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An Evaluation of the Global Potential of Cocoyam (*Colocasia* and *Xanthosoma* species) as An Energy Crop

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Research Article

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ABSTRACT

Aims: To evaluate the potential of cocoyam (*Colocasia* and *Xanthosoma* species) for the production of ethanol and methane for use as energy sources.
Study design: Laboratory experimentation.
Place and duration of study: Federal College of Agriculture Ibadan and Institute of Agricultural Research and Training (IAR&T), Moor Plantation, Ibadan, Nigeria between December 2010 and June 2011.
Methodology: Five, 15, 25 and 35 kg samples of peeled cocoyam corms were weighed in three replicates. Next, the weighed cocoyam was soaked in clean water for 24 hr, and afterwards placed on a clean tray and allowed to air dry naturally for 4 hr. The cocoyam corms were then cut and the pieces transferred to a mortar where they were mashed to attain sufficient size reduction. The mash was then transferred into a plastic bucket. Five hundred, 650, 800 and 950 ml of N-hexane (C_6H_{14}) was added to the 5, 15, 25 and 35kg samples. 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 8 days. The fermented mash was poured onto a 0.6 mm aperture size sieve and completely squeezed to dryness while the liquid filtered through the sieve. N-hexane was removed from the filtered liquid. The collected liquid was poured into a glass dish and then gradually heated at 79°C for a total of 10 hr (at intervals of 2 hr heating followed by 1 hr 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 lab and its mass, volume and other properties were measured.
Results: It was found that ethanol was yielded at the rate of 139 L/tonne of cocoyam. Therefore, 10 million tonnes annual global production of cocoyam is potentially able to

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produce 331 million gallons of ethanol (i.e. 200 million gallons gasoline equivalent) or 39.5 million cubic metres of methane which on burning would produce 179.3 x 10^7 MJ of energy. The mash obtained as byproduct of the processes is capable of supplying 59 calories of food energy per 100g.

Conclusion: Cocoyam has very good potential as a source of ethanol and methane. Its use as a renewable source of energy for the production of biofuels is recommended and doing so poses no threat to the environment or food supply. The mash produced is an excellent feedstock for livestock. The scientific innovation and relevance of this study lies in the fact that cocoyam is a renewable produce and the fermentation and anaerobic digestion methods used are applicable across countries and regions irrespective of available degree of industrialization and climate.

Keywords: Anaerobic digestion; bioethanol; biogas; Cocoyam; fermentation.

1. INTRODUCTION

The world has focused entirely on a comparatively small number of crops to meet the various needs for food and industrial fiber; the total number of economic crops of significance to global trade hovering just above one hundred. The consequence is that thousands of plant species with a considerably larger number of varieties fall into the category of underutilised or neglected crops. These crops are marginalized by agricultural, nutritional and industrial research (Global Forum for Underutilized Species, 2009). One of such neglected crops is cocoyam which over the years has received minimal attention from researchers and other stakeholders of interest. Cocoyam (*Colocasia* and *Xanthosoma* species), a member of the Aracea family of plants, is one of the oldest crops grown, largely in the tropics, for its edible corms and leaves and as an ornamental plant. On a global scale, it ranks 14th as a vegetable crop going by annual production figures of 10million tonnes (FAO, 2005). Its production estimates vary. However, one study points out that Africa accounts for at least 60% of world production and most of the remaining 40% is from Asia and Pacific regions (Mitra et al., 2007). Another study opines that coastal West Africa accounts for 90% of the global output of the crop with Nigeria accounting for 50% of this (Opata and Nweze, 2009). Cocoyam thrives in infertile or difficult terrains that are not well suited for large scale commercial agriculture for growing most conventional staple crops. As observed by Williams and Haq (2002), since the poor are frequently the main occupants of such areas, cultivation of neglected crops such as cocoyam constitute practical alternatives for them to augment their meager incomes. The crop’s supposed association with the poor may be a reason while conventional agricultural research has not bothered much to take a closer look at it.

Climate change, crop failures, unpredictable commodity prices, wars, political unrest and other forms of dislocations in the established pattern of global affairs, variously show that overreliance on just a few crops is risky to the world. However, bringing those crop species with underexploited potentials out of the shadows into the mainstream would help to spread this risk and enhance the utility of marginal lands on which many of them are cultivated. Most of the comparatively few number of studies reported in respect of cocoyam have focused largely on enhancing its value as a food crop, principally to supply carbohydrates and starch; a role which it already shares with so many competing crops. However, the work being reported in this paper looked at cocoyam as an energy crop for the supply of ethanol and biogas; a role which if fully developed can raise the profile of this crop in global energy economics. Points in favour of this research are the fact that it is in line with ongoing global research efforts at discovering more energy crops and developing other sources of renewable energy. The processes used for this research are natural, namely; fermentation and anaerobic biodigestion, and these neither contribute to climate change nor deplete the earth's vital resources. Some progress has been reported in the use of cassava (another neglected tropical crop) as a sustainable source of biofuel in tropical countries for the production of ethanol (Adelekan, 2010) and also methane (Adelekan, 2012). This present paper points out that cocoyam has similar potential for this, most particularly in the tropical and subtropical countries where this crop is cultivated.

Research into renewable energy technologies is still relevant, especially in view of the often very high costs of fossil fuels worldwide (Crude oil has surpassed 100 dollars per barrel, early 2011). Another reason for their relevance is the fact that the rampant use of firewood for domestic and industrial heating in low income countries invariably necessitates the destruction of forests and this is harmful to the environment. Also, it had been pointed out that the use of firewood, kerosene and charcoal in households had adverse effects on human health (Adelekan and Adelekan, 2004). Furthermore, using biomass to produce energy can reduce the use of fossil fuels, reduce pollution and waste management problems and show environmental advantages in terms of life-cycle energy use and greenhouse gas (GHG) emissions (Marshall, 2007; Inderlwildi and King, 2009; Rettenmaeir et al., 2010; Fernando et al., 2010). Overall, these reasons are compatible with the aims and objectives of the Kyoto Protocol which are tailored towards the reduction of greenhouse gases. According to IEA, (2010) bioenergy currently provides 10% of global primary energy supply, 1.3% of electricity production, and 1.5% of transport fuels. Driven by increasing concern over energy security and greenhouse gas mitigation, the global demand for liquid biofuels more than tripled between 2000 and 2007. Production costs are uncertain and vary with the feedstock available, but are currently estimated to be USD 0.80 – 1.00 per litre of gasoline equivalent. Prasad et al., (2007) and Balat et al., (2008) observed that with world reserves of petroleum fast depleting, ethanol has in recent years emerged as the most important alternative source of liquid fuel and has generated a great deal of research interest in ethanol fermentation. The global annual production of fuel ethanol is around 40 to 50 billion litres, of which 90 percent is produced by the USA and Brazil from maize and sugarcane respectively (World Bank, 2008).

According to estimates of the European renewable energy industry around 40% of electricity demand will be generated with renewable energy sources by 2020 (EREC, 2010). Furthermore, the new Renewable Energy Directive will undoubtedly stimulate the renewable energy heating and cooling market, according to EREC's projections, up to 25% of heating and cooling consumption can come from renewable energy by 2020. Moreover, the Renewable Energy Sources (RES) Directive provides a strong incentive to significantly reduce oil dependence in the transport sector over the coming years by setting a minimum target of 10% renewable energy in transport. The RES Directive set an important framework for the future growth of the renewable energy industry and paved the way for a stable investment climate, thereby not only increasing the security of Europe's energy supply, contributing to abating climate change, but also providing high-quality jobs and sustainable economic recovery. EREC published its 'RE-thinking 2050 - A 100% renewable energy vision for the European Union' report in April 2010. 'RE-thinking 2050' outlines a pathway towards a 100% renewable energy supply system by 2050 for electricity, heating and cooling as well as transport for the European Union, examining the effects on Europe's energy supply system, on CO_2 emissions as well as outlining economic and social benefits of a fundamental change towards a sustainable energy system. Similar policies are also being established in other regions. For instance in 2009, India announced a national biofuel policy with a mandate to achieve 20% blend of bioethanol and biodiesel by 2017 (Das and Priese, 2011).

Zegada-Lizarazu et al. (2010) has observed that the recent policies enacted by the EU foresee an increased interest in the cultivation of energy crops. Hence systematized information on new energy crops and cropping strategies is necessary to optimize their production quantitatively and qualitatively and to integrate them into traditional production systems. This kind of information will offer farmers new perspectives and options to diversify their farming activities. Some of these crops, however, may compete for land and resources with existing food crops, while others could be grown in marginal or degraded lands with consequent beneficial effects on the environment. Therefore choosing the appropriate management components and species should be site specific and oriented to minimize inputs and maximize yields. The paper further noted that in some cases, traditional food crops are used as dedicated energy crops with the advantage that their management practices are well known. On the other hand, the management of new dedicated energy crops, such as perennial herbaceous crops, often demands a range of structural features and tactical management approaches that are different to those commonly used for traditional food crops. Most of these crops are largely undomesticated and are at their early stages of development and improvement. The foregoing points strongly at one fact notably that it is important to research into more and more energy crops, wherever they may be found so as to tap their potential for the benefit of global progress. The objective of this paper was therefore to evaluate the potential of cocoyam (*Colocasia* and *Xanthosoma* species) for the production of ethanol and methane for use as energy sources.

2. MATERIALS AND METHODS

2.1 Initial Preparation of the Material

Cocoyam was obtained at the root crops unit of the Institute of Agricultural Research and Training (IAR&T), Moor Plantation, Ibadan, Nigeria. The cocoyam corms were peeled, rinsed in clean water and sun dried for 24 hours. Five, 15, 25 and 35 kg samples of the corms were then weighed on a laboratory scale in three replicates. Afterwards the weighed cocoyam was soaked in clean water for 24 hr to dilute any impurities that may be present in it. The material was afterwards placed on a clean tray and placed outside to dry in the sun for 4 hr. It was later transferred to the laboratory and dried in the oven at 60^0C also for 4 hr. After this de-watering process, the cocoyam corms were cut and the pieces transferred to a mortar where they were mashed using a pestle to attain sufficient size reduction. This created sufficient surface area for the material and this would enhance the process of fermentation.

2.2 Fermentation of the Prepared Material

The mash was then transferred into a plastic bucket. Five hundred, 650, 800 and 950 ml of N-hexane (C_6H_{14}) was added to the 5, 15, 25 and 35 kg samples respectively 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 8 days. Afterwards, the now fermented mash was poured onto a 0.6 mm aperture size sieve placed over a clean plastic bowl. This cocoyam 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°C for a total of 10 hr (at intervals of 2 hr heating followed by 1 hr 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 lab.

2.3 Determination of Properties of Ethanol Produced

The mass, volume and other properties of the ethanol produced were measured. These measured properties were then compared to the known standard 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 lab and allowed to air dry normally. The eventual caked mash was analyzed for its nutritive properties.

2.4 Anaerobic Biodigestion of Cocoyam Corms

For the production of biogas, 5, 15, 25 and 35 kg of peeled corms were measured, cut, mashed and put into 120 L black coated drums. The content of each drum was mixed with water in 1:1 ratio by mass and thorough stirred. 2 kg of fresh cattle manure was added to each drum and sealed. A 30% Total solids (TS) content was ensured in the mixing. Each drum was then placed in open sun and connected through a 2 cm diameter pipe to an arrangement which included a cleaning chamber to remove H_2S, CO_2 and other gasses, a water tank to measure biogas produced through water displacement and a storage chamber to hold the biogas produced. The whole arrangement was left outside in the open without shade for a 30 day detention period. Stirring of the contents of the digester was done twice daily in the morning and evening in order to free trapped gasses and prevent the formation of scum on the surface of the enclosed contents. Biogas production was measured daily and recorded. The methane content of biogas produced was measured. The methane gas was burned and its thermal properties determined.

2.5 Flow Chart of Ethanol Production Process Used

Figure 1 shows the flow chart of the ethanol production process from cocoyam.

3. RESULTS AND DISCUSSION

3.1 Production of Ethanol

National Corn Growers Association (2005) determined that ethanol has a positive net energy balance. Ethanol generates about 35% more energy than it takes to produce. Michigan State University (2002) further pointed out that there is 56% more energy in a gallon of ethanol than it takes to produce it. The available energy from ethanol is much higher than the input energy for producing ethanol. In other words, using ethanol as a liquid transportation fuel would significantly reduce domestic use of petroleum even in the worst case scenarios. According to National Renewable Energy Laboratory (1998) the energy balance and energy life cycle inventory for the various fuels is as shown in Table 1.

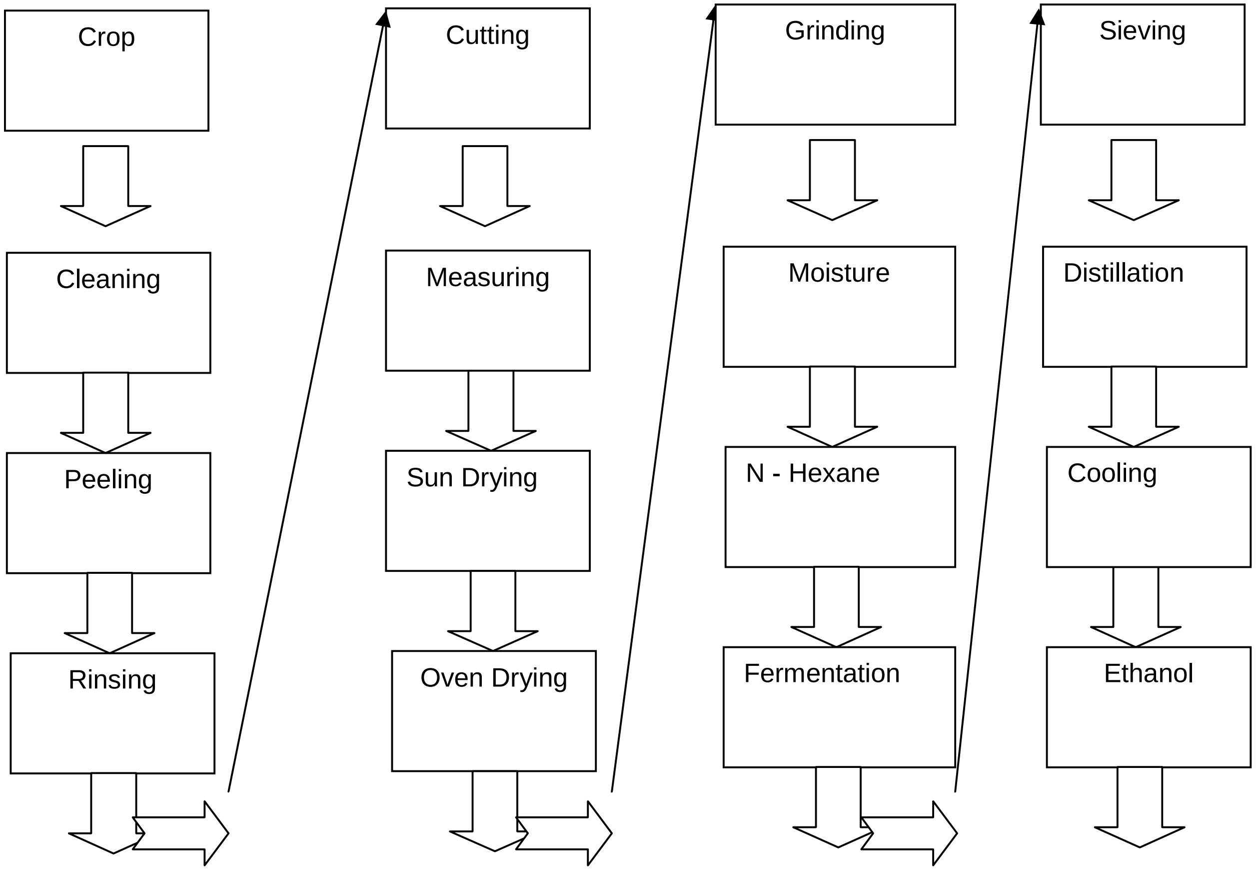

Fig. 1: Flow Chart of the ethanol production process

Table 1: Energy balance and energy life cycle of fuels

S/N	Fuel	*Energy yield	Net energy (loss) or gain
1.	Gasoline (Petrol)	0.805	(19.5%)
2.	Diesel	0.843	(15.7%)
3.	Ethanol	1.34	34%
4.	Biodiesel	3.20	220%

**Life cycle yield in liquid fuel BTUs for each BTU of fossil fuel energy consumed during production.*

Oleskowicz-Popiel et al., (2008) produced ethanol from maize silage and achieved a theoretical ethanol yield of 82%, giving 30.8kg ethanol per 100kg dry mass of maize silage. Lee (1997) stated that the biological process of bioethanol production utilizing lignocellulosic biomass as substrate requires: 1) delignification to liberate cellulose and hemicelluloses from their complex with lignin, 2) depolymerization of the carbohydrate polymers (cellulose and hemicelluloses) to produce free sugars, and 3) fermentation of mixed hexose and pentose sugars to produce ethanol. 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 (European Biomass association 2007).

Laboratory experiments carried out in this study resulted in ethanol production volumes and masses shown in Tables 2 to 8.

Table 2: Production of ethanol from cocoyam (by volume)

Sample (kg)	*Volume of ethanol produced (litres)	Standard deviation
5	0.69	0
15	2.07	0.006
25	3.43	0.006
35	4.89	0

**Values are means of three replicates*

Table 3: Production of ethanol from cocoyam (by mass)

Sample (kg)	* Mass of ethanol produced (kg)	Standard deviation
5	0.55	0.006
15	1.63	0.006
25	2.71	0.006
35	3.86	0.006

**Values are means of three replicates*

Charting these values, figures 2 and 3 are produced. The guiding equation for the volume of ethanol produced from cocoyam is $y = 0.139x - 0.022$. R^2 values of 0.999 obtained for the charts indicate their high preditability of the process. From the equation, it is found that the production rate of ethanol for cocoyam is 139 L/tonne. This compares favorably with rates earlier reported for other crops as shown in table 4 below.

Table 4: Ethanol production rates for selected tropical crops

S/N	Crop	Production rate (L/tonne)
1	Cocoyam	139
2	Cassava	145
3	Dent maize	346
4	Sweet sorghum	135

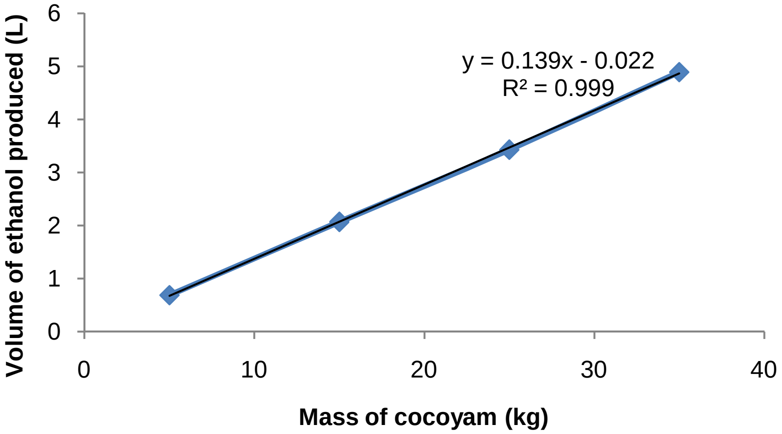

Fig. 2: Volume of ethanol produced from cocoyam

The properties determined for the ethanol produced from the crops are shown in Table 5. The liquid boiled at 78.5^{0}C and had a relative density of 0.791. The liquid was clear and colourless. It had a very sharp alcoholic taste, as well as the typical ethanol odour. When tested on a blue piece of cloth, it readily bleached it to almost white colour.

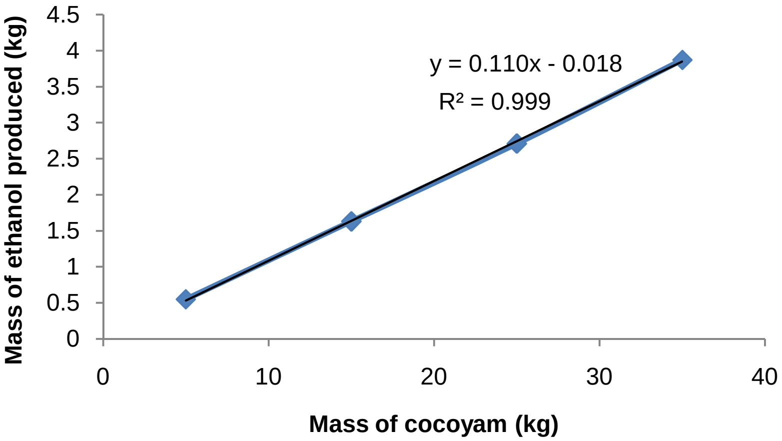

Fig. 3: Mass of ethanol produced from cocoyam

Table 5: Properties of bioethanol produced

Fuel	Melting point (^{0}C)	Boiling point (^{0}C)	Relative density (at 20^{0}C)
Standard ethanol	-114.1	78.5	0.789
Ethanol produced		78.5	0.791

Nutritive analysis of the dried mash of cocoyam, together with that of another important tropical crop, cassava, are as shown in Table 6. Significant quantities of food energy, carbohydrates, proteins, calcium and iron are evident. This shows that the by-product of ethanol production from cocoyam also contain considerable nutritive properties making it suitable for composition in the feed rations of livestock. If this possibility is further investigated, it means that the significance of cocoyam as a concentrate in livestock feeding will be accentuated.

Table 6: Nutritive analysis of dried mash of cassava and cocoyam (per 100g portion)

S/N	Nutrient	Cassava	Cocoyam	Unit
1	Food energy	61.8	59.5	calories
2	Water	2.5	2.1	g
3	Carbohydrates	14.4	13.8	g
4	Proteins	1.2	1.5	g
5	Fat	0.1	0.4	g
6	Calcium	153	4.8	mg
7	Iron	0.5	0.9	mg

From the equation obtained for this process, it is calculated that the yield of bioethanol from cocoyam is 139 L/tonne. This compares very favourably with 145 L/tonne reported for cassava (Adelekan, 2010), 100L/tone for carrot and 70 L/tonne for sugar cane. Given a global annual production quantity of cocoyam to be 10 million tonnes, 331 million gallons of ethanol is potentially available from this. Going by the fact that 1 litre of ethanol contains approximately 66% of the energy provided by a litre of petrol, this potential ethanol production has a gasoline equivalent of 200 million gallons. Although this is far from the gasoline equivalent of 3.3 billion gallons reported for ethanol produced from cassava (Adelekan, 2011), it is still a sizable quantity which will impact on global fuel economics.

The question always arises, with a growing demand for ethanol produced from cocoyam, is there a threat to food security in respect of the crop? The answer to this question is twofold. Firstly, the yield of cocoyam, presently about 30 tonnes per hectare (Ekwe et al., 2009) can be tremendously improved through scientific research directed at producing better yielding varieties. With success in this area, there may not be a need to cultivate more land to increase production of the crop. The present global cultivated total hectares of the crop can still sustain higher improvements in yield. The second part of the answer has to do with the need to husband the crop more efficiently to plug avenues for waste. In many parts of the developing world, between the farm and the consumers, 25 to 50% losses still occur to harvested crops because of poor preservation techniques, inadequate storage facilities, deficient transportation infrastructure, weak market structures and so forth. Therefore there is a pungent need to continue to research options which will enhance preservation and lengthen the storage life of cocoyam. Improvements in the area of preservation of the crop will also increase its availability making its use as an energy crop less deleterious on its use as a food crop and thereby enhancing food security.

As noted by Blume (2007), the following are the key reasons for which ethanol is attractive as a substitute to gasoline: Ethanol is 98% pollution free; biodegradable; renewable; there is no carbon left when ethanol burns in cars; ethanol does not cause climate change; and all the byproducts in the production of ethanol are edible and nontoxic, providing a very good source for animal feedstock. Refering particularly to the U.S.A. experience, Lovins et al., (2005) identified some further advantages that ethanol brings to the global energy sourcing solution to include the following: (i) Sound ethanol production practices would not hamper food and fiber production or cause water or environmental problems, (ii) ethanol improves urban air quality, and can reduce CO_2 emissions by 68% for cellulosic ethanol. (iii) properly grown feedstocks can even reverse CO_2 emissions by taking carbon out of the air and sequestering it in enriched top soil whose improved tilth can boost agronomic yields, (iv) using ethanol as a vehicle for better farm, range, and forest practices can also help to achieve other goals such as reduced soil erosion and improved water quality, and can dramatically improve the economies of rural areas, and (v) fuel ethanol production can lead to increased agriculture employment since there is pungent need to raise farm production levels to meet demand. The chemistry of the process basically involves the fermentation of sugars into ethyl alcohol, carbon dioxide and the production of heat as shown in the equation:

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2 + \text{heat}$$

The basic steps for large scale production of ethanol are: microbial (yeast) fermentation of sugars, distillation, dehydration and denaturing (optional) to render the ethanol unsuitable for human consumption. Enzymes are used to convert starch into sugar (Green Car Congress, 2005). Ethanol is produced by microbial fermentation of the sugar. Carbon dioxide, a greenhouse gas, is emitted during fermentation and combustion. However, this is canceled out by the greater uptake of carbon dioxide by the plants as they grow to produce the biomass (Biomass Energy Homepage, 2005). When compared to petrol, depending on the production method, ethanol releases less greenhouse gases (Wang et al., 1999; Wang, 2002). 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 (Energy Facts, 2008).

3.2 Production of Biogas

Table 7 shows the aggregate production of biogas from cocoyam samples used in the experiment. The carbon: nitrogen (C/N) ratio measured for cocoyam was 40:1. High C/N ratio is not compatible with high gas yields. A biomass material having high C/N ratio such as cocoyam and other corms and tuber crops should be mixed with another material which has low C/N ratio (for example manure) so as to bring the C/N ratio of the mixed mass to around a value between 20:1 and 30:1. If C/N ratio is higher than that range, biogas production will be low. This 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. 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 form of ammonia, and this will raise the pH value of the contents of the digester. A pH value of 8.5 will be toxic to the methanogenic bacteria in the digester. The cumulative effect of this is also reduced biogas production. The methane content measured for the gas was 70.4%. the highest production rate achieved in the digester during the retention period was about 3.9 L/kgTS.

Table 7: Aggregate Production of methane from cocoyam by volume (30 days retention period)

Sample (kg)	*Volume of ethanol produced (litres)	Standard deviation
5	19.5	0.058
15	61.3	0.058
25	98.5	0.1
35	138.6	0

Values are means of three replicates

Plotting the masses of samples against the mean methane volumes produced, figure 4 is obtained.

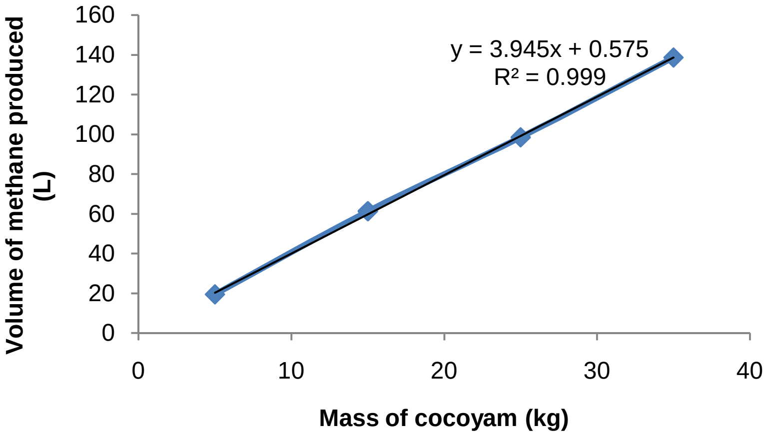

Fig. 4: Volume of methane produced from cocoyam

The guiding equation for the process is given as:
$y = 3.945x + 0.575$

Assuming the 10 million tonnes annual production of cocoyam were to processed completely into biogas, this would result in the production of 39.5 million cubic metres of methane. With the knowledge that 1 litre of methane on burning, produces 22MJ of energy, this quantity of methane on burning would produce 179.3×10^7 MJ of energy.

3.3 Burning Tests

The results of burning tests conducted on the methane produced are as shown in Table 8. Thirty-five kilograms of cocoyam yielded methane over a 30-day retention period which on burning produced 3049MJ. This reading demonstrates that if fully exploited biogas from cocoyam mash 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 (Sehgal et al., 1995), 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). Through the encouragement of cocoyam cultivation in the tropical regions, development of higher yielding varieties of the crop, its introduction into those areas where it is not presently widely cultivated, and combined with its enhanced exploitation for production of biogas for energy supply, these amounts of energy demand can be adequately met.

Table 8: Results of burning tests conducted on the methane produced

Sample (kg)	Retention period (days)	Biogas volume (L)	Burning Time (Mins)	Energy produced (MJ)
5	30	19.5	12.7	429
15	30	61.3	38.2	1349
25	30	98.5	63.7	2167
35	30	138.6	89.1	3049

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 51.7C (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. Biogas production was greatest when the digester temperature was in the range of 32 to 40°C. Digestion temperatures for optimum design all occur in the mesophilic range of 32 to 40°C. 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. Straw or shredded tree bark can be used around the outside of the digester to provide insulation. Black-coated digester works more efficiently than light-coated ones. The microorganisms involved in anaerobic biodigestion require a neutral or mildly alkaline environment, as a too-acidic or too-alkaline environment will be detrimental. 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.

The mash produced as byproduct of methane generation was analyzed for its nutritive content and was found to have similar results as that contained in Table 6.

4. CONCLUSION

An ethanol production rate of 139 L/tonne of cocoyam was obtained and this compares favourably with rates earlier reported for some other tropical crops namely cassava (145 L/tonne) and sweet sorghum (135 L/tonne). Therefore, this study showed that cocoyam has a very good potential for the production of ethanol and methane. The solution to the problem of energy security lies in the integration of several options of which the renewable sources namely biomass, biofuel, and biogas, are crucial. Bioethanol production through fermentation of crops and methane production through anaerobic biodigestion are environmentally safe processes. The byproduct which is mash has excellent nutritive qualities which make it ideal as livestock feed. Therefore, these processes also positively impact livestock production. Different nations and respective areas of the world would have to decide and choose on the combination of renewable energy options which suit them the best giving cognizance to their resource base, technology level, available manpower, as well as economic, environmental and political considerations. For the tropical countries, one of the options should look in the direction of using cocoyam (a neglected but sturdy crop), as a renewable source in the production of ethanol fuel and methane gas for the supply of energy. The production and use of the ethanol and methane from cocoyam as well as continual research to raise the yield of the crop is recommended.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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