



Utilization of Plantain (*Musa species*) Leaves for Biogas Production

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Authors' contributions

This work was carried out in collaboration between all authors. Author AEA performed the interpretation of results and preparation of manuscript. Author JOA managed the analysis of the samples. Author EUI designed the study. All authors read and approved the final manuscript.

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ABSTRACT

Aim: To determine the relationship between the volumes of biogas that can be produced using different biomass/water ratios.

Study Design: Biogas was produced by the anaerobic digestion or fermentation of plantain leaves. A practical laboratory scale experimental design was used to find out the effect of biomass/water ratio and retention time on the volume of biogas generated using sun-dried and ground plantain leaves as the feed stock.

Place and Duration of Study: The research was carried out in Chemistry Department, University of Benin City, Nigeria. Study was done between March and June, 2012.

Methodology: Five (5) biodigesters were used for the biogas production with different biomass/water ratios (1:1, 1:2, 1:3, 1:4 and 1:5) and for a 10-day retention period. The average pH and temperature of the biodigesters were 7.80 ± 0.50 and $30.00 \pm 20.00^\circ\text{C}$ respectively. The biogas produced was characterized using a gas chromatography system 6890 series (and 6890 plus)

Results: Certain amounts of Methane, Nitrogen, and Oxygen were detected in the gas produced. Proximate analysis of the plantain leaves gave the percentage composition by mass of

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Nitrogen (0.14%), Crude protein (0.91%), Potassium (1.15%), Sodium (0.06%), Phosphorus (0.09%), Calcium (2.00%), Magnesium (0.69%), Sulphate (0.08%), Organic carbon (12.52%), Organic matter (28.00%) and ash content (5.30%).

Conclusion: Using plantain leaves as feed stock, optimum biogas production can be attained using a biomass/water ratio of 1:4, over a ten-day period. But there is need for further work to validate reliability and also reduce the volume of nitrogen in the biogas produced.

Keywords: Anaerobic; biogas; biomass; biodigester; plantain; methane.

1. INTRODUCTION

The use and availability of energy for domestic and industrial purposes is a major concern for most people these days. Both developed and developing nations of the world now spend a large proportion of their earnings on gas and oil [1,2]. These fossil fuels are being continuously used to a large extent. However, since these forms of energy are non-renewable, their availability will continue to decrease while costs will continue to be on the rise [3].

The predicted continuous increase in oil price is due to the limited nature of fossil resources. The turbulence in the Nigerian oil and gas industry as a nation and recent global increase in the price of fuels worldwide for example, prove that the above is true. Although Nigeria is an oil and gas producing nation, the country faces a severe energy crisis due to continuous disruptions in the supply of petroleum products. Vandals, rebels, energy hackers and criminals find Nigeria's centralized oil and gas distribution networks as easy targets [4].

A more serious issue of international concern is climate change. There has been a global movement toward reduced use of fossil resources though energy is a very fundamental tool for development. Nigeria and other developing countries of the world are bedeviled by additional challenges regarding environmental protection due to their heavy dependency on biomass and fossil fuel. According to the study by Adaramola and Oyewola, Nigeria is endowed with enormous amounts of conventional energy resources such as crude oil, tar sands, natural gas and coal, as well as a good number of renewable energy resources such as hydro, solar, wind and biomass. It has been reported that most developing nations of the world are facing serious shortage of fuels, the most commonly used fuel being wood [5].

For this reason, the search for new and renewable energy sources has received

worldwide attention. One excellent source of renewable energy is biogas.

Biogas originates from biogenic material and is a type of biofuel. It is normally produced by the anaerobic digestion or fermentation of biodegradable materials such as biomass, manure, sewage, municipal wastes, green wastes, plant materials and crops [6]. In the absence of oxygen, anaerobic bacteria decompose or digest organic matter and produce a mixture of gases mainly composed of methane (CH_4) and carbon (iv) oxide (CO_2) called biogas.

Anaerobic digestion is a natural process and there are digesters that are designed and managed to accomplish this decomposition. As a result of the digestion, organic material is stabilized and gaseous by-products, primarily methane (CH_4) and carbon (iv)oxide (CO_2) are released [7]. The process of biogas production takes place under different temperature regimes. Typically, anaerobic digesters are designed to operate in either the mesophilic (20.00-45.00°C) or thermophilic (45.00-60.00°C) temperature ranges. However, methanogenesis is also possible under low temperature (< 20.00°C), this referred to as psychrophilic digestion [8]. Anaerobic digestion at psychrophilic temperatures has not been as extensively explored as either mesophilic or thermophilic digestion, probably due to little anticipation of the development of economically attractive systems using the latter technology [9]. Generally, the production of methane from anaerobic digestion depends on the temperature, the kind of material added to the digester, the solids loading, the pH and the hydraulic retention time (HRT) [10,11].

There are four metabolic stages involved in the production of methane using anaerobic digestion process. First, polymers from particulate organic matter are converted into monomers by extra cellular enzymes through the process of hydrolysis. Then the soluble organic matter and the products of hydrolysis are converted into organic acids, alcohols, hydrogen and carbon (iv)

oxide by acidogenic bacteria. The third stage involves the conversion of the products of acidogens into acetic acid, hydrogen and carbon dioxide by acetogenic bacteria. Lastly, methanogenic bacteria effect the production of methane from acetogen products. [12]

The main advantage in using anaerobic digestion is that while the biogas produced, can be used for steam heating; cooking and generation of electricity [13,14,15], the effluent produced can be used as a biofertiliser or soil conditioner [16].

Each year some millions tons of methane is released worldwide into the atmosphere through microbial activities [17]. About 90.00% of the emitted methane comes from biogenic sources (decomposition of biomass). The remainder is of fossil origin such as through petrochemical processes. In the northern hemisphere, the present methane concentration amounts to about 1.65 ppm [18]. Unlike fossil fuel combustion, biogas production from biomass is considered CO₂ neutral and therefore does not emit additional greenhouse gases into the atmosphere. However, if biogas is not recovered properly, it will contribute a greenhouse effect twenty times worse than if methane is simply combusted [19]. Therefore, there is a real incentive to transfer biogas combustion energy into heat and/or electricity. Biogas production from anaerobic digestion also helps in treating organic wastes and reducing the environmental impact of these wastes. It contributes to a better image of the farming community while reducing odour, pathogens and weeds from the manure and producing an enhanced fertilizer easily assimilated by plants [20]. So, unlike the situation where when biomass is totally burnt, it is possible to return much of the original material to the land and thereby improve the soil quality and displace the use of chemical fertilizer.

Other advantages of anaerobic production biogas include revenue from possible reuse of digested solids as livestock bedding, reduction of work for firewood collection and cooking, high quality solids for soil amendment and reduced groundwater and surface water contamination potential [21,22].

Production of methane-rich biogas through anaerobic digestion of organic materials provides a versatile carrier of renewable energy, as methane can be used in replacement for fossil fuels in both heat and power generation and as a vehicle fuel, thus contributing to cutting down the

emissions of greenhouse gases and slowing down climate change. Methane production through anaerobic digestion has been evaluated as one of the most energy-efficient and environmentally benign ways of producing vehicle biofuel [2]. The European Union (EU) had set a target of increasing the utilisation of biofuels in vehicles to 5.75% by year 2010 in each member state [3], while in 2005 the market share of biofuels in Finland was 0.10% [23]. Methane production from energy crops and crop residues could be an interesting option for increasing the domestic biofuel production, as it has been estimated that within the agricultural sector in the EU, 1500 million tons of biomass could be anaerobically digested each year, half of this potential accounted for by energy crops [24].

Many researchers have studied the production of biogas from sources ranging from crops, human and animal wastes, municipal waste water and sludge [20,24-26], to non-conventional crops [27-29].

Plantains (*Musa spp.*, AAB genome) are plants producing fruits that remain starchy at maturity [30] and need processing before consumption. Plantain production in Africa is estimated at more than 50.00% of worldwide production. West and Central Africa contribute 61.00% and 21.00%, respectively. Nigeria is one of the largest plantain producing countries in the world [31]. The dried leaves, sheath and petioles are used as tying materials, sponges and roofing material. Plantain leaves are also used for wrapping, packaging, marketing and serving of food [32].

Biogas has been produced from plantain fruit and the peels thereof [20,22,33]. However, in this study, the biogas potentials of plantain leaves was examined on a laboratory scale.

2. MATERIALS AND METHODS

2.1 Sample Collection

Plantain leaves were collected from Ugbowo axis of Benin City (6⁰19'N 5⁰36'E), Nigeria. The leaves were sun dried for two weeks and then milled to powder using a dry grinding machine.

2.2 Gas Production and Measurement

50.00 g of the powdered plantain leaves was charged into a Buckner flask (that acts as

biodigester) and mixed with appropriate amount of water to give various biomass/water ratios of 1:1, 1:2, 1:3, 1:4 and 1:5. The pH of the slurry was 7.70. The Buckner flask was tightly covered with rubber bungs to avoid gas linkage. The flask was connected to a measuring cylinder which had been filled with water and inverted into a trough resting on a beehive shelf. The experiment was carried out at ambient temperature for ten days.

The volume of biogas produced was measured by water displacement in the inverted cylinder. This measurement was carried out daily for the retention period of ten days.

2.3 Gas Collection and Analysis

The same set up used for the measurement of the gas produced was repeated with some modifications. The measuring cylinder was omitted with the Buckner flask directly connected to an improvised gas storing medium. The gas collected was analyzed using gas chromatograph (GC-6890 model) equipped with a thermal conductivity detector.

2.4 Proximate Analysis of Plantain Leaves

Proximate analysis of the plantain leaves was carried out using the methods described by AOAC [34]. The parameters determined include: Nitrogen, Crude protein, Potassium, Sodium, Phosphorus, Calcium, Magnesium, Sulphate, Organic carbon, Organic matter and ash content.

3. RESULTS AND DISCUSSION

The result of proximate analysis of plantain leaves is shown in Table 1. The result shows that plantain leaves have a high concentration of organic matter and organic carbon which is indicative of high biogas yield. The result however shows relatively low contents of phosphorus, nitrogen, potassium, calcium, magnesium and ash. The trend of the various parameters determined is in the order: Organic matter > organic carbon > ash > calcium > Potassium > crude protein > Magnesium > Nitrogen > Phosphorus > Sulphate > sodium.

The results of the chromatographic analysis of the biogas produced are presented in Table 2. It shows that the yield of methane gas (15.40%) was considerably higher than that of other components like CO₂ (1.35%) and O₂ (8.01%).

However the high yield nitrogen gas (75.10%) is undesirable as the Agip standard is 0.13%. The high nitrogen content may be due to contamination by atmospheric nitrogen as a result of the crude method of using surgical hand gloves for the gas collection.

Table 1. Percentage composition of the plantain leaves

| Parameters | % composition |
|----------------|---------------|
| Ash | 5.30 |
| Nitrogen | 0.14 |
| Crude Protein | 0.91 |
| Potassium | 1.15 |
| Sodium | 0.06 |
| Phosphorus | 0.09 |
| Calcium | 2.00 |
| Magnesium | 0.69 |
| Sulphate | 0.08 |
| Organic carbon | 12.52 |
| Organic matter | 28.00 |

Table 2. Quality of biogas from plantain leaves

| Parameters | Value, mol % | Agip standard, mol % |
|--|--------------|----------------------|
| Methane (C ₁) | 15.40 | 96.93 |
| Ethane (C ₂) | 0.14 | 2.55 |
| Propane (C ₃) | 0.00 | 0.40 |
| Isobutene (i C ₄) | 0.00 | 0.00 |
| n-butane (n C ₄) | 0.00 | 0.00 |
| Iso-pentane (i C ₅) | 0.00 | 0.00 |
| n-pentane (n C ₅) | 0.00 | 0.00 |
| Hexane plus (C ₆ ⁺) | 0.00 | 0.00 |
| H ₂ S | 0.01 | 0.00 |
| O ₂ | 8.01 | 0.00 |
| CO ₂ | 1.35 | 0.00 |
| Nitrogen | 75.10 | 0.13 |
| Total | 100.01 | 100.00 |

Figs. 1 and 2 below show the daily biogas production and the cumulative volumes, respectively, for a period of 10 days in five different biodigesters with biomass/water ratios of 1:1, 1:2, 1:3, 1:4 and 1:5, corresponding to A, B, C, D and E respectively. Gas production started in all the biodigesters after the first day except for digester A that had a lag phase of 3 days. This may be due to the limited quantity of water in this biodigester.

Fig. 1 shows that optimum biogas production was achieved on the sixth day. This is because

the marginal volume of biogas produced daily was in incremental amounts up to the sixth day. Therefore, the marginal increase in the volume of biogas produced, with respect to days, became very minimal. This is expected since the population of the microbes responsible for the digestion decreases with time.

ratio of 1:4, while lowest volume was observed in biodigester A (1:5). This shows that the daily and cumulative volumes of biogas produced was substrate dependent, with a maximum at a dilution ratio of 1:4. This is consistent with previous work on Elephant grass [35], in which the dilution regime of 1:4 produced the highest volume of biogas. Generally the order of biogas production with respect to dilution ratio was 1:4 > 1:5 > 1:3 > 1:2 > 1:1.

Fig. 2 shows that the highest cumulative volume of biogas occurred in digester D, with dilution

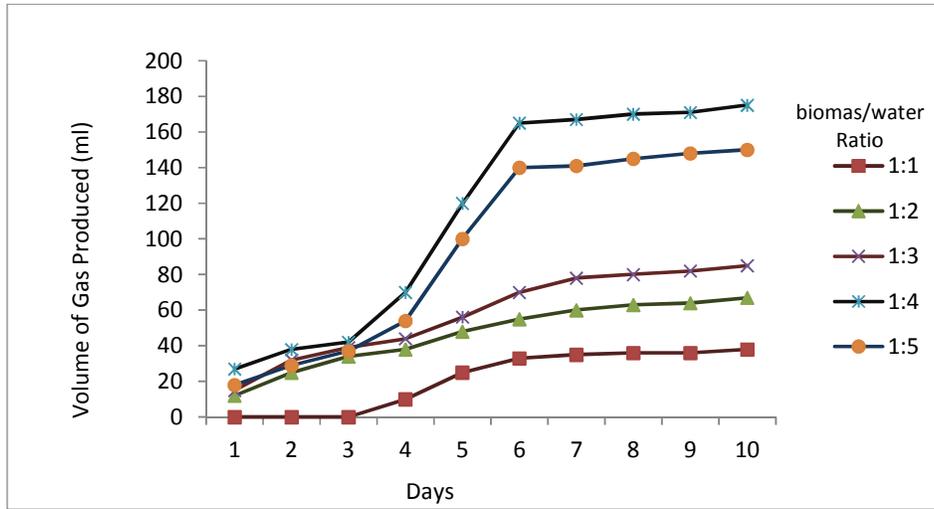


Fig. 1. Daily volume of biogas produced for the different biomass/water ratio regimes

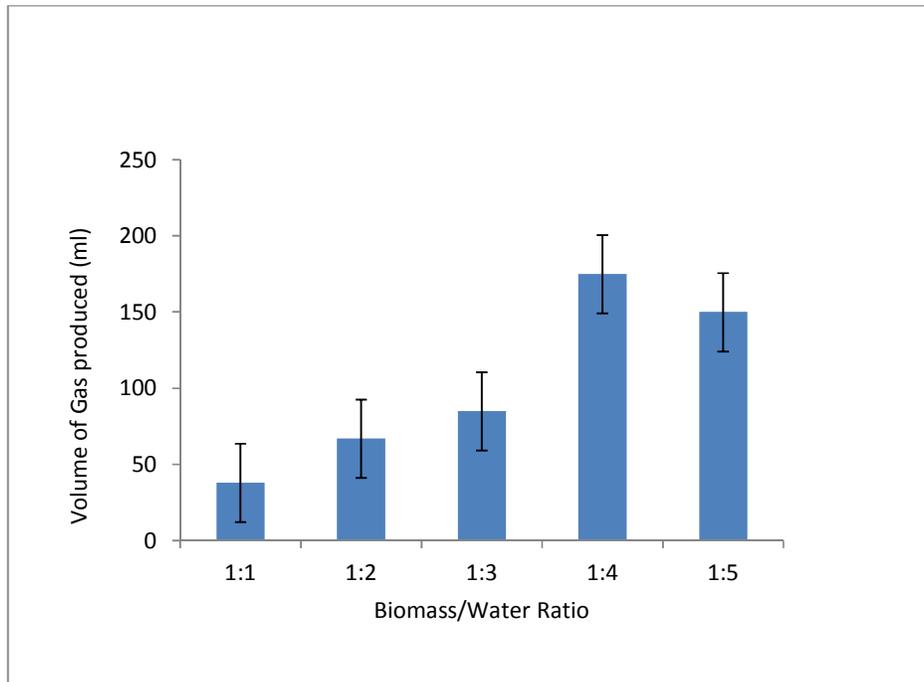


Fig. 2. Cumulative biogas yield from plantain leaves

4. CONCLUSION

Using plantain leaves as feed stock, optimum biogas production can be attained using a biomass/water ratio of 1:4. But there is need for further work to validate reliability and also reduce the volume of nitrogen in the biogas produced.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Kerr RA. Oil resources: The looming oil crisis could arrive uncomfortably soon. *Science*. 2007;316:351.
2. L-B-Systemtechnik LBS. Well-to-Wheel analysis of energy use and greenhouse gas emissions of advanced fuel/vehicle systems – A European Study.133, GmbH, Ottobrunn Germany; 2002.
3. European Parliament. Directive 2003/30/EC of the European parliament and of the council of 8th May 2003 on the promotion of the use of biofuels or other renewable fuels for transport. Official J European Union. 2003;123:42–46.
4. Abdulrahim A. Nigeria's biogas potential estimated at 600,000MW: Quicknote bioenergy potential. Biopact ; 2006.
5. Adaramola MS, Oyewole OM. Wind speed distribution and characteristics in Nigeria. *ARPN J Eng Appl Sci*. 2011;6:2.
6. Barker James C. Methane fuel gas from Livestock wastes: A summary. *EBAE*. 2001;71-80.
7. Mshandete AM, Parawira W. Biogas technology research in selected sub-Saharan Africa. *Afr J Biotech*. 2009;8(2):116-125.
8. Bitsadze A. Recommendations for Construction of Biogas Installations at small Farms (in Georgian.) energy efficiency centre of Georgia, Tbilisi; 2001.
9. Urmila Bala, Eric Buysman, Niccoló Meriggi, Lionel S. Zisengwe, Grietje Zeeman. Biogas production in climates with long cold winters. Wageningen University, The Netherlands. 2008;6.
10. Dinamarca S, Aroca G, Chamy R, Guerrero L. The influence of pH in the hydrolytic stage of anaerobic digestion of the organic fraction of urban solid waste. *Water Sci Technol*. 2003;48(6):249–254.
11. Ilori OM, Adebusoye AS, Lawal AK, Awotiwon AO. Production of biogas from banana and plantain peels. *Ad Environ Biol*. 2007;1(1):33-38.
12. Vavilin VA, Rytov SV. A description of hydrolysis kinetics in anaerobic degradation of particulate organic matter. *Bioresour Technol*. 1996;56(2–3):229–237.
13. Mata-Alvarez J, Cecchi F, Llabres P, Pavan P. Anaerobic digestion of the Barcelona central food market organic wastes: Experimental study, *Biores Technol*. 1992;39:39-48.
14. Misi SN, Forster CF. Semi-continuous anaerobic co-digestion of agrowaste. *Environ Technol*. 2002;23:445-451.
15. Ahring BK, Mladenovska Z, Iranpour R, and Westermann P. State of the art and future perspectives of thermophilic anaerobic digestion. *Water Sci Technol*. 2002;45:298-308.
16. Ali R, Tekin, Coskun Dalgic A. Biogas production from olive pomace, *Resources, Conservation and recycling*. 2000;30:301-313.
17. EPA (US Environmental Protection Agency). A comprehensive analysis of biodiesel impacts on exhaust emission. Draft technical report: EPA 420-P-02-001. 2002;118. Available:www.epa.gov/otaq/models/biodsl.html (Accessed 18 August 2012).
18. EEA: (European Environmental Agency). How much bioenergy can Europe produce without harming the environment. 2006;7:67.
19. IPCC (Inter Governmental Panel on Climate Change 2001); climate change - The scientific Basis; Third Assessment Report; 2001.
20. Dahunsi SO, Oranusi US. Co-digestion of food waste and human excreta for biogas production. *British Biotechnol J*. 2013;3(4): 485-499.
21. Arvanitoyannis S, Kassaveti A, Stefanatos S. Current and potential uses of thermally treated olive oil waste. *Int J food Sci Technol*. 2007;42(7):852-867.
22. Eze JI, Ezeudu CC. Evaluation of biogas generating potentials of animal and food wastes. *Int J Biosci*. 2012;2:10(1)73-81.
23. Commission of the European Communities COM 628 Biomass action plan, communication from the Commission. Commission of the European Communities, Brussels. 2005;47.

24. Amon T, Hackl E, Jeremic D, Amon B, Boxberger J. Biogas production from animal wastes, energy plants and organic wastes. In: van Velsen, A. F. M. & Verstraete, W. H. (eds), Proceedings, 9th World Congress on Anaerobic Digestion: Technology Institute, zw, Antwerp. 2001;381–386.
25. Ojolo SJ, Oke SA, Animasahun OK, Adesuyi BK. Utilization of poultry cow and kitchen wastes for biogas production: A comparative analysis. Iranian J Environ Health Sci Eng. 2007;4:223-228.
26. Mata-Alvarez J, Macé S, Llabres P. Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives. Biores Technol. 2000;74:3–16.
27. Parawira W, Read JS, Mattiasson B. A study of two-stage anaerobic digestion of solid potato waste using reactors under mesophilic and thermophilic conditions. Environ. Technol. 2007;28:1205-1216.
28. Kalia A, Kanwar S. Anaerobic fermentation of Ageratum for biogas production. Biol Wastes. 1990;32:155–158.
29. Parawira W. Biodiesel production from *Jatropha curcas*: A Review. Scientific Research and Essays. 2010;5(14):1796-1808.
30. Marriot J, Lancaster PA Bananas and plantains. In: H.T. Chan (ed.), Handbook of Tropical Food. Dekker, New York. 1983;85-143.
31. Food and Agriculture Organization Production Yearbook 2004. FAO, Rome; 2006.
32. National agricultural extension and research liason services. Annual agricultural performance survey report of nigeria for 2005. NAERLS Press, Ibadan. 2005.
33. Velmurugan B, Alwar Ramanujam R. Anaerobic Digestion of Vegetable Wastes for Biogas Production in a Fed-Batch Reactor. Int J Emerg Sci. 2011;1(3):455-486.
34. AOAC Method of analysis of the Association of Official Analytical Chemist, 15th ed. Washington D.C. USA; 1990.
35. Olugbemide AD, Ufuah MOE, Igbonnazobi LC, Osula JE. Effect of Alkaline pre-treatment on anaerobic batch digestion of elephant grass (*Pennisetum purpureum*). J Chem Soc Nig. 2010;36(1):176-179.

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