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Disintegration of compostable foodware and packaging and its effect on microbial activity and community composition in municipal composting

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A B S T R A C T

Despite the compostability certification of compostable foodware and packaging (CFP) in lab conditions, composting facilities are reluctant to accept CFP. Certified CFP at 10 and 20% by volume were examined in four types of composting practices in British Columbia, Canada to assess disintegration. Laboratory studies were conducted to determine CFP amended with compost feedstocks at 1 and 2% by weight effects on microbial activity and community structure. Results showed disintegration varied significantly by CFP and facility type. Nearly 90% of poly-lactic acid based CFP completely disintegrated in the in-vessel and static pile, followed by turned windrow (63%) but only 30% of CFP in the anaerobic digestion operation. The disintegration of fibre based CFP was significantly lower than other CFP across composting practices. Increased concentration of CFP enhanced disintegration only in the static pile. Doubling the concentration of CFP (2 vs.1%) in laboratory conditions significantly increased microbial activity (150% of CO_2 respiration) and abundance of microbial community groups, i.e., total phospholipid fatty acids, and those of gram-positive bacteria and fungi by 45, 330 and 28%, respectively. These results indicate that under ideal composting conditions CFP products are likely to disintegrate completely and higher concentrations may enhance their biodegradation.

1. Introduction

Compostable foodware and packaging (CFP) products including poly-lactic acid (PLA), PLA lined paper, sugarcane and tree fibre and cellulose film are increasingly employed for a variety of utensils and packaging materials (Siracusa et al., 2008; Ahmed and Varshney, 2011). The CFP products are designed to be biodegradable as they are produced from materials with decomposable carbon (C) and nitrogen (N) compounds that can be used by microorganisms for their metabolic energy (Yabannavar and Bartha, 1993; Beffa et al., 1996; Amir et al., 2008). Products of CFP are marketed to rapidly disintegrate when composted and therefore has the potential to divert large amounts of waste packaging materials from ending up in landfills and instead provide an effective soil amendment that can be used for agricultural production (Yabannavar and Bartha, 1993; Musioł et al., 2016a).

Despite the promise of alternatives to conventional food packaging and third-party certifications of compostability for these CFP products, there is a reluctance from commercial compost operations to accept biopolymer-based CFP largely because the laboratory testing environment does not necessarily replicate real world operating conditions, and some certified compostable products have been observed to not satisfactorily compost in large scale facilities (Briassoulis et al., 2010). Although there are a number of certification protocols for determining the compostability of CFP, including ASTM and ISO, these protocols are largely based on simulated composting conditions in the laboratory and it is largely unclear how these materials impact composting under in-situ conditions (Kale et al., 2007).

There is some evidence that the chemical composition of biopolymer-based CFP can significantly affect biodegradation, yet

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few studies have assessed the biodegradation of CFP in actual municipal composting facilities (Musioł et al., 2016a). There has been some assessment of the impact of various types of CFP on the composting process that show the introduction of these materials can impact microbial activity (e.g. as measured by carbon dioxide (CO_2) respiration) indicating changes in the biodegradation rate (Steger et al., 2003; Kale et al., 2006). Biopolymer products such as CFP can alter compost C:N ratios, thus also impact the biodegradation of the CFP product itself possibly by altering the community structure of the organism responsible for biodegradation (Sterger et al. 2003; VanderGheynst and Lei. 2003). A few studies using phospholipid fatty acid (PLFA) have documented changes in microbial community composition and structure and subsequently the biodegradation in composting environments when biopolymers have been included in the composting process (Klamer and Bååth. 2004; Kato et al., 2005).

While there is evidence that the introduction of CFP can alter the composting process, how increasing the concentration of CFP impacts the composting process under real conditions is generally unknown (Kale et al., 2006; Musioł et al., 2016a). Furthermore, analysis of CFP biodegradation is often limited to laboratory conditions and/or to only a few CFP products (Sikorska et al., 2012). For composting facility managers to accept CFP, their disintegration needs to be assessed under real conditions which would vary by facility type and are likely to include a variety of CFP types in varying concentrations.

To our knowledge there has been no assessment of how increasing the concentration of a wide range of CFP affects CFP disintegration under real world municipal composting conditions.

The aim of this study was to demonstrate that the certified biodegradable CFP products are degraded in municipal composting operations. Specifically, the objectives were to: (1) evaluate the in-situ disintegration of a wide range of CFP products at various rates mixed with typical compost feedstock of the four composting practices: a turned windrow, an anaerobic digester coupled with static pile and windrow curing, a static pile with windrow curing, and an in-vessel composter coupled with windrow curing; (2) determine how two concentrations (10 and 20% by volume) of CFP changes in-situ disintegration; and (3) assess microbial activity and community composition by measuring CO_2 respiration and PLFA in laboratory compost incubations with two levels of mixed CFP concentrations (1 and 2% by weight).

2. Materials and methods

2.1. Selection of compostable foodware and packaging (CFP)

Seventeen typical CFP products were used in this study to represent an array of materials from unlined natural kraft paper, to natural fibres and cellulose, blended bio-polymers, and pure PLA biopolymer (97% L-lactide and 3% D-lactide). The product dimensions, height and width diameters are detailed in Table 1. Products were supplied by BSIbio (Vancouver, Canada). All products are either certified compostable by the Biodegradable Products Institute (BPI) or ASTM D6868.

2.2. Compost facilities

To study the disintegration of CFP under a variety of in-situ composting practices, three facilities in southern British Columbia (BC), Canada, were selected to represent the variability of inputs, process types, and treatment capacities available to this region. These facilities use four commercial composting practices: turned windrow, anaerobic digestion coupled with static pile and windrow curing, static pile with windrow curing, and in-vessel coupled with covered windrow. The typical operating parameters including feedstock composition and acceptance of CFP for the four facility types varied substantially as described in Table 2.

For the turned windrow operation, yard waste and woody materials were received and mixed with food waste in a proportion of 1:2. The mixture then passed through an auger for blending and a magnet for large contaminant removal, before a commercial bulldozer was used to build windrows approximately 76 m long, 3 m wide, 1.5 m high. During the 15 d pathogen reduction period, windrows were turned via a ride-on compost turner (Vermeer Inc., Stoney Creek, Ontario) every 3 d to promote aeration and ensure temperatures were consistently above 60 °C. After the pathogen reduction period, the windrow was turned approximately every 2 weeks. The duration of active composting with biweekly turning ranged from 8 to 10 months and after which the windrow moved to a final screening to separate contamination from the compost. After screening, the compost was piled for curing for an additional 8–12 months before application. The CFP disintegration testing was conducted over four months at this facility, beginning in a pile which had passed the pathogen reduction phase, and the temperature of windrow was recorded between 50 and 60 °C for the duration of the study.

The in-vessel operation consisted of two enclosed tunnels filled with 72 rotating trays, with each tray able to hold approximately 3600 kg of compostable material with a volume of 6 m^3. The tunnels were each 76 m long, 3 m wide and 3 m high. The compost substrate was prepared by mixing bio-solids, food waste and locally available woody materials in the ratio of 6:1:9 by weight, resulting in a moisture content of 60% by weight. Feedstock was combined in a mixing auger and then carried via conveyor belt to the tray within the tunnel entrance. Each tray took approximately 14 d to move through the tunnel (60 °C) and was well mixed and aerated using internal agitator arms. The mixture was then passed over a 2-cm screen to separate larger items from fine materials. Larger items were remixed with new feedstock and recirculated in the tunnel while fine materials were moved to a covered windrow for 6–8 months curing until mature. The CFP disintegration testing was conducted over five months at this facility, with curing for ~4 months.

The static pile operation mixed yard waste, green waste and agriculture/forestry waste with residential food scraps at ratios adjusted according to daily feedstock to achieve a balanced C:N ratio (25:1). The base of the static pile was a concrete bed with 24 rows of sparger pipes designed for reverse aeration, which were covered by a 0.5–1 m high layer of large woody material to prevent blockage and assist in maintaining aerobic conditions. The mix of organic materials was loaded successively on each pipe to form the static pile. The pile was watered frequently to maintain moisture contents of 40–60% by weight. Piles were approximately 30 m long, 10 m wide, and 5 m high. One fan located at the end of the bed pulled air through the sparger pipes which was then released through a bio-filter to promote aeration and control odour. The pile was kept for 6–10 weeks in a pathogen reduction phase during which the material self-heated with temperatures reaching 60 °C. The mixture was then moved to a curing windrow for one month before final screening. The pile was mixed as needed to maintain an aerobic environment and keep moisture and temperature high and uniform, however the section of the pile used in this study was not turned for the duration of the study so as not to disturb the test. The CFP disintegration testing was conducted over 2 months at this facility.

The anaerobic digestion operation mixed woody materials with food waste in a ratio of 1:2 and loaded the mixture into an anaerobic digestion tunnel kept at 35 °C. The tunnel was flooded with water to establish and maintain anaerobic conditions. The tunnel