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Short Communication

Low-cost additive improved silage quality and anaerobic digestion performance of napiergrass

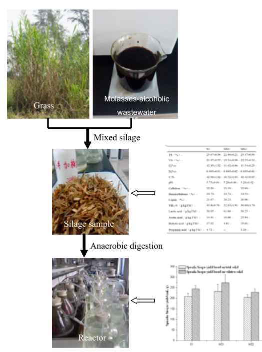
Li Lianhua, Zhen Feng, Sun Yongming, Yuan Zhenhong *, Kong Xiaoying, Zhou Xianyou, Niu Hongzhi

Guangzhou Institute of Energy Conversion, CAS Key Laboratory of Renewable Energy, Chinese Academy of Sciences, Guangzhou 510640, China

HIGHLIGHTS

- Molasses-alcoholic wastewater was used as silage additive.
- Adding molasses-alcoholic wastewater improved the silage quality.
- Specific biogas yield increased by 12% with adding molasses-alcoholic wastewater.
- Adding 11% molasses-alcoholic wastewater was recommended.

GRAPHICAL ABSTRACT



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ABSTRACT

Effects of molasses-alcoholic wastewater on the ensiling quality of napiergrass were investigated at ambient temperature, and its anaerobic digestion performance was assessed at mesophilic temperature. Results showed that the molasses-alcoholic wastewater had positive effect on silage quality and anaerobic digestion performance. Lower pH values of 5.20–5.28, lower NH_3-N contents of 32.65–36.60 g/kg and higher lactic acid contents of 56–61 mg/kg FM were obtained for the silage samples with molasses-alcoholic wastewater addition. Higher specific biogas yield of 273 mL/g VS was obtained for the sample with 11% molasses-alcoholic wastewater added. Therefore 11% molasses-alcoholic wastewater addition was recommended.

1. Introduction

Perennial grasses have been considered as a main feedstock for biogas production, and utilized in over 50% agricultural biogas plants in Europe. In order to conserve the nutrient component and ensure a sustained supply of grass, an effective preservation method is necessary. Ensilage is a well developed method and over 90% of fresh grass are preserved in this way (Mohd-Setapar et al., 2012). The ensiling process is predominated by lactic fermentation, and satisfactory silage material is characterized as low pH value, low ammonia-N content and high lactic acid concentration. Silage additive is used to improve silage quality. Silage additives can be divided into two types: biological additives such as lactic acid bacterial (LAB) and chemical silage additives including molasses, urea, etc (Contreras-Govea et al., 2013; Tyrolova and Vyborna, 2011).

For improving the competitive advantage over fossil fuel and in the application of anaerobic digestion technology, it is important to decrease the costs of biogas production. In general, the expenditure of feedstock in agricultural biogas plant takes up to half of power generation cost (Herrmann et al., 2011). Molasses is an effective additive agent for silage, and the suitable addition amount is

* Corresponding author.
E-mail address: yuanzh@ms.giec.ac.cn (Y. Zhenhong).

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around 3–4% based on the dry matter (DM) of crops. In China, the cost of molasses is about 100 $/t, which means that the preservation cost could increase by 3–4 $/t DM. The analysis of Plöchl et al. showed that the costs of silage additives for fresh material is in the range of 2–6 €/t, and the additional income from increasing methane yield negatively compensate for the costs of additives (Plöchl et al., 2009). Therefore, low-cost and high quality preservation of agricultural feedstock is necessary for sustainable and economic biogas production. The molasses-alcoholic wastewater is characterized as high concentration of organic acid and sulfate, low pH value ranging from 3.5 to 4.5 and rich in sugar, protein, amino acid and inorganic salt (Yetilmezsoy et al., 2013), suggesting that it could be an alternative additive for silage, since all these single components can been used as additives. In order to investigate the feasibility of molasses-alcoholic wastewater as silage additive, the characteristics of silage and the anaerobic digestion performance were determined after the napiergrass co-silage with molasses-alcoholic wastewater.

2. Methods

2.1. Grass material and inoculums for anaerobic digestion

Napiergrass was harvested from North Campus of South China University of Technology located in Guangzhou city on Jan. 14, 2014. The total solids (TS) content of fresh grass was 24.15% and 21.61% for volatile solids (VS). The molasses-alcoholic wastewater was collected from Wuming heli biological chemical co., LTD in Guangxi, the COD concentration and pH value were 120,750 g/mL and 5.05, respectively.

Inoculums (pH = 7.43; TS = 2.349%; VS = 1.383%; NH_3-H = 295 mg/L) for anaerobic digestion were taken from CSTR anaerobic reactor in our lab.

2.2. Experimental setup and procedure

Mixed silage (MS) was conducted in lab-scale silo of 500 mL in duplicate. Fresh grass was manually cut into 2–3 cm pieces. The molasses-alcoholic wastewater was added at a ratio of 11% (MS1) and 14% (MS2) based on the VS mass of grass. Fresh grass and molasses-alcoholic wastewater was completely mixed and then packed into silos. After filling, using lip and parafilm keeps the silos air-tightness. The silage with no molasses-alcoholic wastewater was used as control (S1). The silage lasted for 43d at ambient temperature.

Anaerobic digestion performance of silage grass was determined in batch-tests carried out in 2000 mL reactor at 35 ± 1 °C in duplicate. Silage grass and inoculums were added at a ratio of 1 based on VS. All reactors were filled with 1800 mL inoculums, and 0.5 g/L sodium bicarbonate (NH_4HCO_3) was added to improve the buffer capacity. All reactors were mixed manually twice a day. The experiments lasted for 14 days. The daily and cumulative volume of biogas was converted to norm conditions (1013 mbar, 273 K).

2.3. Analytical methods

Standard analytical method was used to determine the contents of TS and VS of inoculums, fresh and silage feedstock (APHA, 1998); C, N and H contents were measured by Vario EL element analyzer; displacement of saturated brine solutions was used for calculation of daily biogas yield; mixture samples of silage (20 g) and deionized water (180 mL) were placed in 4 °C refrigerator for 24 h, and then filtered through four layer gauze. The filtered liquor was used for pH value, ammonia–nitrogen (NH_3–N) and volatile fatty acids (VFA) analysis of silage sample; pH meter (pHS-3C) was used for pH determination; The concentration of NH_3–N was determined using test kit and spectrophotometer of HACA; The contents of volatile fatty acid (VFA) were determined by HPLC (waters e2695) equipped with refractive index detector. The column was Shodex sugar SH-1011 with 0.005 M H_2SO_4 as mobile phase, 0.5 ml/min for flow rate and 50 °C for column temperature; Mixture of samples with KBr was prepared and used for the analysis of transmittance Fourier transform infrared (FTIR, BRUKER TENSOR 27). All spectra were recorded with a resolution of 4 cm^{-1}, an accumulation of 16 scans, in the range from 4000 to 500 cm^{-1}; The crystallinity index (CrI) was performed by X' Pert Pro MPD (PW3040/60, Philips, Holand). The 2θ size was in the range of 10°–80°, in a step of 0.017° at 40 kV, 40 mA and Cu Kα radiation. CrI was calculated according to the following formula: $CrI = [(I_{002} - I_{am})/I_{002}]^{*} 100$, where I_{am} is the intensity at $2\theta = 18.4°$, I_{002} is the maximum peak intensity at $2\theta = 22.5°$.

2.4. Statistical analysis

The statistic analysis of silage data was performed using one way analysis of variance by SPSS 17.0 software, and the Fisher Least Significant Difference was used for comparisons of the means at 5% significant level.

3. Results and discussion

3.1. physical–chemical characteristic of silage napiergrass

The physical–chemical characteristics of silage feedstock were listed in Table 1. The TS content of fresh feedstock was 24.16%. The ideal dry matter content for ensiling usually is in the range of 30–40%, adding material which can increasing the concentrations of desirable nutritive components were beneficial to the silage quality when the raw material contained high water contents. The TS content of MS1 after silage decreased by 5.34%, this mainly related to metabolism of microorganism, the respiration of plant and fermentative process during ensiling, accompanied with water and CO_2 produced. Compared to S1, the contents of cellulose of MS1 and MS2 slightly increased, while the contents of hemicelluloses and lignin decreased, but no obvious difference was observed for these treatments ($P > 0.05$), suggesting that the microorganisms involved in silage could use the nutrient component in molasses-alcoholic wastewater as carbon sources, and preserve the nutrient component in feedstock. The MS1 and MS2 had lower pH and NH_3–N content than S1 ($P < 0.05$), this suggested that

Table 1
Nutritive value and silage chemical composition of napiergrass with adding low-cost additive "–" means the concentration of propionic acid lower than the detection limit.

	S1	MS1	MS2
TS (%)	25.67 ± 0.56	22.86 ± 0.21	25.47 ± 0.94
VS (%)	21.97 ± 0.55	19.54 ± 0.38	22.55 ± 0.54
C (%)	42.45 ± 1.32	41.62 ± 0.06	41.54 ± 0.23
N (%)	0.995 ± 0.01	0.895 ± 0.02	0.895 ± 0.01
C/N	42.66 ± 1.02	46.52 ± 1.04	46.41 ± 0.63
pH	5.75 ± 0.04	5.20 ± 0.06	5.28 ± 0.02
Cellulose (%)	32.26	33.39	32.88
Hemicelluloses (%)	19.73	19.74	19.53
Lignin (%)	21.67	20.23	20.96
NH_3–N (g/kg FM)	43.8 ± 9.76	32.65 ± 1.91	36.60 ± 1.70
Lactic acid (g/kg FM)	30.05	61.06	56.23
Acetic acid (g/kg FM)	14.91	18.06	25.94
Butyric acid (g/kg FM)	17.92	4.81	15.61
Propionic acid (g/kg FM)	4.72	–	3.20