Correlation between Key Organic Substrate Characteristics and Biogas Production

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INTRODUCTION

Anaerobic digestion is a sustainable process that is employed by wastewater treatment plants (WWTPs) to transform sludge into renewable energy in the form of biogas. Some studies have shown that the mono digestion of wastewater sludge yields low amounts of biogas which makes it economically unattractive for small WWTPs to adopt. However, through anaerobic co-digestion, WWTPs can maximize the full potential of the process. Although co-digestion results in higher biogas yields, complex organic substrate characteristics often inhibit microbial communities from functioning effectively, resulting in decreased biogas production. It is therefore important to understand the correlation between key substrate characteristics and biogas production. Many studies have based their substrate characterization on bulk characteristics such as volatile solids (VS) and chemical oxygen demand (COD). Meanwhile key parameters such as lipids, proteins and carbohydrates which are precursors for inhibitory substances are not measured. Hence, there is limited knowledge on the effects of substrate characteristics such as lipids, proteins and carbohydrates on anaerobic co-digestion process.

RESEARCH OBJECTIVES

The objective of this study was twofold:

1. To investigate the anaerobic co-digestibility of wastewater sludge (WW) with foodwaste (FW) and fats, oils and grease (FOG) in various co-substrate mix ratios.
2. To find the correlation between key substrate characteristics, such as volatile solids (VS), chemical oxygen demand (COD), lipids, proteins and carbohydrates and biogas production using Spearman's Rank Correlation Test

MATERIALS & METHODS

Sample Preparation

Three organic substrates ; wastewater sludge (WW), foodwaste (FW) and fats, oils and grease (FOG) were used to prepare 10 co-substrate mix ratios (as seen in **Table 1** below) based on volume to volume ratio.

Table 1. Co-Substrate Mix Ratios

Sample	WW (%)	FW (%)	FOG (%)
WW	100	-	-
FW	-	100	-
FOG	-	-	100
A	-	75	25
B	-	50	50
C	-	25	75
D	25	-	75
E	50	-	50
F	75	-	25
G	75	25	-
H	50	50	-
I	25	75	-
J	33.33	33.33	33.33

Biomethane Potential Test

Biomethane potential test was used to carry out the anaerobic digestion process. Serum bottles of 160ml capacity were used as digesters. Experiments were carried out in triplicates and at a temperature of 35C. Biogas production was measured with the water displacement method.

Figure 1. Serum bottles used for the anaerobic digestion process.

RESULTS & DISCUSSION

Table 2. Substrate Chemical Characteristics

Sample	pH	TS (g/kg)	VS (g/kg)	COD (g/L)	TN (g/L)	Lipids (as %VS)	Carbs (as %VS)	Protein (as %VS)	NH4-N (mg/L)	C/N
WW	6.5	3.4	2.4	2.1	0.7	46	0	53	5.7	3.2
FW	4.48	86.2	81.9	145.0	27.7	17	35	48	57.85	5.2
FOG	5.69	1000	1007.	1684	0.0	99	0	0	0	N/A
A	4.29	341.2	339.6	165.0	17.5	67	4	29	50.65	9.4
B	4.29	491.6	490.6	329.5	14.3	86	2	11	45.5	23.0
C	4.27	810.8	813.0	371.5	7.7	93	0	7	109	48.6
D	4.36	945.3	945.3	129.0	0.3	80	0	20	11.5	409
E	5.71	470.6	470.4	168.5	0.6	85	0	15	11	306
F	2.33	46.9	46.2	16.8	0.3	62	0	38	3	61.1
G	3.5	27.8	26.2	22.3	4.4	11	23	67	46.35	5.1
H	4.06	47.7	45.5	64.5	13.9	15	24	61	43	4.6
I	4.1	181.2	51.3	94.5	19.1	20	32	48	59.5	4.9
J	3.92	245.7	245.2	124.2	13.8	63	2	35	62	9.0

Table 2 shows the characteristics of the substrates tested. The substrates had considerably low pH except WW which had a pH of 6.5. As expected, the samples containing FOG had significant high lipid concentrations while the samples containing WW and FW were mostly rich in proteins and carbohydrates. Although literature recommends a C/N ratio between 15-25, there was a wide range (3.2-410) of C/N ratio of samples. C/N ratios outside the recommended range did not affect biogas production in this study.

Figure 2. Biogas production from the samples

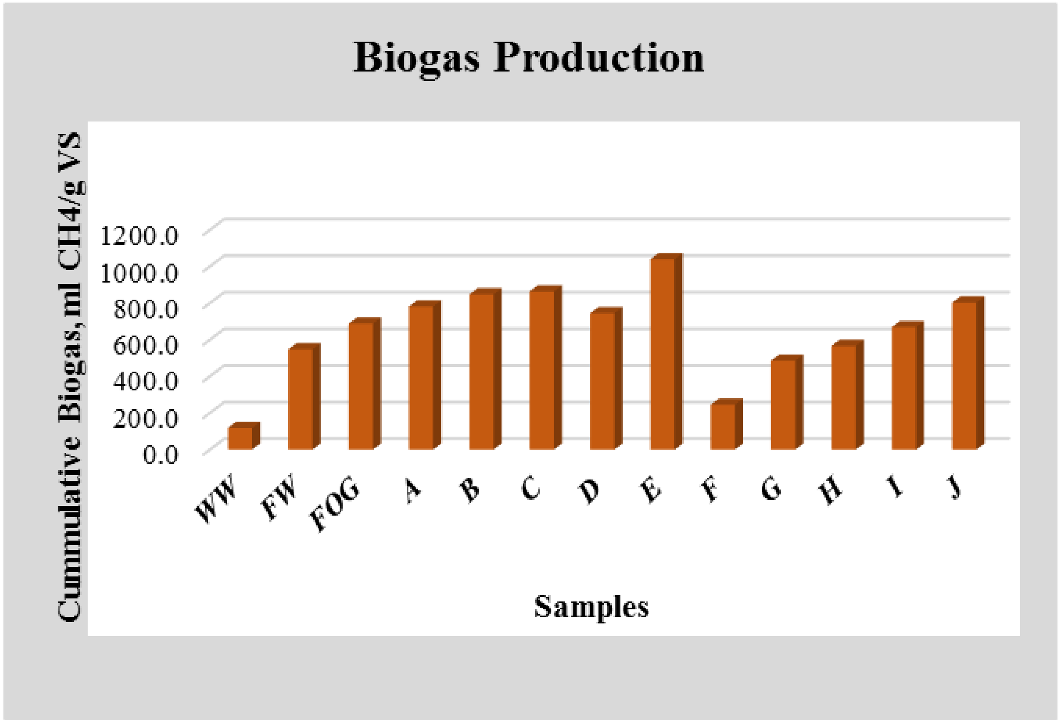


Figure 2 shows the biogas production form the samples tested over the digestion period. Sample E (50% WW + 50% FOG) which was also (85%lipid+ 15%proteins+ 0%carbohydrates) had the highest biogas yield of 1040ml CH4/g VS while the mono digestion of wastewater, WW, produced the least amount of biogas, 118ml CH4/g VS. Also, samples with more than 60% lipid concentration had comparable high biogas yields.

Figure 3. Distinct Biogas Production Curves Observed

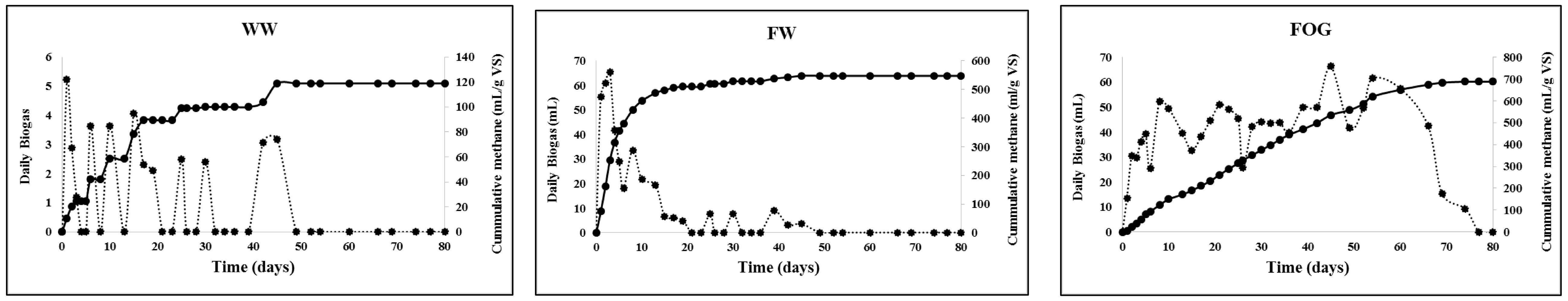


Figure 3a. The biogas production curve observed in WW was characterized by an irregular curve with significantly low biogas yield which demonstrates that the sole digestion of WW may not be economically attractive for WWTPs. Hence, the need for additional co-substrates with high biogas potential.

Figure 3b. The biogas production curve observed in FW was characterized by an uninhibited curve which plateaued after 10days of digestion with most of the biogas produced within the first 10 days of digestion. This shows that FW is a highly digestible substrate.

Figure 3c. The biogas production curve observed in FOG was characterized by a sigmoidal shape which indicated an initial inhibition caused by potential accumulation of long chain and volatile fatty acids during the digestion of lipid-rich substrates.

Spearman's Rank Correlation Results

Table 3. Spearman's Rank Correlation Results
**Correlation is significant at 0.01 *Correlation is significant at 0.05

	Biogas	VS	COD	Lipids	Carbs	Protein
Biogas	1	.742**	.780**	.709**	-0.226	-.748**
VS	.742**	1	.890**	.879**	-0.414	-.933**
COD	.780**	.890**	1	.802**	-0.191	-.872**
Lipids	.709**	.879**	.802**	1	-.686**	-.982**
Carbs	-0.226	-0.414	-0.191	-.686**	1	.580*
Protein	-.748**	-.933**	-.872**	-.982**	.580*	1

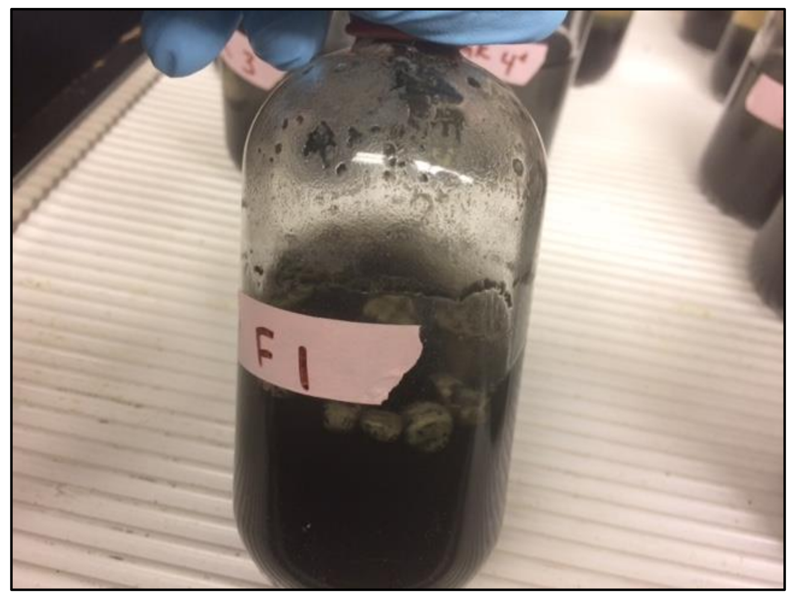
Table 4. Interpretation of Spearman's Rank Coefficient

Spearman's coefficient Scale :+1 (perfect positive) to -1(perfect negative)	
Coefficient	Interpretation of Coefficient
0 - 0.19	very weak
.20 -.39	weak
.40 -.59	moderate
.60 -.79	strong
.80 - 1	very strong

As seen in **Table 3**, the correlation results showed that VS, COD and lipids had a strong positive correlation with biogas production while Proteins had a strong negative correlation with biogas production. Meanwhile, carbohydrates had a weak positive correlation with biogas production. This makes FOG a better choice of co-substrate for WWTPs who desire to increase their biogas production.

RESULTS & DISCUSSION cont'd

Figure 4. Severe Inhibition Observed in Sample F



As previously discussed, the addition of lipid-rich substrate such as FOG can significantly increase biogas yield when co-digested with WW as observed in Sample E (50% FOG +50% WW). However, during this study, although lipids-rich samples yielded high biogas, a unique phenomenon was observed in Sample F (25%FOG +75% WW). Some foam/grease balls formed in those digesters which made it yield the lowest biogas production in the co-digestion set. This means that the influence of lipids can be either beneficial or inhibitory and hence, there is a need for further exploration of the effect of lipids on anaerobic co-digestion.

CONCLUSIONS

1. The addition of FOG increased the biogas potential of WW by 10fold when it was digested in the ratio of 50%FOG and 50%WW. However inhibition was observed when the same substrates were digested in the ratio of 25%FOG and 75%WW.
2. VS, COD and lipids have a strong positive correlation with biogas production while proteins have a strong negative correlation with biogas production. Carbohydrates are weakly correlated with biogas production.

FUTURE STUDIES

- The mechanisms of lipid inhibition needs to be further explored.
- The findings from this study must be ascertained using different organic substrates and other mixing ratios should be tested.

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