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The effect of the labile organic fraction in food waste and the substrate/inoculum ratio on anaerobic digestion for a reliable methane yield

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HIGHLIGHTS

- The effect of labile organic fraction (LOF) in FW and S/I ratio on AD were examined.
- LOF loading caused acidification and contributed to a high methane yield from FW.
- The CH_4 content had a significant relationship with pH but not VFAs concentration.
- Low S/I ratio (<0.33) was required to obtain a reliable methane yield in AD of FW.

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ABSTRACT

Influence of the labile organic fraction (LOF) on anaerobic digestion of food waste was investigated in different S/I ratio of 0.33, 0.5, 1.0, 2.0 and 4.0 g-$VS_{substrate}$/g-$VS_{inoculum}$. Two types of substrate, standard food waste (Substrate 1) and standard food waste with the supernatant (containing LOF) removed (Substrate 2) were used. Highest methane yield of 435 ml-CH_4 g-VS^{-1} in Substrate 1 was observed in the lowest S/I ratio, while the methane yield of the other S/I ratios were 38–73% lower than the highest yield due to acidification. The methane yields in Substrate 2 were relatively stable in all S/I conditions, although the maximum methane yield was low compared with Substrate 1. These results showed that LOF in food waste causes acidification, but also contributes to high methane yields, suggesting that low S/I ratio (<0.33) is required to obtain a reliable methane yield from food waste compared to other organic substrates.

1. Introduction

According to the Ministry of the Environment (2012), more than 19 million tons of food waste is produced annually in Japan, and 78% of it is incinerated. Due to the high moisture content of food waste, a huge amount of energy is expended to incinerate food waste, and alternative treatment methods are highly desirable. Anaerobic digestion of food waste is considered a feasible alternative treatment; because it produces renewable energy, it is one of the most cost effective treatments. Moreover, food waste is a common biodegradable organic waste compared with other organic wastes, such as excess sludge, grass plants and livestock manure. Furthermore, it is suitable substrate for anaerobic digestion (Carrere et al., 2010; Moller et al., 2004; Gunaseelan, 1997; Cho et al., 1995). During anaerobic digestion of food waste, 400–500 mL g-VS^{-1} methane yields were obtained (Izumi et al., 2010; Heo et al., 2004; Cho et al., 1995). However, some papers reported relatively low methane yields ranging from 100 to 250 mL g-VS^{-1}. These low yields were attributed to acidification during the food waste digestion (Liu et al., 2009; Dearman and Bentham, 2007; Kim et al., 2006).

Food waste is easily degraded and therefore rapidly solubilizes. Upon degradation, the labile organic fraction (LOF) which is the initial solubilized product in the degradation process is immediately used by anaerobic microbes and converted to volatile fatty acids (VFAs). During batch experiments, acidification was often observed in the initial phase of digestion (Liu et al., 2009; Forster-Carneiro et al., 2008; Zhang et al., 2007; Neves et al., 2004). This system instability, acidification, is caused by imbalanced production and consumption of VFAs by each microbe in the system (Forster-Carneiro et al., 2008; Aguilar et al., 1995). Stamatelatou et al. (2003) observed that acetate and propionate build up first when VFAs begin to accumulate. Next, butyrate and valerate accumulate

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considerably. They found that the pH dropped below 6 as butyrate and valerate began to accumulate, and the digestion process halted. This progression in the accumulation of VFAs is involved in acidification and is caused by the consumption and production of VFAs in the LOF. Therefore, acidification depends on the LOF initially produced from food waste.

In many previous studies, the relationship between the inoculum quantity and the amount of food waste (based on the volatile solid (VS) content) was investigated to understand the appropriate substrate to inoculum (S/I) ratio (Lu et al., 2012; Zhou et al., 2011; Raposo et al., 2009; Vedrenne et al., 2008). In the case of anaerobic digestion of food waste, methane yields significantly varied based on the inoculum to substrate ratio used, and the optimal amount of inoculum was often higher for food waste than other substrates. Most studies suggested that using S/I ratio below 1.0 $VS_{substrate}$/g-$VS_{inoculum}$ was enough to prevent acidification during anaerobic digestion of food waste (Elbeshbishy et al., 2012; Eskicioglu and Ghorbani, 2011; Neves et al., 2004; Moorhead and Nordstedt, 1993). However, acidification is directly affected by the amount of labile organic matter which is immediately transformed to VFAs in the initial phase of anaerobic digestion. Suitable S/I ratios to maintain efficient anaerobic digestion process are expected to vary with the amount of labile organic matter in the substrate. Therefore, it is important to evaluate the influence of labile organic fraction (LOF) which plays a crucial role in both process stability and productivity of methane gas in the anaerobic digestion of food waste.

The aim of this study was to evaluate the influence of LOF on the anaerobic digestion of food waste in five different S/I ratios, using two types of food waste substrates with different LOF content.

2. Methods

2.1. Preparation of inoculum and food waste substrate

Mesophilic anaerobic sewage sludge was collected from the Hokubu Sludge Treatment Center, Yokohama, Japan. The inoculum was centrifuged to adjust S/I ratio before inoculation. The final TS content was 5.7%, and the VS content was 2.9% (Table 1).

The food waste was obtained from a garbage collection company (Ohmura Co. Ltd., Saitama, Japan) and the composition was adjusted to standard food waste (Izawa et al., 2001). To evaluate the influence of the labile organic fraction (LOF), two types of standard food wastes which have different LOF content were prepared. In preparation of Substrate 1, 2 L of distilled water was added to 1 L of standard food waste and ground with a household disposer (Anaheim, KDF55JK, USA: DP), after which the food waste was solubilized anaerobically in a 4 L glass flask at a mean mesophilic temperature of 37 ± 1 °C for 24 h. The extra space in the reactor (1.8 L) was filled with nitrogen gas to maintain anaerobic condition. The reactor was sealed with a silicone stopper and then constantly agitated at 60 rpm using a shaker (Taitec, NR-150, Japan). The solubilized standard food waste was used as Substrate 1 (High LOF substrate).

Table 1
Substrates and inoculum sludge conditions in this study.

Parameter	Unit	Food waste		Inoculum sludge
		Substrate 1	Substrate 2	
TS	% of wet weight	4.4	10.5	5.7
VS	% of wet weight	4.1	10.1	2.9
VS/TS	% of dry weight	96	93	65.5
Carbon	% of dry weight	45	45	21
TCOD	g L^{-1}	97	230	38
SCOD	g L^{-1}	22	20	8.3
pH	–	–	–	8.4

To prepare Substrate 2 (Low LOF substrate), the solubilized food waste (Substrate 1) was centrifuged (3000 rpm 20 min), and the supernatant which consists largely of LOF was removed to decrease the LOF content. Characteristics of the prepared substrates are shown in Table 1.

2.2. Batch experimental set up

The experiments were performed in 2 L glass reactors (working volume: 1.2 L) at a mean mesophilic temperature of 37 ± 1 °C. Five substrate of inoculum (S/I) ratios at 0.33, 0.5, 1.0, 2.0 and 4.0 g-$VS_{substrate}$/g-$VS_{inoculum}$ were tested using Substrate 1 and 2. Materials were added to the reactor in the following sequence: (1) seeded sludge, (2) substrate (9.8 g-VS) and (3) sufficient distilled water for a total liquid volume of 1.2 L. Next, the reactor was purged with nitrogen to assure that it was anaerobic before it was tightly sealed with silicone stoppers. A 1 L aluminum gas pack (GL Sciences, AAK-2, Japan) was attached for biogas collection. The batch reactors were constantly agitated at 60 rpm using a shaker (Taitec, NR-150, Japan) for a period of 40 days. The 13 sampling points in the experiment were taken at the following times: D0, D0.5, D1, D1.5, D1.7, D1.8, D2.4, D2.9, D3, D5, D8, D9, D10, D11, D15, D19, D20, D22, D24, D26, D29, D37 and D40. Depending on the biogas production rate, the collection interval was varied. At the start of the experiment, samples were collected once every few hours. By the end of the experiment, they were collected once every several days. In each experimental run, the same reactor was prepared with the inoculum but not the substrate as a blank. The same experimental conditions were used for the blank, and the biogas production was measured. All of the experiments were performed in duplicate. The averages of the duplicates are shown in each figure.

2.3. Analytical method

TS, TVS, pH, total chemical oxygen demand ($TCOD_{cr}$), soluble chemical oxygen demand ($SCOD_{cr}$), and the VFA content were determined following the standard methods of the American Public Health Association (APHA, 1998). The TS, TVS, pH, and TCOD of substrates and digestion samples were measured before filtration using a combusted 0.45 μm glass filter (GC-50, Advantec, Japan). The pH of all batch reactors was measured using a pH meter (B212, Horiba, Kyoto, Japan).

VFAs (acetic acid, propionic acid, *n*-butyric acid, *i*-butyric acid, *n*-valeric acid, *i*-valeric acid) were measured on a gas chromatograph (Shimadzu, GC-9A, Japan) that was equipped with a packed column (Shincarbon A) and flame ionization detector. The column temperature was maintained at 140 °C. The temperature in the injector and detector was maintained at 200 °C. Helium was used as the carrier gas. The helium flow rate was 50 mL min^{-1}. The biogas was gathered into an aluminium gas bag (AAK-2, GL Sciences, Japan) and the gas volume was calculated based on the downward displacement of water.

Biogas samples were analyzed for their carbon dioxide (CO_2) and methane (CH_4) content on a gas chromatograph (Shimadzu, GC-2014AT, Japan) equipped with a packed column (Shincarbon ST) and thermal conductivity detector. The injector and detector temperatures were maintained at 120 °C and 260 °C, respectively. The column temperature was gradually increased from 40 to 250 °C. Helium was used as the carrier gas. The helium flow rate in this column was 40 mL min^{-1}. The measured methane volume was adjusted to the volume at standard temperature (0 °C) and pressure (1 atm). The methane yield was calculated as follows:

$$M_{max} = \frac{M_E}{S_L} \quad (1)$$