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COMPARATIVE EVALUATION OF CUMULATIVE BIOGAS YIELD OF YELLOW YAM BRUTE CO–DIGESTED WITH COW PAUNCH MANURE IN BATCH MODE

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Abstract. Anaerobic digesters were used in a study to compare cumulative biogas yield from yellow yam brute, cow paunch and yellow yam brute co–digested with cow paunch manure. It was found out that the mixture slurry of yellow yam brute mixed with cow paunch (YYB+CP) had the highest cumulative biogas yield of 668.65 mL/TMS than the cumulative biogas yield of 587.86mL/TMS and 307.96 mL/TMS obtained from the single base line substrates of cow paunch and yellow yam brute, respectively within the 35 days hydraulic retention time (HRT). It was also observed that YYB+CP and cow paunch (CP) produced almost equal quantity of cumulative biogas yield of 398.76 mL/TMS within the first 15 days of observation compared with cumulative biogas yield 178.45 mL/TMS produced by yellow yam brute (YYB) within the same HRT. It was also observed that gas production reduced seriously in mono–digested substrates YYB and Cp compared with the co–digestate because of lack of synergistic nutrients. It is generally observed that co–digestion of more than one substrate increase cumulative biogas yield. The trend of cumulative biogas yield at the end of 35 days hydraulic retention time was YYB+CP > CP > YYB. This study is aimed to evaluate the performance of biogas production from yellow yam brute mixed with cow paunch manure, and to compare its cumulative biogas yield with cow paunch and yellow yam brute digested as mono–digestate in batch mode.

Keyword*:* Anaerobic digestion, Biogas, Substrate, Co–digestion, Cow paunch, Yellow yam brute.

Introduction

Globally, Nigeria is the sixth largest producer of petroleum products [NWOKOJI, 2012], but this position has not fully solved the energy needs of the country.

Presently, the country produces over 2.4 million barrels of crude oil daily with estimated crude oil reserve of over 40 billion barrels and over 176 trillion cubic feet of natural gas reserve.

However, despite these huge deposits of crude oil and natural gas, the country is experiencing enormous scarcity of petroleum products especially in the rural areas where the price and supply of these products are fluctuating.

A country's economic growth and developmental aspiration is highly dependent on the cost of its energy supply sector.

An investor makes maximum profit when all the economic indices point to low cost of production.

Since Nigerian independence in 1960, her energy supply has been characterized with rising prices of fossil fuels, low reliability of electricity provision from national grids with persistent risk of power cuts and vulnerability of hydro power to drought [CHUKWUMA and CHUKWUMA, 2014].

Presently, power generation in the country fluctuates between 3800 and 4400 MW which has adversely affected the country's economic growth.

Effort by successive governments to break the jinx is yet to be applauded [NWOKOJI, 2012].

Bamikole stated that efforts to expand petroleum oil production by way of expanding the refineries and upgrading of the existing ones will not cut down the country's dependence on oil, will not create the mix, will not be cheap, and will not create the employment envisioned by the year 2020 [BAMIKOLE 2012].

Nigeria therefore, must invest in alternative and renewable fuel drive.

Traditionally, bio–energy derived mainly from the combustion of wood and agricultural residues has negative impacts which include severe health consequences on women and children who are the prime users of these products.

Combustion of wood in confined spaces produce indoor pollution of greenhouse gases (CO and CO_2) which cause respiratory illness and premature deaths.

The use of this type of biomass also increases pressure on local natural resources as communities must satisfy increasing demand for energy services.

Nigeria is an agrarian country with more than 70 % of her work force employed in agricultural sector [NWOKOJI, 2012].

This has given rise to production of millions of tons of biomass which is the major raw materials for bio–fuel production.

These biomasses are usually plentiful in rural areas where they are treated as wastes [MATTOCKS, 1980].

It is clear that the development of bio–fuels is vital for possible diversification of the country's economy, growth in industrial production of goods and services, generation of employment, and possible eradication of poverty as well as saving the country's foreign exchange that could have otherwise be spent on importation of fuels.

Anaerobic digestion (AD)

Anaerobic digestion (AD) is a microbial process in which micro–organisms breakdown biodegradable material in the absence of oxygen [NWABANNE *et al*., 2012].

It is widely used to treat wastewater, sludge and organic waste because it provides volume and mass reduction of the input material.

According to Nwabanne and collab. anaerobic treatment comprises decomposition of organic material in the absence of free oxygen and production of methane, carbon dioxide, ammonia and traces of other gases and organic acids of low molecular weight [NWABANNE *et al*. 2012].

Anaerobic digestion has been considered as waste–to–energy technology and is widely used in treatment of different organic waste for example; organic fraction of municipal solid waste, sewage sludge, food waste, animal manure, among others [CHEN *et al*., 2010].

Anaerobic digestion (AD) is a controlled biological degradation process which allows efficient capturing and utilization of biogas for energy generation.

Anaerobic digestion is a process of controlled decomposition of biodegradable materials under managed conditions where free oxygen is absent at temperature suitable for naturally occurring mesophilic or thermophilic anaerobic and facilitative bacteria and archae species, that convert the inputs to biogas and whole digestate.

Anaerobic digestion consists of several interdependent, complex sequential and parallel biological actions in the absence of oxygen, during which the products from one group of transformation of micro–organisms serve as the substrate for the next, resulting in transformation of organic matter (biomass) mainly into a mixture of methane and carbon dioxide [CHUKWUMA, 2013; AWORANTI *et al*., 2011].

Key products of anaerobic digestion include digested solids and liquids, which may be used as soil amendments or liquid fertilizers [BUENDIA *et al*., 2009; JOHN, 2010; CHEN *et al*., 2010].

Biogas is a colourless, flammable gas produced through anaerobic digestion of animal, plant, human, industrial and municipal waste amongst others.

It is composed of mainly methane (50–70 %), carbon dioxide (20–40 %), water vapour (2–7 %), and traces of other gases such as ammonia, nitrogen, hydrogen, hydrogen sulphide as shown in Table 1 [MAISHANU *et al*., 1990; UMEGHALU *et al*., 2012].

Also, Sagagi and collab. defined biogas as a flammable gas produced when organic materials are fermented under anaerobic condition [SAGAGI *et al*., 2009].

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Banat's Journal of Biotechnology
2016, VII(14)

Biogas originates from biogenic material and is a type of bio–fuel.

To produce biogas, water is added to animal/plant waste in a certain ratio to form slurry and digestion takes place in the process of anaerobic digestion [RAVITA, 2012].

Biogas has globally remained a renewable energy source derived from plants that use solar energy during the process of photosynthesis.

Being a source of renewable natural gas, it has been adopted as one of the best alternative for fossil fuels after 1970's world energy crisis [Al IMAN *et al.*, 2013].

Table 1.
Composition of biogas

Component	Concentration by volume (%)
Methane (CH_4)	50–70
Carbon dioxide (CO_2)	20–40
Water (H_2O)	2–7
Hydrogen sulphide (H_2S)	2
Ammonia (NH_3)	0–0.55
Nitrogen (N)	0–2
Oxygen (O_2)	0–2
Hydrogen (H)	0–1

Source: Mattocks (1980)

Biogas is a product of the metabolism of methane bacteria and is created when the bacteria decomposes a mass of organic materials.

It is smokeless, hygienic and more convenient to use than other solid fuels.

Gas gotten from anaerobic digestion is called several other names such as; drug gas, marsh gas, goober gas and swamp gas [SAGAGI *et al.*, 2009].

Biogas technology is a biochemical conversion technology of bio–energy conversion where decomposition or degradation of organic matter occurs in the absence of oxygen by microorganisms [HARKA *et al.*, 2010].

Biogas technology is based on the phenomenon that when organic matter containing cellulose is fermented in the absence of air (anaerobically), combustible gases (chiefly methane) are emitted [UMEGHALU *et al.*, 2012]. Biogas technologies commonly apply consortia of microbes. These communities form an intricate microbiological food chain.

Co–digestion of substrates. Anaerobic co–digestion of animal and organic wastes provides sustainable cycle of natural resources [VINDIS *et al.*, 2009; BUDIYONO *et al.*, 2010; CHUKWUMA, 2012; CHUKWUMA *et al.*, 2012].

Co–digestion is the simultaneous digestion of a homogenous mixture of two or more substrates with complimentary characteristics so as to enhance biogas production [LARZOR *et al.*, 2010; WEI, 2007; BRAUN and WELLINGER, 2002].

It is employed independently to the ratio of the respective substrates used simultaneously.

The chief aim of co–digestion is to improve the efficiency of the anaerobic process and thereby enhance biogas production [CAMPUS *et al.*, 1999].

Thus, the mixing of several waste types has positively affected both the anaerobic digestion and the treatment economy. For instance, Mata–Alvarez and collab. pointed out that the use of co–substrates usually improves the biogas yields from anaerobic digestion due to positive synergisms established in the digestion medium and the supply of the missing nutrients by the co–substrates with animal wastes [MATA–ALVAREZ *et al*. 2002].

Yam production in Nigeria. Yam (*Dioscorea dumentarum*) is widely cultivated in the tropics and subtropical regions of the world and known for its high carbohydrates and medicinal values [SIDDARAJU *et al.*, 2008].

According to FAO, Nigeria is by far the world's largest producer of yam accounting for over 70–76 % of the world's production [FAO, 1985]. Yam production in Nigeria has nearly doubled since 1985, with Nigeria producing about

35.017 million metric tonnes (MMT) valued at about US $5.654 billion [OSAGIE, 1992].

Yellow Yam as a tropical food crop. Yellow yam is one of the six species of yam grown in Nigeria but is less utilised as major food because of traditional bias which has to recognize the unique quality characteristics and the good agronomic flexibility of the species.

However, the species has high yield, high multiplication ratio and better tuber storability than the preferred indigenous *Dioscorea rotundata*.

However, *Dioscorea dumentarum* has an advantage for sustainable cultivation especially when yam production seems to be on the decline as a result of high cost of production, low yields, and post-harvest losses among others. Starch is the major carbohydrate reserve accounting up to 85 % of dry matter. Yellow yam tubers are known to contain alkaloid, tannins and spooning [OSAGIE, 1992; ADDY, 2011; POLICARP *et al*., 2012].

Yellow yam is cultivated for its carbohydrate content (low in fat and protein), and provides a good source of energy. Unpeeled yam has C Vitamin [POLICARP *et al*., 2012]. Yellow yam is sweet in flavour, rich in medicinal value, and consumed when boiled [ADDY, 2011].

Yellow yam as bio–ethanol feedstock. Food versus fuel has been the major concern with regards to the production of alternative fuels [BUTNARIU and CAUNII, BUTNARIU, 2014]. Most feed stocks are relatively expensive for ethanol production and compete with human and animal food which may lead to higher grain and sugar price in the future [BUTNARIU *et al*., 2013]. At present, corn kernel is being utilized for the production of ethanol because it is easier and less expensive for production of produce ethanol [TAHERZABEH *et al*., 2007].

Yellow yam is another potential feedstock for ethanol and biogas production. The starch of the crop is found to be high in sugar yield which will translate to high ethanol yields. Much attention has not been paid to the crop by researchers leading to underdevelopment of the crop as a potential feedstock for bio fuel production.

Bio–ethanol production from yellow yam may increase due to the vast area of land and abundant labour available for growing this crop in Nigeria. More so, the crop is not widely consumed and as such would not compete largely with human or animal food.

Biogas production using yellow yam brute. The wastes generated after extraction of starch for bio–ethanol production was used for biogas production. These wastes were prepared and studied as yellow yam brute alone (YYB) and yellow yam brut mixed with cow dung (CD). The combination was in the ratio of 50 %: 50 % or 1:1, thus giving (YYB) and (YYB–CD).

Preparation of waste samples. All the wastes (YYB and CD) were allowed to degrade for a period of 20 days. This was followed by soaking them in water for four (4) days to allow for partial decomposition of the waste by aerobic microbes.

Fulford reported that this process aids faster digestion of the waste by anaerobic micro–organisms [FULFORD, 1998].

Large sized mesh screen was then used to strain it from the water while the water was used for the charging of the wastes.

Charging of the digesters

Digester 1

i. For co–digestion of yellow yam brute and cow paunch (YYB +CD). 250g of YYB and 250g of CD were weighed, mixed thoroughly and put into the digester marked 1C. 1000g of water was weighed and added to it and stirred thoroughly. This gave water to waste ratio of 2:1. The digester was stoppard with cork and kept.

Digester 2

ii. For digestion of cow paunch alone (CD). 500g of CD was weighed and put into the digester marked 1B; 1000g of distilled water was weighed and added to it and stirred thoroughly. This gave water to waste ratio of 2:1. The digester was stoppard with cork and kept.

Digester 3

iii. For digestion of Yellow yam brute alone (YYB). 500g of YYB was weighed and put into the digester

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Banat's Journal of Biotechnology
2016, VII(14)

marked 1A. 1000 g of distilled water was weighed and added to it and stirred thoroughly. This gave water to waste ratio of 2:1. The digester was stoppard with cork and kept.

All the digesters were stirred thoroughly on daily basis to ensure intimate contact of the waste with micro–organisms responsible for converting the wastes to biogas.

Daily biogas production was measured by downward displacement of the water in the trough by the gas produced and recorded as the difference between the initial reading at the beginning of each day and the final reading at the end of the same day.

pH of the waste slurries were monitored daily for a period of 5 days to ensure stability of the slurries.

Gas flammability was monitored daily from the second day of charging the micro–digesters till the onset of gas flammability.

Microbial load of the waste slurries were carried out four times during the retention period; at the point of charging the micro–digesters, at the onset of gas flammability, at the peak of gas production and at the end of the retention period. This was done to show the relationship between the microbial load at those significant points and the gas production obtained.

Ambient and slurry temperatures were monitored daily all through the retention period. This was aimed to correlate the biogas production for each day with the temperature of the system.

Material and methods

The samples were poured into the digesters, stirred thoroughly to ensure homogenous mixture and subjected to anaerobic digestion.

Samples were collected every 5 days for analysis of such parameters as Total Suspended Solids (TSS), Total Viable Count (TVC), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH values according to the approved American Public Health Association [APHA, 2005].

The biogas produced was measured once a day by means of downwards displacement of water by the biogas in an inverted measuring cylinder.

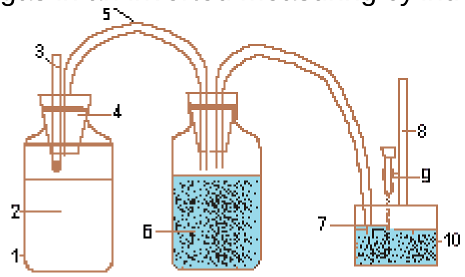

Figure 1. Schematic Diagram of the Experimental Set up for Biogas Production. *Key: 1–Micro–digester; 2–Slurry; 3–Thermometer; 4–Cork; 5–Hose; 6–Plastic Bottle filled with water; 7–Graduated measuring cylinder; 8–Retort Stand with clamp; 9–Biogas produced; 10–Trough with water*

The study was conducted in duplicate sample at ambient temperature of between 26–32^{o}C for a period of 35 days hydraulic retention time (HRT). The schematic diagram of the experimental setup is shown in Figure 1.

Results and discussion

In the study, biogas yield rate tend to obey sigmoid function (S–curve) as generally occurred in batch growth curve and as also reported by Budiyono and collab. [BUDIYONO *et al.*, 1970].

Biogas production is noted to be slow at the beginning and at the end period of observation. This is predicated due to the fact that biogas production rate in batch anaerobic digestion condition directly relies on specific growth rate of methanogenic bacteria in bio–digester [NWBANNE *et al*, 2012; CHUKWUMA *et al*, 2012].

Around the first 5 days, biogas production rate was very slow due to the lag phase of microbial growth.

In the 10–15th day, biogas production rate significantly increased due to exponential growth of micro–organisms. After 15 days, biogas production tends to decrease which may be due to stationary phase of microbial growth [BUDIYONO *et al.*, 1970].

As can be seen from Figure 2 generally after the 30 days still there is the tendency to for biogas production.

This is due to the fact that carbon contained by the wastes constituents have not been totally degraded or converted to biogas through anaerobic digestion. Ezeoha and Idike reported that anaerobic bacteria very slowly degrade lignin content and some other hydrocarbons. Thus, the higher the lignin content will lower biodegradability of a waste [EZEOHA and IDIKE 2007].

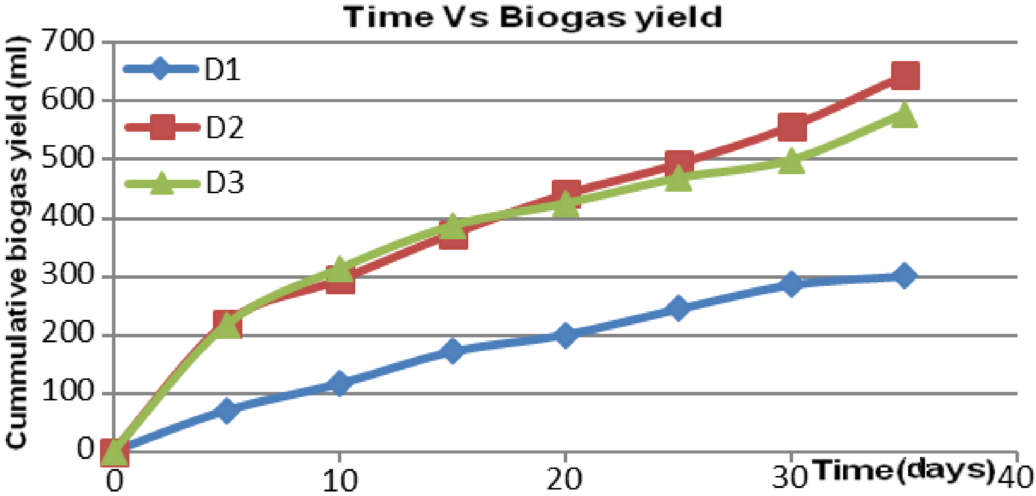

Figure 2. Cumulative biogas yield of various water yam wastes with time.

The comparative evaluation of the cumulative biogas yield of the different variants are in the YYB+CD > CD > YYB.

Generally, in comparing the biogas yield profiles of the three compositions of the substrates, the co–digestate of yellow yam brute mixed with cow paunch (YYB + CD) gave the highest cumulative biogas yield than the single base line substrates.

However, this was followed by cow paunch while yellow yam brute gave the least.

Also, the C/N ratio of the single base line substrates were within the optimum level needed to enhance biogas yield while the pH of the wastes were neutral providing suitable environment for the methanogens responsible for biogas production.

The volatile solids (VS), pH, and C/N ratio of a substrate are vital factors that determine the effectiveness of biogas production [CAMPOS *et al.*, 1999, CHUKWUMA *et al.*, 2012; ANETTE and ANGELIDAKI, 2009].

Conclusions

It was observed that the lag period for these variants were short because of the initial treatment which enhanced faster degradation by microbes.

Research results have shown that using the wastes alone can give reasonable yield of biogas, but co–digesting the wastes with animal wastes (such as cow paunch) would enhance the biogas yield significantly.

Thus, this result is in line with the findings obtained by.

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