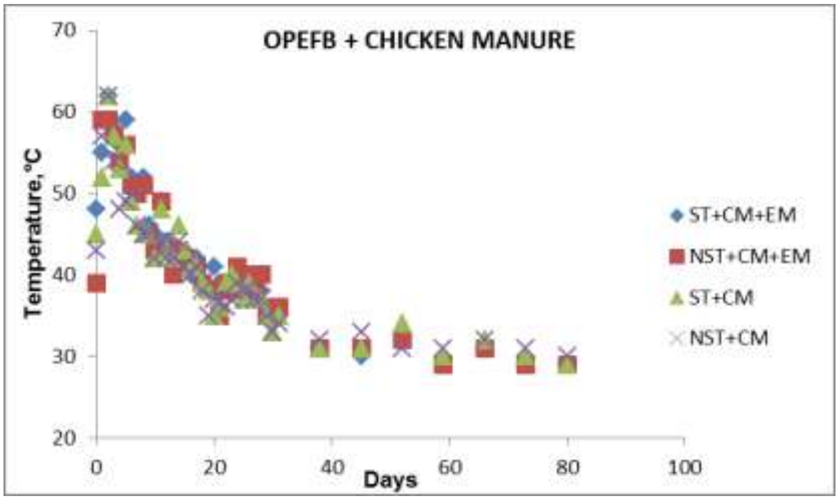

Fig. 3a. Mean temperature profile of OPEFB co-composted with chicken manure

However, steam-treated OPEFB co-composted with anaerobic POME showed a low significance of the mean temperature compared to the non-steam treated OPEFB with POME anaerobic sludge, as shown in Fig. 3b. The steam pretreatment which aimed to alter the OPEFB fibers in order to increase the decomposition process may simultaneously killed the microbes, thus reducing the thermophilic bacteria required to consume the organic materials, but the pretreatment did not affect the OPEFB co-composted with chicken manure.

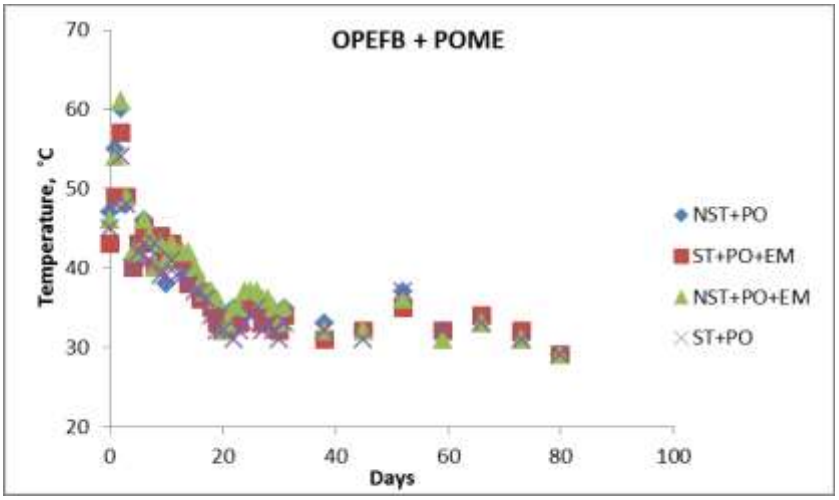

Fig. 3b. Mean temperature profile of OPEFB co-composted with POME anaerobic sludge

Steam-treated OPEFB co-composted with POME anaerobic sludge showed a low significance on the compost temperature compared to the steam-treated OPEFB with chicken manure, as shown in Fig. 3c. This may be due to the moisture from the POME anaerobic sludge, which stops the heat generation inside the plastic drums. Among the non-steam treated OPEFB, the OPEFB co-composted with chicken yielded the highest compost temperature compared to the OPEFB co-composted with POME anaerobic sludge, as shown in Fig. 3d.

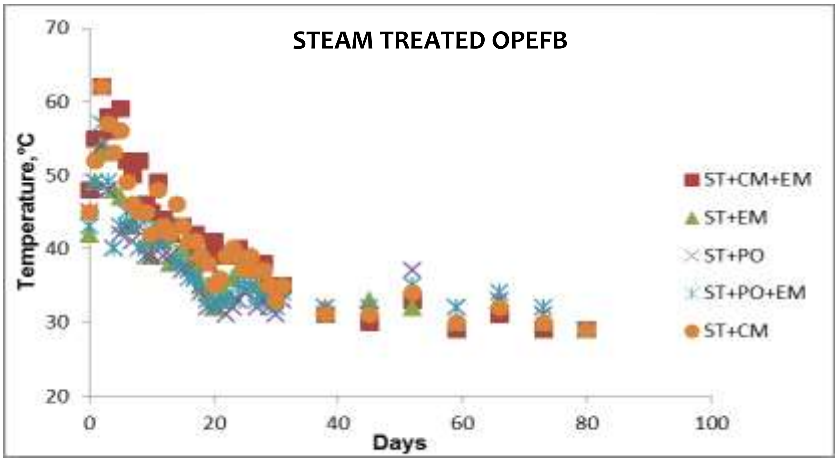

Fig. 3c. Mean temperature profile of steam treated OPEFB during composting

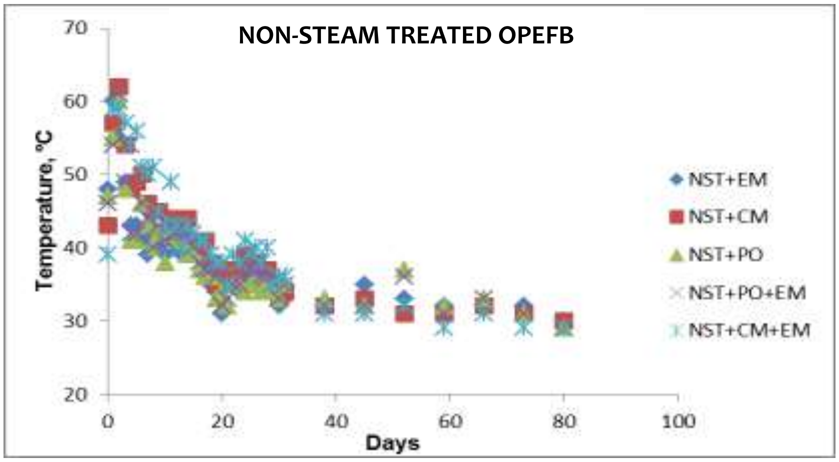

Fig. 3d. Mean temperature profile of non-steam treated OPEFB during composting

Effects of Treatments in Compost Oxygen Level and Moisture Content

During the monitoring of the compost, moisture content and oxygen level was controlled in order for the microbes to survive and consume the organic matter in an optimum condition. Aeration by supplying the oxygen was ensured by the porous nature of the material itself (Suhaimi *et al.* 2001) and by turning the compost frequently. The moisture content of OPEFB co-composting with POME anaerobic sludge was monitored and measured by adding that effluent. High ambient temperature followed by frequent turning resulted in water from the compost and was constantly evaporated. Thus, a proper amount of water from POME anaerobic sludge and pail water are essential to overcome the water loss.

Figure 4 generally shows that the compost oxygen content was initially low but gradually increased as the composting time increases. The compost oxygen gradually increased until the 20th day, where the oxygen content did not continue to change and reached the maximum level (21%). At the beginning of the composting process, higher microbial activity was discovered as reflected by the thermophilic temperature achieved. The rapid expansion of the microbial population due to active consumption of readily degradable material had contributed to the low initial oxygen level (Baffi *et al.* 2006). At this stage, oxygen was heavily consumed by the microbes and was recorded at the lowest levels. However, after the depletion of readily degradable material, the oxygen level had increased and was maintained until the end of the composting process.

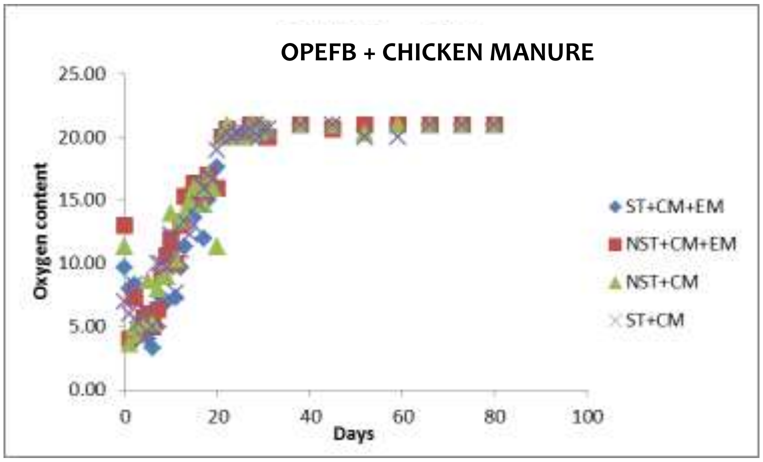

Fig. 4a. Oxygen content profile of the OPEFB co-composted with chicken manure

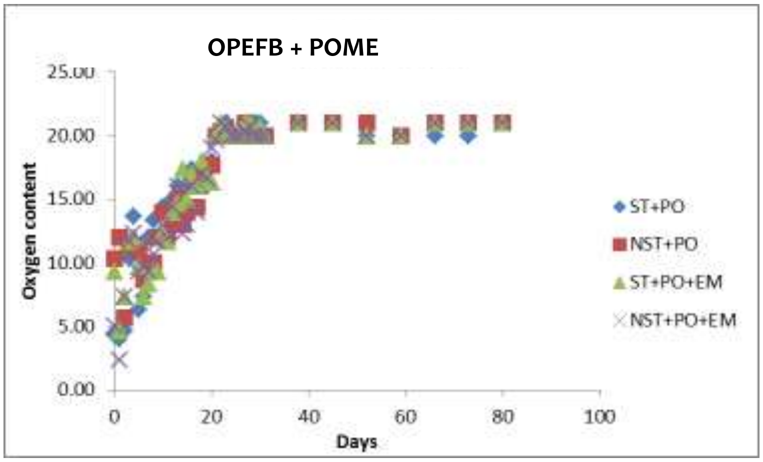

Fig. 4b. Oxygen content profile of the OPEFB co-composted with POME anaerobic sludge

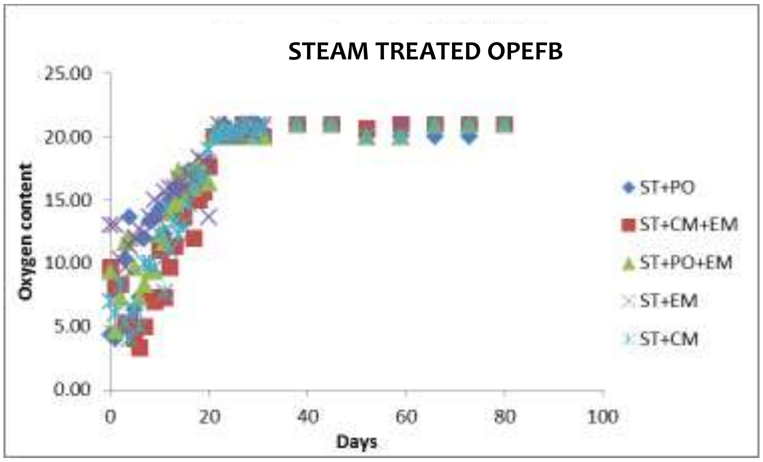

Fig. 4c. Oxygen content profile of the steam treated OPEFB

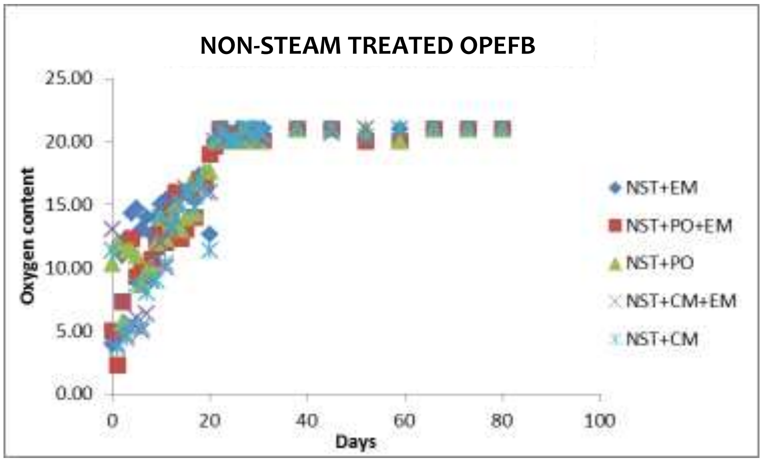

Fig. 4d. Oxygen content profile of non-steam treated OPEFB

Figure 5 shows the moisture content during co-composting with different co-substrates. The moisture content of all compost treatments had a high initial percentage, but eventually the values decreased. Liang *et al.* (2003) reported that the range of 60 to 75% provided the maximum microbial activities. Tiquia *et al.* (2002) also reported that moisture content around 40 to 60% was required for microbial survival while moisture content that exceeded 80% could kill aerobic microorganism. Optimum moisture content and oxygen level help the bacteria to have the optimum conditions to consume all the nutrients in the compost (Tiquia *et al.* 2002; Margesin *et al.* 2006). The reduction percentage is different among the compost treatments. Non-steam treated OPEFB co-composted with chicken manure, non-steam treated OPEFB co-composted with chicken manure and EM, and steam treated OPEFB co-composted with chicken manure yield a lower moisture content at the end of composting period. This is due to the moisture from OPEFB co-composted with chicken manure has evaporated faster compared with OPEFB co-composted with POME anaerobic sludge after the turning operation. Turning was continued in the curing phase to achieve moisture content of 60% in the final compost (70 days) and 40 to 50% after another 20 days.

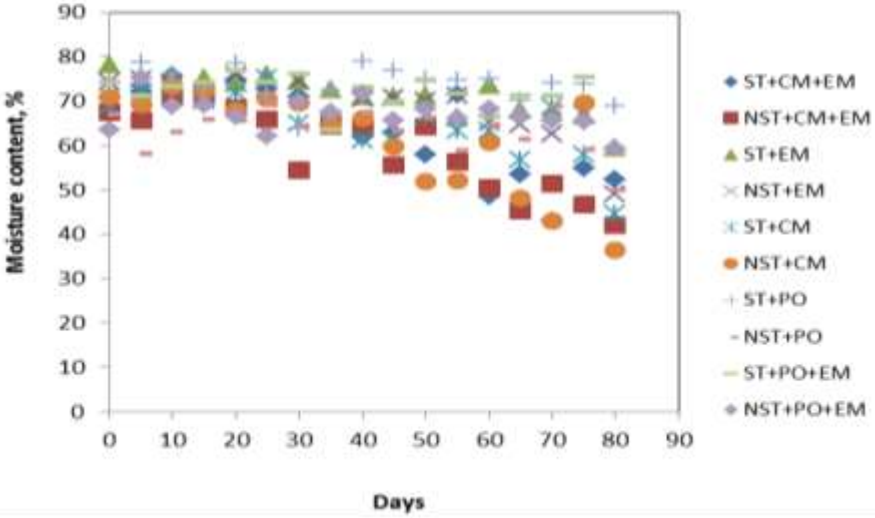

Fig. 5. Compost moisture content profile of the compost treatments

Effects of Treatments in Compost C/N Ratio

The chemical composition of OPEFB was analyzed by considering certain parameters such as carbon, nitrogen, phosphorus, potash, magnesium, sulfur, calcium, and carbon to nitrogen ratio (C/N). The samples were collected, dried, and analyzed by using C/N ratio analyzer. When carbon is released, the C/N ratio in the compost tends to decrease as it approaches the maturity state, which is below 20%. Table 1 shows the initial chemical composition of POME anaerobic sludge and chicken manure. Chicken manure has the higher nutrient content but has a lower C/N ratio compared to the POME anaerobic sludge.

Table 1. Initial Chemical Composition of Compost Materials before Composting

Elements	**Weight (%)**	
	POME anaerobic sludge	**Chicken Manure**
Carbon (C)	38.8	1.33
Nitrogen (N)	1.56	2.20
C/N ratio	24.8	0.60
Phosphorus (P)	0.12	1.72
Potassium (K)	0.15	2.91
Magnesium (Mg)	0.10	0.71
Sulphur (S)	0.2	0.17
Calcium (Ca)	0.07	10.56

Table 2 shows the final C/N ratio at the 80th day of composting. The steam treated OPEFB co-composted with chicken manure yielded the best C/N ratio (8.76), followed by non-steam treated OPEFB co-composted with chicken manure and EM solution (9.50) with 8.5% difference. This result indicates that the steam pre-treatment of OPEFB affects the maturity state of the compost when co-composted with chicken manure. However, the addition of POME anaerobic sludge in the steam pre-treatment yielded a negative effect as its C/N ratio was higher compared to the non-steam treated OPEFB. This is because the pressure and temperature during the pre-treatment were not high enough to change the structure of the fibers. However, after adding the co-substrates during composting, the effect of steam pre-treatment was more visible and had started to take effect. The phosphorus (P) and potassium (K) were not analyzed for the final compost because the C/N ratio is the most significant in compost maturity.

Table 2. Final Compost Chemical Composition of the Compost Treatments

Treatments	**Weight (%)**			**C/N Ratio**
	Nitrogen	**Carbon**	**Sulphur**	
Steam treated OPEFB, CM, EM	3.2	36.1	0.48	11.1
Non-steam treated, CM, EM	3.64	34.6	0.63	9.5
Steam treated OPEFB, EM	1.92	45.7	0.45	23.7
Non-steam treated OPEFB, EM	2.18	43.61	0.48	19.96
Non-steam treated OPEFB, CM	3.58	34.26	0.73	9.58
Steam treated OPEFB, CM	3.22	28.25	0.36	8.76
Steam treated OPEFB, POME	2.36	29.29	0.65	12.41
Non-steam treated OPEFB, POME	1.89	19.21	0.55	10.14
Steam treated OPEFB, POME, EM	1.99	22.43	0.57	11.25
Non-steam treated OPEFB, POME, EM	2.01	22.4	0.59	11.17

Effects of Treatments in Compost Tensile Strength

During the composting, 10 compost treatments were studied to analyze the effects of steam and the addition of nutrient supplementation as co-substrates to the fibers' tensile strength, which is a mechanical property of the fibers. The brittleness of OPEFB fibers indicate the decomposition state by considering their tensile strength property. Baharuddin *et al.* (2013) reported that the steam process removed silica bodies and the remaining holes were assumed to be effective in the swelling of the OPEFB structures, attracting the bacteria and enzymatic reactions for subsequent bioconversions. The silica bodies' removal caused by the steam pre-treatment helped to rupture the cell wall of the fibers, thus, making the fibers have lower tensile strength.

Figure 6 shows the average tensile strength during the first and second week of the composting. The analysis was only performed for two weeks because the fibers easily ruptured while handling for average diameter measurement prior the tensile strength measurement. From the figure, five compost treatments showed a decrease in tensile strength from the first week to the second week, while the other five compost treatments showed an increment. The tensile strength reduction percentage of steam treated and non-steam treated OPEFB co-composted with chicken manure and EM are 40% and 74% respectively, non-steam OPEFB co-composted with EM (26%), non-steam treated OPEFB co-composted with chicken manure (0.8%), non-steam treated OPEFB co-composted with POME anaerobic sludge (2%), and steam treated OPEFB co-composted with POME anaerobic sludge and EM (39.7%). Non-steam treated OPEFB co-composted with chicken manure had the highest tensile strength percentage reduction followed by steam treated OPEFB co-composted with chicken manure and EM, and steam treated OPEFB co-composted with POME anaerobic sludge. These findings showed that steam pre-treatment had a significant effect on the tensile properties. Addition of EM solution into the compost treatments helped to increase the degradation of the OPEFB fibers as indicated by the graph of tensile strength in Fig. 6. However, the tensile strength of non-steam treated OPEFB added with EM was also reduced, which means that EM is a significant factor in composting.

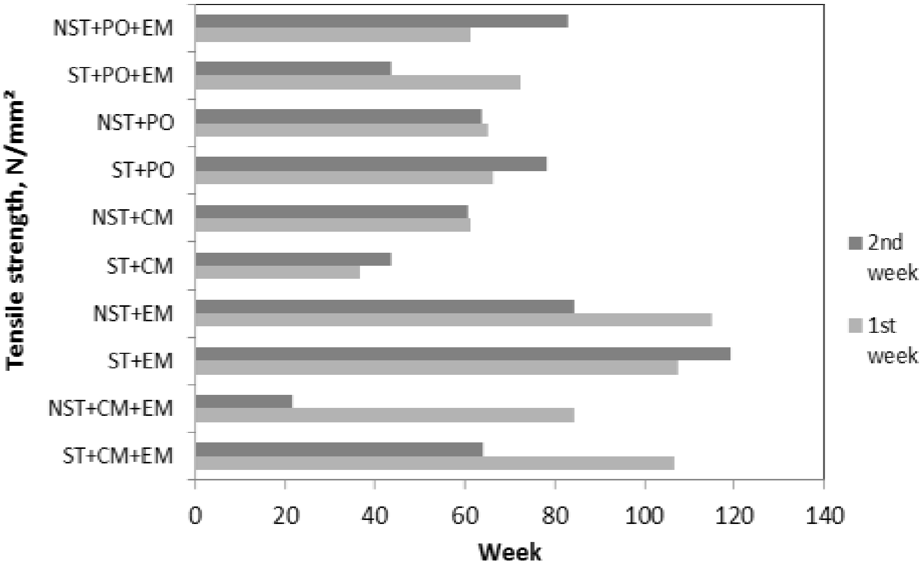

Fig. 6. Mean tensile strength of the compost treatments

Effects of Treatments in Compost Bulk Density

Bulk density is obtained by measuring the mass of a material that occupies a container of known volume. Accordingly, it determines the size reduction of the shredded OPEFB fibers. The volume measurement was obtained without pressing the compost materials, which is known as aerated bulk density (Barbosa-Cánovas *et al.* 2005). Initially, the shredded OPEFB fibers without the addition of any nutrient supplementation had a low bulk density because of the high porosity. However, after being co-composted with many kinds of co-substrates, the bulk density gradually increased because the fibers had become ruptured and decreased in size until they became smaller particles.

Figure 7 shows the compost bulk density profile during composting. The graph trend is a gradual increase as the composting days increased even though many fluctuations occurred. The treatment of steam treated OPEFB co-composted with chicken manure and EM solution showed the highest bulk density peak and maintained the highest bulk density profile compared to the other composting treatments. It indicated the lowest fiber size achieved after the composting process. Higher bulk density is one of the effective indicators for good compost because it relates with less moisture and higher brittleness, which can be easily ruptured and decomposed. The graph also shows that the co-substrates affected the initial bulk density of the compost treatments. Compost with chicken manure had a lower initial bulk density (200 kg/m^3) compared to compost with POME anaerobic sludge, which had a higher bulk density (300 kg/m^3). The difference in the initial bulk density is because of the different initial weight and moisture content of POME anaerobic sludge and chicken manure. Anaerobic POME sludge is sticky and has high viscosity, thus binding the OPEFB fibers together, while chicken manure is dry, thus slightly binding the fibers. This physical characteristic affect the initial and final bulk density of the compost treatments.

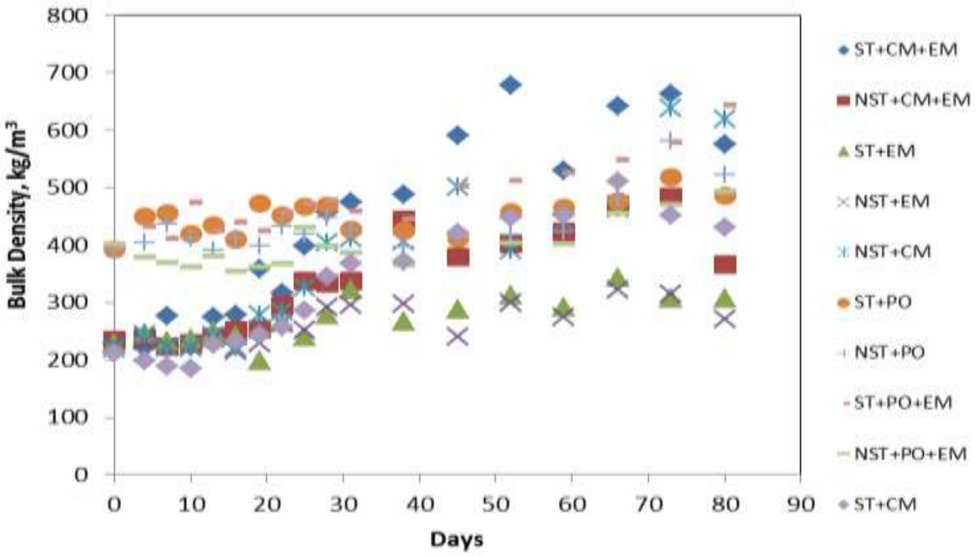

Fig. 7. Bulk density profile of the compost treatments

Therefore, the steam pre-treatment is capable of enhancing the composting process by considering the temperature, C/N ratio, bulk density, and tensile strength of OPEFB fibers. Co-composting steam treated OPEFB with chicken manure increases the decomposition process, but it is not very effective when co-composted with POME anaerobic sludge.

CONCLUSIONS

1. The steam pre-treatment at 140 °C and 40 psi was effective because it helps to reduce the tensile strength and the final C/N ratio. It also increases the bulk density of the compost. The purpose of steam pretreatment is to change the lignocellulosic structure of OPEFB. However, it also caused the destruction of microbes at the same time. In this study, the steam pressure and temperature were high, but the treatment did not significantly change the structure of OPEFB. Therefore, the result of OPEFB co-composted with POME anaerobic sludge was not significant due to the high pressure and temperature that kills the microbes and the unchanged structure of OPEFB. Then, the remaining microbes in POME anaerobic sludge were insufficient to consume the organic material in the compost treatments, whereas the microbes in chicken manure were sufficient to consume the organic materials. It will be a major breakthrough in waste management if steam pre-treatment produces an accelerated composting process and produces higher nitrogen quantity. Thus, the pressure and temperature need to be increased such as 180 °C or 210 °C (Bahrin *et al.* 2012) with the same OPEFB capacity during the steam pretreatment in order to modify the lignocellulosic fibers' structure for an enhanced composting process.
2. The effect of nutrient supplementation by the co-substrates was investigated. Co-composting with chicken manure showed the lowest final C/N ratio compared to co-composting with POME anaerobic sludge. Therefore, the addition of chicken manure yielded a significant effect as compared to the addition of POME anaerobic sludge.

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