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**ORIGINAL ARTICLE**

## Production of Biogas from Banana and Plantain Peels

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### ABSTRACT

The rising cost of fossil oil, potentially diminishing supplies, attendant pollution problems associated with petroleum and allied products as well as desert encroachment have provided the impetus to consider alternative sources of energy. An investigation was launched to produce biogas from agricultural wastes including banana and plantain peels. The experiment was carried out using a 10-liter laboratory scale anaerobic digester for a period of 35 weeks. The volume of gas generated from banana and plantain peel feedstocks were respectively 8,800 cm<sup>3</sup> and 2,409 cm<sup>3</sup>. However, the highest volume of gas (13,356 cm<sup>3</sup>) was obtained in the digester containing equal proportions of banana and plantain peels in combination as feedstocks. The physico-chemistry of respective feedstocks in the digesters revealed an initial drop in pH to acidic range and a steady increase 7.2 – 7.4. The temperature remained relatively constant at mesophilic range: 32 – 35 °C throughout the study period. The C/N ratio was within 26:1.1 and 30:1.2. Population distributions of the microflora show that aerobic and anaerobic bacteria were the active community members although with latter higher than the former. Among the widely distributed are *Micrococcus luteus*, *Bacillus subtilis*, *Escherichia coli* and *Clostridium perfringens*. Methanogens identified belong to the genera *Methanobacterium*, *Methanococcus* and *Desulfovibrio*. In developing countries and especially in the rural areas where electricity and heat are sparse and biological waste is profuse, the anaerobic digestion process could be the light at the end of the tunnel.

**Keywords:** Agricultural wastes; Anaerobic digester; Biogas; Methanogens

### Introduction

Fossil fuel provides the bulk of the world's primary source of energy. Since they are non-renewable natural resources with little to conserve the earth's supply, supplies of fossil fuel (especially oil and gas) may soon get completely depleted. Additionally, the rising cost of petroleum and allied products most especially in Nigeria has triggered a need to develop alternate sources of energy, one to which is biogas production. In Nigeria, majority of the population are rural dwellers without access to gas or electricity[19] and therefore, depend on firewood for cooking and lighting. Unfortunately, this has contributed immensely to

the rapid rate of deforestation and desert encroachment. The establishment of biogas plants in these communities would greatly ameliorate these problems and help preserve the environment.

Biogas is a mixture of colourless, flammable gases obtained by the anaerobic digestion of organic waste materials. The composition of biogas is typically methane (50 – 70%), carbon-dioxide (30 – 40%) and the rest is made up of traces of elements of hydrogen, nitrogen and hydrogen sulphide[6,3,7]. The chemistry of the digestion process leading to biogas involving hydrolysis, acidogenesis acetogenesis and methanogenesis has been well documented[9,14,17]. Any organic matter with the exception of mineral oil can be used as feedstock for

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anaerobic digestion to produce biogas. Generally, the main available substrates for anaerobic digestion include polysaccharides, proteins and lipids that are abundant in manure, plants, industrial wastewater and municipal waste[18].

Agricultural livestock and agro-industrial wastes abound in the rural areas and contribute to the present problems of environmental pollution. These wastes could be efficiently managed if used to produce biogas thereby reducing the problems of environmental pollution[11,18]. In the present study, we investigated production of biogas using plantain and banana peels as feedstocks. Plantain and Banana constitute major food crops in Nigeria, as a result, large quantities of waste are often generated from the peels and has become a perennial problem in Lagos. Indiscriminate disposal of these wastes when decomposed may produce noxious gases such as hydrogen sulphide, ammonia etc., which could pose serious environmental hazards. We reasoned that channeling these peels into the production of biogas could serve as an efficient way for the management of the wastes while the resulting gas could serve as a source of energy for cooking and lighting for the rural communities.

## Materials and methods

### *Sample collection and pre-treatment*

Plantain and banana peels were collected in large quantities from bulk purchasing outlets in Lagos metropolis, Nigeria. The samples were separately homogenized using the Hammer mill (Scotmec model) and thereafter allowed to undergo an initial fermentation in a large plastic container (20 L capacity) for five days with constant agitation.

### *Digester design*

Laboratory type anaerobic digester (10 L), fabricated at the Federal Institute of Industrial Research, Oshodi, Lagos, Nigeria was used for the experiment. The digester as depicted in Fig. 1 is made up essentially of stainless steel (24 cm in diameter and 45 cm high) with two outlet connections, one for gas and the other for the introduction of slurry samples. The gas produced was collected by the downward displacement of water technique over acidified water. The digester was operated at room temperature ( $30 \pm 2$  °C).

### *Preparation of feedstock*

In this study, a total three digesters were used. Digester A contained a mixture of plantain and banana peels (1.25 kg each), digester B contained banana peels (2.5 kg). These digesters were fortified



**Fig. 1:** A 10-L laboratory type anaerobic digester used for the investigation

with 0.5 kg of piggery wastes. Before packaged into the digesters, these feedstock formulations were mixed in separate containers with 2.5 L of lukewarm distilled water. The digesters were allowed to run for 35 days during which the volume of gas produced was recorded. The entire experiment was repeated twice in order to confirm its reproducibility.

### *Analytical methods*

The physical and chemical composition of the feedstocks were evaluated before and after digestion using standard procedures[4]. Parameters analysed included pH, temperature, organic carbon, moisture content, total solids, total nitrogen and ash content.

### *Isolation and assessment of microbial populations*

The microbial species in the anaerobic digester were enumerated by standard plate count technique using 0.1 ml aliquots of appropriate dilution onto nutrient agar plates for bacteria and potato dextrose agar (PDA) plates for fungi. Nutrient agar plates were incubated at 37 °C for 24 – 48 h, while PDA plates were incubated at room temperature for 3 – 5 days. In the case of anaerobic organisms, the dilution was performed under anoxic conditions in a poise diluent. Aliquots were pour plated onto nutrient agar and incubated in an anaerobic jar containing a moistened pack of gas generating kit (Oxoid BR, Basrugstoke, England) at 37 °C for 7 days.

Individual colonies were purified and identified by morphological and biochemical techniques using the taxonomic schemes of Bergey's Mammal of Determinative Bacteriology and Cowan and Steel. In the case of fungal isolates, the microscopic and macroscopic features of the hyphal mass, morphology of cells and spores, nature of the fruiting bodies, sugar fermentation (for yeast isolates) among other criteria were used for identification.

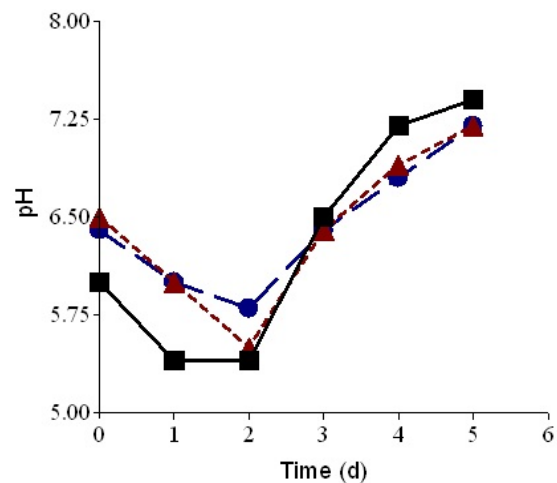
## Results and discussions

### Results

The physical and chemical dynamics of the compositional feedstocks before and after digestion are summarized in Table 1. The temperature remained constant at mesophilic range in all the digesters. The changes observed in the moisture content was insignificant, however, values obtained after digestion showed decreases of 2.5 – 5.0%. Similar trend was observed for ash content and carbon content although with higher and smaller margins respectively. For instance, the carbon content of feedstocks in digester A containing, banana and plantain peels before digestion was 30%, while amount obtained after fermentation was 28.5%; whereas, the ash contents of digesters B and C decreased from 2.5 to 1.3% and 2.6 to 1.2% respectively. It is noteworthy that the ash content of digester A remained constant at 2.7%. In contrast to these observations, an increasing trend was observed for both total solids and nitrogen contents of the feedstocks (Table 1). The highest nitrogen content was observed for digestion A with an approximate increase of 25%. Displayed in Fig. 2 are pH profiles of the three digesters during the 35-day fermentation period. There was a sequential increase in pH values from acidic range to neutral range although not without an initial fall during the first week of fermentation at which time, gas production was very low. Generally, there was no significant difference in the physico-chemical properties of the digesters when subjected to simple analysis of variance at 0.05% level of probability.

The data illustrated in Fig. 3 showed that the feedstocks in digester A generated 13,365 L of biogas which was the highest amount of gas recorded throughout the study. In the case of digester B, 8,800 L of gas was generated distantly followed by 2,409 L obtained in digester C. In all the digesters, the production of biogas lagged significantly. The lag period observed before commencement of gas production was 3 h in digester A whereas 5 h and 12 h were observed for digesters B and C respectively.

The population densities of different microbial communities in the digesters are illustrated in Fig. 4. Amongst the group of microorganisms assayed, aerobic bacteria had the highest population followed by fungi and anaerobic bacteria in that order. Digester B had the lowest microflora populations: population densities determined for aerobic bacteria, anaerobic bacteria and fungi were  $25 \times 10^2$ ,  $11 \times 10^2$  and  $14 \times 10^2$  cfu/g respectively. Both digesters A and C were observed to share similar population ranges for total anaerobic bacteria and total fungi (Fig. 4). A total of nine morphologically- and physiologically-different bacteria species were



**Fig. 2:** Changes in pH profiles digester feedstocks during production of biogas. A, mixture of banana and plantain peels (■); B, banana peels (▲); C, plantain peels (●). Values are averages of two replicate determinations

isolated in this study. The organisms were mostly Gram-negative rods and motile. Five of the isolates were also anaerobes (see Table 2). A total of seven fungal species belonging to 4 genera were isolated from the digesters during the fermentation processes (Table 3). The population distributions of these organisms are summarized in Tables 2 and 3. All the organisms were encountered in the three anaerobic digesters though as depicted in the Tables with varying population densities. Amongst the bacterial communities, *Micrococcus luteus* AB1, *Bacillus subtilis* AB2, *Escherichia coli* AB3 and *Clostridium perfringens* AB4 were observed to have the highest population densities in all three digesters assayed, although the greatest proportions occurred in digester A. Similarly, in the case of fungal distribution, *Saccharomyces cerevisiae* YD2 and *Aspergillus flavus* MD4 had the highest proportion of occurrence most especially in digester A similar to those observed for bacteria (Table 3).

### Discussion

The recovery time for biogas production as well as the quality and quantity of biogas produced from agricultural materials are a function of the nature, and composition of the digester feedstock. Garden wastes are indeed known to yield much less biogas, relative to kitchen wastes, due to the higher proportion of poorly degradable lignocellulosic fibers [16]. Generally, the organic materials must be highly biodegradable in order to achieve a higher yield of biogas. In the present study, we have shown that all the feedstocks formulation generated varying amounts of biogas; however, the use of banana and plantain peels in combination produced significantly

**Table 1:** Physico-chemical analysis of different compositional digester feedstocks before and after digestion. A, mixture of banana and plantain peels; B, banana peels; C, plantain peels. Values are averages of two replicate determinations

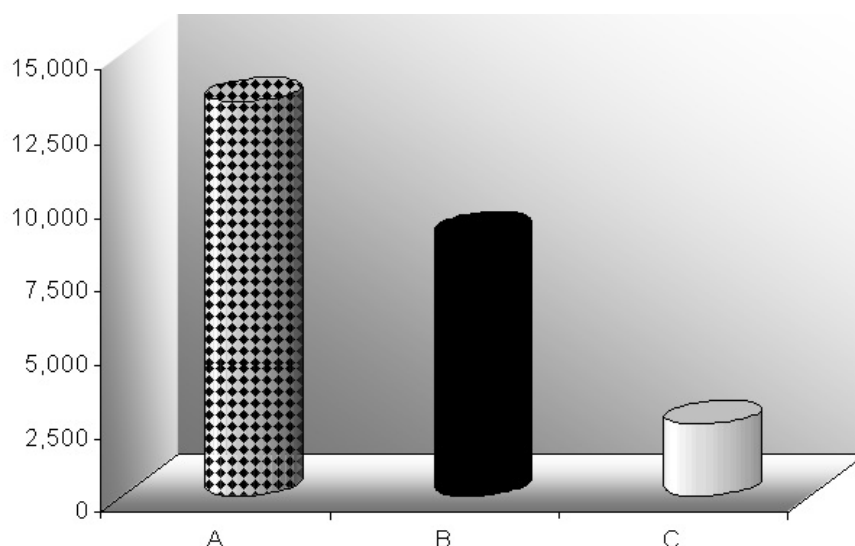
Parameter	Dogeste A		Dogeste B		Dogeste C	
	Before disgestion	After disgestion	Before disgestion	After disgestion	Before disgestion	After disgestion
Ph	6	7.4	6.5	7.2	6.4	7.2
Temprature	32.5	33	31.1	33	32	32.5
Moisture content (%)	94	90	87	85	92.5	90
Ash content (%)	2.7	2.7	2.5	1.3	2.6	1.2
Total solids (%)	6	10	13	15	7.5	10
Carbon content (%)	30	28.5	27.5	24	26	24.5
Nitrogen content (%)	1.2	1.7	1.58	1.65	1.1	1

**Table 2:** Spatial distribution of aerobic and anaerobic bacteria in digesters containing different feedstocks. A, mixture of banana and plantain peels; B, banana peels; C, plantain peels. Values are averages of two replicate determinations

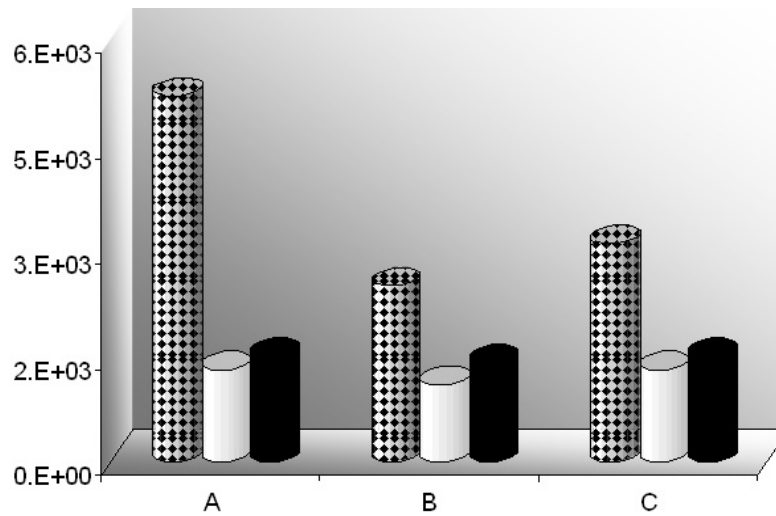
Isolated	x 103 cfu/ml		
	Digester A	Digester B	Digester C
<i>Micrococcus luteus</i> AB 1	1.2	0.5	0.4
<i>Bacillus subtilis</i> AB 2	1.5	0.7	0.3
<i>Escherichia coli</i> AB 3	1.3	0.4	
<i>Clostridium perfringens</i> AB 4	1	0.5	1.2
<i>Flavobacterium</i> sp. AB2	0.3	0.4	0.2
<i>Methanobacterium</i> sp. ANB1	0.1	0.1	0.4
<i>Dedulfovibrio</i> sp. ANB2	0.3	0.4	0.2
<i>Methanococcus</i> sp. ANB3	0.7	0.2	0.3
<i>Bacillus polymyxa</i> ANB4	0.2	0.4	0.4

**Table 3:** Spatial distribution of fungal species in digesters containing different feedstocks. A, mixture of banana and plantain peels; B, banana peels; C, plantain peels. Values are averages of two replicate determinations

Isolated	x 102 cfu/ml		
	Digester A	Digester B	Digester C
<i>Saccharomyces cerevisiae</i> YD1	2	1	2
<i>S. cerevisiae</i> AYD2	4	4	1
<i>S. Chevalier</i> YD3	1	3	4
<i>Penicillium</i> sp. MD1	2	2	2
<i>Aspergillus niger</i> MD2	1	2	1
<i>A. flavus</i> MD3	3	1	1
<i>Rhizopus</i> sp. MD3	2	1	4



**Fig. 3:** Amount of biogas generated from anaerobic digester containing different feedstocks. A, mixture of banana and plantain peels (■); B, banana peels (■); C, plantain peels (□). Each anaerobic digester was fortified with equal amounts of piggery dung before incubation for a period of 35 days. Values are averages of two replicate determinations.



**Fig. 4:** Population densities of feedstock microflora. ■, Total aerobic bacteria; □, Total anaerobic bacteria; ■, total fungi. A B and C represent mixture of banana and plantain peels, banana peels and plantain peels respectively. Values are averages of two replicate determinations.

higher quantity of biogas. Although, each digester was fortified with equal amount of piggery dung (0.5 kg) to provide requisite microbial starter cultures for the fermentation process, it is noteworthy that digester A containing banana and plantain feedstocks exhibited the lowest retention time (3 h) for the commencement of gas production. The use of microbial inoculum as cultures is a common practice during biogas production[12,2,15,10,11]. Lawal *et al.*[11] observed rapid gas production when digester feedstocks were seeded with adequate bacterial isolates from previous digester.

The physico-chemical composition of the digester feedstocks appears to be consistent with previous reports[8,9,11,12,13,15]. The temperature of all the fermenters remained constant at mesophilic range (30 + 3°C) throughout the fermentation period. Temperature has been observed by most workers to be quite critical for anaerobic digestion, since methane – producing bacteria operate most efficiently at temperatures 30 – 40°C or 50 – 60°C. Previously, Lapp *et al.*,[12] observed up source in gas production during summer. The data regarding pH illustrated in Fig. 2 showed an initial fall in all the samples to an acidic level before assuming stable values of neutrality. This initial drop in pH was not unexpected and has been reported previously[1,9] since activities of aerobes and facultative aerobes are essential to produce relevant acidic metabolites, which are acted on by methanogenic bacteria to produce methane. The carbon/nitrogen (C/N) ratio for digesters A, B and C were calculated to be 30:1.2; 27.5:1.58 and 26:1.1 respectively. The C/N ratios obtained were found to be very ideal for gas production[8,10,12].

The two groups of bacteria isolated from the digesters include the acid-formers (*Micrococcus*, *Bacillus*, *Escherichia*, *Clostridium*, *Flavobacterium*) and methoane formers which include species *Methanobacterium*, *Methanococcus* and *Desulfovibrio*. The successful formulation of feedstocks for and operation of anaerobic digesters for biogas production relies on the correct balance between these two groups of microorganisms. The methane formers multiply at a slower rate than acid formers and are very sensitive to environmental changes[5].

The results of this study have shown clearly that banana and plantain peels, when used in combination are good substrates for biogas generation. Without doubt, the current disposal system for agricultural wastes has created a negative impact through pollution and disease problems. The search for alternative energy sources such as biogas when intensified would help arrest this ecological disaster in addition to elimination and/or control of deforestation and erosion of the soil surface. It should be noted however, that development of biogas does not eliminate wastes, but if does make them easier to Manage. In conclusion, in developing countries of Africa and especially, Nigeria, where electricity and heat are sparse and biological waste is profuse, the anaerobic digestion process could be the light at the end of the tunnel.

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