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Short Communication

Increased anaerobic production of methane by co-digestion of sludge with microalgal biomass and food waste leachate

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HIGHLIGHTS

- Effect of different mixing ratio of S, F and A was investigated.
- Each substrate showed different degrees of digestibility.
- Mixing ratio of 1S:1F:1A led to an enhancement of methane yield.

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ABSTRACT

The co-digestion of multiple substrates is a promising method to increase methane production during anaerobic digestion. However, limited reliable data are available on the anaerobic co-digestion of food waste leachate with microalgal biomass. This report evaluated methane production by the anaerobic co-digestion of different mixtures of food waste leachate, algal biomass, and raw sludge. Co-digestion of substrate mixture containing equal amounts of three substrates had higher methane production than anaerobic digestion of individual substrates. This was possibly due to a proliferation of methanogens over the entire digestion period induced by multistage digestion of different substrates with different degrees of degradability. Thus, the co-digestion of food waste, microalgal biomass, and raw sludge appears to be a feasible and efficient method for energy conversion from waste resources.

1. Introduction

The anaerobic wastewater process is an economically attractive alternative to aerobic treatment methods because costs related to electricity, maintenance, and operations may be offset by methane production (Sutton et al., 2011). In addition, anaerobic processes do not require an aeration unit, and this can account for nearly one-half of the total energy input for biological wastewater treatment (Park and Craggs, 2007). For this reason, many recent studies have examined anaerobic digestion for treatment of organic wastes (food waste, sewage sludge, dung, *etc.*). In particular, for efficient production of biogas as an energy source, recent research has focused on co-digestion, the simultaneous anaerobic digestion of multiple organic wastes in a single digester. In most cases, the use of co-substrates can improve biogas yields due to positive interactions in the digestion medium. This may be because use of multiple substrates may supply nutrients that are missing from a single substrate (Zhang et al., 2011) or may dilute toxic compounds from a single substrate to below the toxic thresholds (Sialve et al., 2009).

The characteristics of Korean food waste, such as high moisture content, high salinity, and low pH, have made it difficult to use as the sole substrate for biogas production in an anaerobic digestion process. In particular, ~70–90% of the food waste consists of leachate. The low sulfur content and the ability to uptake CO_2 from generated biogas make microalgal biomass a good option for anaerobic digestion (Converti et al., 2009; Sialve et al., 2009). Therefore, this study examined the co-digestion of food waste leachate with microalgal biomass as a method to improve methane production. Previous research has examined diverse organic substrates with food waste in anaerobic co-digestion, but there has been little research into co-digestion of food waste with microalgal biomass. Co-digestion of food waste with microalgal biomass

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might overcome the problems of separate digestion of each substrate, which are related to C/N ratio, pH, and salinity.

The present study tested the process stability and methane production of anaerobic co-digestion of saline food waste leachate with microalgal biomass by use of different mixing ratios of food waste leachate, microalgal biomass, and raw sludge.

2. Methods

2.1. Inoculum and substrates for anaerobic co-digestion

Seed micro-organisms and raw sludge were collected from the anaerobic digestion tank of the municipal sewage treatment plant in Busan, South Korea. Food waste leachate was taken from a waste processing plant in Busan, South Korea (Supplementary Fig. 1a). The microalgal biomass, *Chlorella* sp., was generously provided by Daesang Co. (South Korea), and concentrated microalgae were refrigerated at 4 °C prior to use (Supplementary Fig. 1b). Table 1 shows the physicochemical characteristics and elemental composition of the raw sludge, food waste leachate, and algal biomass.

2.2. Experimental set-up

The batch anaerobic co-digestion experiments were performed in 500 mL amber-glass bottles with a working volume of 400 mL (Supplementary Fig. 1c). Initially, each digester was sparged with 65% nitrogen gas for 2 min. Then, the bottle was filled with 200 mL of seed microorganisms and 200 mL of substrate. After an additional 10 min of flushing with 65% nitrogen (to ensure anaerobic conditions) the digester was capped with a rubber septum, and then placed in a shaking incubator (35 ± 2 °C and 120 rpm) (Supplementary Fig. 1d). Over a 42-day period, biogas was collected with gas-tight plastic syringes; liquid samples were collected in plastic syringes for volatile fatty acid (VFA) analyses. The effect of different ratios of the 3 substrates on methane production was tested (Table 2). All experiments were run in triplicate and results are presented as means ± standard deviations.

2.3. Analytical methods

Chemical oxygen demand (COD), water content and volatile solids (VS) were determined according to the Standard Methods (APHA, 1995). pH value was determined using a pH meter (Mettler Toledo, Switzerland). Phosphorus and chloride were measured by the ascorbic acid method and mercuric thiocyanate method, respectively, using a spectrophotometer (Hach, USA) (APHA, 1995). Carbon, hydrogen, nitrogen, sulfur and oxygen were assayed using an elemental analyzer (Thermo Fisher Scientific, USA). For VFA determination, 6 VFAs (acetic acid, propionic acid, butyric acid, isobutyric acid, valeric acid, and isovaleric acid) were determined by a gas chromatograph (Agilent, USA) equipped with a flame ionization detector (APHA, 1995). Gaseous methane produced during co-digestion was measured volumetrically using a water substitution method and a gas chromatograph (Agilent, USA) equipped with a thermal conductivity detector (APHA, 1995).

Table 1
Physicochemical characteristics of the microalgae, sewage sludge, and food waste leachate used in experiments.

Parameter	Algal biomass	Raw sludge	Food waste leachate
Protein (% dry weight)	67	–	–
Lipid (% dry weight)	16	–	–
Carbohydrate (% dry weight)	6	–	–
Water content (% fresh weight)	90	81.5	80
Volatiles (% dry weight)	–	11.2	17.7
Ash (% dry weight)	11	7.4	2.3
C (% dry weight)	51.5	32.8	41.1
O (% dry weight)	28.3		
H (% dry weight)	7.5	5	7.4
N (% dry weight)	9.5	4.2	3.9
P (% dry weight)	2		
S (% dry weight)	–	1.5	
Cl (% dry weight)	–		1.5
Others (% dry weight)	2.2	28.5	
C/N ratio	5.4	7.8	10.8

3. Results and discussion

3.1. Effect of different substrate combinations on methane production

Fig. 1 shows the cumulative methane production with different mixtures of food waste leachate (F), algal biomass (A), and raw sludge (S) over 42 days. After incubation, there was a lag phase before methane production commenced. With increasing the raw sludge portion or decreasing the algal sludge and food waste leachate portions in the mixtures, this lag phase was shortened. VFA and soluble COD (sCOD) concentrations increased during this lag phase (Supplementary Fig. 2). Methane production halted at 20–24 days with use of 100% raw sludge (S only), presumably due to substrate depletion.

After the ∼13 day lag phase, increasing methane production corresponded to decreasing concentrations of VFAs and sCOD. However, when two-thirds or more of the substrate consisted of food waste leachate (F only and 1S:4F:1A), VFA accumulation continued and there was virtually no methane production for the entire 42 days. The low methane production at high concentrations of food waste (which has high salinity) could be attributed to the lower growth and activity of microorganisms in the presence of a large salt concentration gradient between the internal and external cellular environments and the subsequent elimination of water and essential nutrients from cells. This finding is in agreement with the work of Lin et al. (2011), which indicated that a higher food waste content in the substrate resulted in increased VFA concentration and inhibition of methanogenesis.

In the case of 100% microalgal biomass (A only), the low methane production from day 0 to 42 may be due to resistance of the cell wall, because pretreatment of the microalgae was not performed in this study. Chen and Oswald (1998) and Keymer et al. (2013) indicated that thermal pretreatment of algal biomass increased methane yield during anaerobic digestion. Also, Keymer et al. (2013) reported algal residue after lipid extraction helped to reduce pretreatment costs. However, costs and energy balances of total anaerobic processes should be considered when pretreating algal biomass. According to Sialve et al. (2009), when algae have a low lipid content (<40%) and algal residue remains after lipid extraction, a positive energy balance in biogas production only occurs when there is no pretreatment. Another reason for the low methane production in the A only medium might be the high nitrogen concentration (especially ammonia) in this substrate (Chen et al., 2008). Ramos-Suárez et al. (2013) indicated that anaerobic digestion of microalgae residues requires a low organic loading rate (OLR) or co-digestion with a high carbon substrate to avoid ammonia toxicity.

Mixing equal amounts of algal biomass and food waste leachate (1A:1F) led to lower methane production than the two-component combinations with raw sludge (1S:1F and 1S:1A). Co-digestion with equal amounts of all three substrates (1S:1F:1A) led to the greater methane production at day-42 than all other three component mixtures (4S:1F:1A, 1S:4F:1A, and 1S:1F:4A). These results