Optimization of Food and Garden Waste Co-digestion with Different Pretreatments for Biogas Production Potential

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Abstract. Methane, a strong greenhouse gas, is released when food and garden waste (FGW) are not disposed of in a structured and sustainable manner. The goal of this study is to assess the biogas potential with equal proportions of garden waste (GW) and three different food waste (FW) digested in mesophilic conditions by anaerobic co-digestion (AcoD). The feedstock consists of GW and three different FW with rice as major, along with lentils with vegetables (VFGW), leafy vegetables (LFGW), and chicken (CFGW). The feedstock is also subjected to various pretreatment procedures, namely thermal at 100 °C for 30 minutes and mechanical (press extrusion). The thermal pretreated LFGW feedstock produced the maximum biogas, followed by CFGW and VFGW that had undergone conventional digestion without any treatment with 444, 185, and 168 mL/g VS fed, respectively. With conventionally digested LFGW feedstock, abnormal biogas generation was seen, which may have been caused by incorrect reactor installation. Pretreated feedstock produces two times more biogas than conventional digestion. The highest biodegradability for LFGW was achieved with thermal pretreatment, which made the reactor-ready organic matter available by the disintegration of the feedstock. Understanding the outputs by pretreatment of the feedstock envisages its potency for efficient biogas generation, making it an effective waste management strategy.

Keywords: Anaerobic co-digestion · Food and garden waste · Pretreatment · Biogas · Waste management

1 Introduction

Anaerobic co-digestion (AcoD) is the most effective technology for the appraisal of ‘waste to energy,’ especially two different organic wastes. This technology has drawn much attention in recent years since it recovers energy as biogas, which can be used for energy purposes [1]. The technological and scientific community is currently concentrating on developing novel process optimization techniques to handle various types of organic waste.

According to a global assessment, 33% of the food produced is wasted, amounting to more than one billion tons, making up a significant component of municipal solid waste

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[2]. Due to the variety of sources from which it comes, food waste (FW) has complicated characteristics and is influenced by geographical location and climatic circumstances. Also, it releases a significant amount of greenhouse gases (21 times as much carbon dioxide, a potent greenhouse gas), which seriously threatens their control [3]. Also, garden waste (GW), one of the leading waste contributors, has an almost similar potency to FW, which can be used with AcoD for biogas production, a precious option.

A few nations have used AcoD of FGW with positive outcomes for methane production. There are still significant challenges when handling FW, particularly system stability [4]. Methanogenesis restricts the anaerobic digestion of leftovers with low cellulose contents because a high concentration of readily biodegradable organic matter results in a high synthesis of volatile fatty acids (VFA) that can prevent further methane conversion [5]. In continuation, lignocellulosic waste, such as leaf waste from gardens and agricultural waste, can optimize the co-digestion process with food waste. The interaction of these residues enhances the material's qualities, such as the C:N ratio, which enhances the effectiveness of the biological treatment [5–7].

A standard method for assessing the production of biogas from the biodegradation of a particular kind of waste is the biochemical methane potential (BMP) test. This method aids in investigating operating conditions optimization and aims to expand the scope of the process's use [8]. The introduction of a potent feedstock into the anaerobic system is the primary reason why anaerobic co-digestion (AcoD) is evolving with this process. Different co-digestates such as leaf waste, rice and wheat straw, and agricultural residues used in the studies with various pretreatments are in the picture for optimizing the feedstock and treatment process [6, 7]. Furthermore, due to their unique features based on complexity and availability, different feedstocks require different treatments.

In this context, this research aims to assess the potential for methane production from AcoD of FGW and determine whether pretreating increases methane production.

2 Materials and Methods

2.1 Inoculum and Substrate

Anaerobic digester sludge (ADS) from a biogas plant's anaerobic reactor served as the inoculum. FW is the leftovers of meals provided in the university mess gathered for three distinct FW using stratified random sampling. After being gathered up, it was then shredded, homogenized, stored, and frozen at -20 °C. The leaf clippings gathered from the university's lawn mowing made up the garden waste (GW). Following collecting, GW was allowed to dry naturally for five days in a protected space before being shredded. The FW of three different compositions is taken in this study for co-digestion along with GW. Rice, the dominator with lentils and vegetables, leafy vegetables, and chicken and garden trimmings, are given as VFGW, LFGW, and CFGW, respectively.

Pretreatment. The substrates underwent a 30-minute heat treatment at 100 °C called thermal pretreatment. Using the presser equipment, the substrate was press extruded to create the extruded sample by mechanical pretreatment. The instrument is a straightforward cylinder-piston design with a stainless-steel perforated bottom with a 2mm diameter. Substrates were placed in the cylinder and manually compacted using a piston, which caused the substrate to undergo compression and extrusion through the perforations for sample distortion by size reduction. The extruded substrate and water squeezed from it were collected and used for subsequent experiments.

2.2 Experimental Setup

A 125 mL capacity conical flask is used as a laboratory scale reactor, where tests were carried out in batches (Fig. 1). Glass tubes for gas outflow and rubber stoppers were used to close the borosilicate glass reactor. Glass tube was positioned above the slurry to catch all of the gas. The reactors were operated at room temperature with a constant adequate capacity of 100 mL, or 80% working volume. The daily water displacement technique monitors the reactors' biogas generation, where the amount of water escaping equals the biogas created. Once every day, the reactor was physically shaken and spun. The experiment was run until the biogas production stopped, typically taking a fortnight.

2.3 Analytical Methods

Temperature, pH, total solids (TS), volatile solids (VS), organic carbon (OC), carbon (C), nitrogen (N), C/N ratio, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and volatile fatty acids (VFA) were analysed before digestion to see whether the characteristics are optimal for AcoD. All analytical values were calculated using the procedures described in the standards for water and wastewater analysis [9]. A digital pH meter with a combination electrode (Systronics, 2011) was employed to measure pH and temperature. To determine TS and VS, samples were dried in an oven (ILE make, 2008) and a furnace (ILE make, 2011) at temperatures of 105–110 °C and 500–550 °C, respectively. C and N levels were determined using a CHNS elemental analyzer. The C and N of the substrate were measured using an elemental analyzer (Flash EA Thermo at NCSCM, Chennai). For the quantitative determination of the contents of C and N, the relative standard deviations were 0.03% and 0.02%, respectively. Titrometry was used to compute the BOD and COD [9].

The following techniques assessed the feedstock samples' composition: high-resolution scanning electron microscope (HR-SEM) (Thermosceintific Apreo S) for textural and structural images. After digestion, the substrate's biodegradation was evaluated using the OC decomposition percent [10]. The phenomenon described by [11] was used in this investigation to determine the percentage of OC. Equation 1 was used to calculate the substrate's rate of biodegradation.

$$\%\, degradation = ((OC_{bd} - OC_{ad})/OC_{bd}) * 100 \tag{1}$$

where, bd- before digestion and ad- after digestion.

3 Results and Discussions

3.1 Characteristics

Moisture Content (MC) of various FW samples varied from 68–73%, with vegetables comprising the highest and meat the lowest. The pH value ranged from 4.61–6.11 as meat is on the neutral side, whereas vegetables at the acidic side. The values of destructible

Table 1. Characteristics of the feedstock.

Parameter	Unit	Inoculum	FW			GW
			VFW	LFW	CFW	
pH	NA	6.92	4.61	6.04	6.11	--
Temp	°C	35.1	32.4	31.9	36.3	--
TS	%	6.70	15.21	7.6	7.51	82
VS	% of TS	2.61	5.08	7.2	5.24	73
VS/TS	%	38.95	33.42	94.78	69.76	89.02
Moisture content	%	--	73	71	68	--
Ash	%	--	7.6	3.71	3.8	--
Organic carbon	%	--	18.57	52.66	38.76	46
Carbon (C)	%	--	40.5	40.5	41.5	50.54
Nitrogen (N)	%	--	1.8	1.7	2.2	1.79
C/N	NA	--	22.5	23.82	18.86	28.23
BOD	mg/L	--	70	150	164	--
COD	mg/L	--	BDL*	BDL*	BDL*	--

*BDL- Below detection limit

dry solids were 7.60–15.21%, and solids after the ignition were 5.08–7.2% of TS for FW samples, whereas 6.70%, 2.61% of TS for ADS, which is inoculum and 82%, 73% of TS to GW respectively. The oxygen demand of FW assorted from 70–164 mg/L while the C/N ratios ranged between 18–24, and ash content varied from 3.71–10.14%.

No colour change is obtained during titration for COD, indicating its absence or below the detection limit in the samples, as mentioned in Table 1.

3.2 Biochemical Methane Potential

The experimental setup at the laboratory scale for three different FW samples with GW, i.e., a total of 9 AcoD reactors was monitored daily for a fortnight (Fig. 1). All the figures with different pretreatments shown in the study are given as daily biogas production (part(a)) and cumulative biogas yield (part(b)) in the Figs. 2, 3 and 4 in the following sections. LFGW, when it is subjected to the conventional AcoD, an abnormality was seen in the reactor, which in this study, we considered a setup error and stopped that reactor for further studies. This can be the limitation of the current study, where a comment can't be made on that specific feedstock with other treated feedstocks. Apart from that, conventional AcoD resulted in 168 and 185 mL/g VS_{fed} for VFGW and LFGW, respectively (Fig. 2). Thermally pretreated feedstock AcoD resulted in a different biogas yield of 70, 444, and 75 mL/g VS_{fed} for VFGW, LFGW, and CFGW, respectively (Fig. 3) which needs to be seen further for a reason behind leafy vegetables excellent biogas yield. Extruded (mechanically pretreatment) feedstock's AcoD resulted in 70, 65, and

122 mL/g VS_{fed} for VFGW, LFGW, and CFGW, respectively, to be intreating biogas yields from different substrates with different pretreatments (Fig. 4).

The generation of biomethane is also increased when GW is Combined with FW after thermal pretreatment [6]. This increased digestion efficiency is also impacted by mild temperatures [12]. Combining these feedstocks as FGW in equal proportions and thermal pretreatment increased the biogas significantly more than the control in this study, which is 444 mL/g VSfed, slightly more than the above-referred studies. In addition to the rise in biogas output, pretreatment has significantly lowered solids degradation [13]. The OC% degradation of all the reactors is a little less side than the conventional due to the little complexity altering through extrusion (Fig. 5).

The most popular technique for particle size reduction, promoting hydrolysis, increasing organic loading, and improving the system reliability of AD for methane is mechanical pretreatment by extrusion [14]. By breaking its structure, extrusion treatment increases the surface area of the substrate. Extrusion technology enhances biogas production from complicated organic waste, such as wheat straw [15]. Even though the extrusion results in more disintegration, the complexity of the feedstock dominated as GW in the AcoD process resulted in less biogas yield. Studies gave a significant increase in the feedstock's surface area which may affect AcoD.

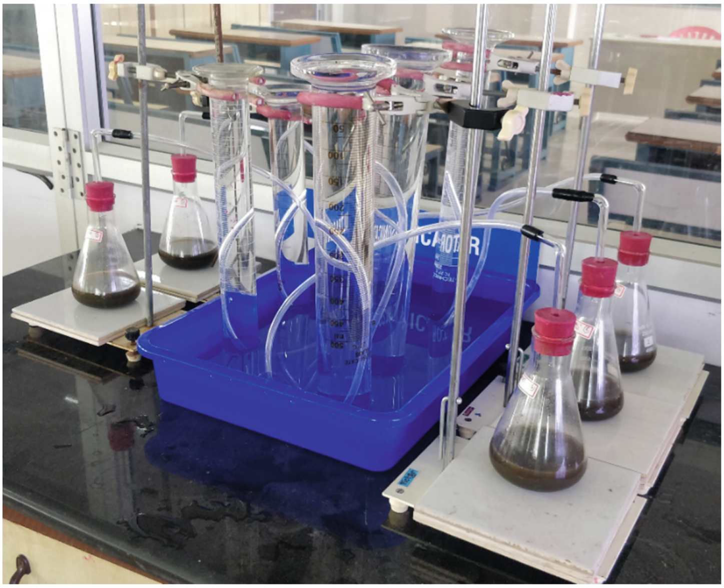

Fig. 1. Experimental setup.

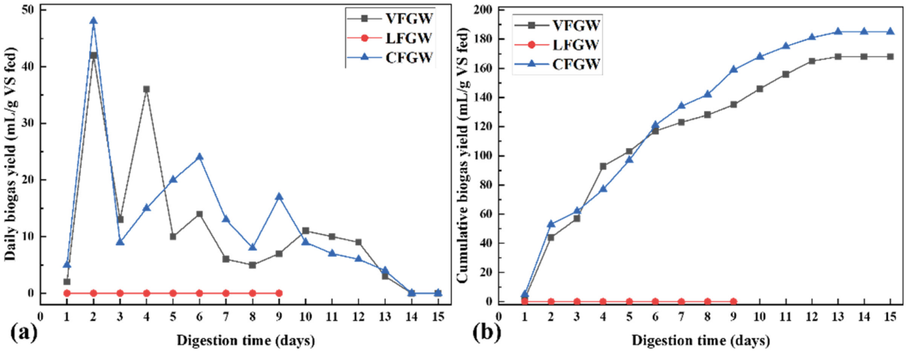

Fig. 2. Daily and cumulative biogas yield of conventional AcoD.

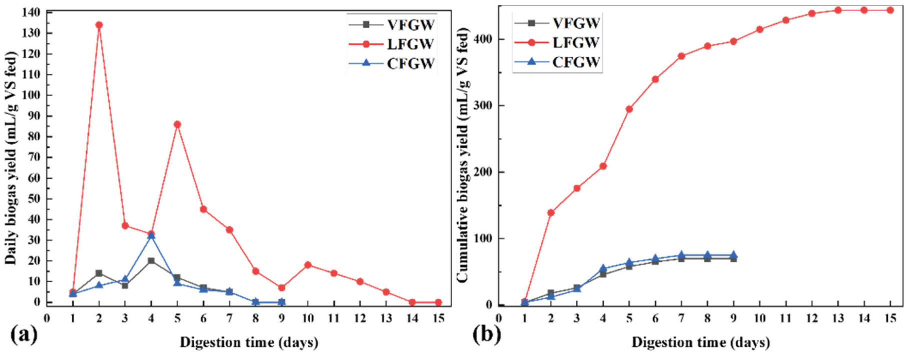

Fig. 3. Daily and cumulative biogas yield of conventional thermal pretreated (T) AcoD.

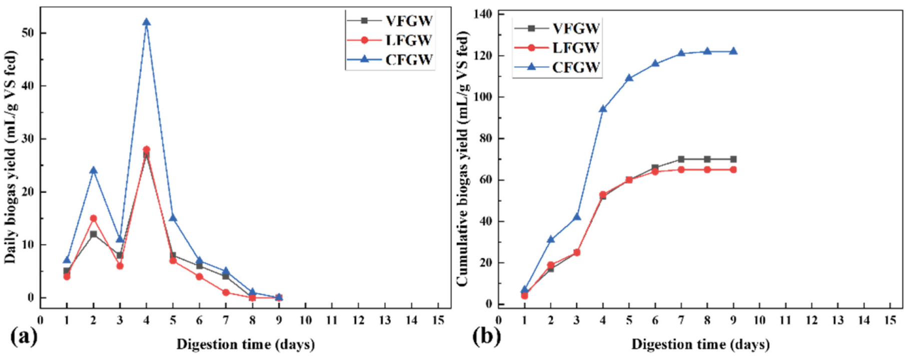

Fig. 4. Daily and cumulative biogas yield of conventional extruded (E) AcoD.

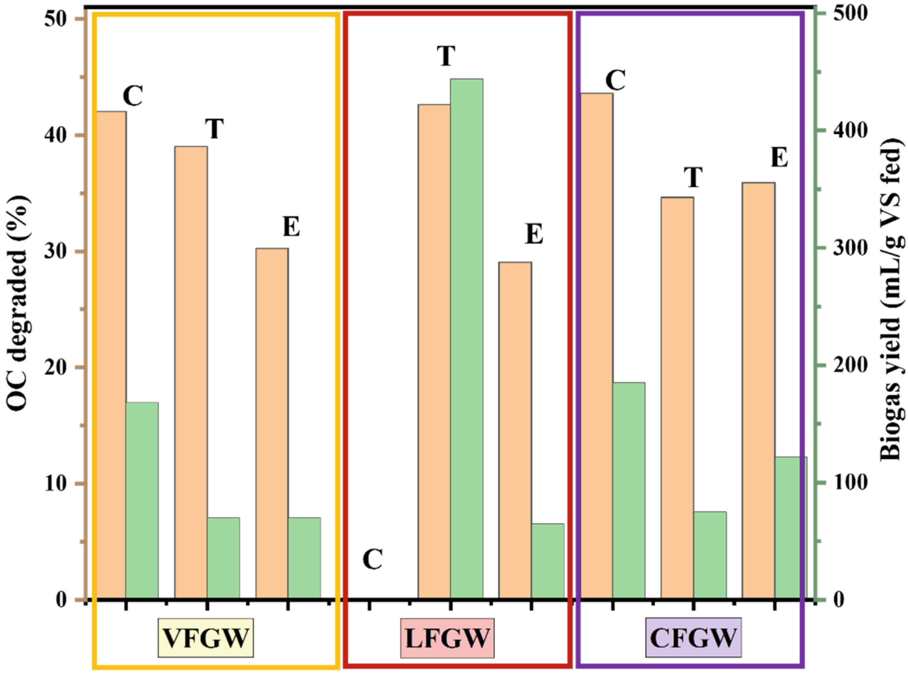

Fig. 5. % OC degradation vs. biogas yield of different feedstocks with different pretreatments.

4 Conclusion

By assessing the tested parameters for the biochemical methane potential, it was found that the only substrate that produced more cumulative methane was the thermally pre-treated LFGW with a cumulative biogas generation of 444 mL/g VS fed. The next major methane production was presented by extruded CFGW followed by conventional co-digestion of VFGW. The mechanical pretreatment method of extrusion has not demonstrated any appreciable methane production. This may be connected to GW's more challenging lignocellulosic compound degradation. Further research on various feedstock types with various pretreatment techniques to speed up biodegradation and, as a result, methane production would be fascinating.

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