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Short communication

Determination of maturity in the vermicompost produced from palm oil mill effluent using spectroscopy, structural characterization and thermogravimetric analysis

Su Lin Lim, Ta Yeong Wu*

Chemical Engineering Discipline, School of Engineering, Monash University, Jalan Lagoon Selatan, 47500 Bandar Sunway, Selangor Darul Ehsan, Malaysia

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ABSTRACT

Vermicompost produced from palm oil mill effluent was evaluated for its maturity using: (i) spectroscopic analysis (Fourier transform infrared spectroscopy (FT-IR) and ultraviolet visible (UV–vis) spectroscopy); (ii) structural characterization (scanning electron microscope (SEM) and Brunauer, Emmett and Teller (BET) surface area) and (iii) thermogravimetric (TG) analysis. The FT-IR showed increased mineralization of polysaccharides, carbohydrates and aliphatic methylene compounds in the vermicompost as compared to the control (without earthworms). A slight increase of aromatic compounds was observed and proven by UV–vis spectroscopy analysis for vermicompost. Structural characterization (SEM micrographs) of the vermicompost was revealed to be more fragmented than initial wastes and control. The vermicompost also showed larger surface area by using BET method. Finally, the TG analysis showed lower mass loss in the vermicompost in comparison with the initial wastes and control, suggesting higher stability in feedstock which had undergone vermicomposting process. The first derivative curve from TG analysis also showed degradation of various compounds, which was consistent with the spectroscopic characterization.

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1. Introduction

Generally, agriculture and industrialization account for higher water consumption in comparison with domestic use worldwide (Teh et al., 2014a). Palm oil mill effluent (POME) is generated due to wet process of crude palm oil processing. Crude palm oil extraction produces approximately 50 million tonnes of POME annually in Malaysia and this figure is expected to rise in the future (Teh et al., 2014b; Wu et al., 2013). The most typical method for managing POME is using ponding system (Wu et al., 2010). Besides, POME could also be utilized as a substrate in composting process (Zahrim, 2014; Zahrim and Asis, 2010). Recently, Lim et al. (2014) found that POME could be treated and transformed into organic fertilizer through vermicomposting process. Unlike normal composting process, vermicomposting process involves both earthworms and microorganisms to biodegrade organic solid waste (Sim and Wu, 2010; Wu et al., 2014). Microorganisms are responsible for the biochemical degradation of organic matter whilst the earthworms help promote aeration conditions, fragment the substrate and subsequently increase the microbial activity (Hanc and Vasak, 2015). The joint action between earthworms and microorganisms leads to higher organic matter mineralization rate during vermicomposting in comparison with composting process (Lim et al., 2015b; Sim and Wu, 2010). Also, the vermicompost is physically, nutritionally and biochemically improved over traditional compost due to the higher humification rate during vermicomposting process (Lim et al., 2015c). This process has emerged as an environmentally friendly waste management method and is proven effective in managing various agricultural wastes such as soybean husk (Lim et al., 2011), rice husk (Lim et al., 2012), tomato-plant waste (Fernández-Goḿez et al., 2013), rice residues (Shak et al., 2014), oil palm empty fruit bunches (Lim et al., 2015a) and others. Furthermore, the uses of organic amendments are gaining popularity in sustainable crop production and nutrient management because long-term application of inorganic fertilizers on lands without organic supplements could potentially damage the properties of the soil (Lim et al., 2015c).

In an earlier study conducted by Lim et al. (2014), POME was absorbed into amendments (soil or rice straw) in different ratios to produce the best quality vermicompost using *Eudrilus eugeniae*. The vermicompost were characterized in terms of C/N ratio, soluble chemical oxygen demand, volatile solids and nutrient contents (Lim et al., 2014). Apart from these parameters, vermicompost maturity and stability can also be analyzed by using spectroscopic

* Corresponding author. Tel.: +60 3 55146258; fax: +60 3 55146207.
E-mail addresses: wu.ta.yeong@monash.edu, tayeong@hotmail.com (T.Y. Wu).

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characteristics (FT-IR and UV–vis spectroscopy) and thermogravimetric (TG) analysis (Smidt and Lechner, 2005; Zbytniewski and Buszewski, 2005). Spectroscopic techniques and TG analysis are promising tools for characterizing the evolution of organic waste as they are simple, fast, relatively inexpensive and reliable techniques (Wu et al., 2011; Zbytniewski and Buszewski, 2005). The use of multiple maturity tests will provide a more complete picture and nature of the vermicompost (Baffi et al., 2007; Wichuk and McCartney, 2010), in which case the information of vermicompost characterization using high-end equipment is generally lacking. Thus, the main aim of the present study was to further characterize the initial wastes and the best vermicompost produced from POME (Lim et al., 2014) using spectroscopic techniques (FT-IR and UV–vis), SEM, BET method and TG analysis.

2. Materials and methods

The detailed procedure to produce the best vermicompost from POME was reported by Lim et al. (2014). The best vermicompost was produced from a mixture of rice straw and POME at 1:3 (w/v). Chemical properties of the mixed initial wastes were: pH 6.96 ± 0.04; electrical conductivity: 898 ± 48; P: 1.70 ± 0.27 g/kg dry wt; K: 12.38 ± 0.07 g/kg dry wt; Ca: 11.15 ± 1.20 g/kg dry wt; Mg: 3.48 ± 0.42 g/kg dry wt; C/N ratio: 31.61 ± 4.36; soluble chemical oxygen demand: 52,800 ± 2263 mg/L; volatile solids: 809.0 ± 45.7 g/kg dry wt. The chemical properties of the vermicompost were: pH: 8.46 ± 0.10; electrical conductivity: 1437 ± 64; P: 6.29 ± 0.74 g/kg dry wt; K: 21.35 ± 0.45 g/kg dry wt; Ca: 24.25 ± 2.34 g/kg dry wt; Mg: 6.88 ± 0.77 g/kg dry wt; C/N ratio: 9.64 ± 0.20; soluble chemical oxygen demand: 6400 ± 1131 mg/L; volatile solids: 449.7 ± 10.6 g/kg dry wt. The control was produced from the same waste mixture without the earthworms. The chemical properties of control were: pH 9.09 ± 0.20; electrical conductivity: 1141 ± 151; P: 3.55 ± 0.31 g/kg dry wt; K: 10.07 ± 1.25 g/kg dry wt; Ca: 17.25 ± 2.76 g/kg dry wt; Mg: 6.19 ± 0.00 g/kg dry wt; C/N ratio: 20.36 ± 3.07; soluble chemical oxygen demand: 140,000 ± 18,102 mg/L; volatile solids: 628.8 ± 34.1 g/kg dry wt (Lim et al., 2014). The functional groups in the samples were analyzed by using FT-IR (Thermo Scientific Nicolet iS10). The FT-IR spectra were recorded in the mid infrared area (wave number ranged from 4000 to 500 cm^{-1}). Degree of humification of the samples was determined using a UV–vis spectroscopy (Agilent Cary 100 Series). 50 mL of 0.5 M NaOH was used to extract alkali-soluble humic substances from one gram of sample and the mixture was shaken for 2 h. After that, the mixture in the form of suspension was left overnight (Zbytniewski and Buszewski, 2005). The microstructures of the samples were determined using a variable-pressure scanning electron microscope or VP-SEM (Hitachi S3400N-II, Japan). The surface areas of the vermicompost and control were measured via BET (Brunauer–Emmett–Teller) method with a Micromeritics ASAP 2020 using N_2 as the adsorbate at 77.3 K. The samples were degassed at 90 °C for 2 h and then at 110 °C for 22 h prior to the adsorption analysis. TG analysis was performed using a TA Instrument TGA Q50. The analysis was combusted from 30 to 1000 °C at a heating rate of 10 °C/min under air atmosphere.

3. Results and discussion

3.1. FT-IR analysis

FT-IR spectroscopy is used for identifying the chemical functional groups of a material in which the changes in the intensity of the absorbance can be used to assess compost stability (Khan et al., 2009). The FT-IR spectra of the initial wastes, vermicompost and control samples are illustrated in Fig. 1. Initial wastes were characterized by a broad hydrogen bonded O—H stretch at 3328 cm^{-1}, strong aliphatic methylene peaks at 2921 and 2852 cm^{-1}, aldehydes and organic esters peak at 1739 cm^{-1}, C═O stretch of amides at 1633 cm^{-1}, a slight amine peak at 1366 cm^{-1}, an intense C—O stretch of polysaccharides, cellulose and hemicelluloses peak at around 1034 cm^{-1}. A slight peak was also observed at 787 cm^{-1} which was attributed to C—O stretching of carbonate and silica (Deka et al., 2011; Gupta and Garg, 2009; Kumar et al., 2013).

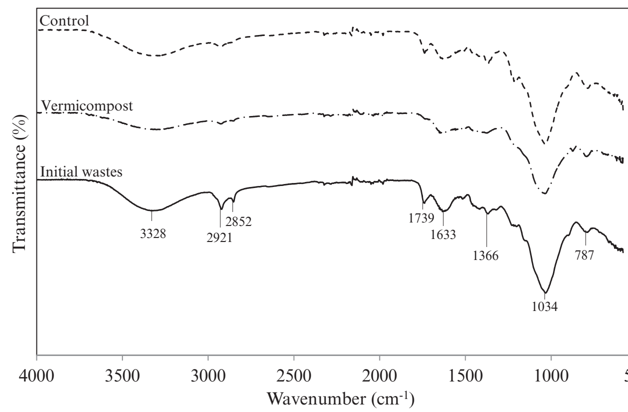

Fig. 1. FT-IR spectra of initial wastes, vermicompost and control.

There were significant differences in the FT-IR spectra between the initial wastes, vermicompost and control. Both the spectra of vermicompost and control showed significant reduction in band height at 3328, 2921, 2852 and 1034 cm^{-1} in which the vermicompost showed larger reduction. The changes in the intensity of the absorbance indicate the changes in the organic matter during vermicomposting process (Wu et al., 2011). For example, the reduction in band height at 3328 cm^{-1} showed the decomposition of carbohydrates due to the decrease in atomic groups and structure of OH and CH_2, while the reductions of band height at 2921 and 2852 cm^{-1} were attributed to the breakdown of aliphatic methylene peaks (Gupta and Garg, 2009). The peak at 1034 cm^{-1} (C—O stretch of polysaccharides) also showed a significant decrease in intensity particularly in the vermicompost. Similarly, Gupta and Garg (2009) also reported a decrease at this peak after the vermicomposting process because of progressive transformation of the polysaccharides in other oxygenated compounds, such as carboxylic and ester groups. Aldehydes and organic esters peak at 1739 cm^{-1} also disappeared completely in the vermicompost by comparison with the control, suggesting higher decomposition of organic waste (Deka et al., 2011) during vermicomposting process. No obvious change of intensity at peak 1633 cm^{-1} for all samples. However, there was a slight shift of the peak towards a higher wavelength in the vermicompost spectra, indicating the appearance of C═C aromatic groups (Wu et al., 2011). The higher decrease in intensity of several indicator peaks in the vermicompost spectra showed that the biodegradations of carbohydrates, polysaccharides and aliphatic methylene groups in the initial wastes were more prominent with the presence of earthworms.

3.2. UV–vis spectroscopy

UV–vis spectra of alkali-soluble humic substances in initial wastes, vermicompost and control showed a shoulder between 250 and 300 nm (Fig. 2). This shoulder represents the absorption by the double bonds of aromatic compounds. During humification process, the concentration of aromatic compounds increased together with modification of the functional groupings. This polymerization process would increase and widen the shoulder (at wavelength

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