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Influence of lime and struvite on microbial community succession and odour emission during food waste composting

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HIGHLIGHTS

- Ammonia and VFAs were the two main odorous components during food waste composting.
- Struvite formation significantly reduced the ammonia OU_{max} from 3.0×10^4 to 1.8×10^4.
- pH was the most important factor of driving bacterial succession.
- Struvite formation positively influenced the bacterial community and decomposition.

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ABSTRACT

Lime addition as well as formation of struvite through the addition of magnesium and phosphorus salts provide good pH buffering and may reduce odour emission. This study investigated the odour emission during food waste composting under the influence of lime addition, and struvite formation. Composting was performed in 20-L reactors for 56 days using artificial food waste mixed with sawdust at 1.2:1 (w/w dry basis). VFA was one of the most important odours during food waste composting. However, during thermophilic phase, ammonia is responsible for max odour index in the exhaust gas. Trapping ammonia through struvite formation significantly reduced the maximum odour unit of ammonia from 3.0×10^4 to 1.8×10^4. The generation and accumulation of acetic acid and butyric acid led to the acidic conditions. The addition of phosphate salts in treatment with struvite formation improved the variation of total bacteria, which in turn increased the organic decomposition.

1. Introduction

A recent study by the Food and Agriculture Organization of the United Nations estimated that ~1.3 billion tons of food waste, accounting for 1/3 of food produced worldwide, were lost or wasted (FAO, 2011). Often, food waste, representing 25–70% of the municipal solid waste (Pham et al., 2015), is buried in landfills/open dumps in developed as well as in developing countries (Levis et al., 2010). In Hong Kong, more than 1.3 million tons of food waste was dumped into the landfills in 2015. The composting of food waste provides valuable organic fertilizer and economic incentives, but its acceptability is low in big cities due to a quick acidification rate (Wang et al., 2013) and malodorous emissions (Tsai et al., 2008; Hanajima et al., 2010) leading to operational failure. Specifically, contribution of organic volatile fatty acids (VFAs) and ammonia gas emissions during food waste composting were reported to be high in the odour index (Tsai et al., 2008; Hanajima et al., 2010). However, the linear correlations between odour concentrations and olfactometric patterns were not strictly established for composting of food waste (Hanajima et al., 2010). For instance, acetic acid has shown a linear correlation with olfactometric patterns at very low concentrations, i.e. 0.1–50 ppm, while ammonia had no significant correlation up to 100 ppm (Tsai et al., 2008). The unpleasant responses people exhibit for these malodours were widely evaluated by human olfactory thresholds, most of which was summarized by Devos et al. (1990). Malodour issues are important for application of composting technology, and are required to be reduced for technological acceptance by the public, especially in densely populated cities like Hong Kong (Mao et al., 2006).

Struvite formation was convincingly demonstrated as a strategy to reduce the ammonia loss as emission during food waste composing and in the same time conserve nitrogen in the composting

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mass (Wang et al., 2013; 2016). This technology drastically changed the pH, temperature and NH_3 emission during food waste composting. Bhatia et al. (2013) pointed out that bacterial communities had undergone changes at different stages of composting, possibly linked to the variations in temperature and availability of metabolic substrates. The accumulation of VFAs were considered as the reason of low pH which was closely related to dominance of lactic acid bacteria (Sundberg et al., 2013). Environmental parameters lead to microbial community shift which is also highly influenced by the microbial metabolic substrates. Ammonia and VFAs, as the microbial metabolic products, are considered as the main odours during food waste composting. However, the correlation between odorous emissions, and compost stability and microbial succession was not adequately addressed and established. Since nitrogen is an important element for bacterial growth and activity, struvite precipitation is expected to influence the carbon degradation and complex nitrogen transformation processes during food waste composting (Liang et al., 2006; de Guardia et al., 2008) which requires a critical understanding. Therefore, this study focused mainly on elucidating the correlation between odorous emissions (i.e., ammonium/ammonia ratio and volatile compounds) and microbial succession coupled with struvite precipitation of ammonium during the food waste composting process.

2. Materials and methods

2.1. Test conditions and requirements

The schematic diagram of the compost reactor and operational details were presented in a previous publication (Wong et al., 2009). In brief, cylindrical composting reactors of 20-L capacity were used. The reactor temperatures were monitored and controlled by an automated PT100 sensor and computer controlled program during the composting process.

Artificial food waste was prepared by mixing bread, rice, cabbage, and boiled pork with the ratio of 13:10:10:5 which simulated the physicochemical properties of the food waste and meanwhile that could make the experiment comparable among different test conditions and provide opportunity to repeat the experiments. The cabbage, boiled pork and bread components were size-reduced to 1 cm^3 before mixed with rice. This mix was subsequently mixed with sawdust to adjust the C/N ratio. A C/N ratio ranged from 25:1 to 30:1 was widely regarded as optimum ratio for microbial activity, and when a higher C/N ratio was applied, less NH_3 was emitted. Therefore, raw materials with C/N ratio ~30:1 was used in this experiment. The initial moisture content of the mixture was adjusted to around 55% which was proved to be the optimum condition for organic matter degradation (Bueno et al., 2008). Selected physicochemical properties of the synthetic food waste are presented in Table 1. Finally, around 500 g of bulking agent (plastic beans) was added to achieve a bulk density of ~0.5 kg/L.

The optimum treatment for struvite formation (M0.3) was selected from previous experiments (data not shown). For comparison, food waste without any pH buffering and food waste with lime buffering were also conducted. Details of the additives applied in the treatments are shown in Table 2.

2.2. Food waste composting

The composting masses inside the reactors were taken out and mixed thoroughly in big plastic box once in three days for the first two weeks and once a week thereafter for a total of 56 days. The compost samples were collected on days 0, 3, 7, 14, 21, 28, 42, and 56 for the analysis of physicochemical properties.

Table 1
Selected physicochemical properties of the synthetic food waste, saw dust and the composting mix used in the study.

Parameter	Food waste	Sawdust	Mix
Moisture content (%)	58.2 ± 0.02	7.24 ± 0.03	55.5 ± 1.19
Total organic carbon (%)	45.5 ± 1.70	52.9 ± 0.91	47.0 ± 1.13
Total Kjeldahl nitrogen (%)	3.28 ± 0.04	0.59 ± 0.04	1.41 ± 0.77
C/N_{solid} ratio	13.9 ± 0.35	89.8 ± 4.56	33.7 ± 2.35

Values are mean ± standard deviation (n = 3).

Table 2
Details of the additives applied during food waste composting in different treatments (given based on dry weight basis).

	Treatments	Lime (M) (dry weight basis)	MgO (M/kg)	K_2HPO_4 (M/kg)
C	Control	0	0	0
L	Lime	0.45	0	0
M0.3	Struvite	0.15	0.3	0.05

The CO_2 evolved from the compost reactors was measured in-line using a WMA-2 gas analyzer (PP systems, Herts, UK). Gaseous NH_3 in the outlet was trapped from the off-gas using boric acid and subsequently the concentrations were estimated through titration with acid. Ethanol (Eth) and VFAs from the outlet gases were absorbed using a modified method from Yang and Choong (2001). Acetic, propionic, butyric, *iso*-butyric, valeric, and *iso*-valeric acids volatilized from the composting reactors were analysed using a gas chromatograph (GC-HP6890) equipped with a flame ionization detector and Econo-Cap EC1000 (15 m × 0.53 mm × 1.20 μm) column. The odour unit (OU) was calculated by dividing the odour substance concentration by the threshold, expressing the intensity of odour. The odour index (OI) was calculated by multiplying the common logarithm of the dilution rate by a factor 10 (Hanajima et al., 2010).

$$\text{Odour unit (OU)} = \text{odour concentration/odour threshold}$$

$$\text{Odour index (OI)} = 10 \times \log(\text{odour unit})$$

In order to gain more understanding of the composting process, the bacterial diversity and population dynamics were analysed through polymerase chain reaction-denaturing gradient gel electrophoresis (PCR-DGGE). In brief, the total genomic DNA was extracted from 200 mg of fresh compost with the PowerSoil DNA isolation kit following the manufacturer recommend protocol. This DNA was PCR amplified using primers BAC338F (5′-ACTCCTACGG GAGGCAG-3′) and BAC805 R (5′-GACTACCAGGGTATCTAATCC-3′) targeting the V3-V5 region (Yu et al., 2005) of the bacterial 16S rDNA. A 40 bp GC clamp was attached to the forward primer as reported by Selvam et al. (2012).

About 100 ng of DNA was used as the template in a 50-μL PCR mixture containing 1× PCR buffer, 200 μM of each dNTP, 0.4 μM of each primer, and 1.25 units of Taq DNA polymerase (Promega, USA). The PCR mixture was amplified using a thermal cycler (DNA Engine Gradient, Bio-Rad, USA) with the following conditions: initial denaturation at 94 °C for 10 min, followed by 35 cycles of denaturation at 94 °C for 30 s, annealing at 55 °C for 30 s, and extension at 72 °C for 1 min; and the final extension was at 72 °C for 10 min.

DGGE was carried out using a D-code system (Bio-Rad Laboratories Inc., California, USA) under the following conditions: 50 μL of the PCR product was loaded onto 7% (w/v) acrylamide gel containing a 30–70% denaturant gradient; electrophoresis was run at 75 V for 16 h in 1× TAE buffer at 60 °C. Following electrophoresis, the gel was stained with SYBR™ Green Gold for 60 min in a staining