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Feasibility of Anaerobic Co-composting Empty Fruit Bunch with Activated Sludge from Palm Oil Mill Wastes for Soil Conditioner

Noor Fauziyah Ishak, Abdul Latif Ahmad* and Suzylawati Ismail

School of Chemical Engineering, Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Seberang Perai Selatan, Pulau Pinang, Malaysia

*Corresponding author: chlatif@eng.usm.my

Abstract: *Utilisation of palm oil mill wastes to make soil conditioner through anaerobic co-composting is feasible and has the potential to maintain the natural resources, and to reduce the impact on environmental quality in the future. Co-composting process uses pressed-shredded-grinded empty fruit bunch (EFB) with activated sludge (AS) from the pond system of a palm oil mill as a suitable option for organic waste disposal with economic and environmental profits, since the process leads to stabilised final compost which can be used to improve and maintain soil quality, and fertility. The temperature, pH, electrical conductivity and moisture profile in the compost was analysed during the experiment. The pH and moisture values remained stable within 6.8%–9.2% and 64%–71% throughout the process. The final matured compost was deemed stable for agricultural uses considering C/N ratio of 12.2 achieved within 100 days. The amount of nutrients and heavy metals were analysed in the final matured compost.*

Keywords: Anaerobic co-composting, compost, palm oil mill activated sludge, pressed-shredded-grinded empty fruit bunch

1. INTRODUCTION

Malaysia is blessed with abundant natural sources such as oil palm trees, leading to many palm oil plantations which covered 4,487,957 ha in 2008. Palm oil production in Malaysia has been a very important element in the development as well as being the supply of dietary oils and fats throughout the world for the last 30 years. Production in Malaysia has increased from only 1.3 million tonnes in 1975 to 4.1 million tonnes in 1985, 7.8 million tonnes in 1995 and 18.2 million tonnes in 2011. The March 2012 Malaysian Palm Oil Board data also revealed that the pace of exports had increased by 11% month-on-month to 1.343 million tonnes.

This huge production of palm oil will produce a lot of wastes which could directly affect the environment. Palm oil mill effluent (POME) and empty fruit bunch (EFB) are major waste products from the palm oil industry which are environmental hazards from the landfill process. It has been reported that in 2005 there was a total of 423 palm oil mills with the production capacity of approximately 89 million tonnes of fresh fruit bunch (FFB) per year as explained by Singh et al.[1] With nearly 4.70 million ha of planted land and 416 mills operating across the country, the Malaysian palm oil industry is expected to generate over 19.8 million tonnes of EFB (wet weight) and 60 million tonnes of POME.[2]

Usually, POME will be further treated with the pond system at the mill. Ponds have been used extensively in Malaysia for industrial wastewaters treatment such as POME, rubber factory effluent and domestic sewage effluent that are amenable to biological treatment. Ponding is a general term which includes waste stabilisation lagoons and oxidation ponds used where land space is available. The oxidation pond consists of aerobic, facultative and anaerobic ponds which employ biological treatment for wastewaters. It is also used for settling sludge or activated sludge (AS).[3]

The disposal of untreated organic waste such as AS causes serious pollution problems as it has a high content of chemical oxidisable components (expressed as chemical oxygen demand or COD) and bio-chemical decomposable components (expressed as BOD or biochemical oxygen demand). While the final disposal of organics presented significant challenges, recovery of organic waste through composting is one alternative. Recycling wastes is capable of improving the environment by reducing the area of landfill and promoting the fertility of the soil referring to Tsai et al.[4]

Composting is widely recognised as an effective method of turning organic wastes into useful products.[5–7] Broadly, these challenges include administrative, human acceptance and participation, management, technological and logistical, and marketing as well as composting process, source separation, contamination, quality of the final product, appropriate composting technologies and final demand and distribution of the final product. Any organic material with the proper ratio of carbon to nitrogen is suitable for composting where the carbon sources provides energy for the microbes, and the nitrogen sources provides proteins in compost.[8] As aforementioned, the EFB and AS are mostly wastes produced in palm oil mills which consists a significant value of nutrients needed to be recycled for agriculture use. So AS would be considered as a nitrogen source and EFB would be a carbon source to complete the co-composting process in anaerobic condition. Application of compost to soil is considered as a good management practice because it stimulates soil microbial growth and activity with the subsequent mineralisation of plant nutrients.

The co-composting process can take place through many different methods and various operational schemes. Three broad methodological categories include aerobic (requires air) was done by Fernandez et al.,[9–11] anaerobic (does not require air) successfully executed by Ruggieri et al.[5,12,13] and vermicompost (requires microbe such as earthworm) achieved by Padmavathiamma et al.[14,15] Aerobic co-composting is the most common method of decomposition. Large quantities of oxygen are required by organisms to break down organic matter aerobically. Since large quantities of oxygen are required, a higher cost is needed for chemical reaction to occur. Meanwhile, anaerobic co-composting occurs in an enclosed container with limited access to oxygen. In this condition, organic material starts to ferment once it breaks down. The container is fully closed and no oxygen is supplied. Bottles of small quantity of wastes sample are applied to measure the microbial activity during short periods of time.[13]

Therefore, the aim of this study is mainly focused on the observation of physicochemical changes and the nutrient content of compost during the co-composting of pressed-shredded-grinded EFB with AS in a small anaerobic container. The method does not require any air supplier that costs a lot of money and a complicated system to control. The efficiency of composting with a control system is low and incurs higher operation cost, e.g., $200/dry ton or higher.[16] The advantages of small-scale experiments compared to pilot-scale composting include requiring low amounts of sample, high amount of variants can be investigated and the experiments can be carried out easily within a short period of time.

2. EXPERIMENTAL

2.1 Feedstock Material

The representative organic waste is EFB which was used as a carbon source in co-composting while the nitrogen source was performed with AS from the ponding system. The EFB was pressed and shredded in the mill for the recovery of the remaining crude palm oil. Then, the collected pressed-shredded EFB was dried and blended to about 0.5–1.0 cm in length by using a blender in order to provide better aeration and moisture control. Both wastes were obtained from United Oil Palm Industries Sdn. Bhd., Nibong Tebal, Pulau Pinang, Malaysia. The selected physicochemical properties of the composting materials are shown in Table 1.

The analyses for COD, biological oxygen demand (BOD), total solid (TS), total suspended solid (TSS) and total dissolved solid (TDS) for AS were conducted before setting up the experiment according to American Public Health Association (APHA) methods.[17] The pH of EFB was 6.86 which is slightly acidic, meanwhile the AS was 8.31 which is slightly alkaline. The high value of

COD (95,300 mg l^{-1}) and BOD (52,800 mg l^{-1}) indicate high amounts of organic matter. The AS was used as the nutrient source with high water content (90.37%) and high C/N (28.38); meanwhile the EFB has low water content (31.27%) with low value of C/N (17.68) as shown in Table 2. From the analysis, it is expected that the combination of these materials (EFB and AS) for co-composting is suitable as substrates due to the availability of major nutrients such as nitrogen, phosphorus, potassium and also some value for micronutrients.

Table 1: Characteristics of raw materials.

Parameter	EFB	AS
pH	6.86	8.31
Moisture (%)	31.27	90.37
Electrical conductivity (µs cm^{-1})	–	363.8
Dissolved oxygen (mg l^{-1})	–	8.78
COD (mg l^{-1})	–	95,300
BOD (mg l^{-1})	–	52,800
Total solid (%)	–	9.6
Total suspended solid (mg l^{-1})	–	70
Total dissolved solid (mg l^{-1})	–	78

Table 2: Composition of nutrients and metal elements for raw materials.

Element	EFB	AS
Carbon (%)	38.19	7.38
Nitrogen (%)	2.16	0.26
Phosphorus (mg kg^{-1})	10.4	311
Potassium (mg kg^{-1})	104.3	57.44
Calcium (mg kg^{-1})	23.02	81.23
Magnesium (mg kg^{-1})	10.46	28.55
Zinc (mg kg^{-1})	1.2502	4.3882
Chromium (mg kg^{-1})	0.0471	1.2706
Manganase (mg kg^{-1})	0.4704	0.6888
Ferum (mg kg^{-1})	n.d	0.4161
Nickel (mg kg^{-1})	2.6637	2.3247
Copper (mg kg^{-1})	n.d	0.0047
Cadmium (mg/kg)	n.d	0.0117

**n.d = not detected.*

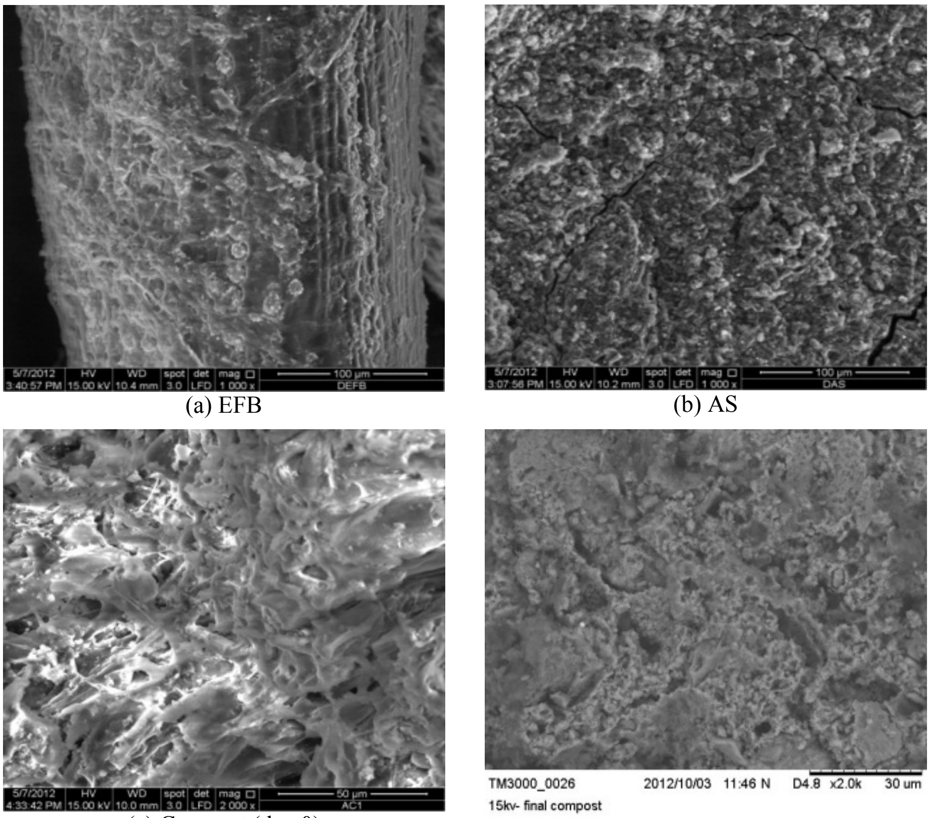
2.2 Experimental Set Up

The study was focused on a cheaper, easier and more valuable method to handle co-composting process. The experiment was conducted in a closed building to avoid direct rainfall. The total AS added into EFB compost throughout the process was about 500 g (1:1 ratio). The compost was mixed homogenously by hand before being kept in an anaerobic cylinder container. The co-composting was implemented in a plastic container (diameter = 20 cm and height = 22 cm) which was fully closed with a lid with conductor for the whole container. Manual turning was conducted once a week for sufficient aeration and material mixing.

2.3 Sample Collection and Analysis

10 g of homogeneously mixed compost was collected for analysis starting from the initial compost at day 0 until the final samples at day 100. Changes in temperature, colour, odour and size of the composts were recorded based on physical observation directly in the container. Observation of the compost structure was carried out using scanning electron microscopy (SEM). The structures of EFB and AS before composting treatment are shown in Figure 1(a) and 1(b).

The fresh compost was used to analyse pH, moisture content (MC), electrical conductivity (EC) and germination index (GI), whereas total Khejdal nitrogen (TKN) and total organic carbon (TOC) were determined using the air-dried samples. Moisture content was determined by drying the sample at 105°C overnight. In order to analyse different parameters, such as pH, EC and GI, water extracts from the composting mixtures were prepared in a ratio of 1:10 (w/v). The suspensions were shaken for 1 h and filtered through filter paper Whatman#2. Total nitrogen was determined with a modified Kjeldahl method and the total organic carbon determination was followed by the Walkley-Black method.[18] Inductive Coupled Plasma (ICP) was used to determine nutrients (Calcium, Potassium and Magnesium) and other metal elements were determined using Atomic Absorption Spectroscopy (AAS).



(a) EFB (b) AS

(c) Compost (day 0) (d) Compost (day 100)

Figure 1: The structures scanning using SEM for EFB and AS.

The GI combines the measurement of relative germination and relative root elongation of lettuce seed to evaluate the toxicity and maturity of the compost. The test was carried out on water extract by mechanically shaking the fresh compost for 1 h at a ratio of compost: distilled water of 1:10 (w:v). Then, about 5 ml of water extract was pipetted into a sterilised plastic petri dish lined with a Whatman#2 filter. Ten lettuce seeds were evenly placed on the filter paper and incubated at 25°C in the dark for 48 h. Treatments were evaluated by counting the number of germinated seeds, and measuring the length of roots. As a control, 5 ml of distilled water were replaced with the extract for very treatment. The responses were calculated by a germination index (GI) that was determined according to the following formula:[10]

GI (%) = [(Seed germination (%)× Root length of treatment) / (Seed germination of control (%)× Root length of control)] × 100

3. RESULTS AND DISCUSSION

3.1 Physical Structure and SEM Analysis

Physical characteristics such as colour, odour and size give a general idea of the decomposition stage reached, but little information regarding the degree of maturation. Matured compost can be observed directly with naked eyes, it is blackish in colour, with soil texture and earthy smell as shown in Table 3. The SEM observation of the final compost revealed that some silica body on the EFB surface [Figure 1(a)] were removed as shown in Figure 1(c) and 1(d). Blending the EFB particle before composting provides higher surface area for microbial attack, but the size of the particle should large enough to maintain certain porosity. Porosity greater than 50% causes the pile to remain at low temperature due to energy loses.[19] The pore was filled with air, water or both in degradation of organic matters.

Table 3: Changes properties for initial compost (0 day) and the final compost (100 day).

Parameter	Compost (day 0)	Compost (day 100)
Colour	Greyish brown	Blackish
Odour	Smelled strongly of ammonia	Earthy smell
Size	0.5–1.0 cm	Soil texture
C/N	23	12.2
GI (%)	12.1	97.8
Composition of nutrients and metal elements:		
Carbon (%)	40.81	8.58
Nitrogen (%)	1.774	0.703
Phosphorus (mg kg^{-1})	31.3	88.6
Magnesium (mg kg^{-1})	19.85	8.35
Calcium (mg kg^{-1})	39.64	9.08
Potassium (mg kg^{-1})	103	77.4
Ferum (mg kg^{-1})	0.05	n.d
Zinc (mg kg^{-1})	n.d	n.d
Chromium (mg kg^{-1})	0.07	0.02
Manganase (mg kg^{-1})	n.d	n.d
Nickel (mg kg^{-1})	4.0198	4.6978

**n.d = not detected.*

Figure 1(b) shows that the structure of AS was compact with no pore exists in the internal structure. Meanwhile, initial composting [Figure 1(c)] shows that there was some pore existing for aeration. However, the porosity and air-flow were influenced by a number of factors such as temperature, moisture content (MC), C/N ratio, aeration, the physical structure of the raw feedstock material and pile dimension.[20] The final compost [Figure 1(d)] has a uniform structure due to complete degradation process.

3.2 Temperature and pH Profile

Temperature is a main factor that can be related to the growth rate, metabolic activity and type of community structure of the compost organism. Changes in temperature during the composting process were recorded using a mercury thermometer kept permanently in the middle of the container. From the temperature profile (Figure 2), it can be observed that the highest temperature was at 34°C for day 1. This is due to the metabolic heat generation by adding the highly organic matter material (AS) into highly cellulosic material (EFB).

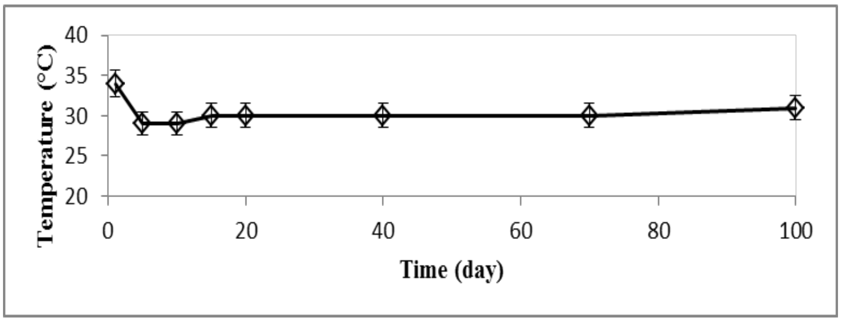


Figure 2: Temperature profile for anaerobic co-composting.

This highest temperature still did not achieve mesophilic/thermophilic condition (exceeding 35°C) because the anaerobic condition with closed container performed at low temperature due to lack of air supply to produce heat. Moreover, it is hard to achieve a stable temperature when there is need to consider the hygienisation temperature of more than 60°C, the maximum biodegradation at 45°C–55°C and for the maximum microbial diversity at 35°C–40°C. According to Grigatti et al.,[21] the compost temperature remained higher than 50°C after one month and then at 20°C after two months, indicating the presence of high quantities of degradable organic matter.

The temperature profile (Figure 2) showed that the sanitation requirement was achieved without external exertion of heat energy to the composting container. The small container with small capacity of sample could preserve heat by limiting heat loss to the surroundings due to low surface to volume ratio. Most data in the literature indicate that the optimum temperature range for effective decomposition is 50 ± 60°C.[22] From the temperature profile

(Figure 2), the lowest temperature was 29°C which is not lower than room temperature (28°C). Chang and Yang[23] reported that lower temperatures might allow more microbial activity but temperatures of composting material below 20°C have been demonstrated to significantly slow or even stop the composting process.

The pH changes due to acid formation during composting by decomposing the organic matter. The initial pH of co-composting in container was slightly increased from 7.57 to 9.28 within the first 10 days (Figure 3). The increase in pH in the compost happened because of decomposition of organic matter in the compost, a consequence of the degradation of acidic compounds, such as carboxylic and phenol groups, and the mineralisation of other organic compounds such as proteins, amino acids and peptides, to ammonia.[24] Then, the value of pH was almost constant until day 20 of composting.

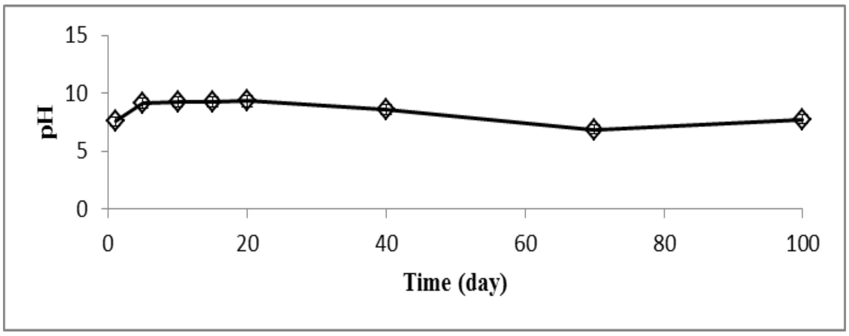


Figure 3: pH profile for anaerobic co-composting.

The slight decline in pH after day 20 was due to the volatilisation of ammonium and release of hydrogen ions from the nitrification process. The pH drop-off at the middle stage until day 70 of composting was associated with the degradation of organic matter and the formation of acidic metabolites.[25] Moreover, addition of AS into pressed-shredded-grinded EFB also contributed to the alkaline condition. The final compost had the pH of 7.75, almost neutral and stabilised, which was due to the buffering nature of humic substances.[26] pH values of composts ranged from 5.8 to 8.8, allowing most microbes to be active.[27] The low acidification could be related to the an anaerobic condition inside the compost.

3.3 Moisture Content

Moisture is necessary to maintain microbial activity throughout the co-composting to achieve a stable end-product. Moisture content is an important environmental variable to provide a medium for the transport of dissolved nutrients required for the metabolic and physiological activities of microorganisms.[16] The moisture content of the final compost (75%) was slightly higher than the initial compost (64.53%) (Figure 4). General recommendation of moisture content is around 50%–60%, referring to Yahya et al. and Wong et al.,[28,29] who reported that a range of 60%–70% provided maximum microbial activities, resulting in higher biodegradation of organic compounds.

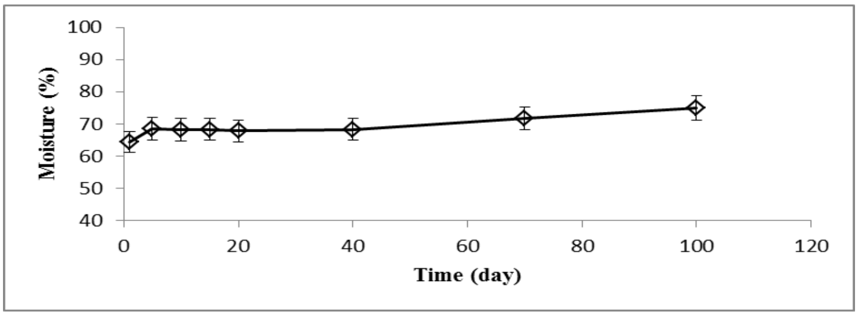


Figure 4: Moisture profile for anaerobic co-composting.

The anaerobic condition would lower the heat of reaction that would not increase the temperature level sufficiently and would not remove excess moisture.[9] Addition of extra water was not required in this study owing to high moisture content already provided during co-composting process. Lim et al.[26] reported that moisture content around 40 to 60% was required for microbial survivality while moisture content exceeding 80% could kill aerobic microorganism due to suffocation.

3.4 Electrical Conductivity

The electrical conductivity of compost was able to conduct an electric current by releasing several ions during the mineralisation of organic matter. EC decreases from the initial value of 495.5 μS cm^{-1} at day 0 to 225.6 μS cm^{-1} during the initial stage within 20 days (Figure 5). The decrease of EC value in the early stage can be explained by the volatilisation of ammonia and the precipitation of mineral salts.[8] After day 20, the EC value was increased to the final compost EC value of 1214 μS cm^{-1}. Baharuddin et al.[12] revealed that the increase was likely due to weight loss and release of other mineral salts such as phosphate and ammonium ions through the decomposition of organic substances.

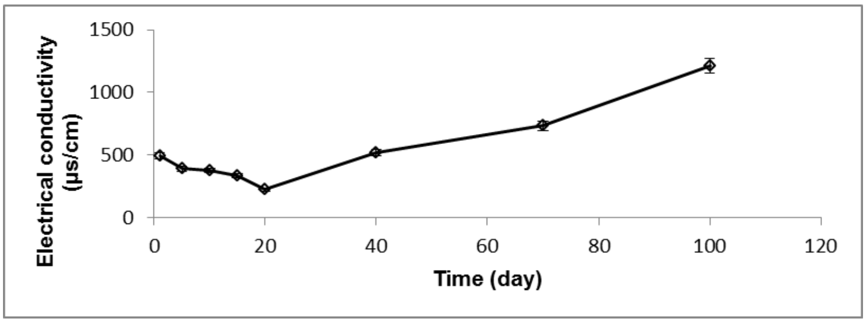


Figure 5: Electrical conductivity profile for anaerobic condition.

For the final EC compost to be at an acceptable level in terms of safe application for plant growth, it should be below 2500 µS cm^{-1} according to Himanen et al.[30] The high conductivity of compost might cause plant phytotoxicity as high concentrations of salts due to the decrease in osmotic pressure between plant roots and growth substrate may affect water availability to the plant. The final compost was ready to be used directly to the plant as it has the lower EC. Meanwhile, the compost with higher EC must be mixed well with soil or other materials with low EC before it can be used for growing crop.

3.5 C/N Ratio

The C/N value describes the parts of C per unit of N required by the microorganism. The C/N ratio is the primary parameter when using compost as soil conditioner because at high C/N values, the materials can immobilise soil nitrogen by the on-going decomposition. The co-composting process will decreases the C/N ratio by the conversion of organic C to CO_2 and part of the nitrogen can be lost in the form of NH_3. The initial C/N ratio of the co-composting materials was adjusted to 23, which decreased to a final C/N ratio of 12.2 as shown in Table 3.

Usually, for mature compost the C/N ratio of less than 20 was thought to be desirable depending on the type of raw materials.[8,12,26] According to An et al.,[31] carbon was used as an energy source by microorganism and the nitrogen was used for protein synthesis. The available carbon was fully utilised and the excess N was lost in the form of NH_3 which could cause decease of C/N value. The high C/N value in raw materials will slow down the co-composting process as there is an excess of degradable substrate for microorganism. Meanwhile, the low C/N ratio shows that there is an excess of N per degradable C. The final compost achieved the requirement for stable C/N value (12.2) which is ready for agricultural use as soil conditioner.

3.6 Phytotoxicity Analysis

Phytotoxicity, expressed as GI which stands for germination is commonly applied to evaluate compost maturity and the phytotoxicity of biowaste materials.[32,33] The final compost produced a GI value of 97.8% (Table 3) which has been proven to be a sensitive parameter that can reveal high toxicity, which adversely affects root growth and germination. Gao et al.[34] reported that a GI content of more than 80% indicate phytotoxic-free and mature compost. The GI test has been related to the presence of different compounds of heavy metals which can be directly used to evaluate the maturity of compost.

The co-composting not only allows the recycling of nutrients for agriculture but also immobilises heavy metals in the soil to which the compost is applied.[32] For the final compost, nutrients may include magnesium (Mg = 8.35 mg kg^{-1}), calcium (Ca = 9.08 mg kg^{-1}), potassium (K = 77.4 mg kg^{-1}) and phosphorus (P = 88.6 mg kg^{-1}). These elements are actually needed by plants for normal growth, although in limited quantities. Meanwhile, the final compost contained traces of chromium (Cr = 0.02 mg kg^{-1}), nickel (Ni = 4.6978 mg kg^{-1}) and others (Ferum, Zinc and Manganase) which were not detected in matured compost (Table 3). Certain trace elements are not biodegradable and become toxic at some concentration; therefore, measuring the concentration of these elements can ensure that soil conditioner requirements are fulfilled for agriculture use.

All metal concentrations after co-composting slightly decreased, except for Zn and Mn which were not detected in the initial and final composts. The decrease of metal level was due to weight loss in the course of composting following organic matter decomposition, release of CO_2, water and mineralisation processes as explained by Kalamdhad and Kazmi.[19] The total metal contents in the final compost was very low and can be considered as soil conditioner with good quality according to the level set by the US EPA (1993) by Stylianou et al.[35] (Table 4) to ensure safe application of compost. This indicated that the final compost was below toxicity limit and is safe to be used as a soil conditioner. Therefore, the characteristics of the raw materials (Table 2) are favourable with co-composting and the heavy metals can be considered to be unproblematic, due to very low concentrations in the final compost.

Table 4: The maximum permissible limits for land application (mg kg^{-1} dw) was shown by Stylianou et al.[35]

Metal	Mean Eu[a]	Mean Us[b]	Sweden[c]	Netherlands[c]	France[c]	Part 503 limits[d]
Zn	1222	1740	800	300	3000	7500
Cu	337	850	600	75	1000	4300
Ni	37	82	50	30	200	420
Cd	2.8	16	2	1.25	20	85
Pb	124	500	100	100	800	840
Cr	141	890	100	75	1000	3000
Hg	2.2	5	2.5	0.75	10	57
Mn	–	260	–	–	–	–

[a]*Data are reported for 13 countries: Austria, Denmark, Finland, France, Germany, Greece (Athens), Ireland, Luxembourg, Norway, Poland, Sweden, The Netherlands and UK.*
[b]*Total elemental composition of over 200 sewage sludge samples from eight US states.*
[c]*National legislation limits.*
[d]*US legislation limits.*

4. CONCLUSION

As waste produced from palm oil mills are biological in nature and have high organic content, composting as well as co-composting can be a good option. Co-composting of pressed-shredded-grinded EFB with AS from palm oil mill wastes showed a feasible approach under anaerobic conditions. The final compost which had already matured is ready to be used as soil conditioner due to comprise considerable amount of nutrients, low heavy metals and met the United State Environmental Protection Agency (USEPA) standard.

The total metal content of the final compost was very low and the available nutrients (P, K, Ca and Mg) were considered as a soil conditioner with good quality according to the standards to ensure safe application of compost. This study also proved the transforming of palm oil mill wastes into more environmentally friendly products such as compost through the integration of POME treatment in pond system and available EFB was successfully done using anaerobic condition for co-composting.

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