



Addition of seaweed and bentonite accelerates the two-stage composting of green waste



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HIGHLIGHTS

- Seaweed (SW) and bentonite (BT) were the additives in green waste (GW) composting.
- SW and/or BT addition enhanced the degradation and the humification of GW composting.
- Water retention, porosity, respiration rate, enzymes, and nutrients were optimized.
- Combination of 35% SW and 4.5% BT reduced the two-stage composting time to 21 days.

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ABSTRACT

Green waste (GW) is an important recyclable resource, and composting is an effective technology for the recycling of organic solid waste, including GW. This study investigated the changes in physical and chemical characteristics during the two-stage composting of GW with or without addition of seaweed (SW, *Ulva ohnoi*) (at 0, 35, and 55%) and bentonite (BT) (at 0.0, 2.5%, and 4.5%). During the bio-oxidative phase, the combined addition of SW and BT improved the physicochemical conditions, increased the respiration rate and enzyme activities, and decreased ammonia and nitrous oxide emissions. The combination of SW and BT also enhanced the quality of the final compost in terms of water-holding capacity, porosity, particle-size distribution, water soluble organic carbon/organic nitrogen ratio, humification, nutrient content, and phytotoxicity. The best quality compost, which matured in only 21 days, was obtained with 35% SW and 4.5% BT.

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1. Introduction

With increases in urbanization and the human population, vast amounts of green waste (GW) are now produced in China (Zhang and Sun, 2014). In Beijing city, for example, approximately 6 million tons of GW is generated each year (Zhang and Sun, 2017). At present, the GW in China is either burned or deposited in landfills. As a result, considerable amounts of nutrients are lost, environmental pollution is increased via emissions of toxic and greenhouse gases, and land resources are wasted (Meng et al., 2017; Zhang and Sun, 2016). Composting is considered effective for reducing the mass of GW, for sanitizing it, and for transforming it into a nutrient-rich product useful for plants and soil (Awasthi

et al., 2016). GW, however, consists primarily of cellulose, hemicellulose, and lignin, which are not readily decomposed by microorganisms. In addition, if composting is improperly managed, it can be slow and require a large area, generate foul smells, and produce an immature product (Shi et al., 2006; Zhang and Sun, 2017). Therefore, the present study investigated the composting of GW with seaweed (SW, *Ulva ohnoi*) and bentonite (BT) with the goal of accelerating the degradation of organic wastes, shortening the composting period, and producing a high quality compost.

Aquatic farming systems in many parts of the world generate large amounts of algal wastes including those from SW like *Ulva ohnoi* and other marine macroalgae (Hardouin et al., 2014; Illera-Vives et al., 2015a; Ozdemir et al., 2014). Drift SW, a kind of natural organic resource, is deposited on beaches in large amounts as a result of tidal or wind action and has been commonly used in agriculture and forestry as a fertilizer (Illera-Vives et al., 2015b). SW contains many macro- and micro-nutrients and trace elements. Kuwada et al. (2006) reported that the advantages of using

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SW-derived fertilisers in agriculture include increased nutrient uptake, enhanced growth rates, and increased resistance to diseases, pests, and climatic stress in crops. SW is particularly rich in bioactive compounds (peptides, proteins, and oligo and polysaccharides) that can increase soil aggregate stability and the rate at which microorganisms respire and mineralize nitrogen (N) (Hardouin et al., 2014; Stutter, 2015). In addition, the lactic acid produced during SW biodegradation can decrease the pH of composts (Dao and Kim, 2011). SW also contains large numbers of microorganisms and substantial quantities of enzymes that could enhance microbial diversity and succession, and thereby reduce the time required to produce a mature compost (Leceta et al., 2014). The addition of SW in the composting of lignocellulosic organic residues, such as GW, could also reduce the hydrophobic nature of GW because the major algal polysaccharide in SW is alginate, which is hydrophilic (Ozdemir et al., 2014). Although adding the appropriate quantity of SW can improve the composting process, addition of high quantities of SW may cause the excessive accumulation of some heavy metals in the compost product; such accumulations can inhibit plant growth and lead to environmental pollution (Khan et al., 2015; Riosmena-Rodriguez et al., 2010). Finally, SW also contains plant growth hormones, such as auxins and cytokinins, which could promote plant root growth (Illera-Vives et al., 2015a). The effects of SW on the “two-stage composting” of GW, however, have not been determined. In the two-stage composting of GW, the GW undergoes two rather than one thermophilic periods (Zhang and Sun, 2014).

BT is a widely distributed, low-cost mineral that mainly consists of montmorillonite, a 2:1 mineral with one octahedral sheet of alumina between two sheets of silica (Jiang et al., 2014). Like SW, BT could improve composting in many ways. BT has been used during composting to improve the structural properties and water-holding capacity (WHC) of the composting feedstock (Li et al., 2012). Another study found that BT has substantial nutrient- and water-adsorbing capacity due to its porous sponge-like structure, high cation exchange capacity (CEC), and large specific surface area (Fernandez-Calvino et al., 2015). BT can also reduce ammonia (NH_3) emissions during composting and thereby increase the total Kjeldahl nitrogen (TKN) content in the compost product. Li et al. (2012) reported that addition of BT can increase organic matter degradation and the TKN content, and decrease the carbon/nitrogen (C/N) ratio and the extractable copper (Cu) and zinc (Zn) contents during the composting of swine manure. Addition of BT can also enhance microbial activity and the temperature increase during the thermophilic phase of composting (Wang et al., 2016). Moreover, BT contains high amounts of N and available phosphorus (P) and potassium (K), which can increase the nutrient content of the compost product (Aranyos et al., 2016). Addition of BT can buffer the increases in pH that typically occur during composting (Fernandez-Calvino et al., 2015). BT can promote the synthesis of urease and alkaline phosphatase during composting (Wyszkowska and Wyszkowski, 2006). Another important property of BT is its hydrophilic surface; when BT is added to composting organic waste, the hydrophilic surface of BT binds to the hydrophobic surface of the organic waste, which accelerates the degradation of lignocellulose and reduces the time required to produce a mature compost (Gedikoglu et al., 2012). Little information is available, however, on the effects of BT on the two-stage composting of GW.

The use of SW and BT as additives in the two-stage composting of GW has not been previously reported. Therefore, the aims of this study were to determine (1) how addition of various quantities and combinations of SW and BT affects the physical and chemical characteristics of GW during composting; (2) how these additives affect the quality of the final compost; and (3) the optimal combination of SW and BT for GW composting.

2. Materials and methods

2.1. Composting feedstock collection and processing

The GW used in this study was collected from urban landscape maintenance in Beijing, China, in the spring of 2016. It was cut into 1-cm-long pieces with a grass-cutting multifunctional shredder (model 9ZF-500B, Shandong, China) to obtain a uniform and appropriate particle size (Zhang and Sun, 2014). The air-dried SW was purchased from the Qingdao Huifulin Marine Biology Technology Co. Ltd., China. The SW was crushed into fine particles and passed through sieves to obtain particles ranging from 1.0 to 1.5 mm (Vendrame and Moore, 2005). BT was purchased from the Guangzhou Danlong Technology Co. Ltd., China. The BT was air dried before it was added to the composting feedstock (Fernandez-Calvino et al., 2015). Urea was obtained from the Beijing Kaiyin Organic Fertilizer Production Co., China, and was used to adjust the C/N ratio of the composting mass (Zhang et al., 2013). Microbial inoculum, which consisted of a mixture of *Trichoderma* spp. (60%, v/v) and *Phanerochaete chrysosporium* Burdsall (40%, v/v), was used to accelerate the initial composting (Wei et al., 2007). Table 1 lists the main physicochemical characteristics of the composting materials.

2.2. Composting procedure

Nine treatments were used in the two-stage composting of GW (Table 2). Two-stage composting includes a primary composting stage (PC) and a secondary composting stage (SC) and results in greater lignocellulose degradation than single-stage composting (Zhang and Sun, 2017).

Before the start of the experiment, SW and/or BT were mixed with GW in nine proportions as indicated in Table 2. The initial moisture and C/N ratio of the nine composting mixtures were then adjusted to 60% and 30%, respectively. The moisture content of the composting mass was determined daily with an SK-100 moisture meter (Tokyo, Japan) and was maintained at about 60% throughout the composting process by addition of water. Finally, after the initial water content and C/N ratio were adjusted, the microbial inoculum (5 ml kg^{-1} dry GW) was added, and the composting mass was well mixed (Zhang and Sun, 2017).

On day 0 (the start of the PC), the composting mixtures were added to digester cells. Each digester cell (6 m long $\times$ 2 m wide $\times$ 1.5 m high) was a non-covered cement container with an automatic compost-turning and -watering system. Three replicate digester cells per treatment were used for the PC. The mixtures were automatically turned over for 40 min every day during the PC to increase aeration. When the composting temperature dropped to 35–45 °C (on day 6 for all cells), the PC was considered complete. On day 6 (the start of the SC), the mixture was removed from each digester cell and formed into windrows (three windrows per digester cell). Each windrow was about 3 m^3 , and was about 2 m long, 1 m high, and 1.5 m wide at the bottom. The windrows were located in a ventilated area and were turned with a mini-excavator (model DLS830-9B, Shandong, China) every 3 days to ensure adequate aeration during the SC. When the temperature of a windrow decreased and remained at the ambient temperature, the composting process was considered complete. During the bio-oxidative phase, the temperatures of treatments T1–T4 and T7 increased to 50–60 °C (the thermophilic temperature range) on day 4 in the PC and on day 18 in the SC. In contrast, the temperatures of treatments T5, T6, T8, and T9 increased to 50–60 °C on day 1 in the PC and on day 10 in the SC. Treatments T1 and treatments T2–T4, and T7 required 30 days and 28 days, respectively, to mature, while treatments T5, T8, and T9 required 24 days to

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