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Reducing nitrogen loss and phytotoxicity during beer vinasse composting with biochar addition

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ABSTRACT

The aim of this study was to investigate the feasibility of composting of beer vinasse generated from brewing industry, the effect of biochar amendment on beer vinasse composting was also evaluated based on the changes of different physicochemical parameters, phytotoxicity and final compost quality. Four different treatments were performed of beer vinasse with biochar addition at 0, 5%, 10%, 15% (w/w dry basis). The final product obtained from beer vinasse composting was phytotoxicity-free (GI: 120.8%), mature (C/N: 19.88, NH_4^+-N: 295.0 mg/kg, DOC: 9.76 g/kg) and nutrient-rich (especially for P: 1.92%) compost except high N loss (60.76%), which had the potential to be as soil amendment or fertilizer. Biochar addition contributed to decomposition of DOC indicating higher microbial activity and attain phytotoxicity-free standard rapidly. N loss significantly reduced by 27% with biochar at 15% addition. And 15% biochar addition ensured all parameters, which was involved in composts quality, to attain the mature standard. Therefore, it was suggested that biochar addition at 15% was optimal.

1. Introduction

Beer is the most popular and largest consumed alcoholic beverage all over the world. It is the third prevalent drink, after water and tea. China possesses the largest output and consumption of beer in the world. Consequently, plenty of beer vinasse which is the main byproduct from brewing industry (approximately accounts 80%) is generated in China. However, the most widely and usually way used to treat it is land disposal without any pretreatment. As the result, presence of putrescible organic compounds could cause pathogenic microorganism generation, unpleasant odour and possible toxicity. Uncontrolled discharge of vinasse, which is of low pH, high organic matters content and heavy metals such as Cd, Cr, Ni and Pb, could have adverse effect on soil and groundwater quality (Christofoletti et al., 2013). Therefore, it is important to treat beer vinasse with an appropriate method, in order to recycle these wastes and minimize the adverse impact on the environment.

Composting is an effective process to convert different organic solid waste materials into stable compost products applying in agriculture, resulting in a way of recycling waste materials. Considering the advantages, many studies have been carried out to discuss the feasibility of composting of vinasse obtained from sugarcane and grape. Bustamante et al. (2009) studied the co-composting process of grape vinasse, exhausted grape marc, grape marc and grape stalk. And the results showed that compost products reached the mature standard, indicating the feasibility of composting of these byproducts. Bertran et al. (2004) observed that composting of grape stalks and sludge had an important agronomic value and was especially suitable for vineyard soils. In addition, it was found that compost products obtained from beet vinasse had a positive effect on soil, and fresh beet vinasse had the opposite results (Tejada and Gonzalez, 2006). In general, composting of these two kinds of vinasse are feasible and the composts could be effectively applied to soil. It is reasonable to speculate that it may be an appropriate strategy to treat beer vinasse by composting method. Nevertheless, it has been pointed out that, due to the different feedstock and process used for distillate production, different kinds of vinasses composition and characteristics may vary. However, little study, which is involved in beer vinasse composting, has been reported.

As it is well known, nutrient loss is an inevitable problem during organic raw materials composting. This is especially true for nitrogen, which is the most important fertilizer nutrient for crop growth (Hua et al., 2009). It was reported that nitrogen loss was ranged from 16% to 76% during composting of different materials (Barrington et al., 2002). Fernández et al. (2010) found that N

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losses were as high as 40% in the study of sewage sludge and winery-distillery waste composting. Nitrogen loss not only decreases nitrogen concentration in the product, but also increases odour generation leading to environmental problems. Recently, biochar which had the characteristics of alkaline pH, water-holding capacity, aromatic clusters and specific surface was considered as a more suitable effective bulking agent to reduce nitrogen loss. Because ammonia could be effectively absorbed by biochar due to its high sorption capacity. Otherwise, the surface acid groups generated from biochar oxidation especially carboxylic groups, could effectively retain ammonium (Hua et al., 2009). Steiner et al. (2010) evaluated the use of biochar during composting of poultry litter. They found that nitrogen loss significantly decreased 52% with 20% biochar addition, compared to no biochar addition. Also, it was reported that biochar addition significantly reduced ammonia volatilization at first week during sewage sludge by Malińska et al. (2014). Oppositely, it was reported by Sánchez-García et al. (2015), who found that biochar had no effect on nitrogen loss and gas emissions. Therefore, due to different raw materials and biochar amendment, influence of biochar on nitrogen conversion during composting is different. Up to date, no information about effect of biochar on nitrogen conversion and compost quality during beer vinasse compost process were found in literature. In addition, it was found that straw biochar enhanced the degradation of organic matter and maturity (Zhang et al., 2016). However, little is known about the effect of biochar addition on the phytotoxicity and final compost quality during beer vinass composting. This study would focus on the relationship between biochar addition, phytotoxicity and compost products quality. Also, how biochar influenced the N conversion was evaluated during beer vinasse composting.

In this work, four piles of beer vinasse with different amount of biochar were aerobically composted. The primary objective was to investigate the feasibility of composting of beer vinasse based on the changes of different physicochemical parameters, phytotoxicity and final compost quality. The effect of biochar amendment on beer vinasse composting was evaluated and optimal proportion of biochar was determined, too. This research will help to provide a suitable method to transform beer vinasse into compost products as soil amendment or fertilizer.

2. Materials and methods

2.1. Composting procedure

The beer vinasse were obtained from brewing industry in Haerbin (China). The biochar was acquired from Heilongjiang Academy of Agricultural Sciences in Haerbin (China), which was made by the high temperature (300–450 °C) pyrolysis of corn stalks. The basic chemical characterization of the raw materials was shown in Table 1. Four experiments were prepared by mixing different percentage biochar as bulking agent on a dry weight basis: V: beer vinasse alone; VB1: beer vinasse + 5% biochar; VB2: beer vinasse + 10% biochar; VB3: beer vinasse + 15% biochar.

Composting materials were put in special small cylinder compost reactor. The diameter of base circle was 18 cm and height was 45 cm. The working volume was 12.5 L (Supplementary Fig. S1). Total 5 kg raw composting materials were mixed in the reactor. Treatments V, VB1, VB2 and VB3 were filled with 5 kg, 4.92 kg, 4.83 kg and 4.73 kg vinasse and 0 g, 80 g, 170 g and 270 g biochar. The changes of reactor temperature see Supplementary Fig. S2. The control of compost temperature was based on the changes of natural composting (Zhou et al., 2015) and reactor composting (Wang et al., 2014). The actual temperature of compost was basically the same as reactor. To ensure that composting was successful, the initial moisture content was adjusted to 40% and the average particle diameter of all raw materials was between 1.5 and 3.0 cm. In addition, each composting pile was turned and mixed once each week. Distilled water would be added to maintain moisture content at 60–70% when the composting pile was turned, and excess water collected from bottom of the pot was added again to the reactor. Samples of each treatment were collected during all stages of composting on days 0, 1, 3, 7, 14, 21, 30, 45, and 60, and then were air dried, ground to 0.25 mm for chemical analysis.

2.2. Analysis methods

Temperature was monitored using a digital thermometer throughout the composting period by inserting the thermometer into the compost reactor. The O_2 concentration of input and output was recorded by an O_2 sensor (O2S-FR-T2-18X). Based on the difference of oxygen concentration between the input and output, oxygen uptake rate (OUR) was calculated according to (Adani et al., 2001). The carbon dioxide concentration was measured on the influent and effluent air of the reactors using an infrared CO_2 sensor (GXH-3010E1) (Vandergheynst et al., 2002). Samples were extracted in water (solid to water ratio of 1:10, w/v) and a pH meter was used to measure material pH (Zhang et al., 2015). Dissolved organic carbon (DOC) (He et al., 2014) and total carbon (TC) were tested using an organic carbon analyzer (TOC-Vcp, Shimadzu, Japan). Total nitrogen (TN) was measured by Kjeldahl method. Total phosphorus (TP) was performed using 0.5 M $HClO_4$-H_2SO_4 and determined by the ascorbic acid/molybdate reagent blue color method (Murphy and Riley, 1962). Ammonia nitrogen (NH_4^+-N) and nitrogen (NO_3^--N) were firstly extracted using 2 M KCl (1:10 ratio) at 200 rpm for 1 h, and then samples were filtered using a 0.45 μm membrane filter, and concentrations were measured using NaRSH'Scolorimetry and spectrophotometry, respectively. Nitrogen loss (N loss) was calculated based on the following formula: N loss (%) = 100 − 100[$(X_1N_2)/(X_2N_1)$] (1), where, X_1, X_2 are initial and final ash contents, and N_1, N_2 are initial and final nitrogen contents (Dias et al., 2010). The germination index (GI) was assayed according to Zucconi et al., 1981 using the following equation:

$$GI(\%) = \frac{\text{Seed germination} \times \text{Root Length of Compost sample(mm)}}{\text{Seed Germination} \times \text{Root Length of Control(mm)}} \times 100 \quad (2)$$

2.3. Statistical analysis

All experiments were performed in triplicate, and the results are shown as mean ± standard deviation. All physical–chemical data analyses were using Origin9.0. And the correlations among different parameters were determined using SPSS19.0.

Table 1
The physico-chemical characteristic of raw materials.

Materials	TOC (%)	TN (%)	C/N	pH	Moisture content (%)
Beer vinasse	49.08 ± 0.69	1.68 ± 0.02	29 ± 0.76	6.28 ± 0.1	71.3 ± 0.92
Biochar	72.6 ± 0.93	1.3 ± 0.03	55.6 ± 0.28	10.71 ± 0.09	9.69 ± 0.3

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