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Full Length Research Paper

Comparison of biogas productivity of cassava peels mixed in selected ratios with major livestock waste types

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Biogas productivity of cassava peels, mixed with poultry, piggery and cattle waste types in ratios 1:1, 2:1, 3:1 and 4:1 by mass, was investigated using 12 Nos. 220l batch type anaerobic digesters in a 3 x 4 factorial experiment using a retention period of 30 days and within the mesophilic temperature range. Biogas yield was significantly ($P \leq 0.05$) influenced by the different mixing ratios of livestock waste with cassava peels. The cumulative average biogas yield from digested cassava peels was 0.6 l/kg-TS. The average cumulative biogas yield increased to 13.7, 12.3, 10.4 and 9.0 l/kg-TS respectively for 1:1, 2:1, 3:1 and 4:1 mixing ratios when cassava peel was mixed with poultry waste. On mixing with piggery waste, the average cumulative biogas yield increased to 35.0, 26.5, 17.1 and 9.3 l/kg-TS respectively for 1:1, 2:1, 3:1 and 4:1 mixing ratios. In the case of mixing with cattle waste, the average cumulative biogas yield increased to 21.3, 19.5, 15.8 and 11.2 l/kg-TS respectively for 1:1, 2:1, 3:1 and 4:1 mixing ratios. Results show that for all livestock waste types, mixing with peels in the ratio 1:1 by mass produced the highest biogas volumes, and highest in piggery waste.

Key words: Anaerobic digestion, biogas, cassava peels, cattle waste, poultry waste, piggery waste.

INTRODUCTION

Cassava (*Manihot esculenta,* Cranz) is a very important crop grown for food and industrial purposes in several parts of the tropics. Nigeria, with the year 2006 production of 49 million tonnes of cassava, is the largest producer of the crop in the world (NPC, 2008). The ongoing encouragement of cassava cultivation by the Federal Government of Nigeria is gradually raising the profile of the crop as a significant cash crop. According to IFAD/FAO (2000), cassava is the fourth most important staple crop in the world after rice, wheat and maize. The processing of cassava results in the production of peels, chaff, fibre, and spoilt or otherwise unwanted tubers. A relatively small quantity of peels and unwanted tubers is fed directly to ruminants. However, the much larger remaining proportion of cassava solid wastes are indiscriminately discharged into the environment and amassed as waste dumps on sites where cassava is processed. With increased production of peels and other cassava-derived wastes. This constitutes an enhanced risk of pollution to the environment. There is, therefore, a pungent need to find an alternative productive use of the peels. One area of possibility is to investigate the potential of cassava peels for the production of biogas and by so doing, reduce its nuisance value to the environment. It is the aim of this paper to report the results of the investigation of potential of cassava peels as biomass for the production of biogas. Finding such an important use for the peel would make it less burdensome on the environment as a pollutant.

Anaerobic biodigestion is a process through which organic materials are decomposed by bacteria in the absence of air to produce biogas. As observed by Buren (1983), biogas is a flammable gas produced by microbes when organic materials are fermented in a certain range of temperatures, moisture contents, and acidities, under air-tight condition. Closer attention is being focused on anaerobic biodigestion. (Hill, 1984; Safley and Westerman, 1990; Nwagbo et al., 1991; Ateya et al., 1997; Ezeonu et al., 2000;

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NCCE, 2000; Itodo and Phillips 2002, Tambawal, 2004) because Waddle et al. (1990) provided a summary of the status of biomass conversion technologies and opportunities for their use in developing countries. The paper observed that although biomass fuels at that time played a large and significant role in energy use worldwide, they were generally used very inefficiently. It opined that utility-scale applications, and perhaps to a lesser extent, the use of liquid fuels and biogas digesters, will play a large role in the changing complexion of biomass energy utilization. Scientific interests and efforts in researching into biogas technology are still relevant, especially in view of contemporary high costs of energy supply worldwide.

Options for biomass exploitation chiefly include plant materials and livestock wastes. Several researchers have reported biogas production from various materials including pigeon droppings (Aliyu et al., 1995); water hyacinth, *Eichhornia* species (Bamgboye and Abayomi, 2000); manure from the major farm animals (Adelekan, 2002); camel and donkey dung, (Dangoggo et al., 2004); onion bulbs (Abubakar et al., 2004) and other bulk organic wastes (Kovacs et al., 1995). Specifically in the case of Nigeria, where this research is on-going, reported values of animal waste production range from 144 million tonnes/year (Energy Commission of Nigeria, 1998) to 285.1 million tonnes/year (Adelekan, 2002). These figures suggest that on a daily basis, Nigeria's farm animals no doubt generate huge quantities of manure which can be anaerobically digested to produce methane gas. While research interests into the use of agricultural biomass to produce methane are increasing, largely due to the global awareness of the inadequacies of the almost total reliance on fossil fuels as energy sources, it is important to investigate the methane productivity of waste product of such an important crop (cassava peels) in combination with individual livestock waste types, so as to provide the most optimal mixing ratios of the various slurries.

According to Carcelon and Clark (2002), anaerobic bacteria communities can endure temperatures ranging from below freezing to above 57.2°C (135°F), but they thrive best at temperatures of about 36.7°C (98°F) (mesophilic) and 54.4°C (130°F) thermophilic. Bacterial activity, and thus biogas production, falls off significantly between about 39.4 and 51.7°C (103 and 125°F) and gradually from 35 to 0° (95 to 32°F). To optimize the digestion process, the digester must be kept at a consistent temperature as rapid changes will upset bacterial activity. Hobson et al. (1981) found biogas production to be greatest when the digester temperature was in the range of 32 to 40°C. Hill (1982) also stated that digestion temperatures for optimum design all occur in the mesophilic range of 32 to 40°C. The paper suggested that temperatures beyond 40°C have little effects on digester performance since the higher volumetric methane productivity is offset by the smaller digestion volume. As observed by the paper, these lower temperatures also represent major savings in energy requirements when compared to thermophilic digestion (that is 60°C). During the process of anaerobic biodigestion in order to reach optimum operating temperatures (30 - 37°C or 85 - 100°F), some measures must be taken to insulate the digester, especially in high altitudes or cold climates (VITA, 1980). Straw or shredded tree bark can be used around the outside of the digester to provide insulation.

According to Buren (1983) the micro-organisms involved in anaerobic biodigestion require a neutral or mildly alkaline environment, as a too-acidic or too-alkaline environment will be detrimental. The work stated that a pH of between 7 and 8.5 is best for biodigestion and normal gas production. The pH value for a digester depends on the ratio of acidity and alkalinity and the carbon dioxide content in the digester, the determining factor being the density of the acids. Buren (1983) noted further that for the normal process of digestion, the concentration of volatile acid measured by acetic acid should be below 2000 ppm, as too high a concentration will greatly inhibit the action of the methanogenic microorganisms. The hydraulic retention time (HTR) in anaerobic digesters is determined by calculating the number of days required for displacement of the fluid volume of the culture. At a given organic loading rate, the HTR is lower when using high water-content feeds than when using those containing less water (Fannin and Biljetina, 1987). The retention time is dependent on all the factors discussed above. Generally, a retention time of between 30 and 45 days, and in some cases, 60 days is enough for substantial gas production (Clanton et al., 1985; Carcelon and Clark, 2002).

The carbon: nitrogen (C/N) ratio expresses the relationship between the quantity of carbon and nitrogen present in organic materials. Materials with different C/N ratios differ widely in their yield of biogas. The ideal C/N ratio for anaerobic biodigestion is between 20:1 and 30:1 (Marchaim, 1992). If C/N ratio is higher than that range, biogas production will be low. This is because the nitrogen will be consumed rapidly by methanogenic bacteria for meeting their protein requirements and will no longer react on the left over carbon remaining in the material. In such a case of high C/N ratio, the gas production can be improved by adding nitrogen in farm cattle urine or by fitting latrine to the plant (Fulford, 1988). Materials with high C/N ratio typically are residues of agricultural plants. Conversely, if C/N ratio is very low, that is, outside the ideal range stated above, nitrogen will be liberated and it will accumulate in the form of ammonia. Ammonia will raise the pH value of the slurry in the digester. A pH value which is higher than 8.5 will be toxic to the methanogenic bacteria in the slurry. The cumulative effect of this is also reduced biogas production. Materials having low C/N ratio could be mixed with those having high C/N ratios so as to bring the average C/N ratio of the mixture to a desirable level. Human excreta, duck dung, chicken dung, and goat dung are some of the materials which typically have low C/N ratios.

Table 1. C/N Ratios of some organic materials.

Organic materials	C/N ratios
Duck dung	8
Human excreta	8
Chicken dung	10
Goat dung	12
Pig dung	18
Sheep dung	19
Cow dung	24
Buffalo dung	24
Water hyacinth	25
Elephant dung	43
Maize straw	60
Rice straw	70
Wheat straw	90
Saw dust	200

Source: Karki and Dixit (1984).

Table 2. Chemical analyses of cassava peels.

Parameters	Undigested peels	Digested peels
% Organic Carbon	48.7	46.4
% Total Nitrogen	1.0	1.0
C/N Ratio	48.7	46.4
% K	1.1	0.7
% P	1.6	0.8
% NO_3	0.16	0.12
Zn (mg/kg)	125	118
Cu (mg/kg)	15	12
Mn (mg/kg)	180	172
pH	6.4	6.1
% Na	0.15	0.13
% Ca	0.9	0.7
Pb (mg/kg)	16.7	14.8
% Ash	52.6	48.7

According to Karki and Dixit (1984), typical C/N ratios of common organic materials are as shown in Table 1.

MATERIALS AND METHODS

The effect of cassava peels mixed with poultry, piggery and cattle wastes in the ratios 1:1, 2:1, 3:1 and 4:1 was investigated using 4 replicates in a 3 × 4 factorial experiment, using a 30 day retention period. 12 Nos., 220 L black-coated, batch type digesters, each of which incorporated a water tank as well as iron sponge and sawdust sealed in a separate cylinder, were used. Fresh cassava peels were collected at the garri processing centre at Ring Road, One-Ten End, Ibadan. Sticks, stones, leaves, and other foreign matter were then hand-picked from the mass of collected peels, after which the peels were chopped, pounded and stirred to break into smaller particles to ensure consistency of mix. Fresh poultry, cattle and piggery wastes were obtained from the livestock farms at IAR and T, Moor Plantation and hand- picked to remove stones, sticks and other foreign matter and thoroughly stirred. A 200 g sample was obtained from the mass of pounded cassava peels and each of the animal waste types are analyzed for organic C, total N, %P, %K, %NO_3, pH, and light metals. Five (5) kg of cassava peels and 5 kg of manure were measured and mixed thoroughly in a tank. The mixture was further mixed with 10 kg of water by stirring continuously for 25 min to achieve even mix. The mixed mass of cassava peels and manure were loaded into the digester and its cap completely sealed to ensure air-tightness. The digesters were shaken twice daily to free trapped gases, ensure continuous mixing and prevention of scum accumulation at the surface of the slurry. Biogas production was measured daily on volume basis by water displacement. The ambient temperatures on site were continually measured using a maximum and minimum thermometer and recorded throughout the detention period. Biogas samples were obtained day 5 and day 25 of the detention period and analyzed for methane content using a gas detector.

The same procedure was repeated for ratios 2:1 (5 kg peels and 2.5 kg manure with 7.5 kg of water added); 3:1 (7.5 kg peels, 2.5 kg manure with 10 kg water added) and 4:1 (8 kg peels, 2 kg manure with 10 kg water added).

RESULTS

The results of the chemical analyses of the cassava peels used are as shown in Table 2.

The effects of mixing cassava peels and different ratios of livestock waste on biogas yield are shown in Table 3 and Figures 1 to 3. All the readings of the biogas yield were analyzed using the Duncan Multiple Range Test (DMRT).

The summary of cumulative biogas production from mixtures of cassava peels and wastes is shown in Table 4.

Table 5 shows the interaction among the mixing ratios and the various waste types.

The methane content of biogas produced from cassava peels and its mixtures with different manure types using the selected mixing ratios are as shown in Table 6.

DISCUSSIONS

Table 2 above shows that cassava peels have high value of organic carbon and low value of total nitrogen, and this result in a particularly high C/N ratio. According to Karki et al. (1994) high C/N ratio is indicative of the fact that the material is not good for biogas production and will not appreciably yield biogas. However, the work points out that such a material could be mixed with another with a much lower C/N ratio to stabilize the ratio to an optimal value between 22 and 30. Table 3 shows that biogas yield was significantly ($P \leq 0.05$) influenced by cassava peels used. The cumulative average biogas yield from digested cassava peels shown in Table 4 was 0.6 l/kg-TS. This value is low compared with values obtained by Bamgboye (1994) from other lignocellulosic materials such as chopped substrate (1.85 - 3.95 l/kg-TS) and ground water hyacinth substrate (4.01 - 5.55 l/kg-TS). Since cassava peel is a material with a high C/N ratio, it will not yield much biogas. Therefore, to enhance biogas production from it, mixing with other readily degradable materials is necessary.

Table 3. Effects of main and interaction on biogas yield.

Source	DF	Sum of squares	Mean square	F value	Significant
REP	3	0.27	0.09	0.08	0.9719
Cassava peels	2	22.72	11.36	9.97	0.0001
Mixture of livestock waste	3	31.78	10.59	9.30	0.0001
Cassava peels × mixture of livestock waste	6	25.14	4.19	3.68	0.0012
Error	1425	1622.70	1.14		
Corrected Total	1439	1702.59			

Mean = 0.58, CV=18.54, R^2 = 0.46.

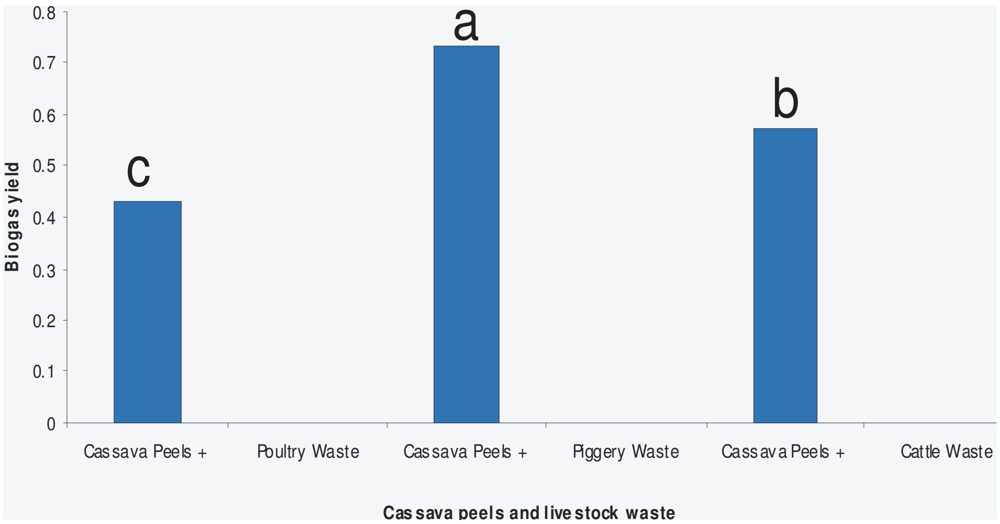

Figure 1. Effect of cassava peels and different wastes mixtures on biogas yield.

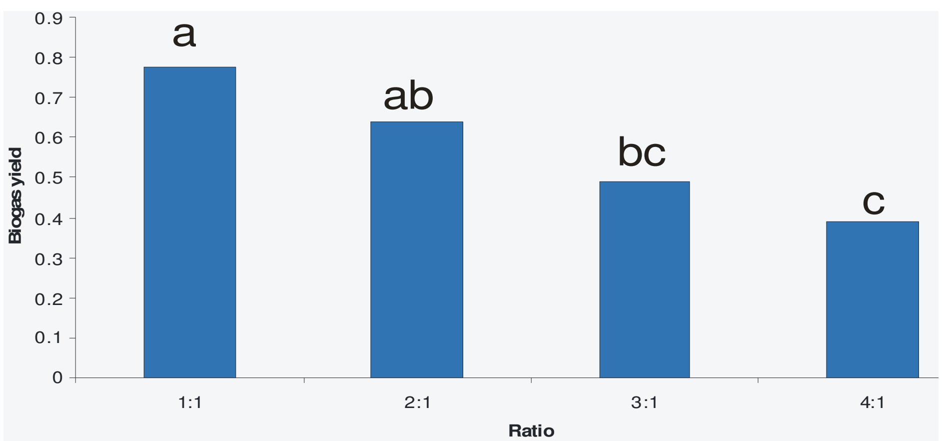

Figure 2. Effect of different mixing ratios of peels and livestock waste on biogas yield.

Also, biogas yield was significantly (P ≤ 0.05) influenced by the different mixing ratios of livestock waste with cassava peels. The average cumulative biogas yield increased to 13.7, 12.3, 10.4 and 9.0 l/kg-TS respectively for 1:1, 2:1, 3:1 and 4:1 mixing ratios when cassava was mixed with poultry waste. On mixing with piggery waste, the average cumulative biogas yield increased to 35.0, 26.5, 17.1 and 9.3 l/kg-TS respectively for 1:1, 2:1, 3:1 and 4:1 mixing ratios. In the case of mixing with cattle waste, the average cumulative biogas yield increased to21.3, 19.5, 15.8 and 11.2 l/kg-TS respectively for 1:1, 2:1, 3:1 and 4:1 mixing ratios. Garba and Uba (2002) obtained total biogas volumes of 1.12, 0.4, 0.15, and 0.52l respectively for Pedilantus, Rose, Josprivate and Thevia when these ornamental plants were anaerobically digested. The results obtained indicated the low viability of

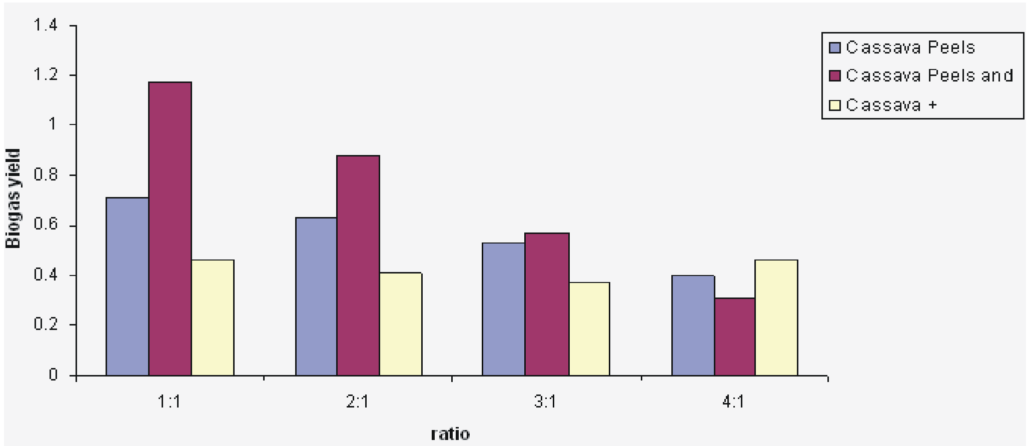

Figure 3. Joint Effect of cassava peels and livestock waste on biogas yield.

Table 4. Summary of cumulative biogas production from mixtures of cassava peels and manures.

Manure type	Peels alone (l/kg-TS)	Biogas volumes of selected mixing ratios of peels and manures (l/kg-TS)			
		1:1	2:1	3:1	4:1
Poultry	0.6	13.7	12.3	10.4	9.0
Piggery	0.6	35.0	26.5	17.1	9.3
Cattle	0.6	21.3	19.5	15.8	11.2

Table 5. Interaction of animal wastes and mixing ratios.

Ratio	Cassava peels and poultry waste	Cassava peels and piggery waste	Cassava + cattle waste
1:1	0.71	1.17	0.46
2:1	0.63	0.88	0.41
3:1	0.53	0.57	0.37
4:1	0.40	0.31	0.46
SE±	0.071		

Table 6. Summary of methane content of biogas from mixtures of cassava peels and livestock wastes.

Waste types	Ratios			
	1:1	2:1	3:1	4:1
Cassava peel	51.4			
Cassava peel + poultry	66.2	65.7	65.1	64.8
Cassava peel + piggery	67.6	66.9	66.3	65.7
Cassava peel + cattle	65.1	65.7	64.8	63.5

of the plants as sources of gaseous fuel. All the plant samples used produced maximum amount of biogas within the first week of digestion. However, the yields were low. Pedilantus and Thevetia are fibrous and have soft tissue just like cassava. They produced more gas than Josprivate and Rose which had more lignin. Lignin suppressed biodegradation and the result is that the higher the lignin content, the lower the biogas yield (Hans-George, 1977). The stalk of cassava plant is very high in lignin content and generally, lignocellulosic materials inhibit biogas production. However, the average cumulative biogas yield increased to 13.7, 35.0, 21.3 l/kgTS when cassava peels were mixed with poultry, piggery and cattle wastes respectively. This was because of the addition of livestock wastes to the peels which lowered the C/N ratio of the mixture, making it more digestible. Furthermore, more organisms contained in the wastes were available for digestion of the mixed mass.

It was noticed that irrespective of livestock waste type, biogas production decreased with increasing mixing ratio used. The reason for this is that higher mixing ratios meant higher quantity of peels in the mixture which also implied increased lignin content and this made digestion activities more difficult for the microorganisms. Reduction in digestion activities of the microbes resulted in lower biogas production. Furthermore, with the passage of time, fresh cassava peels rapidly ferment and become more acidic. Acidic environment is not well tolerated by anaerobic bacteria, and therefore, their rapid multiplication will be severely curtailed at the higher mixing ratios which contained more peels in the mixture. This also con-

Table 7. Summary of bioconversion efficiencies of mixtures of cassava peels and livestock wastes.

Waste types	Ratios			
	1:1	2:1	3:1	4:1
Cassava peel	15.6			
Cassava peel + poultry	34.8	33.6	33.2	32.3
Cassava peel + piggery	21.2	20.9	20.5	20.1
Cassava peel + cattle	31.7	30.8	30.6	30.4

tributed to the reduction in biogas production. Adequate stirring of the substrates will be difficult to accomplish with increasing mixing ratios. Higher mixing ratios meant more mass of cassava peels and more difficulty in stirring. This also causes biogas to be trapped in the slurry making it not readily available to be forced out of the digester.

Figure 1 shows the means and Duncan letters for the mixtures of cassava peels and wastes. The means all have different letters indicating that they are all significantly different. The mixture of cassava peels and piggery waste had the highest Duncan mean while that of cassava peels and cattle had the least. This indicated that biogas yield from the mixtures of the wastes with cassava peels is affected by the type of waste used. Biogas production from the cassava peels mixed with piggery waste was the highest while the mixture of cassava peels with poultry waste produced the least biogas. The quantity produced was significantly higher in all the three wastes used than with peels alone. Figure 2 shows the means and Duncan letters for different mixing ratios of cassava peels and livestock wastes. None of the averages has the same letter with another, which means that there is significant difference in biogas yield as a result of the mixing ratio used. As can be seen in the figure midway situations exist as evidenced by Duncan letters of ab and bc. This point to a linearly correlated significant reduction in biogas yield as mixing ratio changed from 1:1, to 2:1, 3:1 and 4:1. The trend of reduction in biogas yield as mixing ratio increases from 1:1 to 4.1 is significant in terms of the quantity of biogas produced. More biogas was produced with 1:1 ratio, with least biogas coming from 4:1. However, it was observed from Table 4 that in all the different types of waste mixed with cassava peels, biogas production decreased with an increase in the mixing ratio.

Results show that cassava peels mixed with different livestock wastes at the rate of 1:1 produced more biogas yield than at 2:1, 3:1 and 4:1 mixtures. This implies that the highest biogas yield is obtained when peels and wastes are mixed in equal ratios. Hence for biogas production from cassava peels, mixing in ratio 1:1 will be adequate for enhanced biogas production. In all the experiments, biogas production reduced very rapidly from the beginning of the second week of the retention period. The reason for this rapid reduction in gas production in the case of mixtures of wastes and fresh cassava peels appear to be linked to the cassava peel itself. Cassava has a significantly high content of hydrocyanic acid. After loading, this is released unto the mixture, thus making the interior environment of the digester acidic. This inhibits the activities of the anaerobic bacteria with the result that they cannot operate at their optimum. Biogas production is thus inhibited. For all the experiments conducted, cassava peels and livestock waste mixtures produced much non-combustible gases in the first few days of starting the experiment evidenced by higher cumulative volume values.

From Table 6 above, it was noticed that peels digested alone had methane content of 51.4%. This is a low value. The reason for this low value is probably due to the fact that significant quantities of carbon dioxide and other non-combustible gasses were produced in the biodigestion of cassava peels. Although the biogas system used incorporated parts in which the biogas was cleaned, large production of carbon dioxide meant that the methane content of the biogas was reduced. However, on mixing peels with livestock waste, appreciable increase in methane content was recorded. Slight differences exist in the measured values for the various ratios with 1:1 mixing ratio showing the highest methane content of average values of 66.2, 67.6 and 65.1% for poultry, piggery and cattle respectively. It is noticed that the value of 65.1% methane content of biogas obtained from peels mixed with cattle waste was lower than the 66.2 and 67.6% recorded for peels and poultry waste and peels and piggery waste respectively. Another observation is that irrespective of mixing ratio used for each waste type, the values of methane contents are similar. However, slight differences still exist. The mixing ratio of the substrate had a slight effect on methane content of the biogas produced. Values of methane content decreased with increasing concentration of peels.

The bioconversion efficiencies of cassava peels and mixture of cassava peels with various types of livestock waste in different mixing ratios are shown in Table 7. Bioconversion efficiency was calculated thus,

$$Bioconversion\ efficiency\ (BE)$$

$$= 100 \times \frac{(Mass\ of\ VS\ converted\ to\ biogas)}{(Mass\ of\ VS\ available)}$$

$$= 100 \times \frac{(Initial\ mass\ of\ VS - Final\ mass\ of\ VS)}{(Initial\ mass\ of\ VS)}$$

Where;

VS = volatile solids.

Bioconversion efficiency of 15.6% was obtained for cassava peels digested alone. An increase in bioconversion efficiency from 15.6 to 34.8, 21.2, and 31.7% was attained when cassava peels were mixed in ratio 1:1 with poultry, piggery and cattle wastes respectively. Mixing cassava peels in ratio 1:1 with the wastes was, therefore, observed to have high conversion ratio in all the types of livestock waste used. However, for all the different types of waste used with varied ratios, a general trend of decrease in the bioconversion efficiency was observed as the ratios increased from 1:1 to 4:1. However, the mixture of peels and poultry waste had the highest bioconversion efficiency while peels mixed with piggery waste had the least. This shows that the bioconversion efficiency of cassava peels can be enhanced by mixing with livestock wastes.

Conclusions and Recommendations

1.) Slurries containing cassava peels-piggery waste produced more biogas than corresponding mixing ratios of other livestock waste types.
2.) Of all experiments, slurry containing peels-piggery waste in ratio 1:1 produced the most biogas.
3.) For each waste type, mixture of 1:1 by mass with cassava produced more biogas than any other mixing ratio.
4.) Of all experiments, slurry containing cassava peels-poultry waste produced the least biogas.

This paper recommends a cassava peels-livestock wastes mixing ratio of 1:1 by mass for slurries intended for biogas production from methane-generating systems.

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