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Alkaline pretreatment for enhancement of biogas production from banana stem and swine manure by anaerobic codigestion

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HIGHLIGHTS

- A process was proposed to use banana stem for biogas production on industrial scale.
- 6% NaOH (w/w) pretreatment increased biogas and methane yields by 12.1% and 21.4%.
- A combination of NaOH pretreatment, codigestion, and solid-state biogas fermentation.
- Anaerobic codigesiton of banana stem and swine manure for biogas production.

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ABSTRACT

The objective of this research was to propose and investigate the availability of digested banana stem (BS) to produce biogas. Squeezed BS with less moisture content was used for biogas production through a combination of NaOH pretreatment, solid-state fermentation, and codigestion technologies. NaOH doses were optimized according to biogas fermentation performance, and the best dose was 6% (by weight) based on the total solid (TS) of BS. Under this condition, the lignin, cellulose, and hemicellulose contents decreased from 18.36%, 32.36% and 14.6% to 17.10%, 30.07%, and 10.65%, respectively, after pretreatment. After biogas digestion, TS and volatile solid (VS) reductions of the codigestion were 48.5% and 70.4%, respectively, and the biogas and methane yields based on VS loading were 357.9 and 232.4 mL/g, which were 12.1% and 21.4%, respectively, higher than the control. Results indicated that the proposed process could be an effective method for using BS to produce biogas.

1. Introduction

Bananas are one of the world's most important fruit crops and widely cultivated in tropical and subtropical countries (Padam et al., 2012). It is a unique, perennial, single-harvest plant and, after the fruit harvest, the whole plant should be decapitated, allowing young suckers to replace the mother plant (Padam et al., 2012). Such cycles can continue for several generations before banana production significantly declines. Generally, banana by-products include the stem (pseudostem), leaves, inflorescence, fruit stalk (floral stalk/rachis), rhizome, and peels (Clarke et al., 2008; Mohapatra et al., 2010; Padam et al., 2012). The stem is the main by-product, producing about 100 metric tons per hectare annually. Usually, the banana stem (BS) is left to rot in the soil to replenish the nutrients for growth of the next banana generation (Padam et al., 2012). However, this treatment represents a huge loss of biomass and generates a large amount of carbon dioxide as well as an unpleasant odor that present a serious environmental issue (Mohapatra et al., 2010; Padam et al., 2012). Furthermore, this treatment can induce an outbreak of banana *fusarium wilt*, commonly known as Panama disease caused by *Fusarium oxysporum* f. sp. *cubense* (FOC), which is one of the most serious fungal diseases in bananas and a major limiting factor in worldwide banana production (Getha and Vikineswary, 2002; Xiao et al., 2013). Determining strategies to use this valuable biomass and to prevent related environmental and ecological issues is very important.

BS can be used in several processes, such as pulping in the paper industry and for making natural fibers, animal feeds, and biofuels

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(Deivanai, 1995; Kalia et al., 2000; Mohapatra et al., 2010; Padam et al., 2012). Among these options, producing biogas through anaerobic digestion is the choice with the most potential (Padam et al., 2012). Preparation of biogas from agricultural waste to partly replace fossil resources, which can reduce environmental pollution caused by such waste as well as reduce greenhouse gas emissions caused by the use of fossil resources, is a two-way cleaner production method and arousing worldwide attention (Tian et al., 2013). Currently, the Chinese government is actively promoting the construction of large-scale biogas plants. According to medium- and long-term development plans for renewable energy in China, 10,000 large-scale biogas factories using industry and agricultural wastes as raw materials will be built by 2020, and biogas production is projected to reach 14 billion m^3 annually. For a large-scale biogas plant, the raw material supply is one of the most important issues. In Southern Chinese provinces, BS is a potential raw material because of its high biomass production. For example, in Hainan province, the banana plantation area is 40–50,000 ha and stem production at about 4–5 million tonnes annually. Based on reported data, BS, with 90% moisture content, can be converted to 108–136 million m^3 biogas through anaerobic digestion technology (Kalia et al., 2000). However, several issues should be considered before implementing industrial scale biogas production from BS. First, the BS moisture content is usually greater than 90% (Mohapatra et al., 2010; Padam et al., 2012), which significantly increases transportation costs and decreases the useful transportation radius. Second, BS would have a low digestion rate and biogas yield, as its complex structure prevents efficient cell destruction by anaerobic organisms (Maroušek, 2013; Pang et al., 2008; Ye et al., 2013). Moreover, the C/N ratio of BS is too high for established biogas fermentation methods (Borowski and Weatherley, 2013; Li et al., 2009; Shen et al., 2013). Lastly, for a large-scale plant, BS cannot be used as the sole raw material due to its seasonality and, thus, for these reasons, codigestion of raw materials is a practical option. A process is proposed here to resolve the problems mentioned above (Fig. 1). Before transportation, BS should be squeezed to remove excess water and thus reduce transportation costs as well as improve the raw material's processing availability. As an effective and low-cost pretreatment for improving the biogas fermentation performance from lignocellulosic biomass (Krishania et al., 2013; Salehian et al., 2013; Sambusiti et al., 2013; Yao et al., 2013), NaOH-treatment was included applied in this process. After NaOH pretreatment, codigestion with swine manure (SM) can produce a proper C/N ratio for biogas fermentation, concurrently augmenting the supply of raw materials. Solid-state anaerobic fermentation technology was also applied in this process, as the BS moisture after the squeezing process was much lower than that of fresh BS.

In a previous study, it was found that codigestion of BS and SM by solid-state anaerobic digestion exhibited a better fermentation performance than codigestion of BS and cow manure and that the best BS/SM ratio was 1/1 by mass. Based on the results, the effect of NaOH pretreatment on biogas fermentation performance of codigested BS and SM was examined in this study.

2. Methods

2.1. Materials

BS and SM used in this study were, respectively collected from Hainan province and Changping County of Beijing City, China. BS was cut into 1 cm sections, air dried, and stored at −20 °C. SM was crushed after air-drying and also stored at −20 °C. Anaerobic sludge was obtained from an upflow anaerobic sludge blanket reactor of a beer plant from Wuxi City, Jiangsu province, China and used as inoculum for this study. The basic characteristics of the materials used in this paper are shown in Table 1. BS was pretreated by the addition of NaOH with 2%, 6%, and 10% (by weight) at 55 °C for 54 h using a wet-state NaOH pretreatment (Zheng et al., 2009).

2.2. Biogas fermentation conditions

Codigestion of BS and SM was operated in the laboratory in batch tests. The total digester volume was 1000 mL, with an effective volume of 500 mL. Distilled water was added to adjust the total solids (TS) concentration of the fermentation system to 20% (w/v), and the inoculum/feed ratio was 1/4 (based on TS). For the combined feedstock, the BS/SM ratio was 1/1 (based on TS). All experimental codigestion tests were purged with N_2 for 5 min to remove oxygen and sealed with butyl rubber stoppers. Experiments were operated at 35 ± 1 °C and shaken by hand four times daily to assure sufficient mixing. Biogas produced by codigestion of untreated BS and SM was taken as the control.

TS and volatile solids (VS) were measured according to Standard Methods (Association, 1995) and the contents of lignin, hemicellulose, and cellulose determined according to procedures proposed by Van Soest et al. (1991). Methods for water displacement and gas chromatography were employed to collect and analyze the biogas production and methane content, respectively (Tian et al., 2013).

3. Results and discussion

3.1. Feedstock characteristics

Alkali pretreatment can improve the biodegradability of lignocellulosic biomass in anaerobic fermentation by changing the chemical compositions, chemical structures, and physical characteristics of the materials during the pretreatment (Tian et al., 2013). The compositions of BS before and after NaOH pretreatment were investigated and are shown in Table 2. Lignin, cellulose, and hemicellulose (LCH) are the main BS components that comprise the main carbon source for anaerobic microorganisms (Zheng et al., 2009). The BS lignin content before NaOH-treatment was 18.36%, which was similar to reported results (15%, Kalia et al., 2000). The relatively lower lignin content makes BS suitable for biogas fermentation because lignin is hard for anaerobic

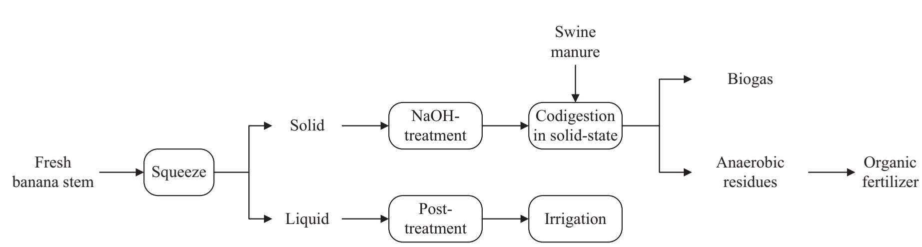

Fig. 1. Flowchart of biogas production from BS.