Waste Management 46 (2015) 133–139

Contents lists available at ScienceDirect

Waste Management

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

Enhanced production of short-chain fatty acid from food waste stimulated by alkyl polyglycosides and its mechanism

Jianwei Zhao [a,b], Qi Yang [a,b,*], Xiaoming Li [a,b,*], Dongbo Wang [a,b], Kun Luo [a,c], Yu Zhong [a,b], Qiuxiang Xu [a,b], Guangming Zeng [a,b]

[a] College of Environmental Science and Engineering, Hunan University, Changsha 410082, PR China
[b] Key Laboratory of Environmental Biology and Pollution Control, Hunan University, Ministry of Education, Changsha 410082, PR China
[c] Department of Bioengineering and Environmental Science, Changsha University, Changsha 410003, PR China

ARTICLE INFO

Article history:
Received 30 March 2015
Revised 25 July 2015
Accepted 1 September 2015
Available online 3 September 2015

Keywords:
Anaerobic fermentation
Food waste
Biosurfactant
Short-chain fatty acids
Alkyl polyglycosides

ABSTRACT

Short-chain fatty acids (SCFAs) are the valuable products derived from the anaerobic fermentation of organic solid waste. However, SCFAs yield was limited by the worse solubilization and hydrolysis of particulate organic matter, and rapid consumption of organic acid by methanogens. In this study, an efficient and green strategy, i.e. adding biosurfactant alkyl polyglycosides (APG) into anaerobic fermentation system, was applied to enhance SCFAs production from food waste. Experimental results showed that APG not only greatly improved SCFAs production but also shortened the fermentation time for the maximum SCFAs accumulation. The SCFAs yield at optimal APG dosage 0.2 g/g TS (total solid) reached 37.2 g/L, which was 3.1-fold of that in blank. Meanwhile, the time to accumulate the maximum SCFAs in the presence of APG was shortened from day 14 to day 6. The activities of key enzymes such as hydrolytic and acid-forming enzymes were greatly promoted due to the presence of APG. These results demonstrated that the enhanced mechanism of SCFAs production should be attributed to the acceleration of solubilization and hydrolysis, enhancement of acidification and inhibition of methanogenesis by APG.

1. Introduction

The eutrophication led by the excessive discharge of phosphorus and nitrogen into water body has become a severe pollution problem all around the world. Under most circumstances, available biodegradable carbon, such as short-chain fatty acids (SCFAs) is a critical substrate for higher performance of biological nutrient removal (BNR). Usually, 1.07–1.82 and 1.87–3.00 mg SCFAs is required to remove 1 mg N and 1 mg P, respectively (Elefsiniotis and Li, 2006; Luo et al., 2015). However, available carbon source in wastewater is always insufficient (Tan et al., 2012; Zhao et al., 2015a). Several studies have demonstrated that fermentative SCFAs as the additional carbon source could result in superior BNR performance (Tong and Chen, 2007; Moser-Engeler et al., 1998).

Compared with the expensive synthetic volatile fatty acids (VFAs), SCFAs derived from anaerobic fermentation of organic solid wastes are more cost-effective and environmentally friendly. In general, anaerobic digestion includes three steps, namely solubilization and hydrolysis, acidification and methanogenesis (Chen et al., 2013a; Luo et al., 2015; Zhao et al., 2015b). Among them, solubilization and hydrolysis are considered as the rate-limiting steps (Chen et al., 2013a), and thermal, chemical, enzymatic and mechanical pretreatments have been applied to accelerate the solubilization and hydrolysis of organic solid wastes (Lee et al., 2014; Zhao et al., 2010, 2015b). Recently, it was reported that surfactant could cause positive effects on waste activated sludge (WAS) solubilization and hydrolysis, thereby improving the production of SCFAs (Jiang et al., 2007a; Chen et al., 2013a). Surfactants possess good solubilization ability, so the additional surfactants can enhance the solubilization of extracellular polymeric substances and break the sludge matrix (Jiang et al., 2007a), resulting in more inner carbohydrate and protein release. These, in turn, provide more substrates for hydrolytic bacteria and acid-producing bacteria (Jiang et al., 2007b). However, these investigated surfactants, such as Tween 20, Tween 80, Triton X-100, sodium dodecyl sulfate (SDS) and sodium dodecyl benzene sulfonate (SDBS) are chemosynthetic, which present a potential risk for environment and human health (Kanga et al., 1997). Biosurfactants, with the characteristics of biodegradation and low toxicity, are more desirable in environmental application (Zhang et al., 2009). In our pre-

* Corresponding authors at: College of Environmental Science and Engineering, Hunan University, Changsha 410082, PR China.
E-mail addresses: yangqi@hnu.edu.cn (Q. Yang), xmli@hnu.edu.cn (X. Li).

http://dx.doi.org/10.1016/j.wasman.2015.09.001
0956-053X/

vious research, rhamnolipid (RL), a common biosurfactant, enhanced VFAs production from WAS fermentation and the maximum yields of VFAs reached 1829.9 mg COD/L at 0.3 g RL/g dry sludge (DS), which almost tripled versus the blank test (Yi et al., 2013).

Because WAS contains large amount of organic matters such as protein and carbohydrate, they are considered as the favourite substrates to produce the SCFAs (Yuan et al., 2006; Jiang et al., 2007a; Wang et al., 2013; Lee et al., 2014). It is well known that food waste is also the main biodegradable solid waste containing higher levels of organic materials such as carbohydrate and protein than WAS (Chen et al., 2013b). Hence, food waste may be another valuable biomass resource for SCFAs production. In China, the total amount of food waste was 88.8 million tons in 2006 (Zhang et al., 2010), and this value kept on increasing. Anaerobic digestion is preferred as an efficient pathway for the recycling and reduction of food waste. However, food waste was only used as carbohydrate substrate to adjust the C/N ratio during the co-fermentation with WAS (Chen et al., 2013b; Feng et al., 2009). Few studies focus on SCFAs production using food waste as the sole substrate (Feng et al., 2009; Chen et al., 2013b; Wang et al., 2014).

Alkyl polyglycoside (APG) is a mild non-ionic surfactant but it has the properties of both non-ionic and anionic surfactants. Recently, it was successfully applied to improve the degradation of agricultural wastes (Zhang et al., 2011) and WAS (Luo et al., 2015). In this study, an efficient and green strategy, i.e. adding APG into anaerobic fermentation systems, was explored to enhance SCFAs generation from food waste. Firstly, the effect of APG dosage on the SCFAs production was comprehensively evaluated, the composition of SCFAs was also examined. Then the mechanism of enhanced SCFAs production was discussed from the views of APG impact on the different phases of anaerobic digestion.

2. Materials and methods

2.1. Food waste, APG and inocula

Food waste, collected from the canteen in the campus of Hunan University (Changsha, China), mainly consisted of rice, vegetables, meat and bean curd. After removing the animal bones, clamshells and the superficial oil, food waste was smashed into small particles (1–3 mm) by an electrical blender. Then, a certain volume of tap water (food waste: tap water = 10/1, V/V) was supplied into the food waste and fully mixed until the mixture presented fluid state. The food waste had 24.9 ± 0.8% total solid (TS), 19.4 ± 0.4% volatile suspended solid (VSS) and 134.5 ± 6.5 g chemical oxygen demand (COD)/L total carbohydrate, 46.8 ± 2.4 g COD/L total protein.

The biosurfactant APG used in this study was obtained from Nanjing Duly Biotech Co. Ltd. (Jiangsu Province, China). The main characteristics of APG were as follows: solid content 50%, density 1.10 g/cm^3.

WAS, the inoculum of anaerobic fermentation, was obtained from the secondary sedimentation tank of a wastewater treatment plant in Changsha, China. The main characteristics of sludge after settling at 4 °C for 24 h are as follows: total chemical oxygen demand (TCOD) 15.2 ± 0.5 g/L, TS 12.6 ± 0.4 g/L, VSS 9.8 ± 0.4 g/L.

2.2. SCFAs production in the presence of APG

Batch experiments of SCFAs production from food waste in presence of APG were conducted in a series of identical anaerobic reactors, which were made of plexiglass and each had a working volume of 1.0 L. C/N ratio is an important factor affecting the anaerobic fermentation of organic substrates, whose suitable value is 20/1–30/1 (Parkin and Owen, 1986). In this study, WAS served as the inoculum as well as balanced the C/N ratio of the fermentation substrate. Thus, the ratio of food waste and inoculated sludge was kept 9:1 (V/V) to ensure that the C/N ratio was in the range of 20–30/1. APG was added with its dosage to total food waste solid ratio of 0.05, 0.1, 0.2, 0.3 and 0.4 g/g TS, respectively. Another two reactors were set as the blank test and comparison test respectively: blank test was without APG addition and comparison test was filled only WAS. After feeding, all reactors were flushed with nitrogen gas to eliminate oxygen, sealed with rubber stoppers and fermented for 15 days. During experiments, all the reactors were mechanically stirred at 120 rpm (rotations per minute) and operated at 37 ± 0.5 °C without pH control. The samples withdrawn from reactors were used to analyze the concentration of SCFAs and their compositions to explore the effect of APG on the production of SCFAs.

2.3. Mechanisms for improved SCFAs production by APG

2.3.1. Effect of APG on solubilization of food waste

As food waste is rich in polysaccharide and protein, thus the effect of APG on solubilization of food waste could be evaluated by assaying the soluble protein and polysaccharide contents in fermentation liquor from above batch fermentation experiments.

2.3.2. Effect of APG on the hydrolysis of solubilized organic matter

In order to investigate the effect of APG on the hydrolysis of solubilized organic matter, bovine serum albumin (BSA, average molecular weight (Mw) 67,000) and dextran (Mw 23,800) were chosen as the model protein compound and polysaccharide compound to stimulate the solubilized food waste, respectively. According to the mass ratio of protein to carbohydrate in raw food waste, 0.5 g BSA and 1.15 g dextran were dissolved into 900 mL tap water, and 100 mL WAS fed as the inocula. Then APG was added with the concentration of 0.2, 0.4, 0.8, 1.2 and 1.6 g/L, which were the same as those applied in parent reactors. 40 mM of 2-bromoethanesulfonate was also added to inhibit the activities of methanogens (Xu et al., 2010). The anaerobic fermentation conditions maintained the same as mentioned above. Then, the hydrolysis efficiencies of BSA and dextran during fermentation process were determined by measuring the degradation rate. The identical simulation method was also conducted in the literatures (Zhao et al., 2010; Chen et al., 2013b; Yuan et al., 2006; Luo et al., 2015).

2.3.3. Effect of APG on acidification of hydrolyzed products

The experiments of the influence of APG on the acidification of hydrolyzed products were similar to the hydrolysis process except that 0.4 g L-alanine (model amino acid compound) and 1.6 g glucose (model monosaccharide compound) were used to stimulate the hydrolyzed products. The effect of APG on the acidification of hydrolyzed products was determined by detecting model compounds degradation.

2.3.4. Effect of APG on the methanogenesis

The impact of APG on the methanogenesis was investigated in serum bottles as batch model with synthetic wastewater containing sodium acetate (NaAc). The chemical composition of synthetic wastewater is: NaAc (0.5 g/L), potassium phosphate (50 mM, pH 7.0), KCl (0.13 g/L), NH_4Cl (0.31 g/L), trace element solution (0.5 mL/L) and vitamin solution (0.5 mL/L). The detail information of trace element solution and vitamin solution are described in the literatures (Atlas, 1993; Zhou et al., 2013). All other operations were the same as the fermentation experiments described above.