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In-vessel composting system for converting food and green wastes into pathogen free soil amendment for sustainable agriculture

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ABSTRACT

To derive new methods for converting food and green wastes into soil amendment, this study researched on a in-vessel composting system. The performance of an in-vessel composting system was evaluated during food and green wastes digestion. A series of experiments was conducted using both pilot-scale and bench-scale in-vessel systems. During the digestion process, external heat and continuous mixing were provided for achieving the typical composting temperature of 60 °C. The feedstock included food waste, horse manure, palm-tree waste, and green waste. The digestate was tested for understanding the inactivation of pathogens (*Escherichia coli* (*E. coli*) and *Salmonella enterica* serovar Typhimurium LT2 (*Salmonella*)). Subsequently, pathogen inactivation models were developed to determine the quantitative time-dependent relationships between digestion time and potential pathogen cells in digestate. The digestate was also analyzed for evaluating the changes in pH, moisture level, variations in carbon content, and carbon to nitrogen ratio during the digestion process. Further, the effects of additives on the digestion process and digestate were evaluated by comparing the digestate quality under additive and without additives conditions. Results showed that the proposed method produced a pathogen-free soil amendment from the food and green wastes. The pH and moisture content of the digestate of pilot-scale experiment varied from 3.8 to 4 and 60.6–67.9%, respectively. The observations showed that *E. coli* survived greater than 10 h, while *Salmonella* counts were not detectable beyond 40 min of digestion. The results of predictive models showed that *Salmonella* could survive till 80 min during in-vessel composting at 60 °C, while the elimination of *E. coli* may take 16–25 h. The authors anticipate that the in-vessel digestion system, which is proposed here, will help in accelerating the conversion of organic waste into pathogen-free soil amendment, thereby, enhancing sustainable agriculture.

1. Introduction

The disposal of excess foodwaste produced in urban environment is a serious issue (Kim et al., 2008; Li et al., 2013; Pandey et al., 2016a). More than 40% of food produced using precious land and water resources goes as a waste (Gustavsson et al., 2011; Gunders, 2012). A major portion of this foodwaste reaches to landfills, and controlling excessive influx of foodwaste into landfills requires improved foodwaste recycling methods. Currently, the two conventional methods for treating food and green wastes are composting and anaerobic digestion (AD) (Parthan et al., 2012; Tsilemou and Panagiotakopoulos, 2006). The major advantage of AD method is that it facilitates production and capture of biomethane, which can be utilized as a renewable energy source (Lins et al., 2014; Pandey et al., 2011; Zhu et al., 2014). Composting is a natural treatment method and requires minimal external energy input to complete the process (Goldstein, 2014; Watteau and Villemin, 2011; Zhou et al., 2014). Both of these methods result in end products which are useful for fertilizing the crops (Razali et al., 2012; Sangamithirai et al., 2015; Zhu et al., 2014). However, currently there is a growing public concern with regards to the risk

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of foodwaste borne pathogens reaching to crop land when digestate (i.e., compost or AD effluent) is used in the form soil amendments (Larney et al., 2003; Pandey et al., 2016a).

The inactivation of pathogens is often uncertain in both the AD (Pandey et al., 2011, 2016b, c) and composting processes (Droffner and Brinton, 1995; Cekmecelioglu et al., 2005; Millner et al., 2014). As an example, previous studies found that the pathogen survival in composting can prolong from 1 to 2 weeks depending on the temperature of compost piles (Vinnerås, 2007; Droffner and Brinton, 1995). In anaerobic digestion, which is mainly run in mesophilic temperature, pathogen survival can extend for several weeks (Pandey et al., 2011). The application of digestate with elevated level of pathogens will likely to increase the influx of pathogens in cropland if the contaminated digestate is applied as a soil amendment (Heringa et al., 2010; Li et al., 2013). In addition to uncertainty in pathogen inactivation, a major drawback of composting and AD processes is that these are slow processes, and often require 30–90 days to complete the process (Iyengar and Bhave, 2006; Kim et al., 2008; Lins et al., 2014). Because these processes are slow, relatively a large space is needed to design AD and composting facilities, which is often cost prohibitive (Parthan et al., 2012; Tsilemou and Panagiotakopoulos, 2006). Therefore, improved treatment methods capable of converting organic wastes including food and green wastes into compost/soil amendments in shorter period and eliminating waste borne pathogens are needed.

Previous studies showed that in-vessel composting can accelerate the composting process (Antizar-Ladislao et al., 2005; Sangamithirai et al., 2015; Walker et al., 2009) and reduce the composting time. Iyengar and Bhave (2006) used a in-vessel (mixed and non-mixed) composting system for converting household wastes into humus for improving the soil nutrients. An et al. (2012) also tested an in-vessel composting system to evaluate the composting of agro-industrial and industrial wastes. In a similar research, Kim et al. (2008) used a pilot-scale in-vessel composting system for reducing the time needed for foodwaste treatment. Although these studies provided important insight in terms of using in-vessel composting system to accelerate the process, understanding of pathogen inactivation during the in-vessel composting process is still weak. The uncertainty in survival of foodborne pathogens during composting is a common concern (Larney et al., 2003; Pandey et al., 2016a, b). The increased emphasis on controlling foodborne pathogens and protecting the public health requires application of soil amendment with minimum pathogen risks to the health of soil and crops, animal, environment, and human (Angulo and Mølbak, 2005; Heringa et al., 2010; Park and Diez-Gonzalez, 2003). Therefore, to better understand the potential benefits of in-vessel composting system, and develop an advanced in-vessel composting system, a series of pilot-scale and lab-scale experiments was executed in this study. The objectives were to: 1) evaluate the performance of in-vessel composting on foodborne pathogen inactivation; 2) assess the quality (pH, carbon, and C: N ratio) of digestate produced during in-vessel composting system; and 3) develop the predictive models for calculating pathogen inactivation in the in-vessel composting system.

2. Materials and methods

2.1. Pilot-scale and bench-scale systems

A pilot-scale study was conducted at Teaching and Research Animal Care Services (TRACS), and a bench-scale study was conducted at Extension Lab of the Department of Population Health and Reproduction, School of Veterinary Medicine, University of California, Davis (UC Davis), California, USA. The schematics of pilot-scale and bench-scale experiments are shown in Fig. 1. The

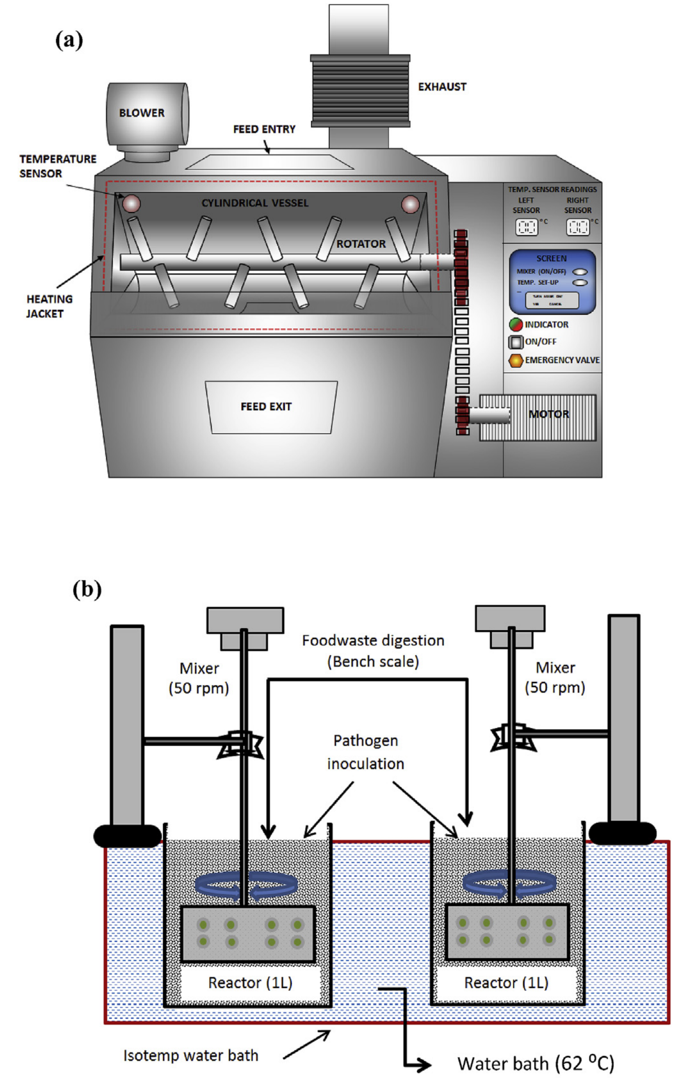

Fig. 1. Schematic of biodigesters used in experiments: a) pilot-scale system; and b) bench-scale system.

bench-scale experiments were carried-out in two reactors (each 1000 mL capacity). The pilot-scale experiments were executed in a bio-digester of 200 L capacity (BioMixer-200L, Daega Powder Systems Co., Ltd). The bench-scale reactors were designed in lab using two sterile glass beakers, a 10 L isotemp water bath (Thermo Fisher Scientific, Waltham, MA, USA), and two overhead mixers. In the bench-scale experiment, mixing was provided using a digital mixer system (Cole-Parmer, Vernon Hills, Illinois, USA), while in the pilot-scale system an in-built 2.2 KW motor (within bio-digester) provided continuous mixing. Given the complexity of scale and size during composting, both bench-scale and pilot-scale experiments were replicated. Each experiment was repeated independently (Run 1 & Run 2) to produce a robust dataset and model and also to understand the variability of the process.

2.2. Feedstock

To prepare feedstock, horse manure was collected from the UC Davis Center for Equine Health, and grass and palm tree wastes were collected from the UC Davis Arboretum. Foodwaste was collected from Yolo County Food Bank, Woodland, California. A total