Optimization of Biogas Yield through Co-digestion of Cassava Biomass, Vegetable and Fruits Waste at Mesophilic Temperatures

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Received: 09.02.2019 Accepted:17.03.2019

Abstract- Biogas is a mixture of gases mainly methane and carbon dioxide, it is considered a clean and renewable form of alternative energy. It can be obtained through fermentation of any biomass in the absence of oxygen called anaerobic digestion. The objective of this paper is to obtain the optimum biogas yield through co-digestion of cassava biomass, vegetable and fruits at different ratios in a single stage fed-batch anaerobic digester for biogas production. The physical pre-treatment of the both substrates was by milling the feedstock into small pieces prior to anaerobic fermentation. Anaerobic digestion of the mix of cassava biomass and vegetable & fruit was investigated in a 600 ml digester for 31 days under mesophilic condition (37ºC). Bio-methane potential of cassava biomass co-digested with vegetable & fruit ranged from 1124.26 to 1641.82 mL CH_4/g VS. Co-digestion of CB and V&F with inoculum at ratio of 40:60 achieved the maximum methane yield of 1641.82 mL/g VS which was 23.08% higher than that of the mono-digestion feedstock.

Keywords Anaerobic digestion; Gompertz model; Performance Index; Mon-digestion; Vegetable & Fruit.

1. Introduction

The increase in urbanization and human population growth has resulted in an increase of demand for services such as electricity and waste management [1-4]. According to FAO (2017) in South Africa urban population (65.8%) is approximately twice the rural population (34.2%) as indicated in Figure 1. In 2012, the urban had an approximately 63.3% and rural 36.7%, this figure shows an increase of 2.5% between 2012 and 2017. Though the increase seem insignificant it is important that the government prepares for the growth well in advance. The population growth implies that the energy demand for both urban and rural communities will also be on the increase [1, 5].

Presently, most rural municipalities power most of the communities under their jurisdiction using candles, paraffin's as well as fire gel. It is reported that in 2016, about 16.6 million households make use of candles for lighting. Based on available statistics, over 86 500 poor households have access to free paraffin in 20 municipalities. Majority of these communities are concentrated in Eastern Cape and Northern Cape, with two municipalities in North West. These sources of energy are not clean and cost effective. They can simply be replace by electricity from biogas [6].

The main source of energy generation in South Africa is coal. It accounts for approximately 74.8% of energy mix [7]. This however, is not environmentally safe. With the increase in urban population still half a million people within South Africa still do not have access to electricity within their homes [8]. According to Brown [9] home with no electricity to meet their cooking demands have to rely on fuelwood/firewood and that has been an hindrance to development in those areas.

Biogas that forms part of the renewable energy is being mostly used in developed and some developing countries such as Asia to meet some of the energy needs [10-12].

South Africa could make use of renewable energy to reduce the dependence on fossil fuels which have both health and environmental consequences.

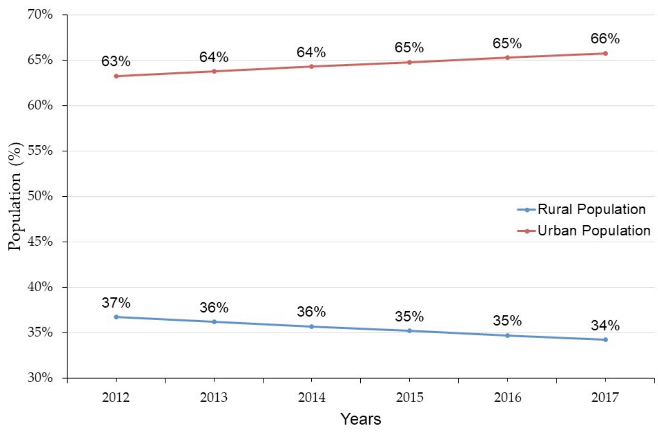


Fig. 1. Rural and Urban Population from 2012 to 2017 [13]

According to Quadrelli and Peterson [14] South Africa is grouped among the top emitters of Green House Gases (GHGs) worldwide [3]. Therefore, there is need for South Africa to decrease its carbon intensity. In the process of decreasing the carbon intensity, the country will be fully and simultaneously exploring renewable energy and improving the life of the citizen of the country [2, 15]. Table 1 shows some of the areas in which biogas has been applied in South Africa. Energy crops are considered to be traditional agricultural crop grown typically normally for food, however due to the crop characteristic it has been considered for energy production [16]. However, there has been agitation on the use of energy crop for energy generation because it may affect the food chain and access to food. In order to mitigate conflict of interest caused by this agitation, the waste products or non-edible parts of energy crop can be used for energy generation, while the edible parts can be used for food production. Alternatively, the growing of energy crop on marginal land can be encouraged, therefore making the crop unsuitable for food crop production. Though the production of energy crop like cassava is low in South Africa, using it as capping crop for landfill would enable the use of it for landfill would enable its planting on landfills for the sole purpose of energy generation.

This is because the landfill capping crop has low biodiversity and economic value as there is high risk of the cassava absorbing toxic trace element which could pose health risk to human. Cassava biomass has many benefits such as biogas production, since it contains large amount of fermentable sugar [17].

The chemical and physical characteristic of feedstock plays an important role in the anaerobic process [18-20]. Therefore, the performance of the digester and the quality of the biogas yield is influenced by the composition of the substrates used. As regards this research area little research has been conducted in South Africa. The aim of this study is therefore to determine the biogas yield of mono and co-digestion of vegetable & fruits and Cassava in a control mesophilic environment by means of batch reactor. This study determines the optimum biogas yield of cassava through co-digestion.

Table 1. Location of Biogas Application in South Africa [21]

Application	Location	Discussion
Agricultural	George	Private client using biogas to supply energy at their farm
Sewage Treatment Works	Elim	Biogas generated using sewage treatment works and the dairy farm
Industrial	Cape Flats	Treatment of sewage sludge and generated biogas used for heating of the digester.

2. Materials and Methods

2.1. Cassava Biomass and Vegetable & Fruits waste collection

The cassava (*Manihot esculenta Crantz*) biomass (CB) (200 kg) used for this study were obtained from cassava plantation in the *"Nampula"* province of Mozambique, while the Vegetable & Fruits waste (VF) (200 kg) were obtained from farm in a small town "Verulam" in KwaZulu-Natal. Both substrates were collected into a plastic bag and stored in a refrigerator at 4 ˚C to preserve the freshness [22, 23]. The physical characteristics of the used substrates are presented in section 3 (Results and Discussion).

2.2. Inoculum

The inoculum used for this study was fresh cow dung (CD) which was collected from *"Ukulinga"* Research Farm, Pietermaritzburg, South Africa. CD was used because of its high buffering capacity including its richness in the required microbes that is essential for the anaerobic digestion process. The CD used was characterized and results presented in section 3 (Results and Discussion).

2.3. Substrate Preparation

The cassava biomass

Approximately one hundred kilograms (100 kg) of the collected fresh cassava tuber was mechanically pre-treated by peeling, while the remaining 100 kg of the fresh cassava was stored for later use. The peeled cassava was washed with tap water and chopped into pieces of about 1 cm^3 using a sharp knife after which it was sundried for 2 days. The sundried cassava biomass were milled with a scientific Republic of South Africa (RSA) hammer mill that is equipped with a 1 mm sieve mesh to obtain the cassava flour. The prepared milled cassava biomass were stored in a refrigerator at 4 ˚C until use. The properties of the substrates are shown in section 3 (Results and Discussion).

The Vegetable and Fruit Waste

The collected vegetable and fruit waste was collected randomly different parts of the volume to be sampled. Sampling of the fruit & vegetable was done following the suggestion of Sitorus and Panjaitan [24], whereby the waste were taken based on the grab sampling method with the feedstock composition having a ± 80% vegetable waste and a ± 20% fruit wastes (Figure 2). A total of 160 kg were collected after which these samples were mixed together. Coning and quartering method was used to reduce the size of the mixed samples. The samples were dried at 60°C in an oven until constant weight. Milling was performed with a scientific RSA hammer mill to reduce sample particle size to < 1mm after which a laboratory blender were used for size reduction. The prepared samples were labelled and packed in plastic sample bags and stored at 4°C for analysis.

Fig. 2. Vegetable and Fruit

Cow Dung Inoculum

Fresh Cow Dung (CD) collected from *"Ukulinga"* Research Farm was used as an inoculum to start up the experiment (Figure 3). The sample of CD was collected in sterile plastic bags and was kept in an airtight container at 4 °C; prior to use. Before utilization the CD was acclimated and degassed at 37 °C for 1 weeks to minimize the production of methane from the inoculum [25, 26]. The inoculum was prepared by soaking CD with deionized warm water to a of 1:1 ratio (Figure 3B). It was thereafter sieved through a cloth of 0.5 mm to separate the solid content from the slurry. The characteristics of the substrates used in this study (i.e. CB, VF and CD) are shown in section 3 (Results and Discussion).

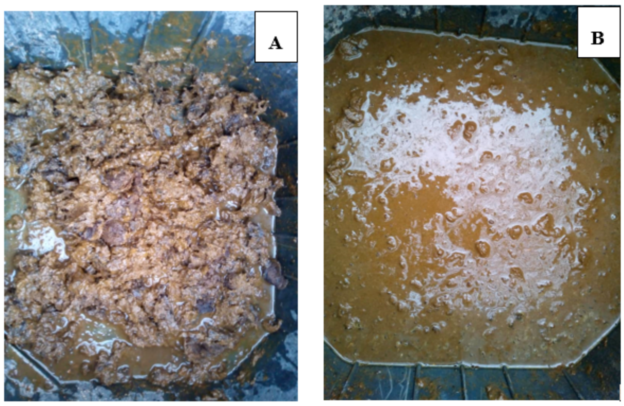


Fig. 3. Cow Dung from Ukulinga Research Farm A) sampled cow dung, B) cow dung with deionized water

2.4. Experimental set-up

A batch system configuration was used when conducting bio-methane potential (BMP) for this study. The study was conducted under controlled conditions at mesophilic temperature 37˚C ± 0.5. Four experimental design which consist of four (4) ratios namely 100:0, 60:40, 40:60 and 50:50 as shown in Table 2 were used and three runs were conducted. The BMP was conducted in a 600 ml SCHOTT DURAN® glass laboratory bottles (bio-digesters) (Figure 4). The bio-digester was filled to 96% of its capacity [27], which signifies 480 ml working volume. The bio-digester was submerged into a water bath to which it had a heating element to keep the water bath at constant temperature of 37˚C ± 0.5 for the duration of the experiment [27, 28].

A total solid 8% [29] was used to obtain a better biogas yield. This was achieved by mixing feedstock with tap water to get to the 8% TS. The amount of water to be added to the feedstock was calculated using the below formula:

$$Amount\ of\ water = \frac{A}{B+C}$$

Where:
A = Mass of fixed total solids
B=Mass of fresh Cassava Biomass + Mass of Vegetable & Fruits waste
C=Mass of water to be added to achieve 8% total solids in digester

Table 2. Biochemical Methane Potential Experimental Design

Digester	Mix Ratio		TS of CB (g)	TS of VF (g)	Contents of the digester				Total Volume (mL)
					Amount of Fresh Substrate		Amount of Water added (mL)	Amount of Inoculum added (mL)	
	%CB	%VF			CB (g)	VF (g)			
R+	-	-	-	-	-	-		480	480
A+	100	0	30.5	0	32.64	0	347.36	100	480
B+	60	40	18.3	12.2	19.58	29.33	331.086	100	480
C+	40	60	12.20	18.30	13.06	43.99	322.954	100	480
D+	50	50	15.25	15.25	16.32	36.66	327.02	100	480
E+	0	100	0	30.5	0	41.75	321.47	100	480
A*	100	0	30.5	0	32.64	0	447.36	0	480
B*	60	40	18.3	12.2	19.58	29.33	431.086	0	480
C*	40	60	12.20	18.30	13.06	43.99	422.954	0	480
D*	50	50	15.25	15.25	16.32	36.66	427.02	0	480
E*	0	100	0	30.5	0	41.75	421.47	0	480

CD: Cow Dung, CB: Cassava Biomass, VF: Vegetable & Fruit waste, R: bio-digester, A* - E*: No inoculum added, R+: control (Inoculum only) and A+ – E+: inoculum added

After preparing the substrate and the inoculum the bio-digesters were filled up with the feedstock (inoculum and substrates) as per Table 2 above. The pH was measured using and adjusted were necessary to pH 7 using 1M sodium hydroxide (NaOH) before the commencement of the anaerobic digestion process. Liquid displacement method was used to measure the biogas yield (Figure 4).

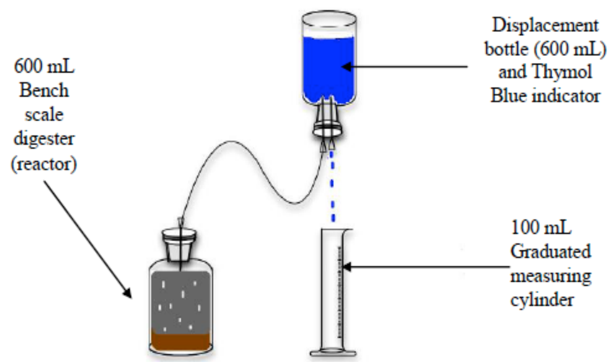


Fig. 4 Schematic diagram of experimental laboratory set [30]

2.5. Experimental procedure and Analytical methods

The bio-digesters were flushed with nitrogen gas for 2 minutes by removing all dissolved oxygen and to set anaerobic conditions and thereby sealing the bio-digester bottles with a plugged with tight rubber plugs to prevent escape and inflow of gas into the bio-digester. To prevent scum accumulating and achieving homogeneity in the bio-digester it was manually shake twice a day at 1pm and 5pm daily.

All the bio-digesters were inoculated with cow dung except for digester A* to D* as shown in Table 16. A 100 ml inoculum was used on digester A^+ to E^+. A blank digester filled with inoculum and water was used as a control digester (R^+). The control digester consisted of 100 ml inoculum and 380 ml water. This served as a control bio-digester which will form the baseline for all the other co-digestion.

Digester B^+ which consisted of a 60:40 (CB:VF) ratio 160 ml of VF was inoculated with CD, C^+ was feed with 160 ml CB and inoculated with CD, while lately D^+ was filled with 80 ml VF and 80 CB and 240 ml CD. Digesters A^+, E^+, A* and E* consisted of mon-digestion were A+ and E+ had CB (100:0 ratio CB:VF) only with inoculum added while A* and E* has VF (0:100 ratio CB:VF) only with no inoculum added. The BMP experiment was carried out for a duration of 40 days before it was terminated.

The total solids (TS) and volatile solids (VS) in the feedstock and inoculum were analysed using standard techniques at the beginning [31, 32] of the AD process and at the end of the 40 d incubation period (APHA, 2005). TS content was determined after drying the sample in an oven overnight at 105 °C. VS content was calculated as TS minus the ash content after ignition at 550 °C in a muffle furnace.

2.6. Biogas Yield Calculation

The biogas yield was measured by using the water displacement method. As the biogas is generated in the bio-digester it is transported by a plastic pipe into the displacement bottle which generates pressure within the displacement bottle thereby forcing water up into a 100 ml graduated measuring cylinder [33].

The bio-digester is kept air tight, thereby preventing the escape of biogas. The biogas produced by the co-digestion substrate was calculated by subtracting the biogas formed by the inoculum only from that of the biogas formed by the co-digestion substrate (Equation 1).

$$Y_1 = Y_{0+1} - Y_0 \tag{1}$$

Where:

Y_1 = Net Biogas Produced Daily (ml)

Y_{0+1} = Biogas Produced from co-digestion substrate Daily (ml)

Y_0=Biogas Produced from control substrate Daily (ml)

The cumulative biogas yield was calculated by summing daily yield, and then the cumulative methane yield was calculated by dividing the net cumulative methane by the mass of the volatile solid added (Equation 2).

$$X = \frac{X_1}{Z} \tag{2}$$

Where:

X = cumulative methane yield (ml CH_4/gVS)

X_1 = Net cumulative methane (ml CH_4)

Z = Mass of Total Solid added (g)

2.7. The Gompertz model

Equation 4 represents the modified Gompertz model that describes the cumulative biogas production curve in batch operated digester [34, 35], this equation assumes that the substrate levels limit growth in a logarithmic relationship [36]. The modified Gompertz Model was applied to compare the model predication and the experimental data. This model was applied on the cumulative methane yield.

$$y(t)=y_m \exp\{-\exp[(U.e)/y_m\ (\lambda - t) + 1]\},\ t\geq 0 \tag{4}$$

where:

ym = biogas yield potential (Lkg^{-1} VS),

y(t) = cumulative biogas at digestion time t days (Lkg^{-1} VS),

U = the maximum biogas production rate (Lkg^{-1} VS. day),

λ = lag phase period or minimum time to produce biogas (days),

t = cumulative time for biogas production (days),

e = mathematical constant (2.718282),

2.8. Co-digestion performance index (CPI)

The performance of combined substrates was investigated to determine the effects which maybe the dilution and/or enhancement of performance by adding valuable nutrients. These nutrients could increase the biodegradability thereby changing the microbiome to either increase the performance and/or decreasing it [37]. The optimal mixture composition between two substrates have been investigated in several studies [38, 39]. A CPI > 1 indicates that there is a synergistic effect of the co-digestion while CPI < 1 shows that there is an aggressive effect [40]. According to Ebner, Labatut [41] the co-digestion performance index (CPI) was calculated using Equation 5:

$$CPI_{i,n} = \frac{B_{i,n}}{B_{oi,n}} = \frac{B_{i,n}}{\sum_i^n \%VS_i B_{o,i}} \tag{5}$$

Where:

$CPI_{i,n}$ = Co-digestion Perfromance Index

$B_{i,n}$ = bio-methane potential of the co-digestion blend

$B_{oi,n}$ = Co-digestion blend to the weighted average ($B_{oi,n}$) based on the VS content (%VS) of the indivial sub-substrate bio-methane potential

3. Results and Discussion

3.1. Substrates and inoculum Characterisation

Table 3 shows the characterization of substrates and inoculum. Characterization is one of the most important steps in the anaerobic digestion as it gives the general composition of the substrate (feedstock). It can be used to calculate the amount and composition of the biogas produced, including the energy content in the biogas. The characterization of the substrates and inoculum shows the physical and chemical characteristics of CB, VF and CD. CD inoculum had higher TN and lower TC compared to Cassava Biomass and Vegetable & Fruits Waste. The mixture of each other could complement each other to achieve the suitable co-digestion nutrient content.

The total solid of both substrates and inoculum is between 19.84% - 93.45%, with the cattle dung having the lowest total solid of 19.84% and the CB with the highest of 93.45%. These are in contradiction to what was reported by Malakahmad, Ezlin [42] which stated that for biogas production, the solid content of the feedstock should be between 10 – 15%. The total solids content has great impact on cumulative biogas, according to Liu, et al. [43] the cumulative biogas decreases with an increase of total solids content from 5% to 10% however, the cumulative biogas further increased subsequently as the total solid increase beyond 10%.

The inoculum had the lowest carbon to nitrogen (C/N) ratio of 18.50 and cassava biomass (CB) with the greatest of 72.18. C/N ratio plays a critical role in the performance and/or yield of biogas. The C/N ratio in the anaerobic digestion should be within the optimal range of 20-30 for optimum performance of the digester [44, 45] as bacteria in the digester uses up carbon 25-35 times faster than compared to that of using up nitrogen [12]. The C/N ratios of CB and VF were above the maximum limit of 30 which is an indication of rapid consumption of nitrogen at methanogens stage which results in the low production of gas. The C/N ratio of the CD however was under 20 which causes accumulation of ammonia and increase in pH level which becomes toxic to the methanogenic bacteria [46-48]. Therefore, co-digestion could be used to balance substrate with high C/N ratio using substrate with low C/N ratio such as cattle manure which are easy available and suitable for renewable energy [49]. Vegetable waste has significant limitation due to its rapid acidification as a result of its low pH level and the high production of volatile fatty acids which affects the methanogenic activities in the digester. The moisture of all substrate CB and VF was found to be 66.15% and 58.40% respectively. This indicates that the deposal of both substrates were not ideal for landfilling and incineration due to its high moisture content [50].

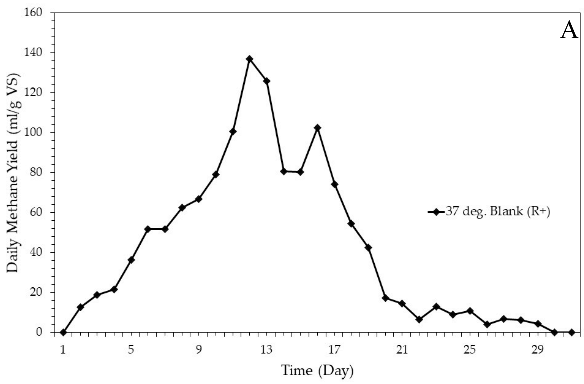
Table 3: The proximate and ultimate analyses of Cassava Biomass, Vegetable & Fruits and Inoculum

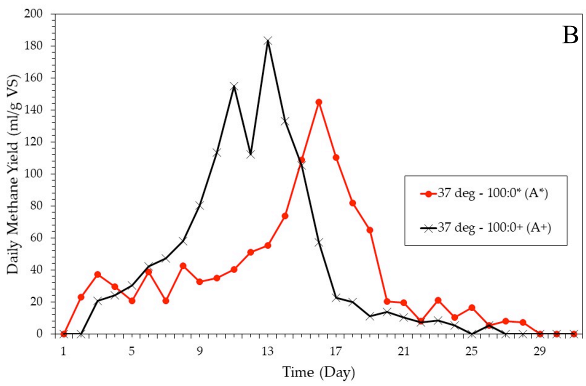
Proximate and Ultimate Analyses	Substrate		Inoculum (Cattle Dung)
	Cassava Biomass (CB)	Vegetable & Fruits Waste (VF)	
Moisture Content (%)	66.15 ± 1.01	58.40 ± 0.61	83.50 ± 0.16
Total Solids (%)	93.45 ± 0.21	41.60 ± 0.22	19.84 ± 0.51
Volatile Solids (%)	97.02 ± 0.52	76.10 ± 0.67	12.40 ± 0.57
Protein	2.35 ± 0.11	77.30 ± 0.91	-
Total Nitrogen (%)	0.55 ± 0.12	0.52 ± 0.28	2.06 ± 0.18
Total Carbon (%)	39.7 ± 0.61	39.06 ± 0.84	38.12 ± 0.81
C/N Ratio	72.18	75.12	18.50
Ash (%)	1.75 ± 0.11	9.44 ± 0.17	30.40 ± 0.15
Calcium (%)	0.02 ± 1.12	0.14 ± 0.19	0.42 ± 1.19
Starch (%)	76.32 ± 2.01	ND	ND
Sugars	77.54 ± 1.11	42.87 ± 1.01	ND

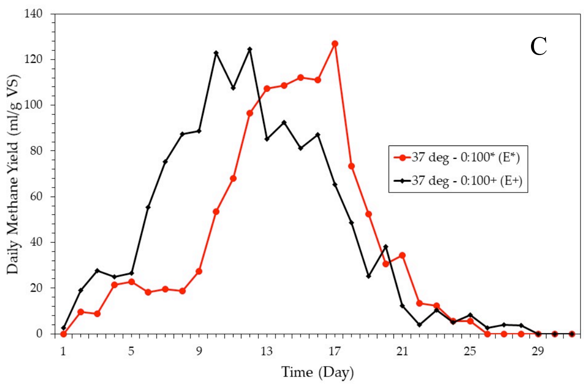
ND: Not determine

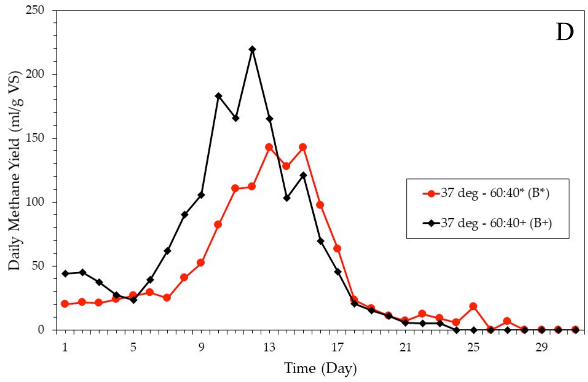
3.2. *Daily and cumulative methane yield at mesophilic (37˚C) temperature*

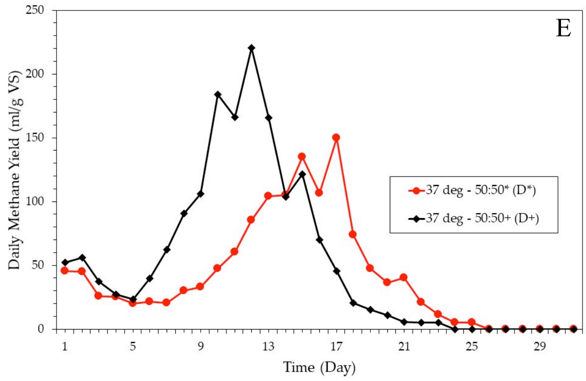
Figure 5 shows the daily methane yield of all the digesters. It can be observed that the methane yield of the blank substrate and single digestion increased gradually (Figure 5A – 5C). The co-digestion (Figure 5D – 5F) started to produce biogas on day one, with co-digestion of cassava biomass and vegetable & fruits waste without inoculum (CB: V&F) at 40:60* ratio producing the highest methane on day one of 59.68 ml/g VS. The maximum methane yield peak (220.55 mL/g VS) was reached on the twelfth day. It was reached by the co-digestion CB: V&F at a ratio of 50:50 (Figure 5E). The next highest was followed by co-digestion CB: V&F (Figure 5F) at a ratio of 40:60 (211.09 mL/g VS). The methane yield of all the co-digestion feedstock (Figure 5D – 5F) decreased significantly after day one. This could be attributed to the acidification in the batch reactors which confirms that hydrolysis and the alcoholic fermentation of the vegetables waste are rapid compared to other organic substrates [24, 51].











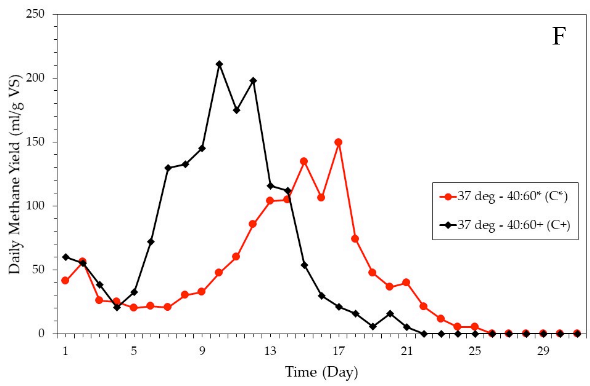
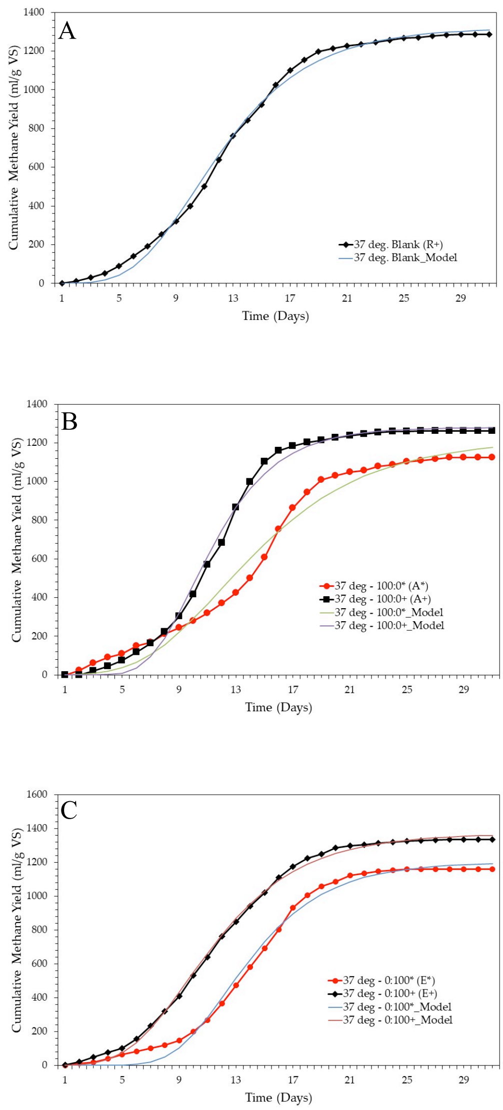


Fig. 5. Daily Methane yield at 37°C of (A) Blank no inoculum, (B & C) single digestion of Cassava tuber and vegetable & fruit, D) co-digestion of Cassava tuber and vegetable & fruit at 60:40, (E) co-digestion of cassava tuber and vegetable & fruit at 50:50, (F) co-digestion of Cassava Tuber and vegetable & fruit at 40:60, ; "+" – with inoculum, "*" – without inoculum

Figure 6 shows the cumulative methane yield (CMYs) of mono-digestion and co-digestion at different ratios. Cassava single digestion without inoculum (Figure 6B) produced the lowest cumulative methane yield (1124.26 mL/g VS) compared to mono-digestion of cassava with inoculum (1262.90 mL/g VS). Co-digestion of CB : V&F with cattle dung inoculum at a 40:60 ratio (Figure 6F) produced the highest cumulative methane (1641.82mL/g

VS) due to more available substrate, It confirms that biogas yield could be improved by co-digestion of the suitable substrate [26, 52, 53]. However, the ratio mix of the substrate is of importance as this could change the digestion process in the digester thereby changing the biogas yield and the rate [45]. When the cassava biomass ratio was reduced and the ratio of the vegetable & fruit waste was increased, the cumulative methane yield increased proportionally. The percentage increase of the cumulative methane yield of co-digestion CB:V&F (40:60) in relation to the mono-digestion of cassava at a ratio 100:0 (CB:V&F) is 13.65%. These implies that co-digestion does enhance performance of the digester for maximum yield. It should be noted that when the co-digestion of CB:V&F ratio increase from 40:60 to 50:50 the cumulative methane yield was negatively affected; suggesting that an increase of CB in relation to the V&F would reduce the methane yield. These results suggest that the suitable co-digestion proportion of CB and V&F for maximum methane yield is 40:60 as the highest methane production of 1641.82 mL/g VS was achieved.



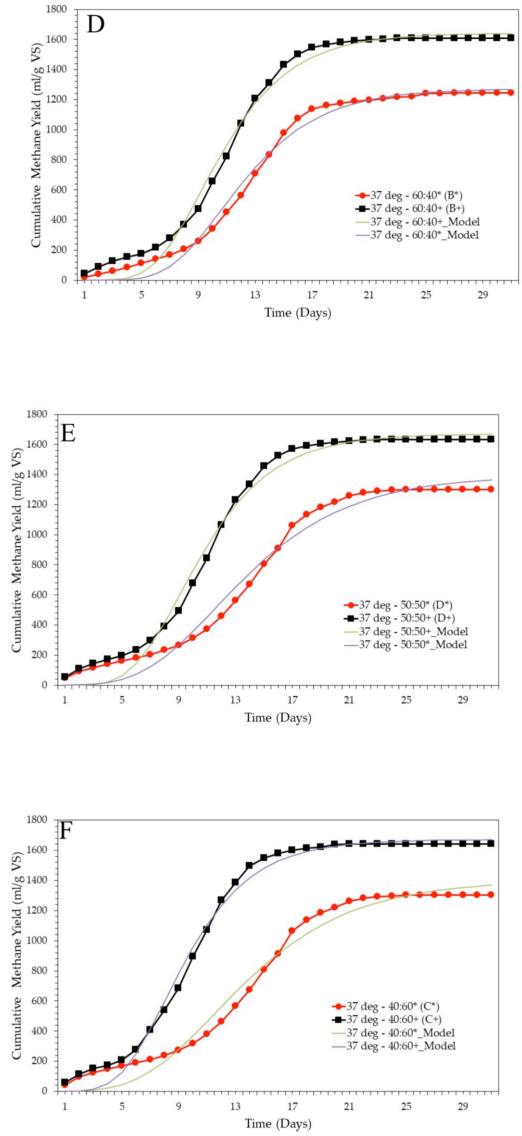


Fig. 6. Cumulative methane yields with (A) Blank inoculum only, (B & C) single digestion of Cassava tuber and vegetable & fruit, (D) co-digestion of Cassava tuber and vegetable & fruit at 60:40, (E) co-digestion of cassava tuber and vegetable & fruit at 50:50, (F) co-digestion of Cassava Tuber and vegetable & fruit at 40:60, ; "+" – with inoculum, "*" – without inoculum

3.3. *The Gompertz model*

The parameters such as ym, λ and μ of Gompertz model were obtained by fitting the equations to the experimental biogas yield data. Table 4 presents the summary of the results of both experimental and predicated biogas yield calculated using the developed coefficients at day 31. The experimental methane yield was model using Gompertz model and presented Figure 6.

These models can be used to estimate the biogas yield at any given time under a specific condition.

Referring to Table 4, the substrate of co-digestion of CB:V&F with inoculum yielded more y_m with a maximum biogas yield of 1671 Lkg-1VS compared to the other substrate, the lowest was obatined from mon-digestion of V&F without inoculum. This results confirmed the finding of Rodriguez-Chiang and Dahl [54] that inoculum improves the biogas yield of s substrates. All the substrates that were inoculumated proformed better than that without inoculum.The biogas yield from the model, predication and also measured shows that the ratio of 40:60 yielded the maximum biogas. This results confirms that vegatable and fruits has certain properties that improved the performation of digester to yield maximum biogas as reported by Phetyim, et al. [55].

Table 4. The coefficients and constants developed by fitting the modified Gompertz to cumulative methane yield data

MODEL	Digester										
	R^+	A^*	B^*	C^*	D^*	E^*	A^+	B^+	C^+	D^+	E^+
MODIFIED GOMPERTZ MODEL	Blank	100:0	60:40	40:60	50:50	0:100	100:0	60:40	40:60	50:50	0:100
λ (days)	10.36	12.01	10.63	11.53	12.53	12.38	10.03	9.27	8.10	9.16	9.62
μ (Lkg^{-1}VS.day)	0.23	0.18	0.27	0.19	0.19	0.27	0.32	0.29	0.31	0.29	0.23
y_m (L/kg VS)	1320	1216	1274	1403	1397	1199	1280	1642	1671	1671	1368
Predicated biogas yield (Lkg^{-1}VS) - 40 d	1308.6	1175.5	1268.5	1368.7	1365.2	1190.6	1278.3	1639.3	1669.5	1667.7	1358.6
Measured biogas yield (Lkg^{-1}VS) - 40 d	1287.3	1124.2	1246.2	1302.1	1300.2	1157.7	1262.9	1607.8	1641.8	1632.7	1335.7
Difference between measured and predicated biogas yield (%)	1.65%	4.56%	1.79%	5.11%	5.00%	2.84%	1.22%	1.96%	1.69%	2.14%	1.71%

3.4. Co-digestion performance Index (CPI)

From Figure 7, it can observed of this study that the CPI of the co-digested substrates range between 1.092 (for, 60:40*) and 1.264 (for, 40:60+). These show that the co-digestion of the substrate has a positive synergistic effect since the CPI is greater the one (CPI > 1). Co-digestion of cassava biomass and vegetable & fruit waste residues with inoculum showed higher methane yields (1641.82 mL/g VS) which is supported by the CPI of 1.264.

When the proportion of cassava biomass was higher to that of the vegetable & fruit waste (60:40*), the CPI decreased with the increase in the cassava biomass. Both ratios (60:40* and 60:40+) of cassava biomass to vegetable & fruit waste without and with inoculum had a CPI of 1.092 and 1.237 respectively.

The lowest CPI came from the co-digestion of CB and V&F without inoculum to a ratio of 60:40*. These results suggest that the increase in ratio of cassava biomass could negatively affect the co-digestion performance. These can also be confirmed by comparing the According to Wang [56], Yang serval factors could impact the synergistic effect, factors such as balanced nutrient composition, stimulated synergistic effects of microorganisms, an associated increase in buffering capacity, and a decreased effect of toxic compounds on the digestion process.

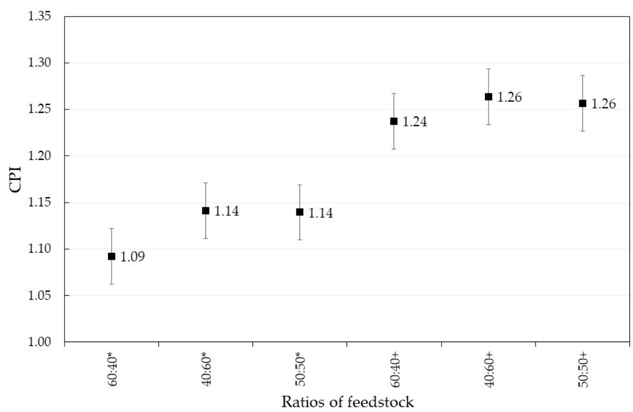


Fig. 7. Co-digestion performance index (CPI) of co-digestion at different mixture ratios, CPI > 1 indicates synergistic effect, CPI < 1 indicates antagonistic effect. Different ratios (Cassava Biomass: Vegetable & Fruits)

4. Conclusion

The determination of biogas yield of mono and co-digestion of vegetable & fruits and Cassava in a control mesophilic environment by means of batch reactor has been carried out. The characterization of the cassava biomass and the vegetable & fruit waste indicated that they have high biogas potential with the cassava biomass having a high carbohydrate. The carbon to nitrogen (C/N) ratio was significantly high with 72.18. To balance the C/N ratio, co-digested with animal manure was performed to make the C/N to be between 20 and 30. Cassava biomass co-digested with vegetable & fruit waste was successful in producing methane. Cassava biomass mono-digestion yielded the lowest methane yield. The maximum methane yield of 1641.82 mL/g VS was obtained from the mixture of CB and V&F with cattle dung inoculum at a ratio of 40:60 which was 23.08% higher than that of the mono-digestion feedstock. In conclusion, the optimal conditions for maximum yield of biogas of cassava biomass co-digested with vegetable & fruit waste were: initial pH of 6.87, ratio of CB:V&F at 40:60 and temperature at 37 °C, for maximum yield inoculum should be used to start the digestion process in the digester. This research can serve as a frontier for the development of a biogas plants location map across South Africa. Finally, before the proposed system can be adopted on a large scale, it is essential to carry out further investigation at pilot level using specific cassava tuber from landfill.

Acknowledgements

The authors thank the University of KwaZulu-Natal for the financial support during this research project.

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