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Comparative evaluation of biogas production from Poultry droppings, Cow dung and Lemon grass

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HIGHLIGHTS

- Biogas was generated efficiently from Poultry droppings, Cow dung and Lemon grass.
- Lemon grass produced less volume but better quality gas than other two substrates.
- Lemon grass also showed highest cooking rate in the cooking test conducted.
- Anaerobic digestion was efficient in pathogen and some parameters reduction.

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ABSTRACT

The study explored the production of biogas from Lemon grass, Cow dung and Poultry droppings. The three substrates were pre-fermented according to standard methods. Six (6) kg of each pre-fermented substrate was mixed with water in ratio 1:1 v/v to form slurry and digested for 30 days. A total of 0.125 m^3, 0.191 m^3 and 0.211 m^3 of biogas were respectively produced from the Lemon grass, Cow dung and Poultry droppings with deviations of 0.00234 m^3, 0.00289 m^3 and 0.00484 m^3 respectively. The cooking test carried out revealed that the scrubbed gas had higher cooking rates for water (0.12 L/min, 0.085 L/min and 0.079 L/min for Lemon grass, Cow dung and Poultry droppings respectively) while the cooking rates for unscrubbed gas were 0.079 L/min, 0.064 L/min and 0.06 L/min respectively. The pH of the medium fluctuated optimally between 6.5 and 7.8. The research demonstrated that Lemon grass produced less volume but better quality biogas compared to Cow dung and Poultry droppings.

1. Introduction

Energy has been identified as a very important factor in the economic, social and political development of any nation (Ojolo et al., 2012). Although the abundant hydrocarbon natural resource (crude oil and natural gas) in Nigeria has been identified as the mainstay of over 80% of revenues to the nation, it has not served as a catalyst for economic growth neither has it served as the major source of energy in the mix of energy supplies (Machunga-Disu and Machunga-Disu, 2012). The annual statistical bulletin of the Organization of Petroleum Exporting Countries (OPEC) 2009 revealed that Nigeria's proven crude oil reserves and natural gas are 37.2 billion barrels and 5292 trillion standard cubic meters, respectively.

In addition, the estimated reserve of tar sands and proven reserves of coals are about 30 billion barrels of oil equivalent and 639 million tonnes (with inferred reserves of about 2.75 billion tonnes), respectively (Adaramola and Oyewola, 2011). On the assumption that new oil and gas reserves are not discovered, it is estimated that the crude oil reserves should run out within the next 50 years and the proven natural gas reserves should run out in about 115 years (Ojolo et al., 2012). This inadequacy of energy supply limits economic growth, restricts socio-economic activities and adversely affects the quality of life. The need for increased energy especially in Sub-Saharan Africa where only 58% of the population is served with safe and clean water supply (WHO, 2005) has made biogas technology a welcomed development. The development of biogas technology will facilitate the achievement of the

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Millennium Development Goals (MDGs) of the United Nations (Alfa et al., 2014).

Furthermore, rising crude oil prices has forced nations of the world to think about alternative energy sources. Of the different available energy options, solar energy is considered the most effective, and can even afford the environmental protection of plants. Plants are known to convert and store enormous solar energy in biomass, harnessing these energy stores will best replace all fossil energy resources in the future (Deublein and Steinhauser, 2008). Unfortunately the new alternative energy sources like the solar, hydro, wind etc. require huge economic investment and technical power to operate, which seem to be very difficult for the developing countries like Nigeria.

Moreover, economic growth and heavy consumption of fossil natural resources are responsible for pollution leading to global warming and the production of acid rain (Thakur, 2006). Biogas technology can serve as a means of reducing energy poverty, which has been a serious barrier to economic development in Africa (Alfa et al., 2012).

Biogas is a renewable, high quality fuel, which can be utilized for various energy services such as heating, combined heat and power, or a vehicle fuel instead of the current practice of using fossil fuels (Machunga-Disu and Machunga-Disu, 2012). Biogas technology can serve as a means of reducing energy poverty, which has been a serious clog in the wheel of economic development in Africa (Adaramola and Oyewola, 2011). The methane and energy content of the gas generated usually varies and is dependent on the physical and chemical properties of the substrate used (Chenxi and Bruce, 2011).

Animal excreta especially Poultry droppings contains more easily degradable organic materials, than other agricultural waste products, but is also known to have a high content of lignin and lignocellulose biofibers (40–50% of the total solids) (Triolo et al., 2011). Besides, a high concentration of poultry manure (PM) with solids content of more than 20%, makes this substrate difficult to digest, therefore, dilution of Poultry droppings to 3–6% total solids provides good mixing conditions in anaerobic digesters (Callaghan et al., 2002). Another option for improving biogas yields is co-digestion of poultry manure with other organic wastes which offers several benefits including increasing biogas production, increased loading of readily biodegradable organics, improved balance of nutrients and C/N ratio, dilution of toxic substances, a better quality gas, and cost reduction due to the ability to process several substrates in one installation (Wang et al., 2012, 2013). Digestion of Poultry droppings have been carried out by many researches in combination with other organic wastes including whey, rice and wheat straws, municipal solid wastes, hog manure, buffalo manure, dairy manure and sewage sludge with different results obtained (Callaghan et al., 2002; Gelegenis et al., 2007; Borowski and Weatherley, 2013).

Past biogas researches in Nigeria utilized animal dung, kitchen wastes and human excreta as feedstocks while the use of succulent plants have been limited to water lettuce, water hyacinth, cassava leaves, *Eupatorium odoratum* and *Cymbopogon citratus* (Ubalua, 2008; Alfa et al., 2012; Dahunsi and Oranusi 2013). Although high quality biogas was recorded from the digestion of these plants, their utilization is bedeviled with the challenge of limited distribution across the nation. These plants are mostly found in the riverine regions of the country which makes them regional substrates. In other parts of the world, powdered leaves of some plants and legumes like *Gulmohar*, *Leucacena leucocephala*, *Acacia auriculiformis*, *Dalbergia sisoo* and *Eucalyptus tereticornis* have been found to increase biogas generation by (Santosh et al., 2004). Although Lemon grass (*C. citratus*) is more widely distributed in Nigeria than the other plants previously tested, its exploration for biogas production is limited. Lemon grass can tolerate a wide range of soils and climatic conditions but its optimal growth is achieved on well-drained, fertile and sunlight exposure sandy loam soil (Sugumaran et al., 2005).

The objective of this study therefore is to compare the production of biogas from Lemon grass (*C. citratus*) with that from well familiar substrates (Cow dung and Poultry droppings) and we hope that the outcome will make a good case for further research and investment into Lemon grass cultivation and utilization in Nigeria.

2. Methods

2.1. Materials

Three (3) identical 25 Litre-biogas digester tanks each of height 0.5 m and diameter 0.25 m were fabricated from Galvanized steel which is strong enough to withstand the weight and pressures of the contained slurry. The cylindrical shape was adopted to enhance better mixing. The tank is air tight and is clearly placed above the ground level and outside the shed where it is exposed to the sunlight for partial heating. The three identical 12.1 L gas holder tanks each of height 0.25 m and diameter 0.25 m were fabricated from thin sheet metal and used to temporarily store the biogas until it was used to produce heat or used to replace or supplement the supply of cooking gas. Plastic hose was used to connect each digester to its gas collection system and the biogas stove burner while plastic valves were installed to control the gas flow.

2.2. Fabrication of digesters, biomass collection, slurry preparation and digester loading

The design volume of the three identical batch flow anaerobic digesters was sized according to the amount of volatile solids that must be treated and the period of time the material will remain in each of the digester (retention time). The design of the digesters was based on Ajoy Karki's Biogas model (Karki, 2002) incorporating the separate floating gas holder system for ease of daily measurement of gas volume. The cylindrical shape was adopted to enhance better mixing. The digester is a separate component, with the gas holder in a separate water jacket.

The theory behind the design is simply "downward delivery and upward displacement" following the example of Uludag-Demirer et al. (2008). The slurry on fermenting in the digester produces gas. This gas is delivered to the bottom of the water jacket via a pipe; the pipe extends above the surface of the water level (water seal) in the water jacket. The gas displaces the gas holder (upward) and gets trapped between the gas holder and the water seal. The displacement of the gas holder is dependent on the pressure and volume of the gas produced. The setup is as shown in Fig. 1.

The Lemon grass (*C. citratus*) was harvested from gardens around some houses within Area BZ Staff Quarters, Ahmadu Bello University, Zaria and crushed to smaller particles using the Hammer mill before they were transported to the research field for further pre-treatment. Cow dung, on the other hand, was collected in sacks fresh and free from impurities from the Zango abattoir and transported to the research ground while Poultry droppings were obtained (fresh and free from impurities such as wood filings) from the Poultry Department (Deep Litter section) of the National Animal Production Research Institute, Shika-Zaria and transported to the research site.

Partly decomposed slaughter house waste was used as seed material for the substrates digested in this study. The Lemon grass (*C. citratus*) was pre-fermented for a period of 40 days while Cow dung and Poultry droppings were pre-fermented for a period of 15 days each in respective plastic drums (Karki et al., 2005). The longer period of pre-fermentation for the Lemon grass was as a

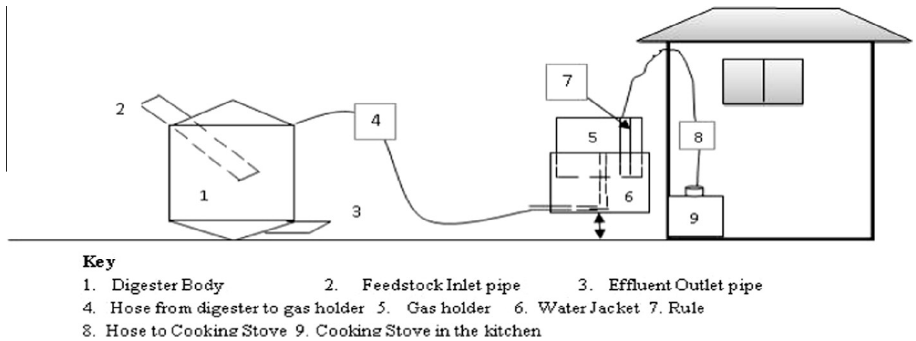

Fig. 1. The anaerobic digester set-up.

result of the slow rate of decomposition of succulent plants which had not undergone any prior digestion unlike the Cow dung and Poultry droppings that had gone through the digestive systems of the respective animals.

The digestion was a batch process and 6 kg each of pre-fermented Lemon grass, Cow dung and Poultry droppings was respectively mixed with water to form slurry in the ratio 1:1 by volume and introduced into Reactor A, B and C respectively through an inlet pipe of 50 mm at the top of each reactor. The slurry was allowed to occupy three quarter of the digester space leaving a clear height of about 0.0625 m as space for the gas production. Before feeding the reactors, the flexible hose connecting the gas outlet from the reactor to the gas holder was disconnected, such that the gas outlets from the reactors were left open. This was done to prevent negative pressure build up in the reactors. The gas was collected from the digesters through a 10 mm diameter flexible hose connected from the digesters to the bottom of the gas collection systems. The collected gas was allowed to pass through water and slaked lime respectively as scrubbers.

Slaked lime ($Ca(OH)_2$) is known to be used for carbon dioxide (CO_2) removal from gas according to earlier finding by Chen et al. (2004) and that there is evidence that the $CO_2/Ca(OH)_2$ reaction also requires the uptake of water to have reaction. The overall reaction is expressed by the Eq. (1) as follows:

$$Ca(OH)_{2(s)} + CO_{2(g)} \rightarrow CaCO_{3(s)} + H_2O_{(ads)} \tag{1}$$

The volumes of gas collected before and after scrubbing were taken and recorded following the method described in the succeeding section. The gases collected before and after scrubbing were used to boil water using Ahmadu Bello University biogas stove burner (Igboro et al., 2011) to estimate and compare the cooking rates. A solid retention time (SRT) of 30 days was chosen for the substrates after a previous study (Gelegenis et al., 2007). During this period, daily ambient temperature of Samaru-Zaria varied from 27 °C to 37 °C which is within the mesophilic temperature range (Bolzonella et al., 2012).

Prior to the digestion, all parameters shown in Table 1 were analyzed for the three substrates used while after digestion; samples of the digestate from the three digesters were concentrated by centrifuging using a Rotofix 32 laboratory centrifuge at 4000 rpm (4226g) for 10 min. The solid residue composed majorly of fibers was analyzed for Total solids (TS), Volatile solids (VS), Chemical oxygen demand (COD), *Escherichia coli* and *Enterobacteriaceae* counts while the liquid portion was analyzed for COD, total ammonium nitrogen (TAN), orthophosphates $\left(PO_4^{3-}\right)$, Volatile fatty acids (VFA), pH as well as *E. coli* and *Enterobacteriaceae* counts.

2.3. Analytical procedures

The Total solids (TS), Volatile solids (VS), Chemical oxygen demand (COD), and pH were measured according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2012). Total Kjeldahl nitrogen (TKN) and Total ammonium nitrogen (TAN) were determined using a spectrophotometer (HACH-LANGE DR 2800) and a modified Nessler method (No. 8038) adopted by HACH. Total phosphorus (TP) and PO_4^{3-} were determined using same spectrophotometer coupled with the PhosVer 3 Phosphate Reagent Powder Pillow Test (method 8048). Volatile fatty acids (VFA) were determined using same spectrophotometer coupled with cuvette tests (HACH-LANGE LCK 365). Metals (K, Na, Mg, Ca, Fe, Cu, Zn, Pb, Cd and Al) were determined using the atomic absorption spectrophotometer, AAS (SOLAAR 969 UNICAM). Composition (CH_4 and CO_2 content) of generated biogas was determined using a gas chromatography (GC) (HP 5890, Avondale, USA) coupled with a Hayesep Q column ($13\ m \times 0.5\ m \times 1/800$) and a flame ionization detector (FID). This was carried out two times a week in duplicate from each digester using a 100 µl gas tight syringe for taking biogas samples from the digesters head space after releasing the gas and followed by injecting the biogas sample into the GC. Enumeration of *Enterobacteriaceae* and *E. coli* count was carried out according to the method of APHA, 2012 using Nutrient agar, MacConkey agar and Eosin methylene blue (EMB) agar. Analyses of individual samples were performed in triplicates and all analyses were performed weekly except for pH value and daily biogas yield which were measured daily.

2.4. Measurement of gas production

The gas holder was calibrated with the aid of a rule marked 7 in the Fig. 1 to enable the reading of the daily gas production from the Lemon grass digested. The volume of biogas produced was measured each day shortly before sunset, by computing the volume of the gas holder floating over water level in the water jacket.

The base area of the gas holder is expressed by Eq. (2):

$$A = \frac{\pi d^2}{4} = \frac{\pi \times 0.25^2}{4} = 0.0491\ m^2 \tag{2}$$

The height of cylinder above water level was read off on the calibration on the gas holder.

Let this height (h) = x, which varies.

Volume of biogas is obtained as the volume of cylinder above water level, given by Eq. (3).

Volume:

$$V = \left(\frac{\pi d^2}{4}\right) h \tag{3}$$

where $h = x$.

Substituting for A in Eq. (2), the volume of biogas:

$$V = 0.0491x\ m^3$$

Table 1
Characteristics of the substrates used in the study.

Parameters	Substrates			
	Unit	Poultry droppings	Cow dung	Lemon grass
pH	–	6.30 ± 1.23	7.40 ± 3.90	6.50 ± 2.80
Total solids	g/kg	68.00 ± 4.10	153.00 ± 34.20	3.00 ± 0.43
Volatile solids	g/kg	37.40 ± 3.13	33.00 ± 4.08	1.20 ± 0.21
Total Kjeldahl nitrogen	gN/kg	72.20 ± 2.78	20.30 ± 3.17	12.00 ± 4.61
Organic carbon	gC/kg	38.61 ± 1.30	34.00 ± 3.43	47.02 ± 5.23
Moisture content	%	59.31 ± 4.03	40.10 ± 4.10	11.24 ± 4.71
COD	gO_2/kg TS	210.00 ± 6.23	873.00 ± 45.23	49.33 ± 6.53
Total phosphorus (TP)	gP/kg	5.10 ± 0.01	3.50 ± 1.03	4.51 ± 1.52
Calcium	gC/kg TS	40.12 ± 3.71	32.10 ± 2.13	51.22 ± 8.43
Sodium	gS/kg TS	4.70 ± 0.02	3.00 ± 0.83	2.09 ± 0.13
Potassium	gK/kg TS	28.11 ± 1.03	20.61 ± 2.13	31.40 ± 4.09
Magnesium	gMg/kg TS	4.97 ± 0.15	2.22 ± 0.02	5.21 ± 1.62
Iron	gFe/kg TS	0.52 ± 0.12	0.41 ± 0.01	0.99 ± 0.18
Zinc	gZn/kg TS	0.12 ± 0.01	0.02 ± 0.03	1.00 ± 0.08
Copper	mgCu/kg TS	92.60 ± 7.41	92.00 ± 7.20	67.40 ± 9.90
Lead	mgPb/kg TS	36.21 ± 3.81	29.10 ± 1.02	27.70 ± 5.00
Aluminium	gAl/kg TS	1.00 ± 1.00	0.62 ± 0.12	1.03 ± 0.09
Cadmium	mgCd/kg TS	13.62 ± 1.80	10.11 ± 2.39	8.20 ± 2.06
E. coli	Cfu/gTS	$11.2 \times 10^5 \pm 3.23$	$9.11 \times 10^5 \pm 2.23$	$3.20 \times 10^5 \pm 1.23$
Enterobacteriaceae	Cfu/gTS	$1.10 \times 10^6 \pm 1.64$	$1.21 \times 10^4 \pm 0.11$	$1.02 \times 10^3 \pm 0.01$

N = 3 for each parameter measured.

In the evening, when the cooking test was concluded (about 7 pm local time), the gas holder was completely emptied. The values given by the calibration were written down in order to obtain the daily production by subtracting this value from the one of the day before. It was assumed that other impurities apart from carbon dioxide were negligible, thus, the difference in volume of gas produced before and after scrubbing were used to estimate the methane content.

2.5. Statistical analysis

Analysis was carried out using IBM SPSS software for Windows version 20.0. The values obtained were confirmed using one-way ANOVA at 0.05 level of significance.

3. Results and Discussion

3.1. The characteristics of the substrates used

The characteristics of the substrates (Poultry droppings, Cow dung and Lemon grass), used for this study are as shown in Table 1. Among these substrates, Cow dung was the densest followed by Poultry dropping while Lemon grass has the lowest in terms of total solid content. Also, great variation was found in the volatile solids content of the three substrates; while Cow dung and Poultry dropping have values close to each other, Lemon grass recorded very low value. Nitrogen was highest in Poultry dropping with a value of 72.2 ± 2.78 and lowest in Lemon grass with 12.0 ± 4.61 as value. Value recorded for phosphorus was highest in Poultry dropping (5.10 ± 0.01) and lowest in Cow dung with value of (3.50 ± 1.03). Calcium value was highest in Lemon grass with 51.22 ± 8.43 while it was lowest in Cow dung with 32.1 ± 2.13 as the value. Sodium was highest in Poultry dropping (4.70 ± 0.02) as it may have been included in the poultry feed during compounding and lowest in Lemon grass (2.09 ± 0.13). For potassium, magnesium, iron and zinc, highest values were recorded in Lemon grass (31.4 ± 4.09; 5.21 ± 1.62; 0.99 ± 0.18 and 1.00 ± 0.08) because they are all elements needed by the green plant in different quantities and for different functions while their lowest values were found in Cow dung (20.61 ± 2.13; 2.22 ± 0.02; 0.41 ± 0.01 and 0.02 ± 0.03) respectively possibly because most of them have undergone modifications/reduction via digestion in the animal's alimentary canal prior to excretion. Also, for copper, lead and cadmium, highest values were recorded in Poultry dropping (92.6 ± 7.41; 36.21 ± 3.81 and 13.62 ± 1.80) probably due to the presence of these metals in the poultry feed as different materials are incorporated into such feeds during production. They were however lowest in Lemon grass (67.4 ± 9.90; 27.7 ± 5.00 and 8.2 ± 2.06) respectively. For aluminium however, Lemon grass recorded the highest value of 1.03 ± 0.09 while the lowest value (0.62 ± 0.12) was recorded for Cow dung. *E. coli* and *Enterobacteriaceae* counts were both highest in Poultry dropping and Cow dung respectively ($11.2 \times 10^5 \pm 3.23$ and $1.21 \times 10^4 \pm 0.11$) and lowest in Lemon grass ($3.2 \times 10^5 \pm 1.23$ and $1.02 \times 10^3 \pm 0.01$).

3.2. Gas production

The quantity of biogas produced from Poultry droppings, Cow dung and Lemon grass over a period of 30 days SRT is shown in Fig. 2. Biogas production was observed on the first day for reactor B (Cow dung), on the second day for reactor C (Poultry droppings) while production in rector A (Lemon grass) started on the third day of loading the digesters and these increased gradually until the maximum values were recorded on the 20th, 23rd and 16th day respectively. Apart from the 22nd and 28th day when sudden increase was observed, biogas production dropped progressively after the day 16 for reactor A. In reactor B, production dropped progressively after the 20th day except on the 22nd and 26th day when sudden increase was observed while the production in reactor C decreased progressively after the 23rd day with a little increase on day 30. It was observed that the digester temperature fluctuated between 28 °C and 36.7 °C while the pH of the medium changed progressively from acidic to slightly alkaline fluctuating optimally between 6.5 and 7.8 except for reactor C (Poultry droppings) that recorded very alkaline pH (8.85) on the 9th day and was maintained above 8.0 till the last day of the study (Fig. 3). This could be attributed to the nature of feed materials used and agrees with earlier submission of Ojolo et al. (2007) and Ahmadu et al. (2009) that the organic matter content of the poultry wastes is a factor that affects the digestion environment as well as the microbial habitat. Also, the observed pH falls within the acceptable range for anaerobic digestion (Abubakar and Ismail, 2012).

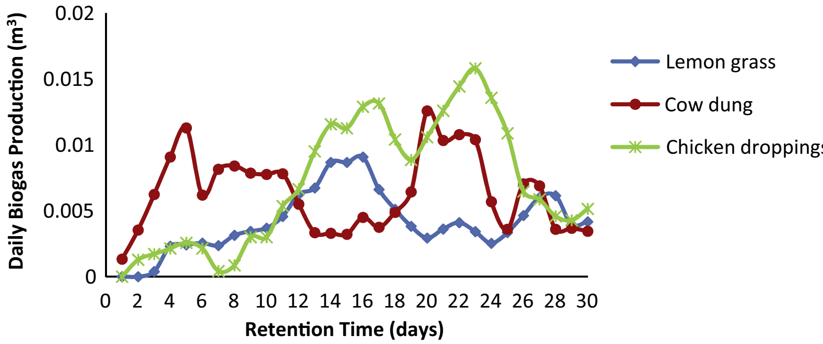

Fig. 2. Daily biogas production from Lemon grass, Cow dung and Chicken droppings.

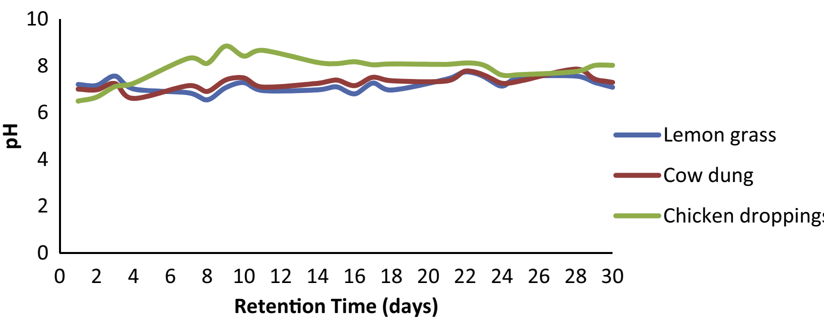

Fig. 3. pH of the Lemon grass, Cow dung and Chicken droppings at various times intervals.

Fig. 4 shows the cumulative biogas production for the 30 days SRT. The result shows that the Poultry droppings produced the highest volume of biogas while Lemon grass produced the least. A total of 1.25×10^{-1} m^3, 1.91×10^{-1} m^3 and 2.11×10^{-1} m^3 of biogas were respectively produced from the Lemon grass, Cow dung and Poultry droppings. The deviations in the volume of biogas produced from reactors A, B and C were 2.34×10^{-3} m^3, 2.89×10^{-3} m^3 and 4.84×10^{-3} m^3 respectively (Table 1). The table further shows the total biogas produced, the biogas yield per day, the biogas yield per kg of slurry as well as the daily biogas yield per kg slurry. The table also shows the estimate of the methane content of the biogas produced on the basis of the decrease in volume after removal of carbon dioxide which ranged between 61.71% and 71.95%. These results correspond with the values stated in Sasse, 1988 for succulent grass and in Borowski and Weatherley (2013) for animal manure.

The higher and faster biogas generation in reactor B (Cow dung) and C (Poultry droppings) could be attributed to the faster rate of decomposition of animal intestinal wastes which have already undergone a form of digestion in the digestive system of the cows and the birds respectively. Therefore, the action of bacteria on this category of waste is fast relative to the Lemon grass which contains fibrous tissues like lignin, suberin, cutin etc. which may not have been completely degraded during the pre-fermentation stage prior to anaerobic digestion.

On scrubbing the gas, the volume of biogas recorded for Lemon grass, Cow dung and Poultry droppings were 9.0×10^{-2} m^3, 1.25×10^{-1} m^3 and 1.3×10^{-1} m^3 respectively (Table 2). The methane contents were estimated to be 71.59%, 65.59% and 61.71% for Lemon grass, Cow dung and Poultry droppings respectively. The fluctuations observed in the volume of biogas produced may be attributed to the change in metabolism of the bacteria in response to the fluctuations in the temperature and pH of the digestion medium. Thus the drop observed after the 16th, 20th and 23rd day for Lemon grass, Cow dung and Poultry droppings could be attributed to the progressive fall in both the digester and ambient temperatures observed during the second halve of the digestion period especially from the 25th day towards the end. Nevertheless, both the digester and ambient temperature remained within the mesophilic range (20–40 °C) throughout the period of observation. Usually, biogas production rate in batch condition is directly equal to specific growth of methanogens (Nopharatana et al., 2007) (Tables 3 and 4).

Fig. 5 gives the result of the cooking test conducted with the biogas before and after scrubbing. The result shows that the scrubbed gas had higher cooking rates for water (0.12 L/min,

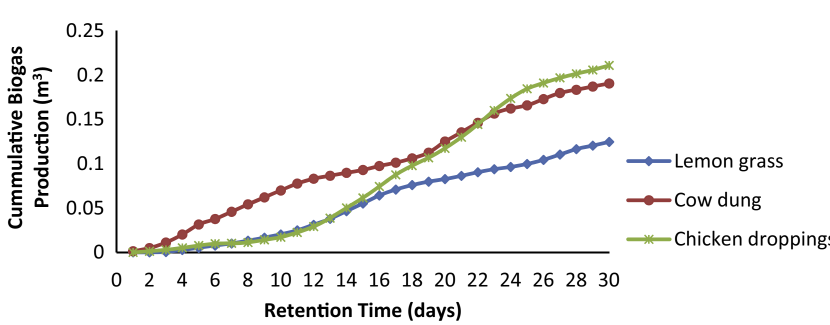

Fig. 4. Cummulative biogas production from Lemon grass, Cow dung and Chicken droppings.

Table 2
Characteristics of the digestates after digestion.

Parameters	Substrates			
	Unit	Poultry droppings	Cow dung	Lemon grass
Residue (fiber)				
TS	g/kg	36.00 ± 2.01	85.02 ± 15.10	2.00 ± 0.23
VS	g/kg	19.01 ± 2.23	20.00 ± 4.08	0.90 ± 0.01
COD	gO_2/kg TS	107.30 ± 4.12	533.00 ± 75.69	38.13 ± 4.30
E. coli	Cfu/gTS	$7.20x10^5$ ± 2.15	$5.11x10^5$ ± 2.10	$2.10x10^4$ ± 1.00
Enterobacteriaceae	Cfu/gTS	$1.10x10^5$ ± 0.31	$1.10x10^3$ ± 0.10	$1.00x10^2$ ± 1.00
Liquid portion				
pH	–	8.60 ± 2.11	8.20 ± 3.91	7.37 ± 3.17
COD	gO_2/m^3	150.10 ± 9.13	773.10 ± 105.21	42.32 ± 5.14
TAN	gN/m^3	1945.10 ± 532.18	1210.30 ± 398.47	1054.00 ± 342.43
P-PO_4^{3-}	gP/m^3	195.17 ± 11.71	163.21 ± 7.90	111.51 ± 8.81
VFA	g/m^3	1932.00 ± 286.27	1132.00 ± 249.19	992.00 ± 196.03
E. coli	Cfu/cm^3	9.20×10^5 ± 3.10	7.21×10^5 ± 1.23	3.10×10^4 ± 1.02
Enterobacteriaceae	Cfu/cm^3	1.10×10^5 ± 0.21	1.10×10^3 ± 0.30	1.00×10^2 ± 1.00

N = 3 for each parameter measured.

Table 3
Biogas yield from Lemon grass, Cow dung and Chicken droppings before scrubbing.

Substrate	Total volume of biogas produced (m^3)	Average biogas yield per day (m^3/day)	Average yield of biogas per kg of slurry (m^3/kg)	Average daily yield of biogas per kg of slurry (m^3/kg/day)	Deviation
Reactor A	1.25×10^{-1}	4.17×10^{-3}	2.08×10^{-2}	6.94×10^{-4}	2.34×10^{-3}
Reactor B	1.91×10^{-1}	6.37×10^{-3}	3.18×10^{-2}	1.06×10^{-3}	2.89×10^{-3}
Reactor C	2.11×10^{-1}	7.03×10^{-3}	3.52×10^{-2}	1.17×10^{-3}	4.84×10^{-3}

0.085 L/min and 0.079 L/min for Lemon grass, Cow dung and Poultry droppings respectively) while the cooking rates for unscrubbed gas were 0.079 L/min, 0.064 L/min and 0.06 L/min respectively. For both cases (before and after scrubbing), the values obtained for the Lemon grass gas were seen to be better than those obtained for Cow dung and Poultry droppings. In addition, the values obtained for the scrubbed Cow dung and Poultry droppings gases where higher than those obtained by Ahmadu et al. (2009). Scrubbing of the gas improved the cooking rates by 51.9%, 32.8% and 31.7% for Lemon grass, Cow dung and Poultry droppings respectively. These cooking periods of time were comparable with those of kerosene, electrical and butane stoves. Scrubbing of the produced gas for removal of impurities such as, but not restricted to, hydrogen sulphide and carbon dioxide will improve the heating efficiency of the biogas.

3.3. Characteristics of digestates

Nutrients that were previously locked up in substrates are known to be released during anaerobic digestion. From the solid residue (fiber) content of the three digestates, Cow dung digestate was found to be the densest while Lemon grass was less dense than Poultry droppings. TS, VS, COD reached maximum values (85.0 ± 15.10; 20.0 ± 4.08 and 533.0 ± 75.69) in Cow dung digestate and recorded lowest values in Lemon grass digestate (2.0 ± 0.23; 0.9 ± 0.01 and 38.13 ± 4.30). The VS reduction observed is consistent with the findings of Bolzonella et al. (2005) and Chen et al. (2012). *E. coli* and *Enterobacteriaceae* on the other hand recorded their maximum values in Poultry droppings (7.2×10^5 ± 2.15 and 1.10×10^5 ± 0.31) and their lowest values (2.1×10^4 ± 1.00 and 1.00×10^2 ± 1.00) in Lemon grass respectively (Table 2). From the liquid portion of the digestates however, Poultry droppings was found to be the densest followed by Cow dung while Lemon grass digestate was less dense than Cow dung. The pH was constantly alkaline ranging between 7.37 ± 3.17 and 8.6 ± 2.11 which supports the observation of Wang et al. (2012) and Rao et al. (2000) who reported decrease in the process pH as a result of high volatile fatty acid (VFA) formation. COD of the liquid was maximum at a value of 773.1 ± 105.21 in Cow dung digestate and lowest (42.32 ± 5.14) in Lemon grass digestate. Castrillon et al. (2002) and Sinbuathong et al. (2011) obtained COD removal from anaerobic digestion of cattle manure and *Jatropha curcas* seed cake respectively.

Values for TAN, P-PO_4^{3-}, VFA, *E. coli* and *Enterobacteriaceae* count were all highest in Poultry droppings digestates (1945.1 ± 532.18; 195.17 ± 11.71; 1932 ± 286.27; 9.20×10^5 ± 3.10 and 1.10×10^5 ± 0.21) and lowest in Lemon grass digestate (1054 ± 342.43; 111.51 ± 8.81; 992 ± 196.03; 3.1×10^4 ± 1.02 and 1.00×10^2 ± 1.00) respectively. High TAN value in the liquid portion may be due to the anaerobic bioconversion of proteins in animal manure into amino acids and then to ammonia as reported earlier by Uludag-Demirer et al. (2008). Consequently, high concentrations of phosphates are due to huge amount of phosphorus in raw Poultry droppings which have their sources from the poultry feeds.

Table 4
Biogas yield from Lemon grass, Cow dung and Chicken droppings after scrubbing.

Substrate	Total volume of biogas produced (m^3)	Average biogas yield per day (m^3/day)	Average yield of biogas per kg of slurry (m^3/kg)	Average daily yield of biogas per kg of slurry (m^3/kg/day)	Estimated methane content (%)
Reactor A	9.0×10^{-2}	3.0×10^{-3}	1.5×10^{-2}	5.0×10^{-4}	71.95
Reactor B	1.25×10^{-1}	4.17×10^{-3}	2.08×10^{-2}	6.94×10^{-4}	65.59
Reactor C	1.3×10^{-1}	4.33×10^{-1}	2.17×10^{-2}	7.22×10^{-4}	61.71

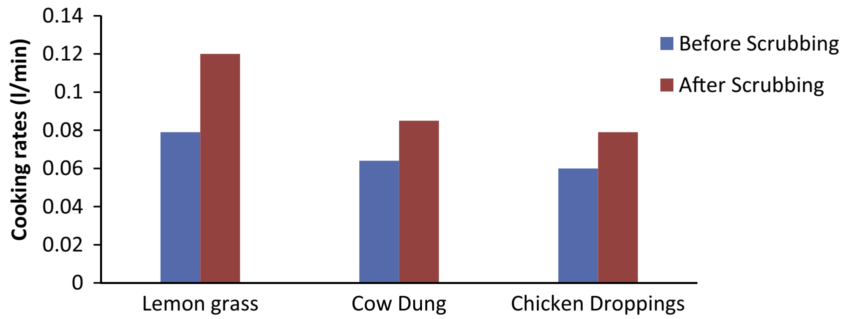

Fig. 5. Comparative biogas cooking rates before and after scrubbing.

As earlier observed in some findings, during anaerobic digestion, most of the phosphorus stored as polyphosphates and a significant part of phosphorus present in organic material is released (Marti et al., 2008) and this is due to high quantities of sodium and potassium in raw poultry manure, which could re-fix phosphates as chemical precipitates.

Considering the effectiveness of the anaerobic digestion on pathogen, the process proved to reduce pathogens a little. Both *Enterobacteriaceae* and *E. coli* counts were in solid fibers and liquid portion of digestates. Previous investigations (Forster-Carneiro et al., 2010; Saunders et al., 2012) have reported decrease in *Enterobacteriaceae* and *E. coli* counts by 1–2 logarithmic units. The SRT used (30 days) also seemed to favor pathogen reduction agreeing with Forster-Carneiro et al. (2010).

4. Conclusion

The research has shown that biogas could be produced from Lemon grass, Cow dung and Poultry droppings. The total biogas yield and methane content for the respective substrates are comparable with those from other substrates. This study also established that, although the volume of biogas from Lemon grass was less than those from others, the quality of Lemon grass biogas was the best. Since Lemon grass is a well-recognized medicinal plant in Nigeria the leaves remaining after boiling could be used for biogas production. The boiling for medicinal purpose would therefore be a form of pre-fermentation for optimum gas production.

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