Original Research Article

Biogas from different parts of a banana plant: A case study of the banana plant from Kisii county

Abstract

Bananas are the main source of stable food among the Kisii people in Kenya. Apart from the banana fruit, the other parts are usually thrown to waste although can be used in a useful manner like to generate biogas. This research sought to investigate biogas production potential from different parts of a banana plant in Kisii County, Kenya. In the study, 2 kg of banana leaves, pseudo-stem, fruit bunch stalk (FBS) and peels were collected as feed-stocks for a laboratory-scale anaerobic digester to produce biogas. The experiment was carried out in a multi-stage anaerobic digestion system operated under mesophilic temperature (30-35^{0}C). Various process parameters were measured including total solid, volatile solid and volume of biogas produced. After completion of 21-day digestion at an average temperature of 33 ^{0}C, specific Biogas yields reached were about 16.5 litres/kg (leaves), 13.5 litres/kg (pseudo-stem), 12.7litres/kg (fruit bunch stalk) and 15.1litres/kg (peels). The optimum daily production of biogas was between the 13th-15thday. Cumulatively, it was observed that after the 15th day, almost all of the biogas had been released from the digester. By doing a simple computation based on energy calculation, it was found that 61% of the energy expected from a similar quantity by other researchers. The study showed that banana leaves have highest potential for biogas as compared to the other parts.

Keywords: Biogas, anaerobic digestion, banana parts, thermal.

1.0 Introduction

Thermal energy is a very critical component of energy especially in the developing countries as it is mostly used for cooking. In developing countries, most of the population live in rural areas and depend on charcoal and wood for thermal fuel supply which requires cutting down of trees leading to deforestation (Kimberly, 2007). To reduce deforestation, there is a need to promote the use of renewable energy technologies that can provide thermal energy. Biogas is one such technology and has many advantages: it does not have any geographical limitations, does not require advanced technology and it is simple to use and apply. The promotion and use of biogas would have far-reaching benefits to rural women's lives. The time and energy used in collecting firewood or burning charcoal can be used for other productive activities. Furthermore, a clean and particulate-free source of energy also reduces the likelihood of chronic diseases that are associated with the indoor combustion of biomass-based fuels such as respiratory infections, ailments of the lungs; bronchitis, asthma, lung cancer, and increased severity of coronary artery disease.

There has been quite some significant research focused on the generation of biogas from different waste and material sources: Kitchen waste and cattle manure (R. Li *et al.*, 2009; Tamrat Aragaw *et al*, 2013; Suyog Vij, 2011; Lusk, 1997), Apple waste, (Gopi Krishna Kafle & Sang Hun Kim, 2013) vegetable waste (B. Velmurugan & R. AlwarRamanujam, 2011), and banana peels (P. Tumutegyereize *et al.*, 2011). A banana plant is one of the promising sources of biogas. P. Tumutegyereize *et al.*, (2011), has carried out some detailed study of biogas production from banana fruit peels. He investigated the chemical changes of the peels as well as the performances of various particle sizes of the same and obtained an optimal particle size for the best anaerobic process. Apart from biogas, the banana plant has been reported as having many other uses. These uses include food, antioxidant, weaving, food wrapping, and even animal feed among others (DebabandyaMohapatra *et al.*, 2010).

According to Al Seadi, 2008, Anaerobic digestion is a biochemical process where complex organic compounds are degraded under anaerobic conditions by a consortium of bacteria. The process is ecofriendly and one of the most efficient methods applied in the conversion of biomass to Methane (CH_4) gas (Horváth *et al.*, 2016). Naturally, anaerobic digestion is a complex microbial process that occurs in an oxygen-free environment (Jingura & Kamusoko., 2017). This process takes place in four stages namely; hydrolysis, acid genesis, acetogenesis, and methanogenesis. The first stage involves acidic operating conditions with methane produced under delayed natural conditions (Ward *et al.,* 2008). Acetogenesis involves the degradation of organic matter which happens under different microorganisms and fermentation environment. Methanogens involves the use of first and second state digestion process products such as H_2, CO_2 and acetate to produce biogas (Deublein and Steinhauser, 2008) .

In Kisii County, farmers pick banana fruits for food and fresh leaves for food wrapping. The other portions of banana plant (pseudo-stems and fruit bunch stalk) are dumped as waste. Hence, these huge stalks are getting accumulated in banana-growing areas and becoming an environmental hazard. Transforming these wastes into energy should be a good consideration for the people of Kisii County. The objective of this study is to generate biogas from the various parts of the banana plant and hence determine which parts of the plant would be of most benefit in terms of biogas generation.

2.0 Materials and Methods

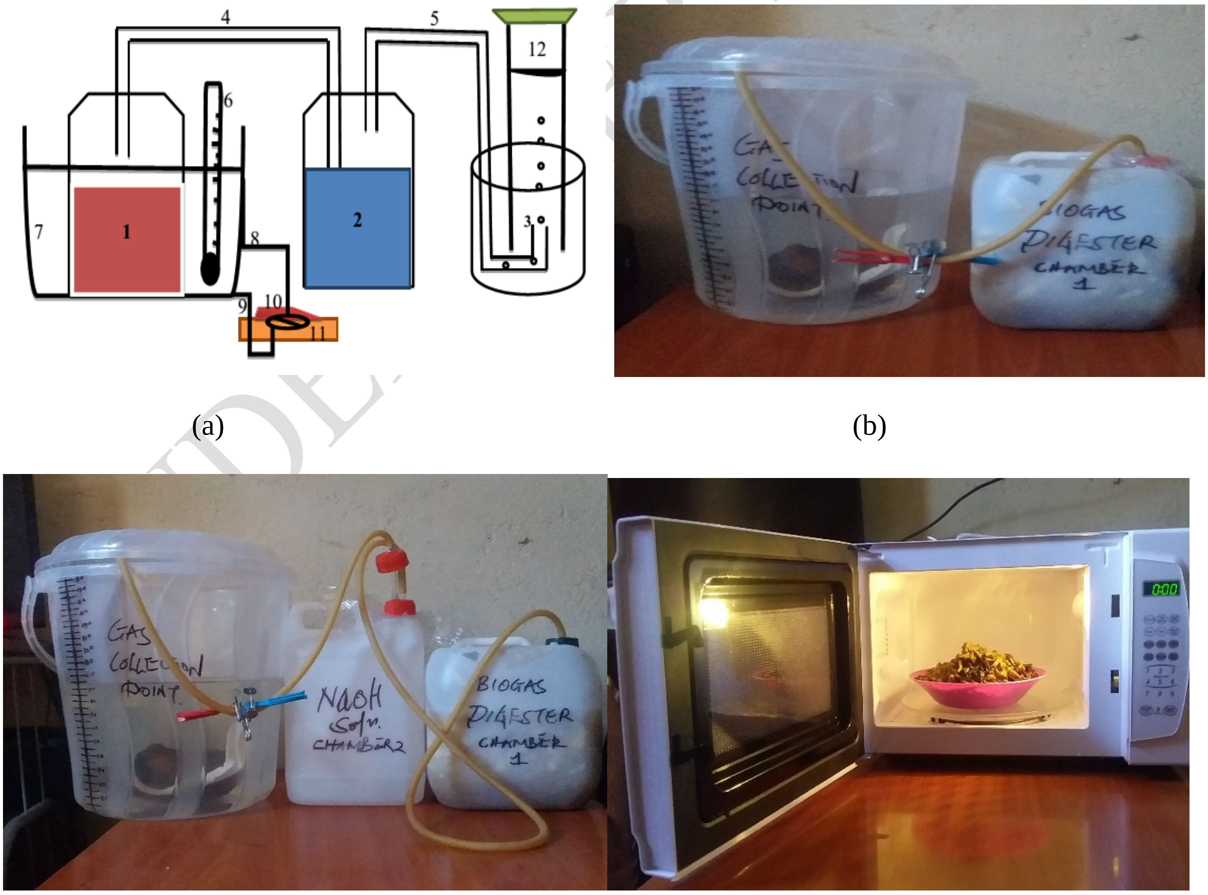
2.1 Sample Preparation.

The banana fraction wastes considered were: banana fruit peels, leaves, pseudo-stem (PS) and fruit bunch stalk (FBS). 2 kg of each waste was mixed with 1 liter of water and about 50 ml of 2M NaOH after cleaning. Each waste was made into a slurry using an electronic blender to assist in the easy and faster decomposition of the feedstock which was then stored in the fridge (4^0C) till it was needed.

2.2 Experimental set-up and procedure.

A locally available 10-litre plastic container was used as a digester. A 2cm diameter hole was made at the Centre of the lid of the 10-litre plastic container. Two plastic containers of five litres each were used one containing water and the other empty to receive displaced water. Thereafter, the gas produced was passed through Sodium Hydroxide (NaOH) to absorb any Carbon Dioxide (CO_2) gas.

The digester was tightly closed to prevent any air from entering in. When the biogas was produced in the digester, it moved through the plastic pipes to one of the plastic container displacing water and then compressed the water in the plastic container, displacing water into the other plastic container as shown in figure 1 below.



(a) (b)

(c) (d)

Fig. 1: Experimental set up of the digester: a schematic diagram (a), photo of the real set up of biogas collection (b), photo of methane collection (c), and Photo for moisture content and total solid determination. In (a): 1 is the digester, 2 is the Sodium Hydroxide, 3 is the Water, 4 is Biogas ,5 is Methane, 6 is the Thermometer, 7 is Water, 8 is Hot water, 9 is Cold water, 10 is the Iron Box 11 is the Coil, 12 is Methane.

2.3 Moisture Content determination

The moisture content was determined using the drying (air-oven) method. A mass of 20g of the banana waste fraction was transferred into a weighed porcelain cup. The cup with the waste was placed in an oven at 105 ^{0}C for 5 hours. The cup was afterwards removed and placed in a desiccator to cool and the dry matter was weighed. The moisture content was determined using equation 1 below (Wellington *et al.*, 2017):

$$Moisture\ \% = \frac{wet\ weight - Dry\ weight}{wet\ weight} \times 100 \qquad (1)$$

2.4 Total Solid (TS) Content Determination.

The total solid is the amount of solid present in the sample after water present in it is vaporized and is given by equation 2 below (Georgiadis *et al.*, 2013):

$$TS\% = \frac{W_d}{W} \times 100 \qquad (2)$$

Where W_d is the dried sample weight and W is the wet weight.

2.5 Volatile Solid (VS) content Determination.

The dried residue from total solid was weighed and heated in porcelain cup for 2 hours at 550 ^{0}C in an oven. After cooling the porcelain cup residue were weighed. The volatile solid was calculated using equation 3 (Georgiadis *et al.*, 2013):

$$VS\% = \frac{W_3 - W_1}{W_2 - W_1} \qquad (3)$$

Where W_1 is the weight of the porcelain cup, W_2 is the weight of the dry residue and porcelain cup, W_3 is the weight of ash content and porcelain cup.

2.6 Theoretical Biochemical Methane Potential (TBMP)

The theoretical biochemical methane potential (TBMP) of banana waste substrates was calculated based on the reaction formula in equation 4 and equation 5 (Feng *et al.*, 2013):

$$C_nH_aO_bN_c + \left(n - \frac{a}{4} - \frac{b}{2} + \frac{3c}{4}\right)H_2O \rightarrow \left(\frac{n}{2} - \frac{a}{8} - \frac{b}{4} + \frac{3z}{8}\right)CO_2 + \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4} - \frac{3z}{8}\right)CH_4 + cNH_3 \qquad (4)$$

$$TBMP\ (ml\ CH_4\ gVS^{-1}) = \frac{22.4 \times \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4} - \frac{3c}{8}\right)}{12n + a + 16b + 14c} \qquad (5)$$

Where C is carbon, H is hydrogen, O is oxygen, N is nitrogen, n is the number of carbon atoms, a is the number of hydrogen atoms, b is the number of oxygen atoms, c is the number of nitrogen atoms, TBMP is the theoretical bio methane potential.

2.7 Methane Based Degradability.

The methane-based degradability of banana waste substrates could be calculated using equation 6 (Raposo et al 2011; Zhou *et al.*, 2011**)** :

$$Methane\ based\ degradability = \frac{BMP}{TBMP} \times 100\% \qquad (6)$$

Where BMP represents the biochemical methane potential (mL CH_4/gVS) and TBMP is the theoretical biochemical methane potential (mL CH_4/gVS).

2.8 Biogas Energy.

The biogas energy was determined by using its flame to heat water and the heat energy calculated using equation 7 (Wellington *et al.*, 2017):

$$E = M_c C_c \Delta\theta + M_w C_w \Delta\theta \qquad (7)$$

Where E is the amount of heat energy dissipated, $M_c$is the mass of calorimeter, C_c is the specific heat capacity of the calorimeter (400Jkg^{-1}K^{-1}), Δθ is the change in temperature, M_w is the mass of water, C_w is the specific heat capacity of water (4200Jkg^{-1}K^{-1}).

2.9 Biogas power potential

The amount of biogas energy was converted into power by dividing the energy obtained in equation 7 above by the time taken for the said heat energy to heat water (equation 8 below). (Wellington *et al.*, 2017):

$$Power = \frac{(E)}{(t)} \qquad (8)$$

Where E is the amount of heat energy calculated in equation 7 and t is the time taken in seconds for the energy to be dissipated.

3.0 Results and Discussion

3.1 Total Solid and Moisture Content Determination.

The total solid and moisture content for the substrates under study were determined by set up 1 (d) and the results are as shown in Table 1 below;

Table 1. Assessment of total solid and moisture content determination.

Sample substrate	Net Wet weight ±0.1(g)	Net dry Weight ±0.1 (g)	Moisture Content ±0.1 (g)	TS %	%Moisture content
Leaves	20.0	16.0	4.0	80	20
Pseudo-stem	20.0	3.0	17.0	15	85
FBS	20.0	2.8	17.2	14	86
Peels	20.0	3.8	16.2	19	81

Leaves had the least moisture content at 20 % and the other three parts had moisture content between 81-86 %. The FBS had the highest moisture content (86 %) but the PS is a close 85 %.

3.2. Volatile Solid and Ash Content Determination.

The volatile solids and Ash content for the substrates under study are indicated in Table 2 below.

Table 2. Assessment of total solid and Volatile Solid Determination

Sample substrate	Net dry weight ±0.1 (g)	Ash Content ±0.1 (g)	Volatile Solid Content ±0.1 (g)	VS ±0.1%	Ash content±0.1%
Leaves	16.0	4.2	11.8	73.8	26.3
Pseudo-stem	3.0	0.6	2.4	80.0	20.0
FBS	2.8	0.5	2.3	82.1	17.9
Peels	3.8	0.4	3.4	89.5	10.5

It is observed that the leaves had the least volatile content at 73.75 % and the other three parts had moisture content in the same range, 80-89 %.

3.2. Daily biogas production.

A graph of daily biogases produced from banana waste substrates for 21 days was plotted in figure 2 below.

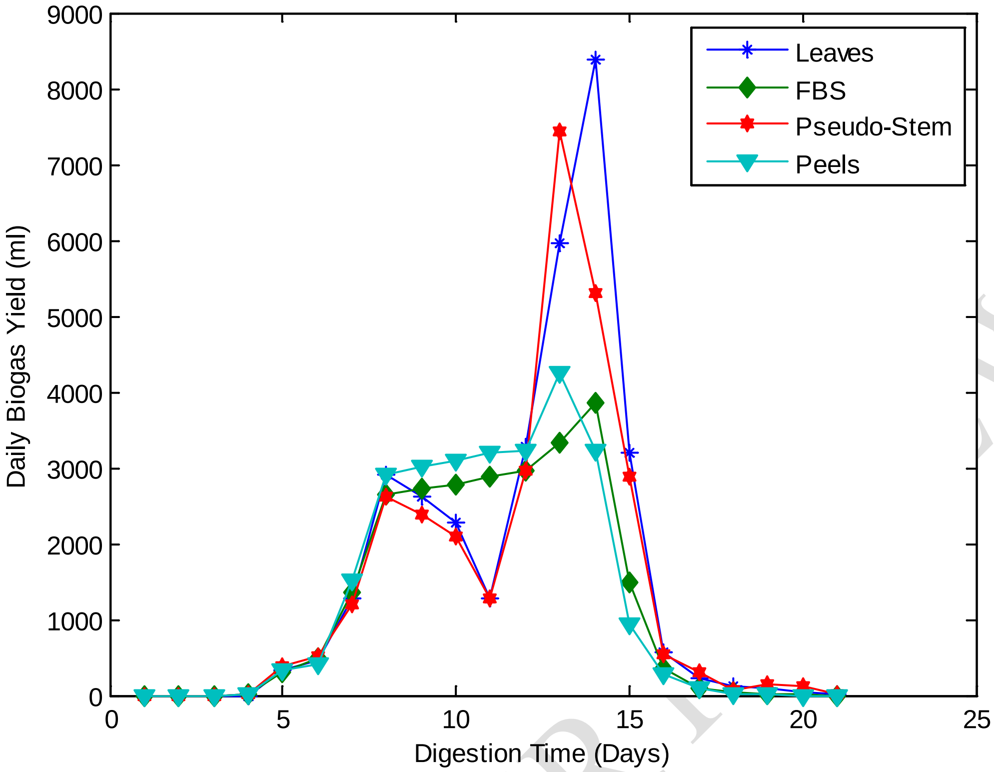


Fig. 2. Daily biogas yield against digestion days for the different banana substrates.

The biogas yield per day assumes an approximate normal curve distribution with low yields in the first, about 5 days and the last 5 days. The peak yield for all the substrates is around 13th-15th days. Leaf substrates yield 8373 litres, fruit bunch stalk 3854 litres, peels 7443litres and pseudo-stem 4263 litres. The maximum peak production of pseudo-stem and fruit bunch stem was much lower than that of the peels and the leaves, this would be because stems contain significant amounts of complex lignocellulose structure which limits the anaerobic biodegradability.

3.2Cumulative Biogas Production

After completion of 21-day digestion at an average temperature 33^{0}C, specific cumulative Biogas yields reached were plotted against digestion time as shown in figure 2 below. The yields accumulate to the maximum values in about 15 days, and plateau thereafter. P. Tumutegyereize *et al*., (2011) obtained a retention period of about 10 days. It is noted that the leaves produce the highest yields of the gas followed by the peels. The individual yields were obtained as follows: about 33.0 litres (leaves), 26.5 litres (pseudo-stem), 25.3 litres (fruit bunch stem) and 30.2 litres (peels).

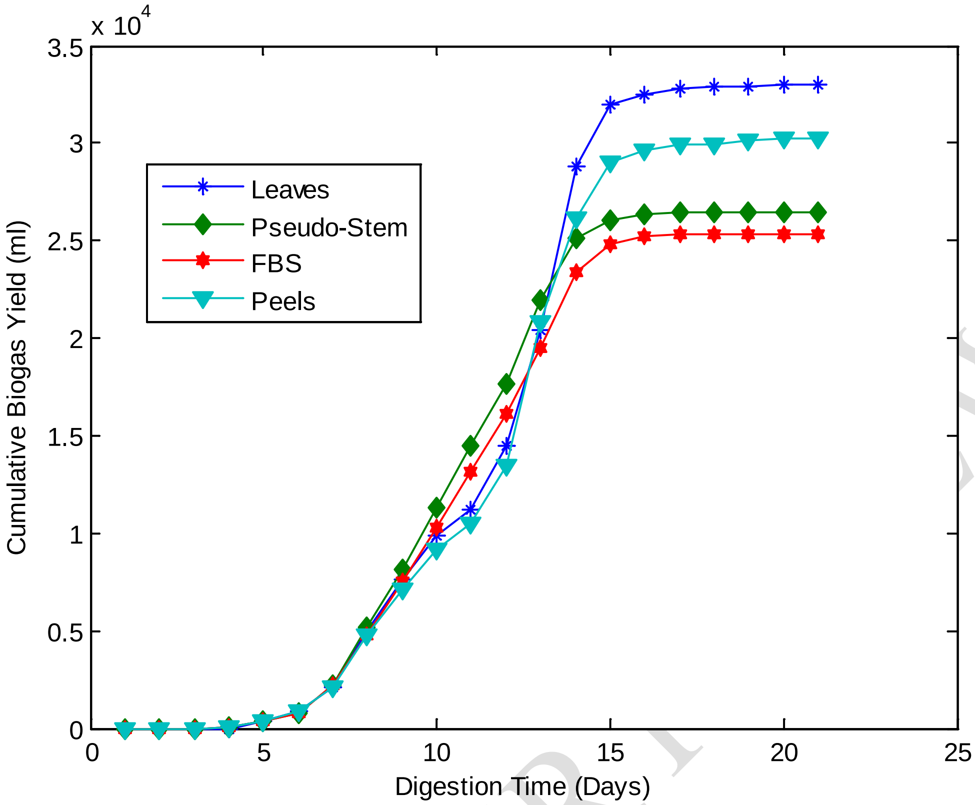


Fig. 3. Cumulative biogas production for the different banana plant substrates for 21 days.

3.3 Theoretical Methane Potential.

The chemical molecular formulae of banana leaves are $C_{52}H_{89}O_{44}N$, Pseudo-stem $C_{24}H_{33}O_{26}N$ and Fruit Bunch Stem $C_{19}H_{30}O_{33}N$ (Nurhayati *et al.*, 2014) and that of banana peels is $C_{20}H_{44}O_{24}N$ (Isa Kabange *et al.*, 2018). The theoretical methane potential can be estimated from the elemental ($C_nH_aO_bN_c$) composition of the substrates as in equation 5 above. The results obtained from the theoretical method were 403.1, 279.3, 249.0 and 299.7 ml CH_4/gVS for Leaves, Pseudo-stem, FBS and Peels respectively.

3.4 Methane production.

Biogas produced from banana waste fractions was passed through sodium hydroxide solution to absorb carbon dioxide gas leaving only methane gas to penetrate as shown in figure 1(b). The daily Methane production after passing through sodium hydroxide solution, as a function of days for Banana leaves, pseudo-stem, fruit bunch stalk, and peels are presented in figure 4 below. The spectra for the yields look the same as in figure 2, but with the reduced total yield for each substrate. This is attributed to the purification of the biogas to methane through absorption of the unwanted gases like CO_2. From figure 4, the maximum daily Methane production peak of peels (4615 ml) and pseudo-stem (2865 ml) occurred on the 13th day, while that of leaves (4940 ml) and FBS (2389 ml) occurred on the 14th day. The maximum peak values for the pseudo-stem and the fruit bunch stalk were much lower than that of the peels and leaves. This could be primarily because stems contain significant amounts of complex lignocellulose structure which limits the anaerobic biodegradability ***(Xiyan Ji et al., 2015***)

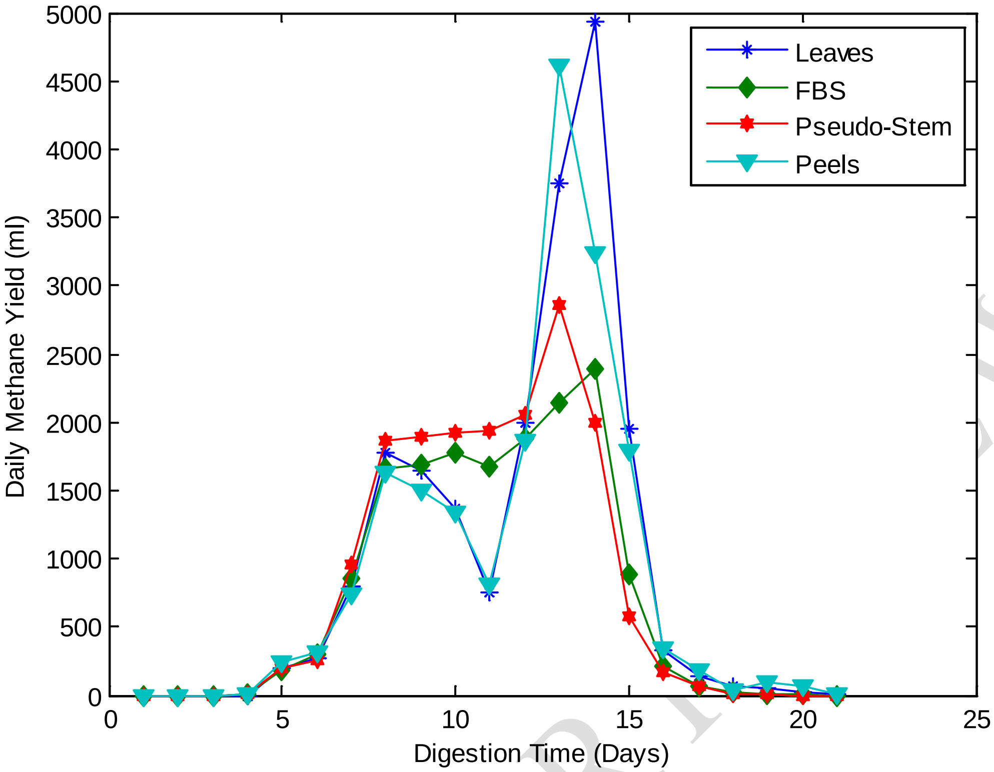


Fig. 4. Daily Methane Yield versus Digestion time for banana substrates.

Figure 5 below presents the Cumulative Methane production as a function of days for the Banana substrates. The spectra for the yields look the same as in figure 3 but with reduced yields. The accumulated gas is reduced by about 39.4 % in the case of the leaves (figs 3 and 5).

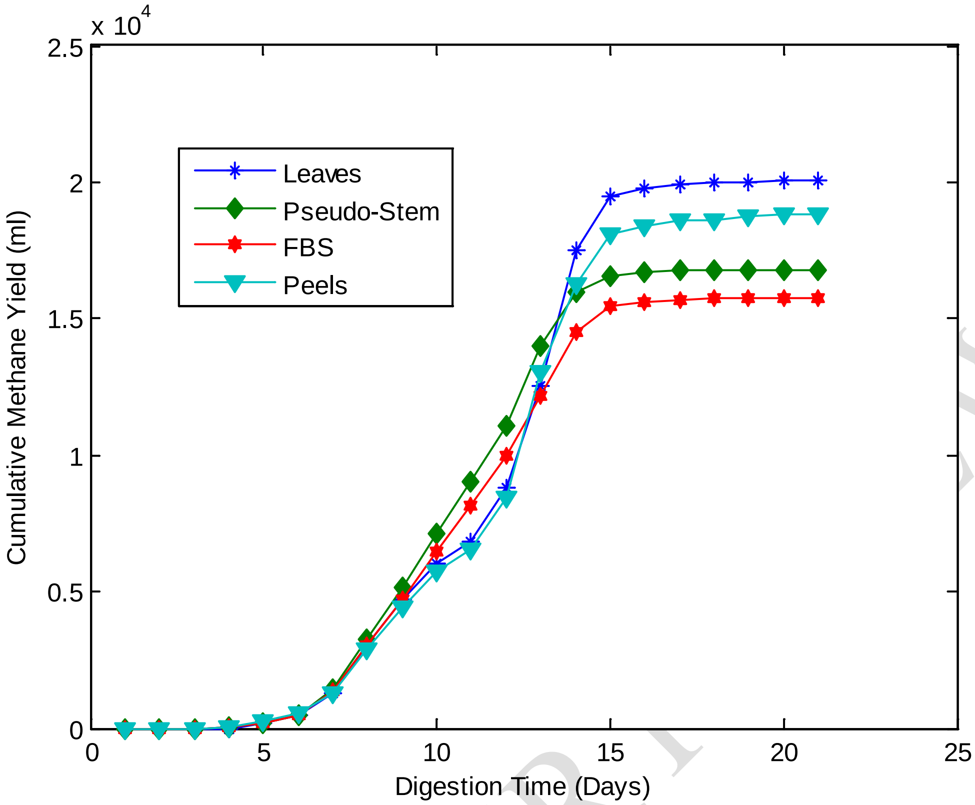


Fig. 5. Cumulative Methane yield versus Digestion time for banana substrates.

3.5. Comparison of Biogas and Methane Production.

Figure 6 shown below compares the biogas and the methane gas produced. From the figure, it's very clear that as the amount of biogas production picks, production of other gases accompanying methane also picks. This is evidenced between day 6 and 16 where the gap between the amounts of biogas methane widens. Figure 6 (a) compares biogas and methane production from the banana peels, 6 (b), from FBS 6(c) from Pseudo stem and 6(c) from leaves.

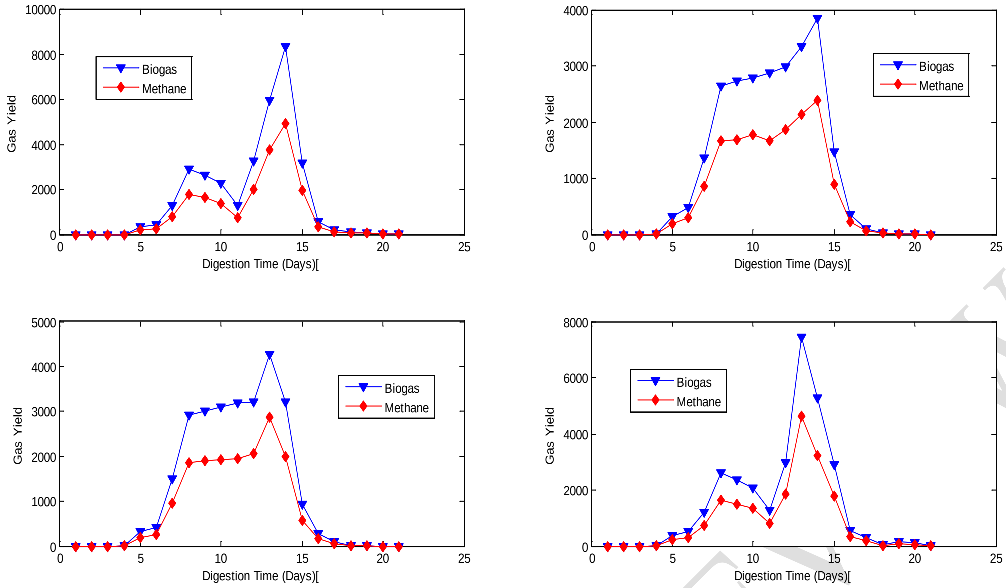


Fig 6. Comparison between Biogas and Methane production.

3.6. Methane Potential in banana Substrates

The methane potential of the banana substrates was obtained and tabulated as in table 3 below.

Table 3. The potential of methane in various banana substrates

Sample substrate	**Mass of wet weight (kg)**	**Volatile Solid±0.01 (Kg)**	**Volume of Biogas±0.01 (ltrs)**	**The volume of Methane ±0.01 (ltrs)**	**Methane Potential. ±0.01 (mL CH_4/gVS)**
Leaves	2	0.36	32.99	20.05	55.69
Pseudo-stem	2	0.24	26.43	15.74	65.58
FBS	2	0.23	25.33	16.78	72.96
Peels	2	0.34	30.25	18.80	55.29

From a practical point of view, an average family in Kenya uses about 13 Kg of commercial cooking gas for about one to one and half months (30-45 days) (McNutt et. al., 1975). This is about 8.7-13 kg per month, or about 289-433 g or 437,879 - 656,061 cm^3 of cooking gas per day (taking the density of methane to be 6.6 $x10^{-4}$ g/cm^3 under normal temperature and pressure (McNutt et. al., 1975). From our study (Table 3 above), 2 Kgs of banana leaves gives about 20.05 litres (20050 cm^3) of methane gas. This means an estimated 22-33 Kgs of banana leaves is needed daily to provide an average family with adequate gas for cooking.

3.7 Energy and power assessment.

Table 4 below shows the data used to compute and convert the energy into power for the banana substrates.

Table 4: Assessment of energy and power of biogas produced.

	The volume of gas Used (cm^3)	Mass of water & calorimeter **±0.1** (g)	Change in temp (^{0}C)	Energy gained by water & calorimeter **±0.01** (J)	Time taken **±0.1** (s)	Power **±0.01** (Watts)
Calorimeter						
Test 1	1570	50.7	13	3205.45	157.5	20.35
Test 2	694	54.0	7	1079.21	54.6	19.78
Test 3	385	32.0	5	945.17	47.2	20.03
Average	883	43.0	?	?	?	20.05

The average power of 20.05 Watts was realized for an average volume of 883 cm^3 of Methane gas. Converting this to Watts/m^3 we have 22,706.68 W/m^3. According to Balat *et al.,* (2009), 1 m^3 of pure methane generates about 37,258.9 J of energy. Thus, the biogas from our banana substrates generated about 60.94% of the expected energy rating for pure methane. However, this is just an estimate and more sophisticated methods are needed to analyze the biogas constituents.

Conclusion

A comparative assessment of the potential of biogas in the different parts of a banana plant has been done for 21 days. The optimum daily production of biogas was between the 13th-15thday. Cumulatively, we observed that after the 15th day, almost all the biogas had been released and there was very little extra gas produced. A 2 kg slurry made from each part of a wet banana plant and digested in an anaerobic digester under mesophilic conditions for 21 days released 32.9 litres, 26.4 litres, 25.2 litres and 30.2 litres of biogas for the leaves, pseudo-stem, fruit bunch stalk and peels respectively. After filtration of the trace gases in the biogas, the methane gas present was 20.05 litres (Leaves), 15.74 litres (Pseudo-stem), 16.78 litres (FBS) and 18.80 litres (peels). From our study, the leaves of a banana plant have the highest potential for biogas. By doing a simple computation using energy calculation only, it was found that our biogas was about 61 % of the energy expected from a similar quantity by other researchers. It has been shown that banana parts have significant potential for biogas. From our study, an estimated 22-33 Kgs of banana leaves is needed daily to provide an average family with adequate gas for cooking. We believe that with more resources directed to developing a better digester, better results can be realized.

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