Pertanika J. Trop. Agric. Sci. 40 (1): 143 - 160 (2017)

TROPICAL AGRICULTURAL SCIENCE

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

Physicochemical Characteristics of Oil Palm Frond (OPF) Composting with Fungal Inoculants

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ABSTRACT

This investigation highlights the chemical and physical properties of oil palm frond (OPF) observed during 14 weeks of composting. Composting is a controlled biological decomposition process that converts organic waste into humus-like material. Two white rot fungi species, *Trametes versicolor* and *Schizophyllum commune*, were introduced as inoculants for the composting process. Oil palm fronds (OPF) were composted for 14 weeks, with four treatments, i) control (untreated OPF), ii) OPF treated with *T. versicolor*, iii) OPF treated with *S. commune*, iv) OPF treated with both *T. versicolor* and *S. commune*, with four replications. The resulting compost was brown in colour with a homogenous appearance, and no unpleasant odour was detected. In this study, C/N ratio and percentage volume reduction became the most important parameters to be monitored. Inoculation with *S. commune* achieved the acceptable C/N ratio of 63.2 at the end of the composting period. Compared to other treatments, single inoculation of *S. commune* indicated a higher percentage of volume reduction with a value of 62.8%. Single inoculation of *S. commune*, therefore, provides a suitable medium for composting of OPF.

Keywords: composting, oil palm frond, white-rot fungi, inoculants, compost

INTRODUCTION

In Malaysia, cultivated oil palm covers 4.49 million hectares with a production of 17.73 MnT of palm oil and 2.13 tonnes of palm kernel oil (MPOC, 2011). The oil palm industry is a major provider of employment in Malaysia. The addition of cultivated areas from 1.02 million ha in 1980 to 4.24 million ha in 2007 expanded the workforce from 92,352 workers in 1980 to about 405,000 workers in 2007 (Yusof, 2008). According to Salathong (2007), one hectare of oil

ARTICLE INFO

Article history:
Received: 18 April 2016
Accepted: 10 November 2016

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ISSN: 1511-3701

palm plantation can produce about 50 to 70 tonnes of biomass residue, while its oil consists only 10% of the biomass produced in the plantation. Hassan and Yacob (2005) reported that the main contributor of biomass in Malaysia is the palm oil industry, and this biomass consists of empty fruit bunch (EFB), palm oil mill effluent (POME), mesocarpfiber, palm kernel shells and residue of palm kernel cake. Oil palm fronds (OPF) are normally left to rot in between oil palm trees in plantation sites or as mulching component. Fronds can be recycled as mulch, paper pulp and animal feed (Chan, 1999). Oil palm fronds cut during pruning and harvesting can be processed into green feed or silage, and the fibrous characteristic is similar to rice straw (Abu Hassan & Yeong, 1999). The possible uses of OPF in Malaysia still lack attention; however, several studies have been carried out regarding fronds as ruminant feed (Abu Hassan et al., 1996), herbivore feedstock (Dahlan, 2000), pulp production (Wanrosli et al., 2007), fuel pellet (Trangkaprasith & Chavalparit, 2010) and pressed juice (Zahari et al., 2012).

Composting of organic waste is now seen as an option for restoring soil health, building soil environment complex and achieving sustainability in agricultural production. Composting is an alternative method of dealing with agricultural and industrial waste produced worldwide. Transformation of agricultural waste into compost is one of the validated recycling methods; it is also a good way to produce bio-fertilisers and soil conditioners. The stable composted product helps in replenishment of plant nutrients, maintenance of soil organic matter and improving the physical and microbial properties of soil. In nature, animal and plant residue will undergo complex microbial degradation and transformation by various microbiological processes. Panda and Hota (2007) concluded that the biodegradation of biomass is carried out by different groups of heterotrophic microorganisms, bacteria, fungi, actinomycetes and protozoa.

The objectives of this research were to investigate the usefulness of oil palm fronds (OPF) as composting material with a microbial system and to assess the suitability of filamentous fungi as decomposing agents of frond waste. In this study, the inoculants of *Trametes versicolor* and *Schizophyllum commune* were introduced in composting of OPF as decomposing agents. The physical and chemical changes that occurred during 14 weeks of composting were observed.

MATERIALS AND METHODS

Preparation of Composting Media

Pruned oil palm fronds (the petiole and leaflets) were obtained from a plantation in Batu 10, Jalan Sungai Batang, Sandakan. These collected fronds were already about four weeks into decomposition, providing a suitable inoculation medium than freshly pruned fronds. The frond samples were manually shredded to reduce their size to about 3 to 5 cm for efficient microbial action during the decomposition process. Shredded OPF were dried in a drying oven (Memmert, Germany) at 60°C for 24 h and ground prior to analytical tests. Fungal strains of

Trametes versicolor and *Schizophyllum commune* were selected as inoculants for the composting purposes. *T. versicolor* and *S. commune* were used as inoculants due to their ability as white rot fungi to degrade components of lignin, hemicellulose and cellulose in woody materials. They were maintained on potato dextrose agar (PDA, Merck), prepared and sterilised according to the manufacturer's instructions for strain characterisation.

Decomposition of OPF Waste

Composting of shredded frond waste (500 g on dry basis) was carried out in a white polystyrene box measuring 30 cm (length), 30 cm (width) and 15 cm (height) using Complete Randomised Design (CRD). The compost mixture was left for 14 weeks (98 days). Turning was done once every 10 days to mix the outer and inner part of the compost. A volume of 100 mL of water was sprayed on each compost mixture to maintain their moisture level. The experiments were conducted in an open area with ambient temperature (27 to 30°C), and consisted of a control (un-inoculated fronds), inoculated fronds with *T. versicolor*, inoculated fronds with *S. commune* and co-inoculated fronds with *T. versicolor* and *S. commune*, with four replicates each. Their weight was recorded as initial mass before being decomposed further with the selected fungi. The inoculations were carried out by direct transfer of agar block (1 cmx1 cm) and the microbial suspension method (Haddadin et al., 2009; Zeng et al, 2009; Wang et al., 2011).

Chemical Analysis

A total of 20 g of composted samples was collected from each box every three days in the first week and then at intervals of 12 to 15 days until the end of the experiment to measure the physical and chemical changes in the material. All analyses were done in triplicate and data presented as mean values with standard deviation.

Macronutrient, Micronutrient and Heavy Metal Content. Analysis of selected micronutrients and heavy metals (Pb, Cd, Cu, Ni, Zn and Fe) and macronutrient (Mg) were carried out using inductively coupled plasma-optical emission spectroscopy, ICP-OES (Perkin Elmer, USA) based on the aqua-regia method. The digestion was made using hydrochloric acid (HCl) and 65% nitric acid (HNO3) solution in a volume ratio of 3:1.

pH Determination. The pH was determined in a suspension of 1:10 (w/v) compost and distilled water using a pH meter (Mettler Toledo FE20).

Temperature Measurement. Temperature was measured daily during composting at specific times (day 1, 5, 14, 25, 37, 48, 57, 70, 84, 97). Measurement was made at four different points in the composting heaps, at the corner and centre of the heaps using a thermometer. The thermometer was placed inside the compost heaps to about approximately 3 to 4 inches, for 5 min before the data were recorded.

Moisture Content Determination. Compost moisture content was determined by gravimetric method whereby 10 g of compost was air-dried at ambient temperature overnight before samples were placed in the oven at 105°C for 24 h. The samples were then removed from the oven and placed at room temperature to cool off. The weight of the oven-dried compost was recorded.

C/N Ratio Determination. Organic C was determined according to the combustion method whereas total N was determined using the Kjeldahl method. In the combustion method, 3 g of the oven-dried (60°C) sample was thoroughly ground and sieved through a 0.2-mm sieve and then transferred to a crucible and weighed accurately. The contents of the crucible were ignited in a furnace (Thermo Scientific, USA) at 550°C for 4 h. The crucible was cooled in a desiccator and the loss in weight during ignition was calculated. As for total N determination, the Kjeldahl method was divided into three steps: i) sample digestion in digestion block (Gerhardt, Germany) at 180°C for 1 h and 320°C for 4 to 5 h until the content became colourless, ii) distillation of 10 mL of sample and 10 mL of 40% (w/v) NaOH in a distillation apparatus (Büchi, Switzerland) and the distillate was collected in 10 mL of 2% boric acid-indicator solution, iii) the collected distillate was titrated against 0.01 M H2SO4 until the colour changed from green to purple.

Physical Characteristics

The physical characteristics of composted OPF were observed throughout the composting period. The criteria monitored were compost texture and colour displayed. Percentage volume reduction of composted OPF was evaluated at the end of the composting process, by taking the difference between the volume of the composting material at the beginning and volume of the compost after 14 weeks of the composting period. Percentage of volume reduction was calculated using the procedure suggested by Kala et al. (2009). The calculations took into account all the composted samples (in gram) that were removed throughout the composting period.

Compost Maturity Indices

In order to evaluate the maturity of the composted OPF, the germination of mustard (*Brassica chinensis*) and mungbean (*Vigna radiata*) seeds in extracts of the compost were analysed by the method proposed by Tam and Tiquia (1994) and Zeng et al. (2009). Glass petri dishes were used for the experiment. A fresh compost sample was extracted with distilled water at a compost to water ratio of 1:10 (w/v) and shaken for 1 h and then filtered. The compost was allowed to settle for approximately 20 min. The top solution was skimmed off and filtered leaving the filtrate (extract). For the germination experiments, 7 mL aqueous extract was dispensed into glass petri dishes lined with Whatman filter paper.

Experiments were conducted in triplicate and distilled water was used as the control. Ten seeds were placed in each dish and then incubated at 27°C in the dark. The dishes were labelled. Seed germination and root length were measured after three days. The germinated seeds were counted and of these, the length of the radicle, the part that looks like a root, was measured properly. The end point of the germination process was considered when the seeds started to germinate with a primary root ≥5mm.The relative seed germination (SG), relative root elongation (RE) and germination index (GI) were calculated as suggested by Zeng et al. (2009):

SG (%) = (number of seeds germinated in extract / number of seeds germinated in control) x 100

RE (%) = (mean root length in extract / mean root length in control) x 100

GI = [SG (%) x RE (%)] / 100

Statistical Analysis

Statistical analysis was carried out using the SPSS 21 for Windows. All experimental data were analysed statistically using analysis of variance (ANOVA). Duncan's Multiple Range Test was used for comparison of treatment means when F values were significant at $p<0.05$.

RESULTS AND DISCUSSION

In this study, the whole branch of OPF consisting of petiole and leaflets was selected as composting material. In composting, the particle size of the substrate influences the decomposition time and the extent to which fungi inoculants penetrate the substrate. Thus, a smaller size of OPF was required to maximise the surface area of the substrate for efficient decomposition by introduced and indigenous microorganisms. Morphologically, OPF fibre contains a huge amount of hemicellulose but lacks lignin. It has a comparatively high ash content, with polysaccharide monomers made up of glucose and xylose and a low concentration of arabinose, mannose and galactose (Wan Rosli et al., 2007). Zahari et al. (2012) found that the content of cellulose, hemicellulose and lignin in fresh OPF was 41.7%, 16.4% and 15.5%, respectively. Table 1 shows some of the chemical characteristics of oil palm frond waste used in composting.

Table 1
Some Chemical Characteristics of Oil Palm Frond Waste Used in Composting

Parameter	Composting substrate
	Oil palm frond (OPF)
pH	6.35±0.15
Moist. cont. (%)	53.93±2.25
TOC (%)	48.07±0.08
N (%)	0.59±0.04
C/N	82.2±6.02
Mg (g.kg^{-1})	0.06±0.01
Cu (mg.kg^{-1})	4.89±3.12
Zn (mg.kg^{-1})	1.10±0.09
Fe (mg.kg^{-1})	7.24±0.35
Ni (mg.kg^{-1})	0.02±0.01
Cd (mg.kg^{-1})	0.04±0.01
Pb (mg.kg^{-1})	2.18±0.37

*Moist. cont. - moisture content
Data include mean±SD of four replicates

Turning was done once every 10 days and watering was done every two days to prevent dryness. Turning of compost helps to break up clumps of compost and provides new surfaces for microbial attack; however, it must be carried out carefully and not too often to avoid interference with growth of some microorganisms such as filamentous fungi. The moisture content of 50-60% will encourage dispersal of inoculated fungi, and it was observed that when moisture content was low (below 30%), fungi dispersal was retarded. Diaz et al. (2002) proposed that turning not only allows aeration in the windrows, but also facilitates in producing homogenous compost mass. The chemical and physical characteristics of OPF after 14 weeks of composting were evaluated and the results are summarised in Table 2.

Macronutrient, Micronutrient and Heavy Metal Content

The presence of Ni, Cd and Pb at high concentration enhances toxicity levels as they are absorbed by the plants and then introduced into the food chain system. High concentration of these elements in the plant samples might have been contributed by improper waste or land management and application of excessive fertilisers. Kala et al. (2009) found that addition of sludge to oil palm waste significantly increased heavy metal content due to higher heavy metal content in sewage sludge. The analysis of

Table 2
Chemical Characteristics of Composts Obtained After 14 Weeks of Composting

Parameter	Treatment			
	T1	T2	T3	T4
pH	5.80±0.46 a	5.97±0.07 a	6.78±0.10 b	6.53±0.05 b
Vol. red.	50.4±3.37 a	57.5±5.27 bc	62.8±6.03 c	54.3±1.24 ab
Moist. cont.	58.26±0.27 ab	58.19±0.47ab	58.55±0.22 b	57.85±0.37 a
TOC%	48.66±1.74 a	50.33±1.42 ab	51.30±0.48 b	51.88±0.33 b
N%	0.64±0.01 b	0.70±0.02 c	0.81±0.01 d	0.59±0.02 a
C/N	75.7±2.62 a	72.4±5.42 a	63.2±1.39 a	88.6±6.15 b
Mg ($g.kg^{-1}$)	0.07±0.00 c	0.06±0.00 a	0.07±0.01 d	0.07±0.00 b
Cu ($mg.kg^{-1}$)	0.95±0.85 c	0.38±0.11 a	0.34±0.19 a	0.67±0.34 b
Zn ($mg.kg^{-1}$)	1.55±0.17 b	4.49±0.85 c	0.90±0.12 a	0.94±0.13 a
Fe ($mg.kg^{-1}$)	8.87±0.02 d	7.46±0.08 c	6.26±0.07 b	6.16±0.02 a
Ni ($mg.kg^{-1}$)	0.04±0.01 c	0.06±0.01 d	0.03±0.01 b	0.01±0.01 a
Cd ($mg.kg^{-1}$)	0.03±0.00 a	0.04±0.02 a	0.03±0.01 a	0.04±0.01 a
Pb ($mg.kg^{-1}$)	6.45±0.15 d	0.46±0.11 a	4.91±0.05 b	5.52±0.08 c

T1, T2, T3 and T4 represent the control (without inoculation), inoculation of *T. versicolor*, inoculation of *S. commune* and co-inoculation of *T. versicolor* and *S. commune*, respectively

*Vol. red.-volume reduction; moist. cont. - moisture content

**Data include mean±SD of four replicates. Means with a different letter within the row indicate significant differences (p<00.5) using Duncan's multiple range test heavy metal was important in this study as good compost should contain little or almost no heavy metal that can induce phytotoxic effects on plant growth in the field. Micronutrient and heavy metal content observed in the OPF compost was within the safety limit for general agricultural use as outlined by HKORC (2005) and TAS (2005).

pH

At the end of 14 weeks of composting, pH for the control (un-inoculated) was reduced to 5.80, inducing higher acidity compared to the initial pH of 6.37. This decrease in pH probably occurred due to organic acids being released when fungi and bacteria digested the organic materials, as described by Kala et al. (2009). The OPF inoculated with *T. versicolor* recorded a pH of 5.97 at the end of composting. There were slight increases in pH observed for OPF treated with *S. commune* and co-inoculated with both species (*T. versicolor* and *S. commune*), which gave pH values of 6.78 and 6.53, respectively. The control (un-inoculated) treatment had no significant difference when compared with inoculation of *T. versicolor* at $p<0.05$; however, both were significantly different in comparison to inoculation of *S. commune* and co-inoculation of both species ($p<0.05$) based on Duncan's multiple range test. Haddadin et al. (2009), who studied olive pomace composting, stated that the increase of pH value from 4.0 to 6.7 in treatment bioreactors could be influenced by degradation of organic acids and production of ammonium. Liu et al. (2011) added that decreasing pH was probably due to organic acid production and incomplete oxidation of organic matter. The decrease in pH might have occurred due to mineralisation of nitrogen and organic acids and easily degradable carbon sources, such as monosaccharide and lipids (Nair & Okamitsu, 2010).

Temperature Fluctuation

Figure 1 illustrates the changes in temperature of the composting substrate during 14 weeks of composting. The highest temperature for all composting substrates could be observed on day 70; un-inoculated fronds recorded 30°C, whereas the inoculated fronds with *S. commune* and *T. versicolor* were 34°C and 35°C, respectively. The temperature for co-inoculated frond (*S. commune* and *T. versicolor*) also showed 35°C, which was the highest point reached during the whole composting process.

Tuomela et al. (2000) pointed out that in the composting mass that achieved

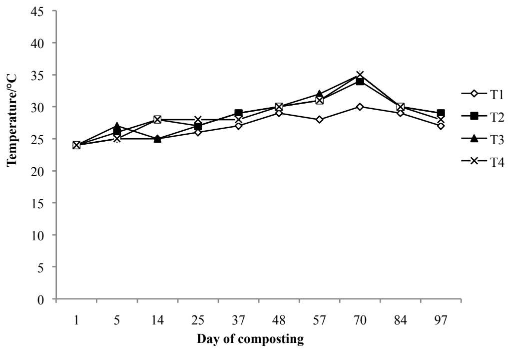

Figure 1. Changes in temperature of the composting substrate during 14 weeks of composting. T1, T2, T3 and T4 represent the control (without inoculation), inoculation of *T. versicolor*, inoculation of *S. commune* and co-inoculation of *T. versicolor* & *S. commune*, respectively

50°C elevation, the microbial population started with thermophilic fungi and was continued by bacteria and actinomycetes, which developed on the fungal mycelium. In this study, the temperature did not reach the thermophilic phase (>45°C) in all the treatments, probably because of heat dissipation due to the small volume of substrate used (Kala et al., 2009). Nair and Okamitsu (2010) stated that the compost needed to be kept at 55°C for 15 days for efficient maturity and pathogen reduction; however, their compost thermophilic phases only lasted a week at the maximum temperature of 55°C for two days only. This was commonly observed in a system that used small volumes since they were prone to temperature fluctuation and heat loss contributed by high surface-to-volume ratio (Nair et al., 2006; Nair & Okamitsu, 2010). Taiwo and Oso (2004) concluded that large heaps generally generate high temperature, while small heaps generate lower temperature, and suggested the use of plastic pots as they conserve the heat produced by microorganisms.

Moisture Content

At Week 1, the initial moisture content of the control (un-inoculated OPF), inoculation with *T. versicolor*, the inoculation with *S. commune* and the co-inoculated fronds recorded moisture content of 53.90%, 54.80%, 54.05% and 52.97%, respectively. The moisture content ranging from 50% to 55% was recommended for composting (Riahi & Fakhari, 2004). The high moisture content at initial composting times would encourage fermentative metabolism, which produces incomplete decomposed product such as organic acid, therefore reducing the compost pH (Liu et al., 2011). Apparently, after 14 weeks of composting, moisture content for the control (un-inoculated OPF) was 58.26%, while for the inoculation with *T. versicolor* and *S. commune*, the moisture content recorded was 58.19% and 58.55%, respectively. Co-inoculated fronds with both species (*T. versicolor* and *S. commune*) gave moisture content values of 57.85%, which was the lowest compared to other treatments. This slightly lower value might be due to vaporisation in compost treatment (Tsai et al., 2007). In spite of that, it was observed that the moisture content of all treatments increased gradually compared to their initial moisture content at Week 1. This could be due to the presence of water vapour inside the composting materials that resulted from the gradual watering process. Aini (2005) elaborated the squeeze ball test, in which moisture can be analysed by squeezing a ball of compost taken from the centre of the heap. If the ball crumbles at a slight tap of the finger, then the moisture is adequate. If water oozes through the clenched fingers, this indicates too much moisture, and if the compost does not form a ball at all, then it is too dry. Haddadin et al. (2009) mentioned that enough moisture in a compost pile will promote biological activity without obstructing the amount of accessible oxygen in the pile. Nevertheless, moisture content exceeding 70% would be unfavourable to fungal growth as fungi rarely survive in an environment with too high a moisture content (Thambirajah, 1994).

C/N Ratio

Figure 2 summarises the mean percentage of TOC in the OPF compost during 14 weeks of composting.

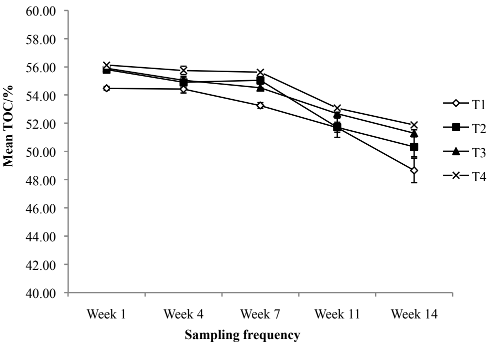

Figure 2. Mean percentage of TOC in composted OPF during 14 weeks of composting. T1, T2, T3 and T4 represent the control (without inoculation), inoculation of *T. versicolor*, inoculation of *S. commune* and co-inoculation of *T. versicolor* & *S. commune*, respectively

In all treatments, except T2 (inoculation with *T. versicolor*) showed a similar pattern of decreasing TOC as the composting continued until the end. This was correlated with findings by Lopez et al. (2006), Goyal et al. (2005) and Fang et al. (1999), who reported that organic carbon content decreased as decomposition proceeded due to conversion of TOC to carbon dioxide (CO_2). During decomposition of compost substrate, the mineralisation of organic matter causes a reduction in TOC values (Liu et al., 2011). Bernal et al. (1998) stated that a decrease in organic matter and organic carbon in waste mixtures reflected the degradation of organic materials during the composting process. The highest value of TOC reflected the presence of recalcitrant carbon compounds, such as lignin, which is slowly decomposed (Goyal et al., 2005). At the end of the sampling, the highest TOC recorded in this study was in the OPF compost co-inoculated with *T. versicolor* and *S. commune* with a value of 51.88%. Interestingly, the TOC value for un-inoculated OPF was the lowest at 48.66%, indicating that the rate of substrate decomposition was the highest in that treatment when compared to inoculated OPF. This could have been due to the environmental and nutrient conditions that favoured the growth of indigenous micro-organisms inside the heap even though no inoculants were added.

Figure 3 illustrates the percentage of nitrogen (N) in the OPF compost during 14 weeks of composting. Before the composting started, the N content of the OPF compost was recorded as 0.59%. During the first week of composting, the N content varied from 0.18% to 0.62% in all the treatments. The high N content of 0.62% in T1 (un-inoculated OPF) could be observed at Week 1 possibly due to indigenous microbial activity that resulted in N accumulation. The N content was recorded in a range of 0.18% to 0.22% at the end of Week 4 for all un-inoculated and inoculated treatments. Goyal et al. (2005) discussed that although total N content decreased at early stages of organic waste composting due to nitrogen losses, the main factors were material used and its initial C/N ratio. Ammonia is highly soluble in water; however, in low moisture content, the ammonium and ammonia present in composting substrate will induce higher vapour pressure, which is most likely to cause nitrogen loss (Hubbe et al., 2010). At Week 7, the treatment of control, inoculation with *T. versicolor*, inoculation with *S. commune*, and co-inoculation with both species recorded 0.24%, 0.15%, 0.20% and 0.14% of N content, respectively.

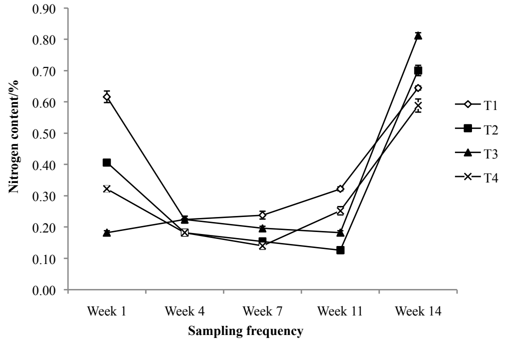

Figure 3. Mean percentage of nitrogen in composted OPF during 14 weeks of composting. T1, T2, T3 and T4 represent the control (without inoculation), inoculation of *T. versicolor*, inoculation of *S. commune* and co-inoculation of *T. versicolor* and *S. commune*, respectively

During Week 11 and Week 14, there were significant changes in N content, as the values increased rapidly towards the end of composting. In co-composting of sewage sludge with coal fly ash, Fang et al. (1999) claimed that total N content increased for all treatments due to a net loss of dry mass. Bernal et al. (1998) also suggested that total N increased due to concentration effect caused by strong degradation of labile organic carbon compound, which also reduced the weight of composting materials. Piškur et al. (2011) observed that N content in wood chips increased (0.14% in fresh wood chips to 0.36% in aged chips) in a 17-month period due to an increase in microbial biomass and N accumulation. In vermicomposting, Pramanik et al. (2007) explained that a smaller value of C/N ratio would accelerate the organic waste decomposition rate, causing the increment of total Kjeldahl nitrogen (TKN) content in vermicompost. At the end of composting, the N values for control, inoculation of *T. versicolor*, inoculation of *S. commune* and co-inoculation of *T. versicolor & S. commune* were 0.64%, 0.70%, 0.81% and 0.59%, respectively. After 14 weeks of composting, it was observed that all treatments of un-inoculated and inoculated OPF were significantly different ($p<0.05$) in N content according to Duncan's multiple range test.

The C/N ratio of raw OPF was 82.2 at the beginning of the study, which was higher than expected. Based on previous research, it was quantified that OPF C/N ratio was 61.0 (Aini, 2005) and 69.7 (Kala et al., 2009). According to Rao (2007) and Haddadin et al. (2009), C/N ratio of the composting substrate influenced the length of the composting period and degree of compost maturity. In the case of substrate with initial C/N ratio of 25, the composting process could be carried out in a relatively short period. Figure 4 summarises the C/N ratio of OPF compost at each sampling time throughout the 14 weeks of composting. At the first week of composting, C/N ranged from 88.8 up to 307.3 and continued to increase until Week 4 with a C/N of 249.0 to 310.3. The similar trend could be observed in Week 7 of composting, in which the C/N of the control, inoculation of *T. versicolor*, inoculation of *S. commune* and co-inoculation of *T. versicolor* and *S. commune* were 221.3, 362.8, 280.5 and 405.3, respectively. Goyal et al. (2005) found that C/N ratio of poultry manure increased as a result of N losses mostly through ammonia volatilisation. In Week 11, treatments of the control, inoculation of *T. versicolor*, inoculation of *S. commune* and co-inoculation of *T. versicolor* and *S. commune* recorded C/N ratios of 160.4, 422.0, 289.7 and 211.8, respectively.

After 14 weeks of OPF composting, the C/N ratio of the end product varied from 63.2 to 88.6, and the highest value was recorded in treatment T4 (co-inoculated with *T. versicolor* and *S. commune*, while the lowest of 63.2 was recorded in treatment T3 (inoculated with *S. commune*). This observation is in agreement with those reported by Kostov et al. (1991) that after six months of decomposition, the C/N ratio of bark reduced from 251 to 61, while for sawdust the decrease was from 473 to 41. This reduction in C/N ratio showed significant microbial activity present in the substrate used (Kostov et al., 1991). Nair and Okamitsu (2010) detected that in the first seven days of kitchen waste composting, the initial C/N ratio of 79.1 was decreased to <35.0, probably due to carbon loss, which directly correlates to volume reduction in the composting substrate. Rao (2007) stated that in composting, irrespective of substrate used, the C/N ratio will drastically decrease in the final product compared to the initial C/N value. Goyal et al. (2005) mentioned that as decomposition proceeded with time, the carbon content in compost materials decreased and nitrogen per unit material increased, resulting in a decrease of C/N value. Liu et al. (2011) also agreed that C/N ratio decreased during composting due to carbon loss and nitrogen content increment per unit material. In the case of wood degradation, mineralisation of carbon components and nitrogen accumulation led to a decrease in the C/N ratio for beech wood chips from 360 (starting material) to 230 after six months and 160 after 17 months (Piškur et al., 2011). It was observed that at the end of composting, all treatments were significantly different in their C/N ratio except for treatment of T1 (un-inoculated OPF) and T2 (inoculation of *T. versicolor*)

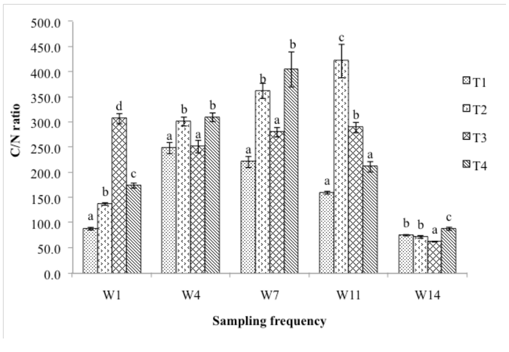

Figure 4. C/N ratio of composted OPF during 14 weeks of composting. T1, T2, T3 and T4 represent the control (without inoculation), inoculation of *T. versicolor*, inoculation of *S. commune* and co-inoculation of *T. versicolor* & *S. commune*, respectively. Columns displaying different letters are significantly different ($p<0.05$) according to Duncan's multiple range test

at $p<0.05$, based on Duncan's multiple range test. In this experiment, the C/N ratio of OPF inoculated with *S. commune* was the lowest (63.2), which, remarkably, corresponded with the highest volume reduction in the same treatment of T3 with 62.8% (Figure 5). Based on these results, it was found that single inoculation of *S. commune* gave the best decomposition rate in OPF composting.

Volume Reduction

Figure 5 illustrates the mean volume reduction of compost recorded during the 14 weeks of the composting process.

The maximum volume reduction of 62.8% was recorded in OPF treated with *S. commune,* whereas the least volume reduction of 50.4% was in the control (un-inoculated OPF). Treatments of T2 (inoculation of *T. versicolor*) and T4 (co-inoculation of *T. versicolor* and *S. commune*) recorded a volume reduction of 57.5% and 54.3%, respectively. All treatments had no significant difference in their percentage volume reduction, except for T1 (control) and T3 (inoculation of *S. commune*), which were significantly different at $p<0.05$ based on Duncan's multiple range test. In this study, it could be summarised that *S. commune* inoculant degraded OPF efficiently when compared to the other treatments. According to Kala et al. (2009), the percentage of volume reduction depends on starting materials used and initial moisture content in the compost pile. In municipal solid waste compost, it was recorded that the weight reduction of waste was more significant in the first week of composting, and this was attributed to maximum microbial activity during this period (Gautam et al., 2010). In this study, although no inoculant was introduced in the control treatment, the presence of an adequate population of microorganisms helped to decompose the frond substrate progressively. Biologically, it was found that inoculants helped in wood decomposition by penetrating inside the wood components and with their enzymatic reaction, the composting proceeded rapidly.

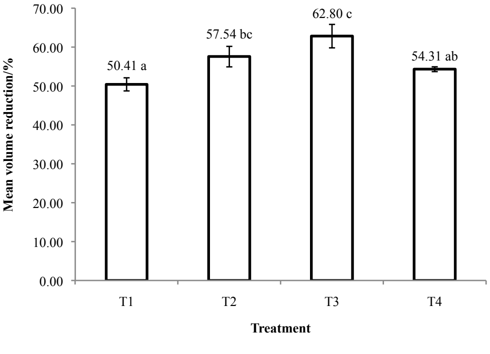

Figure 5. Mean volume reduction of the composting substrate during 14 weeks of composting. T1, T2, T3 and T4 represent the control (without inoculation), inoculation of *T. versicolor*, inoculation of *S. commune* and co-inoculation of *T. versicolor* & *S. commune*, respectively. Columns displaying different letters are significantly different ($p<0.05$) according to Duncan's multiple range test

Germination Index Analysis

Table 3 illustrates percentage seed germination (SG), root elongation (RE) and germination index (GI) for mungbean and mustard seeds, respectively, at the end of the composting period.

Compost obtained through biodegradation of the OPF promoted seed germination.

Table 3
Percentage Seed Germination (SG), Root Elongation (RE) and Germination Index (GI)

Treatment	Mungbean			Mustard		
	SG (%)	RE (%)	GI	SG (%)	RE (%)	GI
T1	96.7±5.77	109.6±18.36	106.0±11.81	108.0±0.01	94.1±11.91	101.6±12.87
T2	100.0	95.4±5.17	95.4±5.16	100.0±18.34	123.5±27.65	123.5±33.61
T3	100.0	92.3±5.19	92.3±5.18	96.0	78.9±2.91	75.7±2.80
T4	100.0	114.1±17.32	114.1±17.32	92.0±6.93	105.3±13.45	96.9±18.76

for Mungbean and Mustard Seed
T1, T2, T3 and T4 represent the control (without inoculation),inoculation of *T. versicolor*, inoculation of *S. commune*, and co-inoculation of *T. Versicolor* and *S. commune*, respectively.
*Test results were expressed as % control

These results were in contrast with those of Mitelut and Popa (2011), in whose study biodegradable compost from synthetic solid waste inhibited radish seed germination. It was found that all their tested compost was toxic compared to the control, which had a germination rate of 95% and 100%. In this study, the GI of un-inoculated compost for mungbean and mustard was 106% and 102% of the control, respectively. Surprisingly, some of the GI values in these tests were recorded above 100% of the control. All the GI above 100% reflected that the compost had a higher number of total germinated seeds and mean root length when compared to the control (distilled water). Kutsanedzie et al. (2012) observed that in finished compost from agricultural waste and poultry manure, GI exceeded 150%, showing the absence of phytotoxicity in the final compost. In evaluating olive pomace compost, Haddadin et al. (2009) observed that wheat seed germinated up to 100% in a treated sample; however, no germination was found in the control. Wang et al. (2011) reported that by the end of straw-cattle manure composting, Run 1 (un-inoculated) exhibited 100% of GI, while Run 2 and 3 (inoculated with *Penicillium expansum*) achieved 150% of GI. The high GI of inoculated samples implied that phytotoxic substances such as NH_3 and organic acid were removed faster in that respective sample (Wang et al., 2011).

van Heerdeen et al. (2002) found that cress-seed germination index increased gradually with maturation of the compost from 0% at days 1, 10 and 25 to 77% at day 90, showing a decrease in phytotoxicity with time. Mitelut and Popa (2011) performed radish seed germination using different concentrations of the compost extract (25%, 50%, 75% and 100%), and concluded that the increase in compost concentration affected radish seed germination. A study by Riffaldi et al. (1986) showed that GI increased faster during the first 20 days, and after 30 days of composting, phytotoxicity almost completely disappeared in waste water sludge compost. Diaz et al. (2002)

observed that a decrease in phytotoxicity during composting resulted perhaps from a breakdown of toxic substances in compost.

It was observed that the resulted compost was brown in colour with a homogenous appearance and no unpleasant odour was detected. This was in agreement with studies by Pacheco et al. (2010), in which the organic waste compost had a homogenous appearance, was brown in colour and emitted a fungal odour. As summarised by Aini (2005), at the end of composting, the temperature slowly recedes to ambient temperature, the compost turns brownish black and the original constituents are no longer recognisable. Based on the high germination index of mungbean and mustard seeds in composted OPF, it is obvious that the OPF compost has potential for use in soil amendment as it leads to decrease in phytotoxicity levels over time.

CONCLUSION

Oil palm frond (OPF) is an eco-friendly compost that contains appropriate amounts of micronutrients and heavy metals; therefore, it is safe for general agricultural use. In this study, although all parameters correlated with each other, C/N ratio and percentage volume reduction became the most important parameters to be monitored. Inoculation with *S. commune* promoted the acceptable C/N ratio of 63.2 at the end of the composting period. Compared to other treatments, single inoculation of *S. commune* indicated a higher percentage of volume reduction, with a value of 62.8%. Therefore, single inoculation of *S. commune* is suggested as a medium in OPF composting. Nevertheless, further studies are required to discover a suitable species or strain of microorganism specific to OPF as a substrate and to enhance the composting process for generating compost of high chemical and physical quality.

ACKNOWLEDGEMENT

The first author gratefully acknowledges the award of the UMS Graduate Teaching Assistance Scheme Scholarship from Universiti Malaysia Sabah during the course of this study.

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