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Cassava as a Potent Energy Crop for the Production of Ethanol and Methane in Tropical Countries

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Abstract

The ethanol productivity of cassava crop (variety TMS 30555) and the methane productivity of its waste product (peels) mixed with livestock wastes were investigated in laboratory experiments, and the capability of tropical countries in this respect was computed. Cassava tubers were peeled, cut and washed. Five, 15, 25 and 35kg samples of the tubers were weighed in three replicates, soaked in water for a period of 1day, after which each sample was dried, crushed and the mash mixed with 500ml of N-hexane (C_6H_{14}). This crushed mash was then allowed to ferment for a period of 8days and afterwards pressed on a 0.6mm aperture size sieve to yield the alcohol contained in it. This alcohol was heated at 79°C for 5hours at intervals of 1hour followed by 1hour cooling. Ethanol was yielded at the average volumes of 0.73, 2.18, 3.63 and 5.08 litres respectively for the selected masses of cassava sample. The rate of ethanol production was computed to be 145 l/tonne. This study found that a total of 6.77 million tonnes or 1338.77 million gallons of ethanol are available from total cassava production from tropical countries. Methane productivity of cassava peels, were investigated by mixing with poultry, piggery and cattle wastes in ratios 1:1, 2:1, 3:1 and 4:1 by mass, using 12 Nos. 220l batch type anaerobic digesters in a 3x4 factorial experiment using a retention period of 30 days and within the mesophilic temperature range. Methane 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 0.6l/kg-TS. The average cumulative methane 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. For 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. For cattle waste, the methane 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. For all livestock waste types, mixing with peels in the ratio 1:1 by mass produced the highest methane volumes, and highest was piggery waste. Results show an environmentally safe means of managing the huge wastes produced from cassava processing. The production and use of cassava crop as a potent source of fuel for producing ethanol and methane is recommended in the cassava-growing tropical countries of the world.

Keywords: *Cassava, Cassava peels, Ethanol, Methane, Cattle waste, Poultry waste, Piggery waste.*

1. Introduction

Renewable energy processes rely principally on plant and animal materials as their feedstock, of which the most dominant among the plant materials are the energy crops. An energy crop is a plant grown as a low cost and low maintenance harvest used to make biofuels, or directly exploited for its energy content. Conventional energy crops include sunflower (*Helianthus annus*), Barbados nut (*Jatropha curcas*), maize (*Zea mays*), sugarcane (*Saccharum officinarum*), and soyabean (*Glycine max*). Cassava (*Manihot esculenta*) is yet to gain global recognition as an energy crop, although its importance in this regard is known in several places. Efforts being reported in this paper, point at its capability as a potent source of ethanol and methane and its potential to gain a vivid presence in global energy economics. Finding such an important use for cassava crop would help to reduce the current almost total reliance on wood and expensive fossil fuels as industrial energy sources in tropical countries. Cassava (*Manihot esculenta* Cranz) is a very important crop grown for food and industrial purposes in several parts of the tropics. Nigeria, with a 2006 production of 49 million tonnes of cassava is the largest producer of the crop in the world [1]. Other countries which grow significant quantities of the crop include Brazil, Congo Democratic Republic, Thailand, Indonesia and Ghana. A handful of others also grow the crop but at much lower production quantities. The present annual global production of the crop is estimated at about 160million tonnes.

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Ethanol fuel is ethanol (ethyl alcohol, $2C_2H_5OH$), the same type of alcohol found in alcoholic beverages. It can be used as fuel, mainly as a biofuel alternative to gasoline, and is widely used by flex-fuel light vehicles in Brazil, and as an oxygenate to gasoline in the United States. Together both countries were responsible for 89% of the world's ethanol production in 2008 [2]. Because it is easy to manufacture and process and can be made from common crops such as sugar and maize, in several countries ethanol is increasingly being blended as gasohol or used as an oxygenate in gasoline. As noted by [3], the following are the key reasons why ethanol is attractive as a substitute to gasoline; ethanol is (1) 98% pollution free, (2) biodegradable, (3) renewable, (4) there is no carbon left when ethanol burns in cars, (5) ethanol does not cause climate change, and (6) all the by-products in the production of ethanol are edible and non-toxic, providing a very good source for animal feedstock. The first-generation biofuels are those made from sugar, starch, vegetable oil, or animal fats using conventional technology [4]. The basic feedstocks for the production of first generation biofuels are often seeds or grains such as wheat, which yields starch that is fermented into bioethanol, or sunflower seeds, which are pressed to yield vegetable oil that can be converted into biodiesel. Some researchers have reported biofuel production from various agricultural materials including ethanol from cassava [5], ethanol from non-edible plant parts [6], biogas from mixtures of cassava peels and livestock wastes [7], methanol from cowdung [8] and fuel from indigenous biomass wastes [10].

Reference [10] noted two common strategies of producing liquid and gaseous agrofuels. One is to grow crops high in sugar (sugar cane, sugar beet, and sweet sorghum) or starch (maize, cassava, yam), and then use yeast fermentation to produce ethyl alcohol (ethanol). The second is to grow plants that contain high amounts of vegetable oil, such as oil palm, groundnut, soybean, castor oil, algae, jatropha, or *pongamia pinnata*. When these oils are heated, their viscosity is reduced, and they can be burned directly in a diesel engine, or in the alternative, chemically processed to produce fuels such as biodiesel. The chemistry of the process basically involves the microbial fermentation of sugars into ethyl alcohol, carbon dioxide and the production of heat as shown in the equation

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + \text{heat} \quad (1)$$

For the ethanol to be usable as fuel, water must be removed. Most of the water is removed by distillation, but the purity is limited to 95-96% due to the formation of a low-boiling water-ethanol azeotrope. The 95.6% m/m (96.5% v/v) ethanol, 4.4% m/m (3.5% v/v) water mixture may be used as fuel alone, but unlike anhydrous ethanol, is immiscible in petrol (gasoline), so the water fraction is typically removed by further treatment in order to burn in combination with petrol in engines. Ethanol is most commonly used to power cars, although it may be used to power other vehicles, such as farm tractors and airplanes. Consumption of 100% ethanol (i.e E100) in an engine is approximately 51% higher than for petrol since the energy per unit volume of ethanol is 34% lower than for petrol [11]. However, the higher compression ratios in an ethanol-only engine allow for increased power output and better fuel economy than could be obtained with lower compression ratios [12]. In Europe the consumption of bioethanol is largest in Germany, Sweden, France and Spain. Europe produced 90% of its consumption in 2006. Germany produced about 70% of its consumption, Spain 60% and Sweden 50% in the same year. In 2006, in Sweden, there were 792, 85% ethanol (i.e E85) filling stations and in France 131 E85 service stations with 550 more under construction [13]. Reference [14] stated further that since 1989, there have also been ethanol engines based on the diesel principle operating in Sweden. They are used primarily in city buses, but also distribution trucks, and waste collectors use this technology. The engines have a modified compression ratio, and the fuel (known as ED95) used is a mix of 93.6% ethanol and 3.6% ignition improver, and 2.8% denaturants [15].

As reported by [16], the Nigerian experience as regards the adoption and use of ethanol in local energy supply is also of interest. In August 2005, under the directive of the former President of the Federal Republic of Nigeria, Chief Olusegun O. Obasanjo, the Nigerian National Petroleum Corporation (NNPC) inaugurated its Renewable Energy Department (RED) which was given the mandate to develop the biofuels industry in Nigeria. In essence, the Nigerian biofuels program seeks to produce ethanol and diesel using agricultural base materials. There has been a strong desire in this program to establish a synergistic connection between the energy and agricultural sectors. The desire had been very rightly placed because up till this time, the level of performance of the energy sector of the country had been very poor. The country's renewable energy program was set up as a catalyst to improve performance in these sectors. Although it had been planned to produce ethanol and diesel under this program, efforts so far made have concentrated on the production of ethanol (to achieve a first blending phase of 90% petrol with 10% ethanol), making the initiative known as the Nigerian E-10 Policy.

Advantages exist in the production and use of bioethanol. Studies conducted in Belgium at Flemish Institute for Technological Research and in Germany at Stuttgart, Heidelberg and Bochum Universities for the life-cycle assessment (LCA) of biofuels proved that the net environmental impact of biofuels is sure to be advantageous in supporting sustainable agriculture and sustainable development, provided the feedstock of biofuels is produced under appropriate agricultural and climatic conditions [17]. When compared to petrol, depending on the production method, ethanol releases less greenhouse gases [18], [19].

Another option for renewable energy production from cassava crop is through anaerobic biodigestion. Anaerobic biodigestion is a process through which organic materials are decomposed by bacteria in the absence of air to produce biogas and this is majorly methane. Methane 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; [20], [21], [22], [23], [24], [25]. Scientific interests and efforts in researching into biomethane producing technology are still relevant, especially in view of contemporary high costs of energy supply worldwide.

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 cassava, there is also 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. Part of the aim of this paper is also to report the results of the investigation of the potential of cassava peels as biomass for the production of methane. Finding such an important use for the peel would make it less burdensome on the environment as a pollutant.

A paper [26] opined that the demand for biofuels may create a huge demand for cereals, sugar and oilseeds which may result in an increase in food price, greater food insecurity and higher level of poverty. A negative impact on the environment resulting from deforestation, intensive tillage and cultivation practices may also occur. In other words, biofuel is competing for arable land that would have been used for growing food crops but is now being used to grow energy crops. Given these possibilities, it would be desirable to find more energy efficient biofuel sources and produce them under appropriate agricultural and climatic conditions thereby supporting sustainable agriculture and sustainable development. One of such sources of interest is cassava and the efforts made in this regard for producing ethanol and methane are reported in this paper.

2. Materials and Methods

2.1 Investigation of Ethanol Productivity of Cassava

The experiments were carried out at the Institute of Agricultural Research and Training (IAR&T), Moor Plantation, Ibadan, Nigeria. Cassava variety TMS 30555 was obtained at the cassava unit of the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria. The cassava tubers were peeled and rinsed in clean water. Five, 15, 25 and 35kg samples of the tubers were then weighed in three replicates. Afterwards the weighed cassava was soaked in clean water for 24hours to dilute any impurities that may be present in it. Then the cassava tubers were placed on a clean tray in the laboratory and allowed to dry naturally for 4hours. After this dewatering process, the cassava tubers were cut and the pieces transferred to a mortar where they were mashed using a pestle to attain sufficient size reduction. This ensures the creation of sufficient surface area for the material to aid the process of fermentation. The mash was then transferred into a plastic bucket. 500ml of N-hexane (C_6H_{14}) was added to the suspension to aid fermentation. The mash was thoroughly stirred to achieve an even mixture with the hexane. It was then covered and left undisturbed in the laboratory at room temperature for 8days. Afterwards, the now fermented mash was poured onto a 0.6mm aperture size sieve placed over a clean plastic bowl. This cassava mash was then completely squeezed to dryness while the liquid filtered through the sieve. The filtered liquid was afterwards transferred to the soxhlet machine for removal of N-hexane that may still be present in it. The collected liquid was poured into a glass dish and then gradually heated at 79^0C for a total of 10hours (at intervals of 1hour heating followed by 1hour cooling) to ensure complete evaporation of any trapped H_2O or CO_2 remaining in it. Afterwards the final liquid (ethanol) was allowed to cool normally in the laboratory and its mass, volume and other properties were determined. The properties of the ethanol produced were determined and compared to the known properties of ethanol. Temperature was measured with a thermometer. Relative density was measured with a pictometer. The squeezed mash was placed on trays in the laboratory and allowed to air dry normally. The eventual caked mash was analyzed for its nutritive properties.

2.2 Investigation of methane Productivity of cassava Peels

The methane productivity of cassava peels mixed with poultry, piggery and cattle wastes in the ratios 1:1, 2:1, 3:1 and 4:1 by mass was investigated using 4 replicates in a 3x4 factorial experiment, using a 30-day retention period. 12 Nos., 220-litre 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, Nigeria. 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&T, Moor Plantation and hand-picked to remove stones, sticks, and other foreign matter, and thoroughly stirred. A 200g sample was obtained from the mass of pounded cassava peels and each of the animal waste types and analyzed for organic C, total N, %P, %K, $\%NO_3$, pH, and heavy metals. Five kg of cassava peels and 5kg 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 minutes 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 on 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).

3. Results

From this experiment, the volumes and masses of ethanol produced which corresponded to the mean mass of cassava samples used were found and relationships derived as shown in Figure 1 and Figure 2. Based on these relationships, the projected ethanol production from cassava produced in tropical countries is shown in Table 1. The effects of mixing cassava peels and different ratios of livestock waste on biogas yield are shown in Table 2 and Figs 3 to 5. All the readings of the biogas yield were analyzed using the Duncan Multiple Range Test (DMRT)

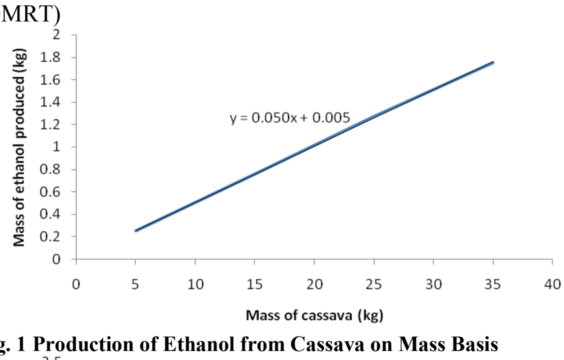

Fig. 1 Production of Ethanol from Cassava on Mass Basis

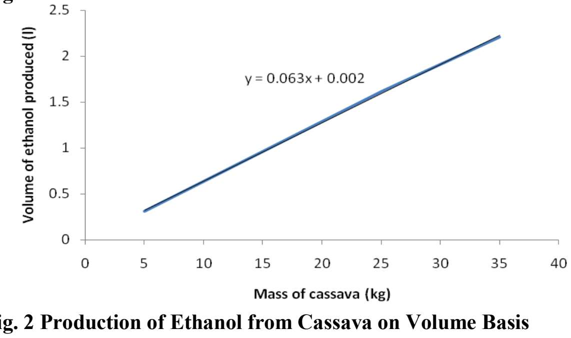

Fig. 2 Production of Ethanol from Cassava on Volume Basis

Table 1. Projected Ethanol Production from Cassava

Region/country	Cassava Production (million tonnes)	Projected ethanol Production (million tonnes)	Projected ethanol Production (million gallons)
Africa			
Nigeria	30.41	1.52	300.58
Congo Dem. Rep.	16.5	0.83	164.13
Ghana	7.17	0.36	71.19
Tanzania	6.19	0.31	61.30
Mozambique	5.64	0.29	57.35
Uganda	2.28	0.15	29.66
Asia			
Thailand	15.96	0.80	158.2
Indonesia	14.73	0.74	146.33
India	5.87	0.29	57.35
China	3.60	0.18	35.60
Vietnam	1.78	0.09	17.80
Latin America			
Brazil	19.81	0.99	195.77
Paraguay	3.30	0.17	33.62
Others	1.0	0.05	9.89
TOTAL	134.24	6.77	1338.77

Table 2. 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 x 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

Table 3. 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 4. Interaction of Animal Wastes and Mixing Ratios

Ratio	Cassava Peels and Poultry Waste	Cassava Peels and Piggery Waste	Cassava and 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		

SE: standard error

Table 5. Results of Burning Tests Conducted on Produced Biogas

Waste Type	Retention Period (Days)	Biogas Volume (l)	Burning Time (Mins)	Energy Produced (MJ)
Poultry	30	98.4	63.7	2200.2
Piggery	30	110.2	70.4	2464.1
Cattle	30	46.8	32.0	1046.5
Peels and Poultry (1:1)	30	78.4	16.2	606.6
Peels and Piggery (1:1)	30	93.7	16.6	725.1
Peels and Cattle (1:1)	30	35.5	14.5	584.6

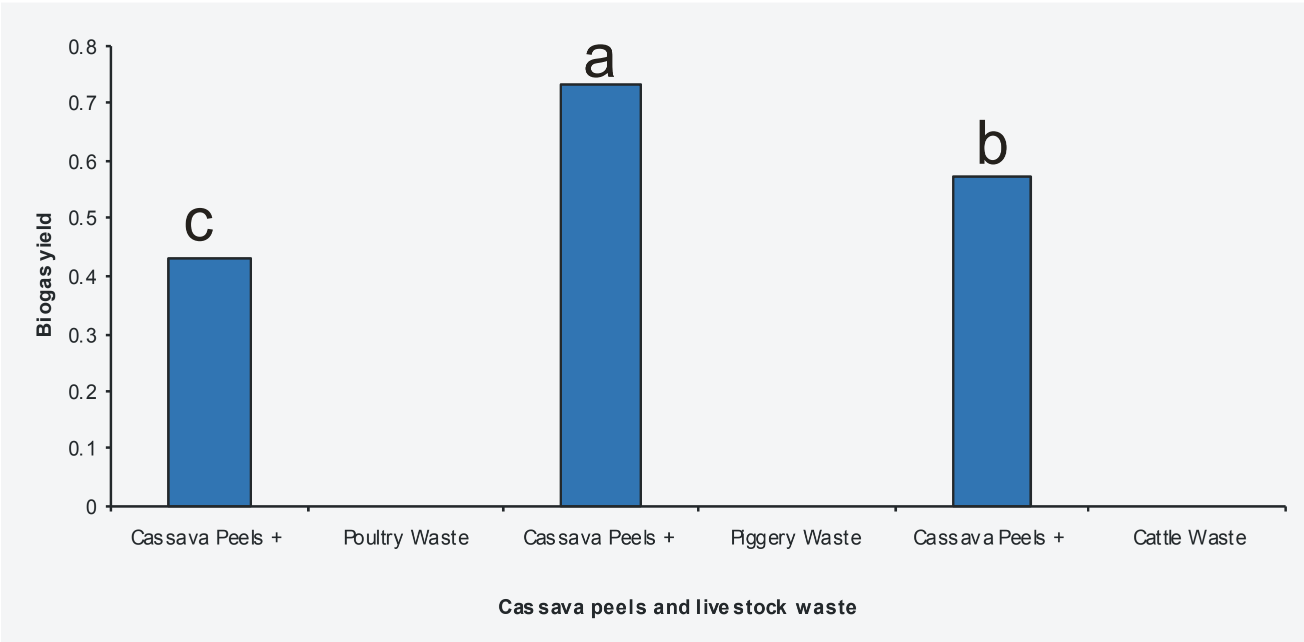

Fig. 3 Effect of Cassava Peels and Different Wastes Mixtures on Biogas Yield

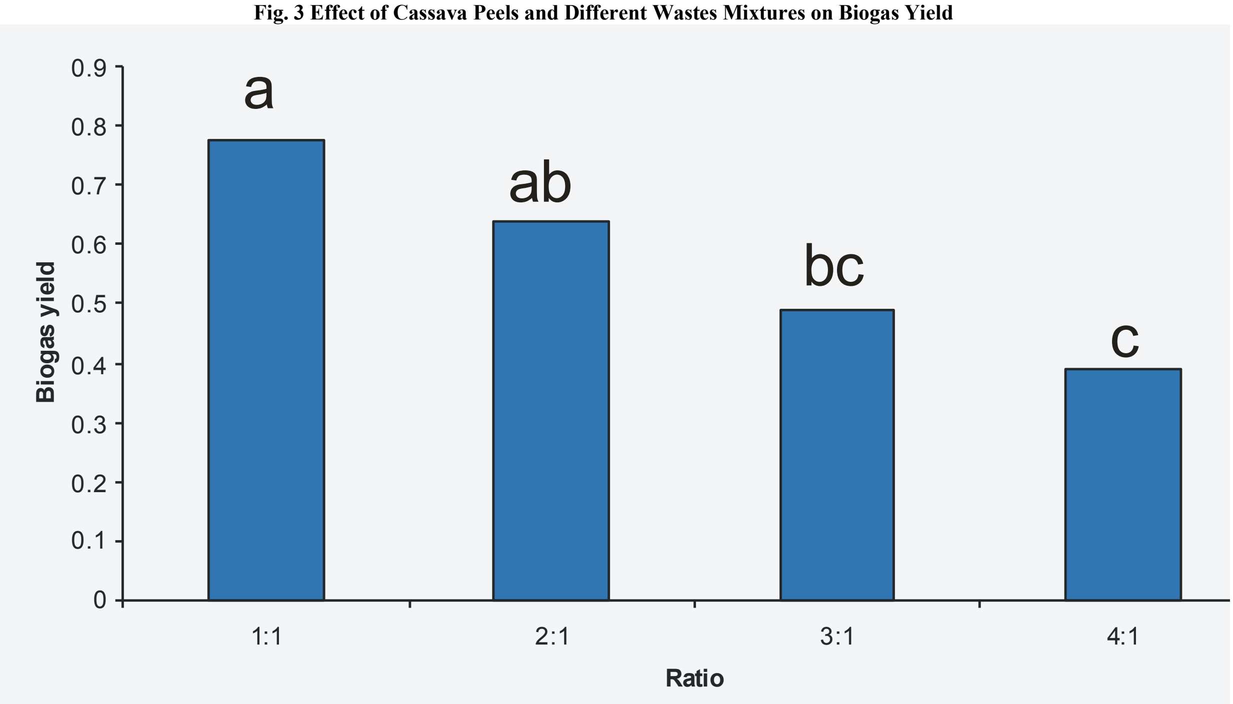

Fig. 4 Effect of Different Mixing Ratios of Peels and Livestock Waste on Biogas Yield

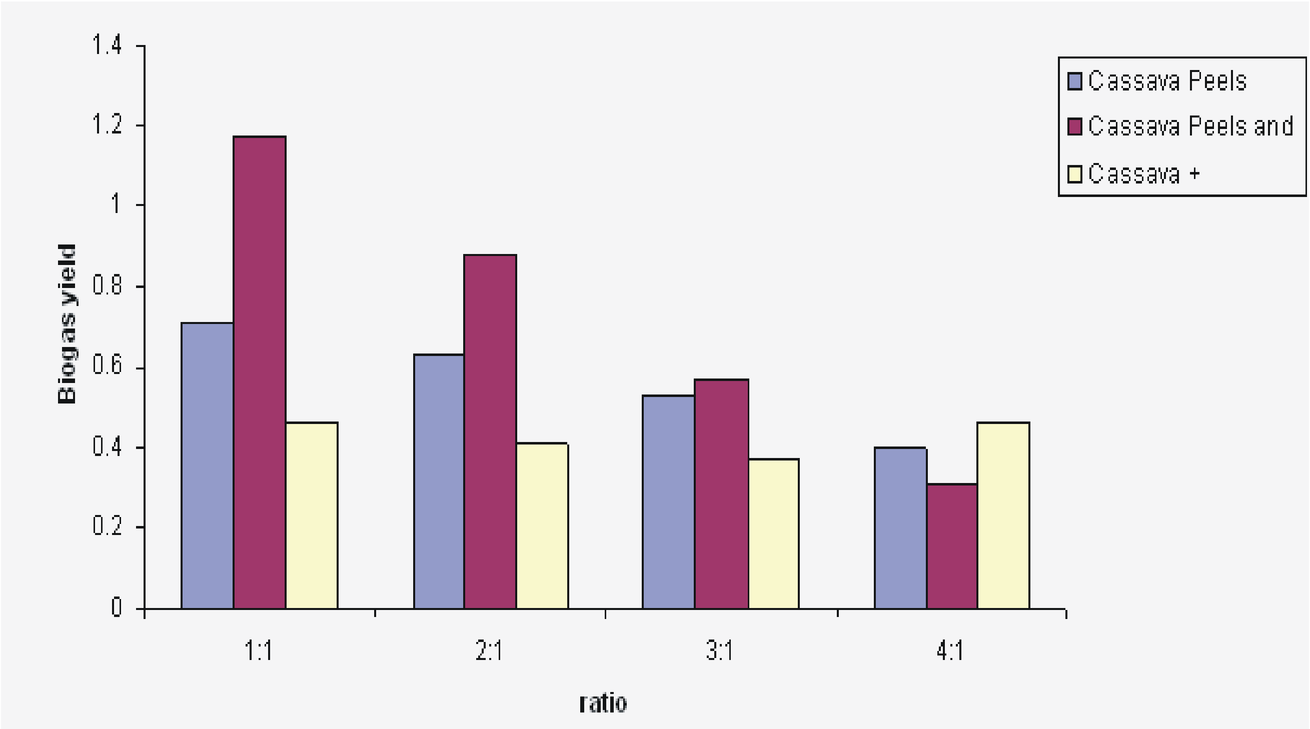

Fig. 5 Joint Effect of Cassava Peels and Livestock Waste on Biogas Yield

The summary of cumulative biogas production from mixtures of cassava peels and wastes is shown in Table 3. However, Table 4 shows the interaction among the mixing ratios and the various waste types. Table 5 shows results of burning tests conducted on the biogas produced.

4. Discussions

Table 1 shows the global production of cassava crop for year 2000 for tropical countries spread over Africa, Asia and Latin America. The sourcing and supply of energy are pertinent issues in all of these countries. Significant increase in production of the crop has occurred over the recent years in many of these countries most especially in Nigeria, Brazil, Thailand and the Democratic republic of Congo. Options for use of the crop have to be investigated of which one of such is the production of ethanol for energy supply. Laboratory experiments carried out in this study resulted in ethanol production volumes and masses which were used to produce the graphs shown in Figure 1 and Figure 2 and the guiding equations are shown as well. Based on these mathematical relationships, the projected production of ethanol from cassava producing nations is also shown in Table 1. A total of 6.77 million tonnes or 1338.77 million gallons of ethanol are available from total cassava production from tropical countries. The cassava crop is a readily renewable resource unlike the hydrocarbon fuels. The tropical countries where this crop is grown have tremendous capacity for the conversion of the crop into ethanol and this can be used as fuel. By doing this, it will help to mitigate their dependence on fossil fuels.

Cassava peels have high organic carbon and low total nitrogen content, and this results in a particularly high C/N ratio which was found to be 48 in this study. According to [27], 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, in this research, cassava peels were mixed with livestock wastes having a much lower C/N ratio to stabilize the ratio to an optimal value between 22 and 30. Table 2 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 3 was 0.6l/kg-TS. This value is low. The stalk of cassava plant is very high in lignin content and generally, lignocellulosic materials inhibit biogas production. The explanation for this is that lignin suppresses biodegradation [28] . 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. Also, biogas yield was significantly ($P \leq 0.05$) influenced by the different mixing ratios of livestock waste with cassava peels. As shown in Table 3, 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 (by mass) 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 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. Since lignin suppressed biodegradation [28], the result is that the higher the lignin content, the lower the biogas yield. 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. Figure 3 above 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 4 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 indicates 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, and the least quantity of biogas came from 4:1 ratio. However, it was observed from Tables 3 and 4 that in all the different types of waste mixed with cassava peels, biogas production decreased with an increase in the mixing ratio.It is noticed from Table 5 that the higher volume of biogas produced by poultry manure translated to burning time which was the highest among the single manure types. This also resulted in a higher quantity of energy produced. Among the single manure experiments, cattle manure had the least cumulative biogas volume, burning time and energy produced. Biogas from cassava peels digested alone did not burn to any measurable degree because of the very low volume produced. These readings demonstrate that if fully exploited biogas from mixtures of livestock wastes and cassava peels can become a significant source of rural energy supply in many developing areas of the world where this crop is grown. This group includes most of the tropical countries. A study [29], evaluated the potential of non-commercial domestic cooking fuels and energy consumption patterns in rural households of Hisar district of Haryana state in India. It found that the highest amount of non-commercial energy per month was consumed by large farming families (4040 MJ) followed by medium (3336 MJ) and small (3156 MJ). With enhanced exploitation, of biogas production for energy supply, these amounts of energy demand can be adequately met. The feedstock for biogas systems is essentially biomass and very significantly livestock waste and crop waste. These are renewable materials whose use does not deplete the earth's resources. Their use is well adapted to rural settings since that is where the feedstock is produced.

5. Conclusions and Recommendations

The solution to the energy problem lies in the integration of several options and technologies from diversified fields, specifically, biomass, biofuel, biogas, solar energy, wind energy, hydropower and other reasonably ecofriendly options. No particular option may be regarded as the panacea. Different nations and respective areas of the world would have to decide and choose on the combination of options which suit them the best giving cognizance to their resource base, technology level, and available manpower to operate these various systems as well as economic, environmental and political considerations. For the tropical countries, one of the options should look in the direction of tremendously raising the production of cassava (an often neglected but sturdy crop) as a potent source in the production of ethanol fuel and biomethane for the supply of energy. This will serve as a two pronged strategy namely first raising the production of ethanol biofuel and secondly mitigating the negative environmental impacts of wastes so produced by producing another fuel from it. The increased cultivation of cassava and the production as well as use of ethanol derived from it and biogas from its peels is recommended particularly in the tropical regions of the world. Furthermore, 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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