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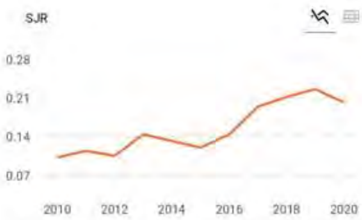

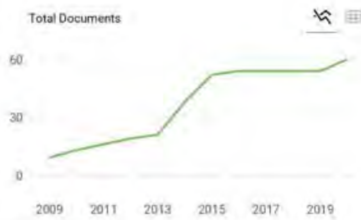

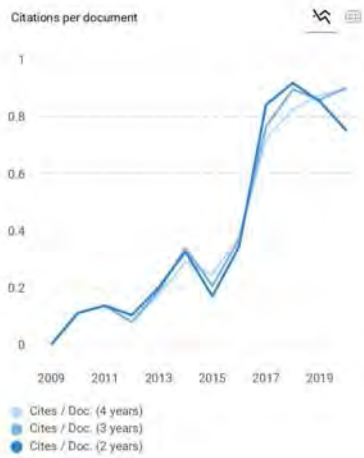

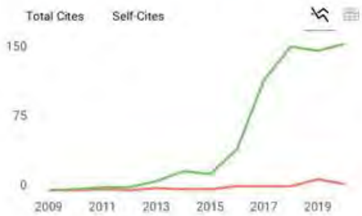

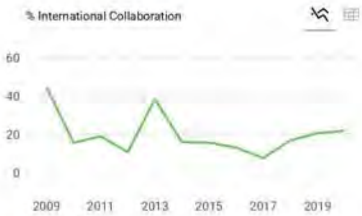

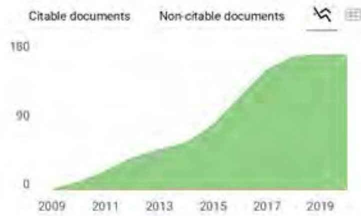

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Articles

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Characterization of Food Waste from a Campus Canteen as Potential Feedstock for Biogas Production

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Highlights:

- Food waste from the Ubaya canteen was characterized and found to be suitable as biogas feedstock.
- The effect of organic loading rate on cumulative and specific methane yield under mesophilic condition.
- The effect of feeding frequency in specific methane yield under mesophilic condition was investigated.

Abstract. Food waste collected from the Ubaya canteen was characterized for its potential for use as anaerobic feedstock. It was collected for 3 weeks on a daily basis and treated with 2 different pretreatments, i.e. mechanic and mechanic-thermal. The result showed that the physical and chemical properties of the food waste in the 3-week time period of collecting were not significantly different for both pretreatments. The VS/TS ratio was around 96.4% to 97.076% and C/N was in the range of 17.295 to 17.813 for the mechanic and mechanic-thermal treatments. Four semi-batch mesophilic anaerobic digesters were used in this study, with 1.215 gVS/L fed once (R1) and twice daily (R3); 2.43 gVS/L fed once (R2) and twice daily (R4). The maximum methane yield was determined to be 64.61 mL/gVS in R1 after 5 days of incubation and 57.41 mL/gVS in R3 after 4 days of incubation. Systems R2 and R4 showed maximum methane yields of 43.15 mL/gVS and 19.1 mL/gVS respectively.

Keywords: *anaerobic digestion; biogas introduction; characteristics; feeding frequency; food waste; organic loading rate.*

1 Introduction

Indonesia is the country with the second largest amount of food disposal with 300 kg food waste per person each year. The total amount of food waste in Indonesia is around 13 million ton annually [1]. As a rapidly growing country, Indonesia has to face handling its food waste more properly, as most food waste is dumped

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in landfills. Several studies have characterized food waste [2-6], as its characteristics are highly variable depending on the sources, with moisture content at 74%-90%, volatile solid to total solid (VS/TS) ratio at 80%-97% and carbon to nitrogen ratio at 14.7-36.4 [3]. Since it has a high moisture content, food waste is suitable to serve as feedstock for anaerobic digestion and as substrate for co-digestion [7]. Anaerobic digestion is an alternative technology for managing food waste. Several aspects affect the performance of the anaerobic digestion process, such as feedstock characteristics, reactor design, and operating conditions. One of the challenges for anaerobic digestion is its ability to adapt to high organic loading (OLR) operation without suffering organic loading shock, which can lead to anaerobic digestion failure. The physical and chemical characteristics of the food waste are crucial for designing and operating anaerobic conditions. The aims of this study were to characterize food waste collected from one of our campus' canteens and to assess its potential as feedstock for a mesophilic anaerobic digestion. The effects of the organic loading rate (OLR) and feeding frequency were also investigated.

2 Materials and Methods

2.1 Food Waste Collection and Analysis

The food waste was provided by Ubaya, one of our campus' canteens. The food waste collected each day was about 5-7 wet kg. It was collected continuously for 5 days during 3 weeks. Bones and paper were separated from the food waste. It was then mixed for sampling and analyzed with the following procedures. There were two different treatments for food waste prior analysis, mechanic and mechanic-thermal treatment, allowing all food waste to be blended and analyzed. The mechanic-thermal treatment was carried out by heating the blended food waste in a water bath at 90 °C for one hour. The food waste was then stored at 0 °C. All food waste samples were analyzed for total solid (TS) and volatile solid (VS) contents according to the APHA method (1998). The contents of nutrients and metals were measured. The food waste was digested using a microwave digestion method (EPA 3052) and then measured using an ICP Perkin Elmer NexIon 300 for heavy metals analysis. Fat was measured by the soxhlet method (SNI 01-2891-1992). The protein content was measured using the Kjedahl method and the organic carbon content was measured using a TOC analyzer Shimadzu TOC-VCPN (*Organic Carbon Content Handbook of Soil Analysis*).

2.2 Anaerobic digestion

A total of 4 semi-batch reactors were used in this study, each with 500 mL total volume and 400 mL working volume. The food waste samples collected from weekly sampling were digested in a 500 mL semi-batch digester (Figure 1) at an initial organic loading rate (OLR) of 3 grams food waste or 1.215 g VS/L (R1) and 6 gram food waste or 2.43 g VS/L (R2). The food waste was prepared to get a TS of 10.5% with the ratio between food waste and water of 30:70. Inoculum used in this study was collected from cow manure of which 20% mixed was with the food waste. All digesters were incubated at 35 °C for 9 days. Agitation was carried out at 300 rpm to ensure proper mixing and pH was monitored daily. The parameters used in this study were OLR and feeding frequency. Both R1 and R2 were fed with 1.215 and 2.43 g VS/L daily respectively. The other systems (R3 and R4) were fed twice daily with 1.215 and 2.43 g VS/L respectively. The gas produced was measured for methane, VFA (acetic acid, propionic acid and butyric acid) contents and accumulative methane.

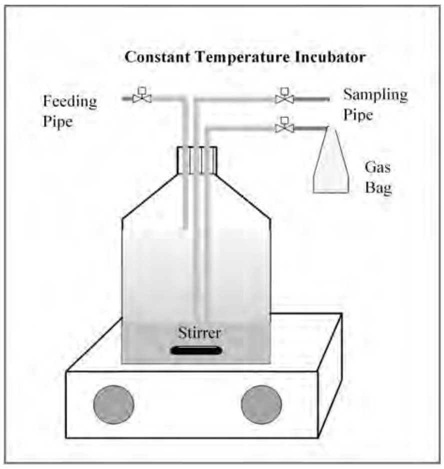

Figure 1 Experimental diagram of the semi-batch anaerobic digestion system.

2.3 Biogas, COD and VFA Measurements

Methane production in each digester was measured daily using gas chromatography (Hewlett Packard HP 6890 series) with flame ionization detector. A 30-m column length with ID 0.53 mm was used (HP-PLOT-Q and helium gas was the carrier gas). The column head pressure was maintained at 16.25 psi. Temperatures of 250 °C for the injector port, 150 °C for the oven and 275 °C for the detector were used. The measured methane volume was adjusted from the methane concentration. COD was measured using a closed reflux and colorimetric method based on the APHA method. Volatile fatty acids (acetic, butyric and propionic acids) were measured using gas chromatography with an FID detector; the temperature of the injector and detector was 275 °C and 275 °C respectively.

3 Results and Discussion

3.1 Characteristics of Food Waste

The chemical and physical components of the canteen food waste that were detected were TS, VS, organic carbons, proteins, fat and heavy metals such as Al, Cr, Mn, Cu, Na, Mg, K, Fe and Zn. Figure 1 shows the average value of TS, VS, VS/TS ratio, moisture content (MC) of the food waste. The TS value (%) in the food waste was in the range of 30-35% with standard deviation 1.05-2.63, while the VS (%) was in the range of 30%-34% with standard deviation 0.97-2.67. Food waste was collected every day for 5 days and was mixed prior to mechanic treatment (grinding). The sample was then analyzed in order to elaborate physical and chemical elements.

As shown in Table 1, the total organic carbon and nitrogen contents of the food waste were in the range of 45%-57% and 2%-3% respectively. Macronutrients (e.g. Na, K, Ca and Mg) were identified as well as micronutrients or metal elements (e.g. Fe, Cu, Zn, Al, Cr, Mn). Table 1 shows that Na and K contents were relatively high compared to other macronutrients. These elements could be from salt, mono sodium glutamate, milk and vegetables. Meanwhile Fe and Zn were the two major components among the other micronutrients. There was no significant difference between the food waste characteristics from the mechanic and the mechanic-thermal pretreatment.

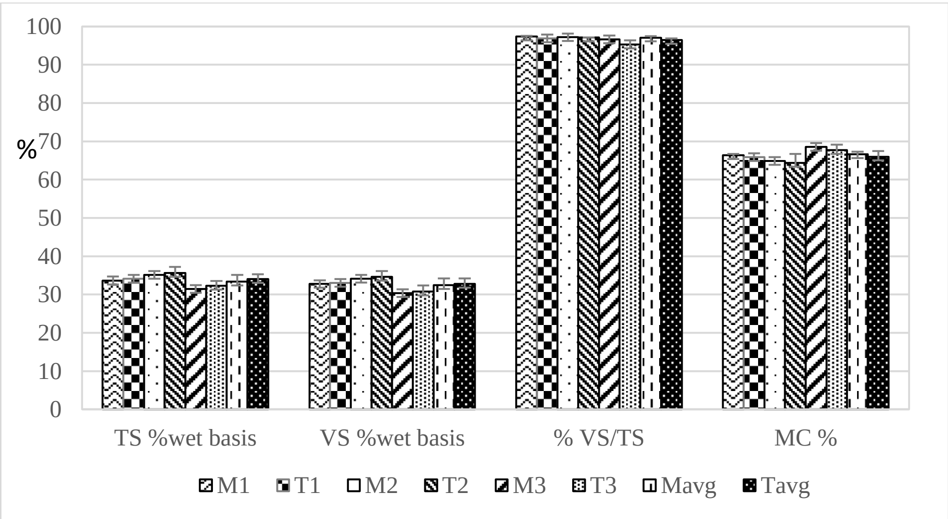

Figure 2 Average percentage for TS, VS, VS/TS ratio and moisture content for weekly intake at different types of pretreatment.

Table 1 Characteriztic of food waste from Ubaya canteen with mechanic treatment.

Characteristic	**Unit**	**Mechanic Week 1**	**Mechanic Week 2**	**Mechanic Week 3**
TS %	Wet weight	33.6436 (1.05)	35.1314 (2.63)	31.4132 (1.58)
VS %	Wet weight	32.7732 (0.96)	34.1389 (2.67)	30.3581 (1.71)
% VS/TS		97.4127 (0.16)	97.1748 (0.38)	96.6411 (0.38)
Organic carbon (C) %	Dry weight	57.2	57.8	47
N %	Dry weight	2.8800	3.408	3.12
C/N	-	19.8611	16.9601	15.0641
Protein %	Dry weight	18	21.3	19.5
Fat %	Dry weight	10	11.7	10.7
Na	ppm, Dry weight	7499	5884	7534
K	ppm, Dry weight	3753	3276	3827
Ca	ppm, Dry weight	1067	1129	1034
Mg	ppm, Dry weight	653	497	679
Fe	ppm, Dry weight	28.6	42.9	33.6
Cu	ppm, Dry weight	5.99	3.94	3.64
Zn	ppm, Dry weight	29.9	25.8	22.3
Al	ppm, Dry weight	24.8	25.8	30.1
Mn	ppm, Dry weight	10.2	10.9	9.25
Cr	ppm, Dry weight	0.303	0.364	0.215

The values of TS (%) and VS (%) of the food waste with mechanic-thermal pretreatment was higher compared to the ones with mechanic pretreatment only, but overall (including C/N ratio and moisture content) there were no significant differences between both treatments. In principle, the heating process is conducted to reduce fat and moisture contents in food waste, as suggested by Kondusamy and Kalamdhad [8], but in this study no significant reduction was observed. However, several studies, such as Zhang *et al.* [3], have reported that moisture content is less important than the VS/TS and C/N ratio.

A higher VS/TS ratio indicates more organic contents inside the food waste; the amount of organic substances is important, as this is material that will be biodegraded. Meanwhile, the C/N ratio is another crucial factor to stimulate better biodegradation resulting in methane gas. From the characterization process, it was found that the VS/TS and C/N ratios of the food waste from the Ubaya canteen were in the range from 96.6%-97.4% and 15.06%-19.8% respectively. These values are similar to the findings of Zhang *et al*. [3]. As for the heavy metals content, the food waste from the Ubaya canteen had a lower concentration compared to the result of Zhang *et al*. [9] but similar to the one reported by Zhang *et al.* [10]. Overall, there was no significant variation in the concentration of all components in the food waste from the Ubaya canteen for the three weeks of observation. A comparison of physical, chemical, mineral and heavy metals components of the food waste from the Ubaya canteen and several other studies is summarized in Table 2 and Table 3.

Table 2 Comparison of food waste characteristics from Ubaya canteen compared with previous studies (dry weight).

Characteristic	Mechanic	Mechanic-Thermal	Zhang, *et al.* [2]	Zhang, *et al.* [9]	Liu, *et al.* [11]	Banks, *et al.* [12]	Browne, *et al.* [6]
*TS(%)	33.396 (1.75)	34.001 (1.67)	23.1 (0.3)	30.9	24.3	23.74	31.5
*VS (%)	32.423 (1.78)	32.789 (1.41)	21 (0.3)	26.35	22.5	21.71	34.539
% VS/TS	97.076 (0.39)	96.407 (0.98)	90.9 (0.2)	85.3	92.593	91.4490	91.2
Organic Carbon (C) %	54	57	56.3	46.78	55.39	-	49
N %	3.1360	3.200	2.3	3.16	2.31	8.12±0.01	3.4
C/N	17.2951	17.813	24.5	14.8	23.113	-	14.412
Protein %	19.6	20	14.375	19.75	33.75	-	29.6
Fat %	10.8	11.58	-	-	-	-	26.7

(* wet basis)

Table 3 Comparison of mineral and heavy metals contents in food waste from Ubaya canteen compared with previous studies.

Characteristic mineral and heavy metals (ppm)	Mechanic	Mechanic -Thermal	Wang, *et al.* [13]	Zhang, *et al.* [2]	Zhang, *et al.* [10]	Zhang, *et al.* [9]	Banks, *et al.* [13]
Na	6972.333	6759	16.080	34.500	8400	-	
K	3618.667	3266	4.26	23.000	3000	9000	3.39
Ca	1076.667	1132	3.03	4000	700	21600	-
Mg	609.667	378	0.62	1600	300	1400	-
Fe	35.033	20.3	0.14	432.900	17.514	2478.964	54
Cu	4.523	3.35	6.54×10^{-3}	-	16.906	100.324	1.7
Zn	26	19.8	2.45×10^{-2}	692.641	45.691	245.955	7.8
Al	26.9	21.4	0.22	-	23.812	3889.968	-
Mn	10.117	8.3	9.35×10^{-3}	476.191	5.304	194.175	-
Cr	0.294	0.249	8.76×10^{-4}	-	0.939	-	6.9

3.2 Effect of Loading Rate and Feeding Frequency in Preliminary Anaerobic Digestion Study

Since there was no significant difference in food waste characteristics under the mechanic and mechanic-thermal treatments, we used food waste under mechanic treatment for our preliminary anaerobic digestion study.

3.2.1 Cumulative Methane Production

Both reactors each loading rate of 1.215 g VS/L (R1) and 2.43 g VS/L (R2) showed a similar trend of an increase in cumulative production of methane throughout the experiment. The cumulative of methane at R2 was 15.06% higher than R1 at 9 days incubation, as depicted in Figure 2. The cumulative methane production at higher loading rate was higher during the first 5 days of incubation; after that the methane produced slowly decreased.

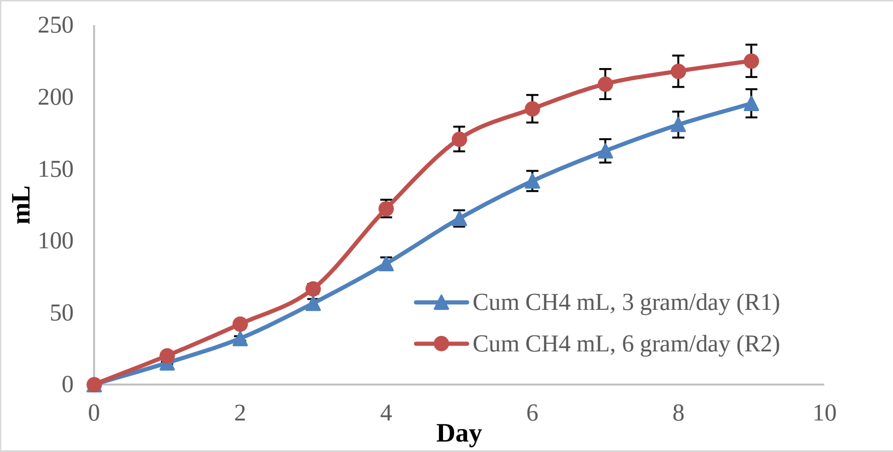

Figure 3 Cumulative production of methane (mL) in reactors R1 and R2 during 9-day experiment.

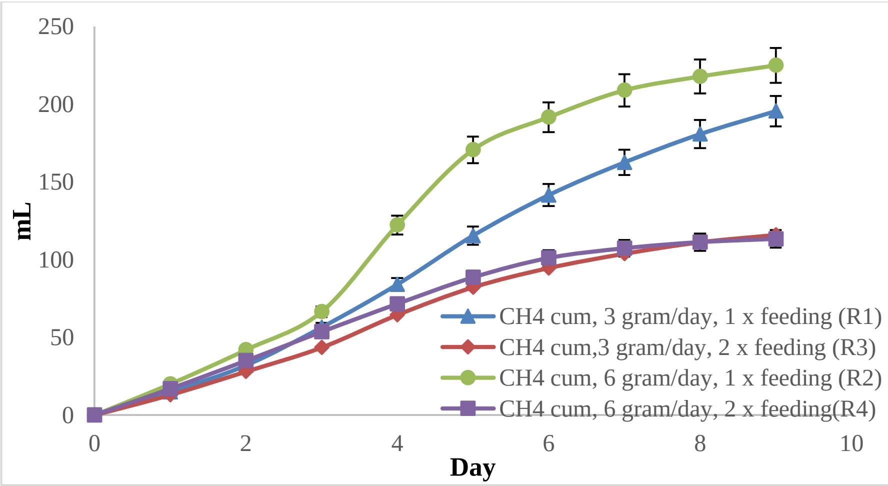

Figure 4 Comparison of cumulative methane production (mL) under four different conditions of the experiment.

Figure 3 shows that the cumulative methane production (mL) was lower with the more frequently fed reactors. The reactor fed twice daily with OLR of 1.215 g VS/L (R3) showed lower cumulative methane production than once daily feeding (R1). The same phenomenon was also observed in the system of the reactor fed twice daily with OLR 2.43 g VS/L (R4), which shows lower cumulative methane production than once daily feeding (R2). More frequent feeding did not have an impact on the cumulative methane production, which implies that the methanogenesis pathway did not work properly. Even though a higher cumulative methane production was observed in the high loading rate system, frequent feeding actually did not have a positive effect on the cumulative methane production. The systems with more frequent feeding (R3 and R4) showed that less than half methane was produced compared to R1 and R2 after 5 days of incubation, leading to system failure.

3.2.2 Specific Methane Yield

The specific methane yield was high at the beginning of the experiment and decreased throughout the rest experiment, as can be seen in Figure 4. Increasing the loading rate for daily feeding did not increase the high specific methane yield. The highest methane yield was obtained at the fifth day of the R1 system, and was reduced during the remaining 4 days of the experiment. The same trend was also observed in the other 3 systems. The reduced quantity of specific methane yield for the remaining 4 days of the experiment may be due to the fermentation and acetogenesis pathways, which are more dominant than the methanogenesis pathway.

The highest methane yield obtained in this study by R1 (64.6 mL/gVS) was lower compared to that from similar experiments conducted by Zhang et al. [10] and Zhang et al. [14], which were 187 mL/g VS and 343 mL/g VS respectively. The lower value of methane yield could be attributed to several factors. A low capacity of buffering could be the first, which will result in pH decreasing along the hydrolysis and acidogenesis process.

Table 4 shows the gradual decrease of pH in both reactors (R1 and R2) from day to day during the digestion period. More frequent feeding (R3 and R4) led to the accumulation of substrate (measured as COD, in Table 4), causing a sharper decrease of pH and as a result the specific methane yields for both rectors (R3 and R4) were lower than the single feeding reactors (R1 and R2), as can be seen in Figure 4. Guo et al. [15] also observed the correlation between heavy acidification because of a high loading rate and methane yield. Food waste with low buffering capacity will only produce methane at the initial stage of the digestion period and the methanogenesis pathway will be blocked whenever the pH value is under 6.5 [16]. Secondly, still corresponding to the buffer capacity, higher availability of organic nitrogen is needed when applying a higher loading rate of the substrate (food waste) for the anaerobic digestion process. Zhang *et al*. [14] reported that higher ammonia content neutralizes VFA through ionization in water phase. Neutralization process of VFA by ammonia can be described by the following reactions:

$$CxHyCOOH \longleftrightarrow CxHyCOO^- + H^+ \quad (1)$$

$$NH_3.H_2O \longleftrightarrow NH_4^+ + OH^- \quad (2)$$

Considering that CxHyCOOH represents VFA, combining these two reactions results in:

$$CxHyCOOH + NH_3.H_2O \longleftrightarrow CxHyCOO- + NH_4^+ + H_2O \quad (3)$$

The high concentration of VFA depicted in Figure 5, which is comparable to the VFA production in Zhang's work, will be neutralized if there is a sufficient amount of organic nitrogen, avoiding a pH decrease that will lead to a limpid methanogenesis process. Zhang *et al*. [14] suggest maintaining the C/N ratio as high as 15.8 in order to apply a high loading rate in anaerobic digestion of food waste. In our case, the C/N ratio was 17.3, which is considered low in nitrogen content. Thirdly, production of methane is impeded due to inhibition by sodium. McCarty [17] has reported that a relatively high sodium concentration of 3500-5500 mg/L creates moderate inhibition and at 8000 mg/L or higher, it stimulates a serious inhibitory effect on anaerobic digestion. Thereafter, from more a specific study using kitchen waste, Anwar *et al*. [18] confirmed that a sodium concentration of 8000 mg/L hampers methane production. In this study, it was found that the concentration of sodium was in the range from 6000-7500 mg/L (Table 1 and Table 3), which is relatively close to the baseline concentration. Also, the presence of calcium at a high concentration (1000-1100 mg/L) as identified in the food waste from the Ubaya canteen (Table 1 and Table 3) could be a limiting factor for microorganism performance.

Several researchers (Yu *et al*., Huang and Pinder, Kugelman and McCarty), as mentioned in the review of Zhang *et al*. [16], have pointed out that the inhibitory threshold concentration of calcium was 300 mg/L, 120 mg/L and 200 mg/L respectively. Beyond that limit, these researchers reported that the anaerobic digestion was hindered because of inhibition of the cellular metabolism in the biofilm system. The systems with more frequent feeding (R3 and R4) showed a sharper decrease in pH compared to R1 and R2, which implies that more VFAs were produced in the system, which may hinder the production of methane, which is supported by the accumulation of VFA shown in Figure 5. Hence, frequent feeding actually did not help to alleviate the accumulation of VFA and led to failure of the anaerobic digestion system at high OLR, as supported by Jiang *et* *al*. [19]. One of the reasons for this may be that the operating temperature (35 °C) is too low.

Tamkin *et al*. [20] explained that under low temperature, the acidogens have better tolerance toward the temperature condition compared to methanogens, as can be seen in Figure 5, when VFAs are being produced, while the conversion of the acids to methane is slowed down. More VFAs were produced in the more frequent feeding systems for all OLRs. The maximum VFA concentration at pH uncontrolled in another study was 3.94 g/L while 2.6 g/L of VFAs were produced in this study. More frequent feeding did not really have an impact on increasing the high specific methane yield. The R3 system had a lower specific methane yield compare to R1 and the R4 system had a lower specific methane yield compared to R2 (Figure 5). The specific methane yield constantly decreased although the OLR fed to the reactors were larger and more frequent. Perhaps the OLR that was fed to the system was too large in general, which would eventually lead to the accumulation of VFA, as has been proved by another study, which showed that the operation of the reactor at high loading was more unstable [19].

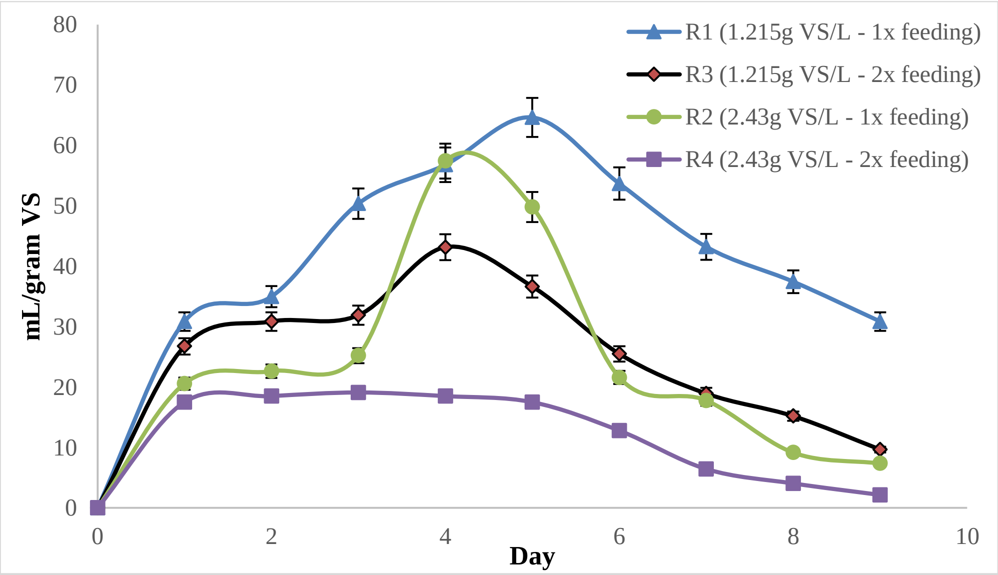

Figure 5 Effect of feeding frequency on specific methane yield.

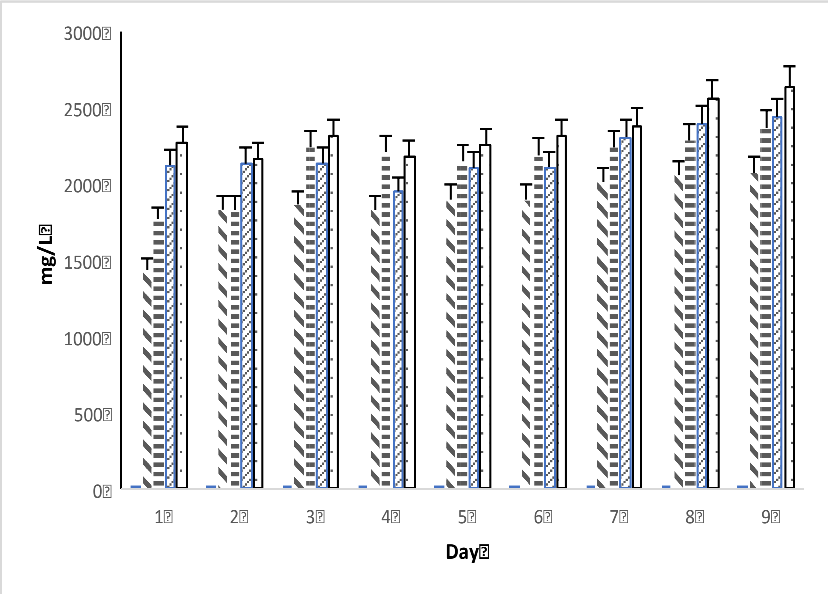

Figure 6 TVA concentration in R1 in R3 ▤ in R2 ▨ in R4 ⬚

Table 4. PH and COD Concentration During Anaerobic Digestion in Four Systems

Time (Day)	pH				COD (mg/L)			
	R1	R2	R3	R4	R1	R2	R3	R4
0	7.3	7.3	7.1	7.1	8022	9340	9044	9466
1	7.3	7.3	6.5	6.3	6324	7751	9340	9987
2	6.8	6.9	6.0	5.3	8059	8047	9367	9502
3	6.2	6.6	6.2	5.9	8210	9825	9394	10176
4	6.2	6.5	5.9	5.9	9266	9717	8559	9583
5	6.3	6.3	5.9	5.8	9625	9421	9259	9906
6	6.3	6.1	5.8	4.3	7050	9620	9287	10175
7	6.1	5.8	5.8	3.9	8840	9824	10148	10445
8	6.1	5.5	5.8	3.4	9034	10030	10520	11240
9	6.1	5.6	5.9	3.6	9120	10413	10740	11620

The increase of TVFA (ppm) produced confirmed that the metabolic pathway was more dominant in fermentation and acetogenesis than in methanogenesis, as depicted in Figure 6. A high VFA concentration of 2641mg/L (R4) at 2.43 gVS/L OLRs that were fed twice daily indicated R4 overload as the pH sharply decreased throughout the experiment. For all reactors, the specific methane yields decreased after 5 days of experiment, while the VFA kept increasing throughout the experiment as indicated by the value of pH in all systems. The pH in all systems was 6.33-3.4 (Table 4), which is not favorable for methanogens with the limiting range of 6.5-7.2 [16].

Another study has shown that systems with controlled pH give better methane production performance [19]. The decreased value of specific methane yield after 5 days of experiment showed a need to stop feeding and let the reactor stabilize for several days to attain a normal methane production level. A high COD amount throughout the experiment was also observed. This proves that an accumulation of organic matter happens in the system. It explains that the VFA produced in the acidogenesis process cannot be converted fast enough to methane, which leads to a decrease in methane production in all systems. Based on the results, we recommend working at OLR 1.215 gVS/L under controlled pH, thermophilic condition with a strategy of feeding once every two days to avoid the system collapsing after 5 days of experiment and to let the reactor stabilize to attain a normal methane production level.

4 Conclusions

The average VS/TS and C/N values under mechanic and mechanic thermal pretreatment were not significantly different (the VS/TS and C/N values were 97.07% and 17.3% under mechanical pretreatment, and 96.04% and 17.8% under mechanical thermal pretreatment, respectively). The average C/N ratio was 17.3%, which shows that the food waste contained limited nutrients. The results of the anaerobic digestion showed that the food waste had a maximum methane yield of 64.6 mL/gVS after 5 days of incubation at 1.215 gVS/L OLR and feeding once daily. The feeding frequency did not necessarily affect the methane production under mesophilic condition. Future studies are warranted to look into a system with controlled pH and thermophilic condition.

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