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Research article

Efficient bioconversion of organic wastes to value-added chemicals by soaking, black soldier fly (*Hermetia illucens* L.) and anaerobic fermentation

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ABSTRACT

Corncob degradation is an issue that needs to be address for it to be further utilized as bioenergy. We explored a new comprehensive degradation strategy for corncob. First, restaurant wastewater was used to improve the corncob biochemical characteristics and partly degrade the lignocelluloses. After the restaurant wastewater treatment, the residue was converted using black soldier fly larvae (BSFL), and the supernatant was utilized for biogas production by anaerobic fermentation. The highest product rates of glucose, xylose, and arabinose were obtained at the optimal corncob soaking condition at 75 °C, 5 h, and 60 g/L from lignocellulose. The soaking residue was converted using BSFL for 10 days, and 24.34% grease yield was extracted. The soaking residue can be utilized by BSFL and produce grease, which is similar to other wastes such as rice straw and pig manure. The corncob soaking supernatant was utilized for biogas production by anaerobic fermentation. The degradation of cellulose, hemicellulose, and lignin reached about 27.34%, 45.14%, and 29.33%, respectively. A total of 500 mL supernatant mixed with 30% anaerobic sludge under 35 ± 2 °C produced about 7.52 L of biogas with about 3.22 L methane. In conclusion, the above comprehensive process can effectively degrade lignocellulose in corncob and obtain two bioenergy products, namely insect grease and biogas.

1. Introduction

Waste biomass is one of the resources that originate from the nature and human life. It can be utilized for renewable energy production, and can be obtained in different forms, such as tar (Machin et al., 2015), ethanol (Gupta and Verma, 2015), methane (Bohutskyi et al., 2015), biodiesel (Wan et al., 2015), electricity (Hanifzadeh et al., 2017), and other high-grade energy by using different physical, chemical and biological methods. However, the challenge of the production of high quality energy carrier is enormous, especially the feedstock for biodiesel production has changed over time and it varies depending on regions, which cause the difference of the compatibility with combustion engine and the characteristics of the emission after combustion process (Kim et al., 2017). Researchers focus on solving this problem to find a comprehensive method of obtaining more high-quality energy to address the shortage of fossil fuels (Gonçalves and Simões, 2017).

Corncob has the highest hemicellulose content among all agricultural by-products and is a potential raw material for energy recycling (Li et al., 2015a; Trninić et al., 2014). Presently, the production of xylitol, furfural, methane, hydrogen, ethanol, and other value-added products from corncob is explored (Cheng et al., 2014; Ken-Ichi et al., 2013; Branca et al., 2012), and the pretreatment of corncob for the degradation of lignocelluloses is an indispensable process in well-known studies (Chen et al., 2016; Cheng et al., 2014). However, cellulose (Li et al., 2015a), physical explosion (Fan et al., 2014), acid and alkali (Baadhe et al., 2014) have been utilized as pretreatment for corncob in recent researches.

Restaurant wastewater is a kind of organic waste and it is different from municipal wastewater which contains organic and inorganic composition. It is an important leftover resource that is obtained after restaurant waste is treated and utilized for resource recycling. Organic matter is also abundant in restaurant wastewater. The demand for water resources may be alleviated if the organic load of restaurant wastewater is converted into clean energy. The biological treatment of anaerobic digestion for restaurant waste has not been easy but is by far one of the most popular treatment methods (Ariunbaatar et al., 2014; Wu et al., 2016). Few reports are available about the biological treatment of restaurant wastewater for energy recycling, especially the

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production of biogas, possibly because of the limitation that the normally low pH value of restaurant wastewater inhibits anaerobic digestion. Considerable research has been conducted on the anaerobic digestion of restaurant waste for biogas production (Brown and Li, 2013; Zhang et al., 2014). These researches were used as references for the utilization of restaurant wastewater in this study.

Nowadays, more and more attention has been focused on the conversion of waste into insect biomass, which will be a new industry with characteristics of sustainably and environmentally friendly in the future. Black soldier fly (Hermetia illucens L.) can convert organic wastes (e.g., animal manure, restaurant waste, and plant material) into insect biomass with high levels of protein and grease (Li et al., 2011; Rehman et al., 2017b). It also helps convert the extra energy from organic residues, such as biogas residue, from biological treatments and restart-biomass recycling (Li et al., 2015c). Moreover, black soldier fly larvae (BSFL) is used as a protein feed, and grease extracted from the larvae is used as a low-cost biodiesel feedstock (Zheng et al., 2012a), which alleviates the energy and environmental problems. In this study, BSFL played a main role in the simultaneous utilization of corncob and restaurant wastewater for biomass accumulation.

The use of acidic wastewater as pretreatment for lignocellulose materials has not been reported. Restaurant wastewater was used for soaking corncob in this study because of its acidification characteristics. Orthogonal soaking experiments between corncob and restaurant wastewater were conducted to determine the optimal soaking condition. Then, corncob was soaked by restaurant wastewater at optimal condition and cellulase hydrolysis was conducted for further degradation of lignocellulose. To achieve the recycling utilization of corncob and restaurant wastewater, BSFL was inoculated into the soaking residue to obtain grease, and the soaking liquid was collected for anaerobic fermentation to produce biogas. All the methods aimed to evaluate the bioconversion capability of BSFL and anaerobic fermentation in the biomass utilization of restaurant wastewater and corncob. The results of this study can serve as reference in choosing wastes with similar characteristics as acid or alkali that can be utilized as the pretreatment for lignocellulose materials.

However, in order to demonstrate the efficient bioconversion of corncob to value-added chemicals, the treatments of restaurant wastewater soaking, black soldier fly larvae conversion and anaerobic fermentation were performed in this study. The details of the experiments are described as follows.

2. Materials and methods

2.1. Raw materials

Corncob was collected from the experimental fields at Huazhong Agricultural University. Corncob was chopped and ground into small particles less than 2 mm in size. The main characteristics of corncob were determined before the experiment and are showed in Table 1. Restaurant wastewater was collected from Taoyuan Restaurant at Huazhong Agricultural University and filtered using 1 mm × 1 mm mesh to remove large particle residues. The main characteristics of the restaurant wastewater were determined and are showed in Table 2. The anaerobic sludge was taken from the bottom of the anaerobic digester, which continued producing methane for more the 7 years at the College of Engineering, Huazhong Agricultural University, Wuhan, China. The main characteristics of the anaerobic sludge are shown in Table 1.

Table 1
Characteristics of corncob and anaerobic sludge.

Characteristics	Corncob	Anaerobic sludge
pH	NA	7.48
Total solids (%w)	88.89 ± 0.79	8.55 ± 0.11
Volatile solids (%w)	86.41 ± 0.78	5.75 ± 0.12
Cellulose (%)	31.31 ± 1.61	NA
Hemicellulose (%)	42.51 ± 1.48	NA
Lignin (%)	23.62 ± 1.60	NA

Note: NA (no analysis), w (wet base).

Table 2
Characteristics of restaurant wastewater.

Characteristics	Restaurant wastewater
pH	3.35
Total nitrogen (mg/L)	321.76 ± 12.33
Total phosphorus (mg/L)	68.16 ± 6.83
Glucose (mg/dL)	12 ± 1
L-lactic acid (mg/dL)	121 ± 4
Ethanol (g/L)	6.56 ± 0.21
Acetic acid (g/L)	3.29 ± 0.33
Propionic acid (g/L)	0.88 ± 0.17
Butyric acid (g/L)	0.76 ± 0.12
Crude oil (g/L)	6.76 ± 0.32

BSFL were obtained from a colony in Huazhong Agricultural University. This colony was a local Wuhan strain (Zhou et al., 2013) and established with the help of the Texas Agricultural Experiment Station (Texas A&M University, USA, which has been operating for approximately 8 years now. BSFL were fed with standard colony diet for 6 days before use.

2.2. Experimental design

Fig. 1 describes the process of the high-grade bioenergy production by converting corncob to larval grease and biogas. Orthogonal experiments of corncob soaking using restaurant wastewater were performed to determine the optimal soaking condition for the succeeding experiments. After the restaurant wastewater soaking and cellulase hydrolysis, the corncob residue was converted using BSFL for larval grease production, and the supernatant was utilized for biogas production by anaerobic fermentation. The details of the experimental design are as follows.

2.2.1. Orthogonal experiments of corncob soaking using restaurant wastewater

To determine the optimal restaurant wastewater soaking condition for the further utilization of corncob, orthogonal experiments were performed. The experiments involved three factors and four levels are described in Table 3. The soaking factors included temperature, time, and mixture concentration between corncob and restaurant wastewater (g corncob/L restaurant wastewater). The four soaking temperatures contained 15 °C, 35 °C, 55 °C, and 75 °C. The soaking times were 5, 15, 25 and 35 h. The mixture concentrations between corncob and restaurant wastewater were 10, 20, 40, and 60 g/L. A total of 16 soaking condition groups (A1B1C1, A1B2C2, A1B3C3, A1B4C4, A2B1C2, A2B2C1, A2B3C4, A2B4C3, A3B1C3, A3B2C4, A3B3C1, A3B4C2, A4B1C4, A4B2C3, A4B3C2, and A4B4C1) were created in 1 L bottles. The bottles were covered with bottle stoppers and placed in a water bath at controlled orthogonal conditions. All the experiments were conducted in triplicate.

2.2.2. Restaurant wastewater soaking and cellulose hydrolysis for the degradation of corncob

After the orthogonal soaking experiments described in 2.2.1, three of the 5 L glass bottles with a working volume of 4 L under the optimal soaking conditions were performed in the water bath. The bottles were covered with bottle stoppers. The bottles were taken out after soaking. Cellulase (2%, according to the solid weight; Yuhe Food additives Co., Ltd., Zhengzhou, China) was added into the solution, and the bottles were covered with three layers of gauze. The bottles were placed in a water bath at a controlled temperature of 35 ± 2 °C for 24 h. Then, the

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