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Biogas Production from Agricultural Wastes and *Kigelia Africana* Leaves: A Sustainable Approach for Renewable Energy Generation

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ABSTRACT: Biogas, derived from organic waste treatment, harnesses methane for clean energy, reducing waste and bolstering economic sustainability. In this study we evaluate the physiochemical analysis of the waste samples, generated biogas from a well design biodigester, purified the biogas generated and characterize both the untreated and treated biogas. The physicochemical analysis was carried out using a standard method, the gases were characterized using of GC-MS. The result of the physicochemical analysis of the domestic wastes includes; Moisture content (55.2- 59.2 %), Total solid (40.8- 44.7 %), Volatile solid (76.5- 80.1%) and Carbon content (41.7- 44.7%). The untreated biogas generated revealed CH_4 (61.2 %), CO_2 (36.7 %), CO (1.3 %), NH_3 (0.5 %), and H_2S (0.3 %) with a calorific value of 23.41 MJ/ m^3, while the treated biogas revealed CH_4 (70 %), CO_2 (28 %), CO (1.3 %), NH_3 (0.5 %), H_2S (0.2 %) with a calorific value of 26.78 MJ/ m^3. In addition, the production and use of biogas contribute to sustainability by providing access to contemporary, clean energy that is dependable, as well as by reducing emissions and reducing climate change's effects.

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An increase in the cost of fuels like coal and oil is a threat to global fuel supplies. This has prompted research in several fields to find alternative energy sources, such as renewable energy sources (Guan *et al.,* 2023). Examples of renewable energy sources include solar, wind, various thermal, hydroelectric, and biogas sources (Ang *et al*., 2022). Unlike other renewable energy sources, biogas is unique in that it can manage, collect, and use organic wastes while also providing crop fertilizer (Kabeyi and Olanrewaju, 2022). Biogas also has advantages such as non-geographical limitations and low equipment requirements, making it easy to utilize and implement (Gebretsadik, 2018). Moreover, agricultural waste can significantly enhance methane production due to its high calorific value and nutritional value for bacteria (Ajewole *et al.,* 2021). As a result, biogas is a cost-effective solution, leading to increased reactor size and efficiency. On the other hand, improper waste management practices, such as unregulated dumping of agricultural waste, have adverse effects on public health and the environment. These practices can lead

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to the pollution of surface and groundwater with leachate, as well as the proliferation of disease-carrying vectors like rodents, flies, and mosquitoes (Karthick *et al.,* 2014). In addition, improper waste management releases foul odors and methane, a potent greenhouse gas that contributes to global warming (Lynch *et al.,* 2021). Biogas is primarily composed of methane and carbon dioxide. It is generated when organic materials degrade in the absence of oxygen (Cruz-Monterrosa and Bribiesca, 2022). Biogas itself is odorless and colorless, producing a blue flame when ignited, reminiscent of liquefied petroleum gas (Muhibbu-din *et al.,* 2020). It is a versatile fuel, capable of replacing electricity, agricultural waste, and firewood. Furthermore, the production of biogas from waste has been proven to reduce air and soil pollution (Bond *et al*., 2004). Biogas can be substituted with compressed natural gas, providing an environmentally friendly fuel alternative. Additionally, the residue leftover from the biogas production process can be used as organic fertilizer, replacing expensive inorganic options. Implementing biogas systems for waste removal and treatment contributes to the creation of clean environments (Kabeyi and Olanrewaju, 2022; Kasinath *et al*., 2021). Anaerobic digestion, also known as biomethanization, is a natural process that occurs in the absence of oxygen (Adekunle and Okolie, 2015). It involves the biochemical breakdown of complex organic material, releasing energy-rich biogas and producing nutrient-rich effluents (Kumar and Ankaram, 2019). In the process of biogas production, enzymes produced by microorganisms such as cellulose, amylase, lipase, and protease are responsible for breaking down organic compounds. Bacteria play a key role in decomposing proteins, lipids, and carbohydrates into simpler forms, including monosaccharides (from polysaccharides), amino acids, and peptides (Meegoda *et al*., 2018). Acid-producing bacteria transform fermenting bacteria's intermediates into acetic acid, hydrogen, and carbon dioxide. They thrive in acidic conditions, needing carbon and oxygen to produce acetic acid, utilizing bound or dissolved oxygen (Anukam *et al*., 2019). These bacteria also yield alcohols, organic acids, amino acids, carbon dioxide, hydrogen sulfide, and trace methane from low molecular weight compounds. The process is endergonic, demanding external energy, as bacteria can't sustain it independently (Dang *et al.,* 2016). Methane-producing microbes break down low molecular weight materials using acetic acid, carbon dioxide, and hydrogen to produce methane and carbon dioxide. These CH_4-producing microorganisms naturally thrive in anaerobic environments such as marshes or underwater, such as marine sediments (Xiao *et al.,* 2012). They are highly sensitive to changes in their environment and rely on anaerobic conditions. Methanogenic bacteria belong to the Archaebacter genus, which differentiates them from other bacteria in terms of molecular and biochemical characteristics as well as shape due to variations in their cell walls (Zupancic and Grilc, 2012). The production of biogas occurs naturally as part of the biogeochemical carbon cycle. Both urban and rural communities can harness its benefits (Appels *et al.,* 2008; Sundberg *et al.,* 2013). *Kigelia africana* leaves are an excellent substrate for biogas production. They contain large amounts of cellulose and lignin when viewed as waste. These leaves aid in biogas production due to their high carbon content, which accelerates microbial decomposition during anaerobic digestion. Using them not only manages organic waste efficiently but also increases biogas yield, promoting the creation of sustainable energy and reducing environmental pollution (Sjoberg *et al.,* 2004). Hence, the objective of this paper was to evaluate the physiochemical analysis of the waste samples, generated biogas from a well design biodigester, purified the biogas generated and characterizes both the untreated and treated biogas.

MATERIALS AND METHODS

Sample Collection and Preparation: The agricultural wastes (cow dung, chicken manure, and cow rumen) utilized as the inoculum were collected at the Ladoke Akintola University of Technology poultry farm and the Atenda abattoir in Ogbomosho. *Kigelia africana* leaves were also collected from Ladoke Akintola University of Technology Ogbomoso environment in February 2022. The extra materials utilized in this research are of high analytical quality and were purchased from Merck. In the experiment, distilled water was used.

Physicochemical Analysis of Waste Samples: The study was conducted to ascertain the modifications in the waste samples that occurred during anaerobic digestion. Prior to introducing the slurry state into the digester, the parameters were tested. The physicochemical research includes the following measurements: Moisture Content (% moisture), Total Solids (TS %), Volatile Solids (VS %), and Carbon content (% C). Prior to the anaerobic digestion process, the TS, VS, moisture content, and carbon content of agricultural wastes and *Kigelia africana* leaves were assessed using the Standard Procedures outlined by Lami (2016) for the Examination of Water and Wastewater.

Total solids: Before being used, a spotless evaporating dish was weighed, cooled in a desiccator, and oven-dried for an hour at 105 ^{0}C. A 10 g sample was put on the evaporating dish and left to evaporate for 24 hours using a crucible and a Contherm 260M oven set to 105 °C. After a day in the oven, the crucible was taken out and allowed to cool in desiccators before being weighed with an electronic balance (PB602). The percentage of TS was calculated using the formula in Equation 1.

$$\% TS = \frac{mDS}{mFS} \times 100 \quad (1)$$

Where, %TS= percentage of total solids; mDS= mass of dry sample (final weight) in gram; mFS= mass of fresh sample in gram.

Volatile solids: Following the determination of the TS, the oven-dried sample was ignited at 550°C for 3 hours in a muffle furnace (BiBBY, Stuart) to ascertain the volatile solids. To determine the percentage of volatile solids in the TS, the formula in Equation 2 was used.

$$\% VS = \frac{mDS - m(ash)}{mDS} \times 100 \quad (2)$$

Where, % VS = percentage of volatile solids; mDS= mass of dry solids in gram; m(ash)=remaining mass after ignition.

Moisture content determination: Ten grams of fresh samples were dried in a Contherm 260M oven at 105 °C for 24 hours in order to calculate the samples' moisture content (MC) %. The samples were then reweighed. After that, the moisture content was computed as follows as in Equation 3.

$$\% MC = \frac{W-D}{W} \times 100 \quad (3)$$

Where, MC = moisture content; W = initial weight of sample in grams, D = weight of sample after drying at 105 °C in grams.

Organic carbon content: Jigar *et al*. (2011) claimed that the carbon content of the substrates was derived by an empirical equation based on volatile solids data based on Equation 4.

$$\% \ Carbon = \frac{\%VS}{1.8} \quad (4)$$

Where, VS= Volatile solids.

Requirements and Build-up of the Unique Biogas Digester: The biogas anaerobic digester was designed utilizing a 25-litre keg as an improvised reactor tank. It was connected to a gas collector via its gas outlet. It was designed to have a gas exit, a waste outlet (discharge) that functions like a tap at the bottom of the keg, an inlet (for replenishing), and a bulb that produces heat at a temperature between 45^0C – 50^0C beneath.

Preparation of the Inoculum and substrate: The inoculum (cow rumen, cow dung, and chicken manure) was weighed out in the proportions of 1:2:1 and carefully mixed; the cow dung is in a higher proportion because it is the primary source of microbial fermentation. Freshly obtained *Kigelia africana* leaves were used as the substrate, which was rigorously collected, cleaned, and allowed to dry naturally for fifteen days. Then, an electric blender was used to pulverize it. Slurry was made by combining the inoculum mixture and substrate in a1:4 ratio with just enough distilled water.

Production of Biogas: The slurry (mixture of inoculum and substrate) was loaded into the designed digested system and closed tightly. To ensure thorough mixing and promote the growth of microorganisms, the system was continuously shaken at intervals of 15 minutes. This facilitated complete digestion and production of the biogas at a daily ambient temperature ranging from 41 °C to 50 °C.

Biogas treatment: Various tests were carried out to remove corrosive and incombustible gas to boost the gas energy density. Iron dust, water, and silica gel were employed to remove the contaminants. Iron dust is expected to react with the hydrogen sulphide, water is intended to lower the amount of carbon dioxide, and silica gel is expected to lower the amount of water vapour in the treated biogas.

Biogas Characterization: Biogas is characterized using a gas chromatograph, which is a reliable and accurate method of identifying the elements contained in the gas. The head space jacket that has been attached to the gas chromatography equipment was filled with the gas after being connected to the head space vial via a sealed tube. The head space operating conditions include the vial properties, the event time, and the temperature of the zone. Additionally, each constituent is detected and measured using a detector included into the gas chromatograph (Bothi, 2007). Employing an HP 6890 Gas Chromatography system driven by an HP Chem Station Rev. A 0901[1206] Software, the sample was characterized at 150°C for the injector, 300°C for the detector, 35°C for the initial oven temperature, 100°C for the final temperature, and a rate of 5°C/minute.

By using a Junker's Calorimeter, which measures the temperature rise of a known volume of water as a result of the combustion of a known volume of gas, the calorific value was also carried out to calculate the heat content of the biogas upon complete combustion (Akansu *et al.,* 2004).

RESULTS AND DISCUSSION

The results of the physicochemical analysis conducted on the blended agricultural waste and *Kigelia africana* leaves sample used in the experiment were compared to a previous study, as shown in table 1. According to Sadaka and Engler (2003), moisture is a significant factor that affects anaerobic digestion of agricultural waste due to water mobility, microorganism growth, and their impact on nutrient breakdown and passage. Furthermore, water reduces the restriction on bulk transfer of non-homogenous substrate. The water content in the digestion state typically increases as the reduction of volatile solids and total solids increases. The moisture content of the inoculum mixture in this research was 58.4% according to equation 3, which closely aligns with the 59.2% moisture content reported in the study by Muhibbu-din *et al.* (2020). Additionally, an average total solids content of 44.3% was calculated using equation 1 is observed in the agricultural waste. The total solids of agricultural waste play a crucial role in determining the quantity of nutrients available for bacterial action during digestion. In comparison to Dupade *et al.* (2020), the total solids in this study fall within the range for biogas production. However, the percentage of total solids is likely lower due to active microbial breakdown of the agricultural waste facilitated by the presence of sufficient moisture in the digester. In this study, agricultural waste exhibited a high average mixture of volatile solids (77.9%) as being calculated using equation 2 and 4, which is responsible for biogas generation according to Muhibbu-din *et al.* Therefore, agricultural waste has promising potential as a raw material for biogas production.

Table 1: Results of the physicochemical analysis of agricultural waste and *Kigelia africana* leaves.

Parameters			Moisture content (%)	Total solids (%)	Volatile solids (%)	Carbon Content (%)
This study	Inoculum	Cow rumen	57.2	43.5	80.1	41.7
		Cow dung	58.7	42.1	77.2	42.7
		Chicken manure	59.3	44.6	76.5	44.3
		mix. of inoculum	58.4	43.4	77.9	42.9
	Substrate	*Kigelia Africana*	55.2	44.7	75.2	44.7
Previous study	Muhibbu-din *et al.* (2020)	% of Inoculum	59.2	40.8	77.3	42.9
	Dupade *et al.* (2020)	% of Inoculum	55	45	80	Nd

Key: ND represents (Not Determine)

The analysis of untreated and treated biogas samples provides valuable insights into the effectiveness of purification processes and the quality of the resulting biogas. The composition of the untreated biogas sample was as follows: methane (CH_4) - 61.2%, carbon dioxide (CO_2) - 36.7%, hydrogen sulfide (H_2S) - 0.3%, carbon monoxide (CO) - 1.3%, and ammonia (NH_3) - 0.5%. These levels indicate a relatively high concentration of methane, which is desirable as it is the main component of biogas and the primary source of its energy potential. However, the presence of carbon dioxide, hydrogen sulfide, carbon monoxide, and ammonia suggest the existence of impurities that can affect combustion efficiency and potentially pose environmental and health risks. After purification, the composition of the treated biogas sample showed improvements. The methane content increased to 70.3%, indicating a more concentrated and energetically potent gas. The carbon dioxide level decreased to 27.6%, which is crucial for enhancing the energy content of biogas and reducing greenhouse gas emissions during combustion. The levels of hydrogen sulfide, carbon monoxide, and ammonia remained relatively unchanged, indicating that the purification process primarily targeted the removal of carbon dioxide. The increase in methane content and reduction in carbon dioxide levels demonstrate the effectiveness of the purification process in upgrading the quality of biogas. Higher methane content enhances the energy yield per volume of biogas, making it more suitable for various applications, including electricity generation, heating, and transportation fuel. Additionally, the lower carbon dioxide content improves the environmental sustainability of biogas utilization by reducing greenhouse gas emissions. These results are consistent with studies by Muhibbu-din *et al.* (2020), which determined that biogas typically consists of CH_4 (50–64% by volume), CO_2 (25–31%), H_2S (1–3% vol.), and NH_3 (1–2% vol.), and Khan *et al*. (2017), whose study included CH_4 (50–60%), CO_2 (34–38%), H_2S (trace), O (0–1), and H_2O (6%). Furthermore, Karellas *et al.* found that CH_4 (55-75%), CO_2 (25-45%), and H_2S (less than 1%) make up the majority of the biogas produced by dairy manure digesters.

Table 2: Results for composition of unpurified and purified biogas sample

S/N	Components	% Composition of untreated biogas	% Composition of treated biogas
1	CH_4	61.2	70.3
2	CO_2	36.7	27.6
3	H_2S	0.3	0.2
4	CO	1.3	1.4
5	NH_3	0.5	0.5

The calorific value is the amount of heat energy produced through complete combustion. A higher calorific value indicates greater efficiency. The percentage of methane (%) plays a significant role in determining the total calorific value of biogas, as a higher percentage of methane results in a higher calorific value. In this study, the calorific values of the untreated and treated biogas are 23.51 MJ/m^3 and 26.88 MJ/m^3, respectively. Methane (CH_4) is the most important component of biogas in terms of calorific value.

Table 3: Results of the unpurified and purified biogas analysis for calorific value

Parameter	Untreated biogas	Treated biogas
Calorific value (MJ/ m^3)	23.41	26.78

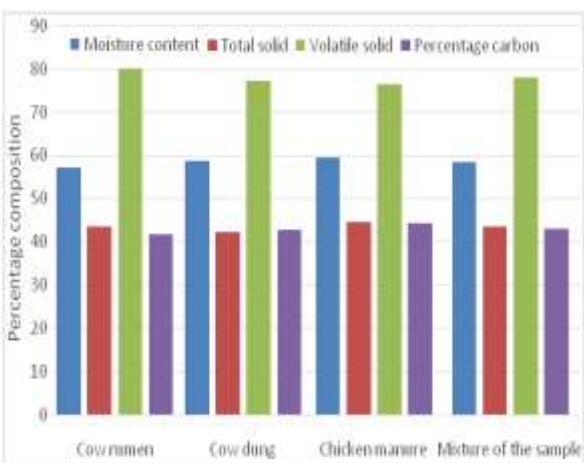

Fig 1: Physicochemical analysis of Inoculums

According to Kabeyi and Olanrewaju (2022), the calorific value of biogas can range from 20-25 MJ/m^3, depending on the methane percentage (50-75% volume). Abdulfatah *et al.* (2022) state that biogas is odorless, colorless, and burns with a blue flame, similar to LPG gas. They report a calorific value of 20 MJ/m^3 with a methane percentage of 55-60% (by volume). Therefore, based on this study, biogas with methane percentages of approximately 61.2% (untreated) and 70.3% (treated) have calorific values of 23.41 MJ/m^3 and 26.78 MJ/m^3, respectively.

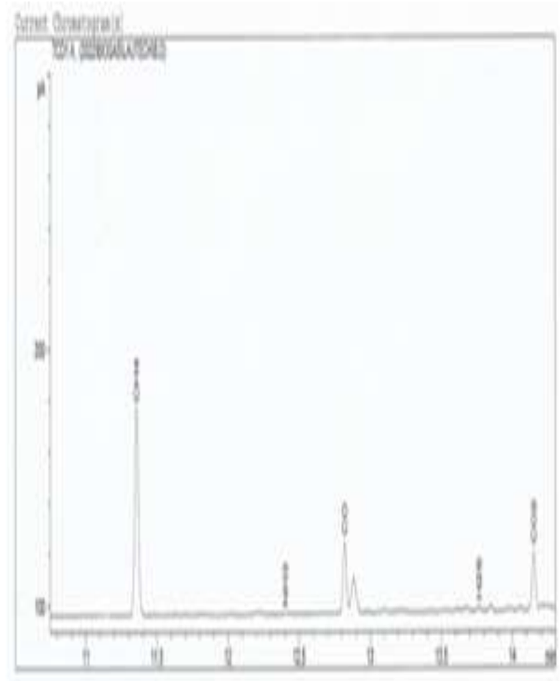

Fig 2: Untreated chromatogram peaks

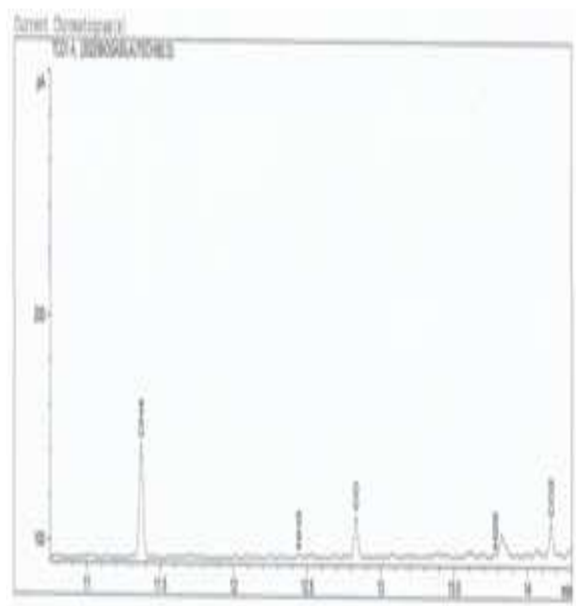

Fig 3: Treated chromatogram peaks

Conclusions: According to this study, agricultural wastes have a high volatile solids content, which suggests that they have a good chance of being used as raw materials for the production of biogas. In addition, the production and use of biogas contribute to sustainability by providing access to contemporary, clean energy that is dependable, as well as by reducing emissions and reducing climate change's effects.

Declaration of Conflict of Interest: The authors declare no conflict of interest.

Data Availability Statement: Data are available upon request from the first author or corresponding author.

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