Bioresource Technology 217 (2016) 50–55

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Solid state anaerobic co-digestion of tomato residues with dairy manure and corn stover for biogas production

Yangyang Li, Yu Li, Difang Zhang, Guoxue Li *, Jiaxin Lu, Shuyan Li

College of Resource and Environmental Science, China Agricultural University, Beijing 100193, China

HIGHLIGHTS

- Co-digestion of tomato residues with dairy manure and corn stover.
- Compared to mono-feedstock, co-digestion leads to increased methane production.
- Maximum methane yield of 415.4 L/kg VS_{feed} was obtained in SS-AD of ternary mixtures.
- More than 40% tomato residues addition caused overproduction of volatile fatty acids.
- Ternary mixtures diluted the inhibitors which caused inhibition in mono-digestion.

ARTICLE INFO

Article history:
Received 16 December 2015
Received in revised form 26 January 2016
Accepted 28 January 2016
Available online 3 February 2016

Keywords:
Solid state anaerobic digestion
Tomato residues
Methane yield
Co-digestion

ABSTRACT

Solid-state anaerobic co-digestion of tomato residues with dairy manure and corn stover was conducted at 20% total solids under 35 °C for 45 days. Results showed digestion of mixed tomato residues with dairy manure and corn stover improved methane yields. The highest VS reduction (46.2%) and methane yield (415.4 L/kg VS_{feed}) were achieved with the ternary mixtures of 33% corn stover, 54% dairy manure, and 13% tomato residues, lead to a 0.5–10.2-fold higher than that of individual feedstocks. Inhibition of volatile fatty acids (VFAs) to biogas production occurred when more than 40% tomato residues were added. The results indicated that ternary mixtures diluted the inhibitors that would otherwise cause inhibition in the digestion of tomato residues as a mono-feedstock.

1. Introduction

Agricultural residues have been successfully converted to methane-rich biogas in anaerobic digestion (AD) (Wang et al., 2012; Khalid et al., 2011; Li et al., 2011). Biogas can be used for co-generation of electricity and heat or be upgraded to transportation fuels, and thus, can lead to reductions in greenhouse gas emissions and reduce our dependence on fossil fuels. Compared to conventional liquid anaerobic digestion (L-AD, <15% TS), SS-AD features high organic loading rate, small digester volume, low energy demand for heating, and high volumetric methane production (Li et al., 2011; Yang and Li, 2014).

In China, with the rapid development of greenhouse vegetable cultivation, vegetables are available year round, and some of them produce abundant residues such as tomato. Tomato residues were a source of nuisance in municipal landfills because of their high biodegrade ability (Viturtia et al., 1989; Misi and Forster, 2002). Owing to the characteristics of 8–18% total solids (TS), with a total volatile solids (VS) content of 86–92%, the organic fraction includes about 75% easy biodegradable matter (sugars and hemicellulose). Tomato residues have great potential as a feedstock for biogas production (Bouallagui et al., 2003, 2005). However, the imbalanced nutrients such as carbon and nitrogen and the low buffering capacity are the limitations for tomato residues used as mono-substrate in AD process.

Analysis in literature indicates that co-digestion of mixed substrates offers many advantages, such as balanced nutrients (C/N ratio and macro- and micronutrients) and reduced inhibitors/toxic compounds accumulation (Himmel et al., 2007; Ye et al., 2013; Li et al., 2013a,b). However, combining two or more different types of substrate requires careful selection of feedstocks and mixing ratios in order to improve the efficiency of AD (Álvarez et al., 2010). Manure is a well-studied co-substrate due to its high buffering capacity and high nitrogen content, and the fact that it is rich in a wide variety of nutrients necessary for optimum bacterial growth (Callaghan et al., 2002). Dairy manure is the largest waste manure stream in China, except for recyclables, accounting for 45.5%

* Corresponding author.
E-mail address: ligx@cau.edu.cn (G. Li).

http://dx.doi.org/10.1016/j.biortech.2016.01.111
0960-8524/

(810 million tons) of the total manure in 2011 in China (Sheng, 2011). The optimum C/N ratio is agreed to be in the range of 20–30 for anaerobic microbial performance in an AD system (Parkin and Owen, 1986; Pang et al., 2008; Li et al., 2011). The C/N ratios of tomato residues and dairy manure were under 20 (Li et al., 2009; Chen et al., 2010; Ahn et al., 2010; Zhang et al., 2013). Corn stover, which was found to have a high C/N ratio, could be added to balance the C/N ratio of dairy manure and tomato residues. In addition, crop residues are widely available and believed to be a promising feedstock for renewable energy production (Wu et al., 2010; Xu and Li, 2012).

During co-digestion, the mixing ratio of substrate is a crucial factor, which will change the nature of the digestion process, and further affect the biogas yield and volumetric biogas yield rate. Li et al. (2013a,b) found that co-digestion of corn stover and chicken manure at a ratio of 1:1 achieved the highest volumetric productivity of 14.2 $L_{methane}/L_{reactor\ volume}$. Co-digestion of kitchen waste, pig manure, and rice straw at an optimal ratio of 0.4:1.6:1 obtained the highest biogas yield of 674.4 L/kg VS which was 71.67% and 10.41% higher than that of the solo-digestion of rice straw and pig manure, respectively (Ye et al., 2013). Brown and Li (2013) reported that higher methane yields and volumetric productivities were observed with the increase of food waste to 10% and 20% of the substrate at substrate/effluent (F/E) ratios of 2 and 1, respectively.

There have been many studies on the co-digestion of manure and crop residues (Wu et al., 2010; Panichnumsin et al., 2010; Ye et al., 2013; Li et al., 2013a,b). However, there is limited information available on the co-digestion of tomato residues with dairy manure and corn stover in SS-AD. The objectives of this study were to (1) evaluate the performance of co-digestion tomato residues with dairy manure and corn stover in terms of methane yield and system stability, and (2) study the effect of feedstock mixing ratio on methane yields and system stability for solid state co-digestion of tomato residues with dairy manure and corn stover.

2. Methods

2.1. Feedstock and inoculum

Tomato residues were obtained from a farm located in Fangshan district of Beijing, China, including all the above-ground parts of the tomato plant (stalks, leaves, and residual tomatoes). Once collected, the tomato residues were shredded to particle size less than 5.0 mm by a food waste disposer (Daogrs MCD-56, Daogrs Inc., China). Dairy manure was collected from a dairy farm located in Beijing, China. The dairy manure was homogenized using a kitchen blender (Braun-MQ705, Braun Inc., Poland). Both the homogenized dairy manure and shredded tomato residues were stored in a refrigerator at 4 °C. Corn stover collected from a farm operated by China Agricultural University in Beijing, China was air dried to a moisture content of less than 15% and then ground to pass 40 mm sieves (Huafeng Inc., Zhejiang, China).

Inoculum from a mesophilic liquid AD system (operated by Beilangzhong pig farm, Beijing, China) fed with pig manure. The inoculum was kept in air-tight buckets at 4 °C in a walk-in cooler. Prior to use, the inoculum was acclimated and degassed at 35 °C for 3 weeks to minimize the effect of methane production from inoculum on the methane yield of SS-AD reactors (Li et al., 2013a,b). The average values of three measurements are presented in Table 1.

2.2. Liquid anaerobic digestion

L-AD experiments were conducted to evaluate the methane potential of the three individual feedstocks, i.e., tomato residues, dairy manure, and corn stover. Each feedstock was mixed with deionized (DI) water and inoculum to obtain a mixture of 12% TS and a feedstock to effluent (F/E) ratio of 6 (VS based). The mixture was loaded into 1 L glass reactors and incubated in a walk-in incubation room for up to 45 days at 35 ± 1 °C (Boxun Inc., Shanghai, China). Triplicate reactors were run for each condition. Each reactor was manually mixed twice a day. Biogas produced was collected in a 1-L Tedlar gas bag (Safe-laboratory Inc., Beijing, China). Biogas composition and volume were measured every day. Inoculum without any feedstock addition was used as a control.

Table 1
Characteristics of feedstocks and inoculum for SS-AD.

Parameter	Dairy manure	Corn stover	Tomato residues	Inoculum
Moisture content (%)	84.9 ± 0.3	12.9 ± 0.5	87.5 ± 0.4	88.7 ± 0.3
Total solids (TS) (%)	15.1 ± 0.3	87.1 ± 0.5	12.5 ± 0.4	11.3 ± 0.3
Volatile solids (VS) (%)	12.2 ± 0.2	76.3 ± 0.3	10.2 ± 0.1	3.8 ± 0.1
VS/TS (%)	80.5 ± 0.0	87.5 ± 0.0	81.8 ± 0.0	33.4 ± 0.0
pH	7.5 ± 0.5	NA	4.6 ± 0.4	8.3 ± 0.2
VFAs (g/kg)	ND[a]	ND	ND	2.8 ± 0.1
TAN (g/kg)	3.3 ± 0.2	ND	1.2 ± 0.1	3.0 ± 0.0
TC (%)[b]	38.4 ± 0.3	38.9 ± 0.6	38.0 ± 0.4	17.7 ± 0.0
TN (%)[b]	1.9 ± 0.1	1.0 ± 0.0	2.4 ± 0.1	1.9 ± 0.0
C/N	19.8 ± 1.2	37.5 ± 0.6	15.8 ± 0.8	9.5 ± 0.0
Cellulose (%)[b]	14.0 ± 0.1	20.4 ± 0.3	5.1 ± 0.0	3.1 ± 0.1
Hemicellulose (%)[b]	17.3 ± 0.3	31.8 ± 0.6	12.2 ± 0.2	4.2 ± 0.2
Lignin (%)[b]	20.2 ± 0.4	20.0 ± 0.2	9.7 ± 0.0	19.5 ± 0.4

[a] ND = not determined.
[b] TS based, the others are wet weight based.

2.3. Solid-state anaerobic digestion

The effect of percentage of tomato residues (13%, 27%, 40%, 54%, based on wet weight) in the mixed feedstocks (dairy manure, tomato residues and corn stover) on the performance of SS-AD was studied. Dairy manure, tomato resides, and corn stover were weighted and mixed to obtain the designed mixing ratio of feedstocks as shown in Table 2. For each treatment, DI water and inoculum were mixed with the mixed feedstock using a hand-mixer (Braun-MQ705, Braun Inc., Poland) to achieve a mixture with 20% TS and a F/E ratio of 6 (VS based). The mixture was loaded into 1 L glass reactors and incubated for up to 45 days in a 35 ± 1 °C incubator. Duplicate reactors were run for each condition. Each reactor was manually mixed twice a day. Inoculum without any feedstock addition was used as a control. Biogas was collected in 1-L Tedlar gas bags (Safe-laboratory Inc., Beijing, China), and the biogas composition and volume were measured every day.

2.4. Analytical methods

The volume of biogas was measured with a drum-type gas meter (Ritter, Bochum, Germany) and the composition of biogas

Table 2
Experimental design.

Treatments	Dairy manure: corn stover: tomato residues (wet base)	C/N of co-substrate
1	100:0:0	17.1 ± 0.2
2	0:100:0	28.7 ± 3.2
3	0:0:100	11.7 ± 1.2
4	33:13:54	19.1 ± 0.6
5	33:27:40	21.0 ± 0.4
6	33:40:27	23.9 ± 0.3
7	33:54:13	22.5 ± 1.2
8	13:33:54	21.5 ± 0.5
9	27:33:40	27.8 ± 0.3
10	40:33:27	28.2 ± 0.2
11	54:33:13	22.4 ± 1.0