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Evaluation of humic substances during co-composting of food waste, sawdust and Chinese medicinal herbal residues

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HIGHLIGHTS

- Influence of Chinese medicinal herbal residues (CMHRs) on humification was revealed
- CMHRs accelerated humification and rate of food waste composting maturity.
- Lignin and its derivatives from CMHR provided nucleus for humic acid formation.
- Increase of aromatic functional groups reflects compost stability and maturity.
- CMHRs positively influenced the HA/FA ratio during co-composting with food waste.

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ABSTRACT

Humification during co-composting of food waste, sawdust and Chinese medicinal herbal residues (CMHRs) was investigated to reveal its correlation with compost maturity. Food waste, sawdust and CMHRs were mixed at 5:5:1 and 1:1:1 (dry weight basis) while food waste:sawdust at 1:1 (dry wt. basis) served as control. Lime at 2.25% was added to all the treatments to alleviate low pH, and composted for 56 days. Humic acid/fulvic acid (HA/FA) ratio increased to 0.5, 2.0 and 3.6 in the control and treatment at 5:5:1, and 1:1:1 mixing ratio, respectively at the end of composting. The decrease in aliphatic organics in HA demonstrated the degradation of the readily available organics, while an increase in aromatic functional groups indicated the maturity of compost. Disappearance of hemicellulose and weak intensity of lignin in the CMHRs treatments indicated that the lignin provided the nucleus for HA formation; and the CMHRs accelerated the compost maturity.

1. Introduction

Landfill disposal of food waste was 3337 tons per day in Hong Kong during 2012 (HKEPD, 2014), representing about 40% of total municipal solid waste generated per day. The life span of three landfills in operation will reach their end of life by 2019 and there is growing pressure of diverting MSW from landfilling. Landfill disposal of food waste not just increases the burden of landfill disposal but also causing disturbance to the residents living nearby due to the odor generated from the poorly managed trucks and the unloading of refuse during operation.

Composting, a biological treatment method, provides a potential sustainable way to convert these huge quantity of food waste into salable compost. During composting, the addition of bulking agents is important to improve the porosity of the composting mix, especially for feedstock with high nitrogen contents and high bulk density such as food wastes. Sawdust was the widely used bulking agent in the composting systems; while the use of other waste material, Chinese medicinal herbal residues (CMHRs) as a supplement bulking agent along with sawdust was demonstrated in our previous study (Zhou et al., unpublished data).

Humic substances are a cluster of polymers of organic materials with different molecular weights resulted from the actions of microorganisms and enzymes. They have variable charges and contain a variety of functional groups such as carboxylic, phenolic and hydroxylic compounds. It normally contains one or more aromatic nuclei connecting more than one reactive functional groups of the outer most structure and plays an important role due to its ability to affect the water holding capacity, pH and nutrient dynamics in soil (Stevenson, 1994). Thus investigating the nature of humic substances in compost is important in terms of predicting its efficiency

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during application. Despite previous published data, there is no uniform agreement on the structures and dynamics of the components of humic substances in the final products, mainly as a consequence of the differences in the composting substrate and operating conditions. There are two ways of humic substances generation (Lopez et al., 2002): (1) lignin derivatives oxidized from side chains of lignin constitute the core structure of humic substances under microbial activities, and (2) the polymerization of the monomers through microbial metabolism. Therefore, the composting mix containing higher contents of lignin may accelerate the formation of stable humic substances. Generally, the bulking agents such as the widely used sawdust can provide the lignin; however, the degradation rate of sawdust was normally slow. In contrast, CMHRs after decoction may be easily accessible for microbial attack and the lignin contents might be easily available for the formation of humic substances. However, no report on this issue is available from the literature and warrants further investigation.

Humic substances include humic acid (HA), fulvic acid (FA) and other components such as humin. However, HA and FA represent the majority of the humic substances and have been the foci of studies involving the transformation of humic substances. Humic acid is a series of polymer polycondensates with different molecular weights, and has the capacity of polydispersity, which is one of the general characteristics of macromolecular substances. Soil with HA is usually well buffered because of their dissociation of acidic functional groups (Campitelli et al., 2003). In contrast, FA includes compounds with smaller molecular weight, high activity and high oxidation level. Fulvic acid contains lower mass fraction of carbon, hydrogen and nitrogen but higher oxygen when compared with HA. In general, the immature composts contain high content of FA and relatively low content of HA while HA dominates the mature composts (Tuomela et al., 2000; Garcia et al., 1992). After composting, HA content is significantly increased resulting in the stability of organic matter, indicating that the compost is mature enough for land application.

Carbon/Nitrogen (C/N) ratio is widely used as the indicator for compost maturity; however, it may not be a stand-alone parameter to indicate the maturity and should be considered along with other maturity and stability parameters. Nevertheless, HA content or HA/FA ratio could be considered as parameters to assess the maturity of compost as well as to assess the impact of compost on subsequent soil application because HA and FA elicit different responses in the soil regulating carbon and nitrogen dynamics.

Non-destructive method such as Fourier transform infrared (FTIR) spectroscopy has been used to monitor the functional groups and transformation between HA and FA during composting (Spaccini and Piccolo, 2009). The functional groups revealed using FTIR can be used to predict the groups of compounds, which in turn can be used to assess the correlation between humification and compost maturity. Analysis of humic substances was reported previously with other bulking agent such as sawdust (Tuomela et al., 2000); however influence of CMHRs on the humification has never been investigated.

Therefore, the aim of this study was to correlate the functional groups of the composting mass at various stages of composting and maturity of the composts when CMHRs was supplemented as a bulking agent with the understanding that the rate of humification can reflect the rate of compost maturity.

2. Methods

2.1. Experimental design and composting conditions

The CMHRs were collected daily for a period of one month from the clinic of the School of Chinese Medicine, Hong Kong Baptist University to minimize species variation of the CMHRs samples. A synthetic food waste prepared by mixing 1.3 kg boiled rice, 1 kg bread, 1 kg cabbage and 0.5 kg boiled pork, as described previously (Wong et al., 2009), was used in this experiment. Selected physicochemical properties of the substrates used are presented in Table 1. For the two treatments containing CMHRs, the food waste, sawdust and CMHRs were mixed in the ratio of 5:5:1 and 1:1:1 (dry weight basis, w/w), respectively, while food waste and sawdust mixed at 1:1 (dry weight basis, w/w) served as the control to reveal the influence of the CMHRs on the humification process. The initial moisture contents of the composting mixtures were adjusted to 55–60%; while mixing different components in the above mentioned treatments resulted in a C/N ratio of ~25. Besides, based on our previous experience with food waste composting (Wong et al., 2009; Wang et al., 2013), 2.25% lime (dry weight basis, w/w) was added to all the treatments to alleviate the onset of low pH during the initial stages of composting. About 7.5 kg of composting mixture was prepared for each treatment and composted for 56 days in 20-L composting reactors. The reactors were connected to a computer control system with WMA-2 gas analyzer (PP systems, Herts, UK) and thermosensors for on-line measurement of carbon dioxide and temperature, respectively; and the data were logged continuously (Wong et al., 2009). Aeration rate was set at 0.5 L/min/kg dry composting mass through an aerator pump for the first two weeks; then the rate of aeration was reduced to 0.25 L/min/kg based on the O_2 requirement as observed in our previous studies. Periodically the composting mass in each reactor was mixed and about 200 g of samples from each treatment collected on day 0, 7, 28 and 56 were used to extract the humic substances.

Table 1
Selected physicochemical properties of the synthetic food waste, sawdust and the Chinese medicinal herbal residues used in the study.

Parameters	Food waste	Sawdust	Chinese medicinal herbal residues
Moisture content (%)	59.0 (0.02)	7.24 (0.03)	63.0 (0.13)
Total organic carbon (%)	45.5 (1.70)	52.9 (0.91)	48.0 (0.41)
Total Kjeldahl nitrogen (%)	3.28 (0.04)	0.59 (0.04)	1.62 (1.32)
C/N ratio	13.9 (0.35)	89.8 (4.56)	29.6 (2.21)

Values represent mean and standard deviation ($n = 3$).

2.2. Extraction of humic substances

The humic substances from the compost mass were extracted following the procedure of Huang et al. (2006). Air-dried sample was extracted with a proportional mix of 0.1 M $Na_4P_2O_7 \cdot 10H_2O$ and 0.1 N NaOH, with a solid: extractant ratio of 1:10 (w/v, dry weight basis) after shaking at room temperature for 24 h. The supernatant containing soluble humic substances were collected after centrifugation at 25,931*g* for 15 min, and the procedure was repeated for two more times and the extracts were pooled together. The pH of the extractant was adjusted to 7.0 with 0.5 M HCl and the total organic carbon (TOC) of the humic substances was analyzed using Walkey–Black method (Nelson and Sommers, 1982). The HA and FA contents from the extracted humic substances were separated as follows: the pH of the extract was adjusted to 1.0 with 3 M HCl, and was allowed to stand for layer separation overnight at room temperature before centrifuged at 25,931*g* for 15 min. The pellet (precipitate) contained the HA while the supernatant contained the FA. The HA was washed with 0.05 M HCl several times and the pH was adjusted to 7.0. The fractions were lyophilized to obtain the solid mass and used to analyze the TOC contents using Walkey–Black method.