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COMPARATIVE EVALUATION OF BIOGAS PRODUCTION POTENTIAL OF PLANTAIN PEELS, COW DUNG, CHICKEN DROPPINGS AND PIGGERY DUNG UNDER ANAEROBIC DIGESTION

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ABSTRACT
This study comparatively evaluated the biogas production potential of plantain peels, cow dung, chicken droppings and piggery dung under anaerobic digestion. The experiment was conducted using four 60-litre metallic biogas digesters at the National Centre for Energy Research and Development, University of Nigeria, Nsukka, under ambient (uncontrolled) temperature conditions (slurry temperatures of 45.9–47 °C). Each feedstock was mixed with water in waste-to-water ratios (1:2 for cow dung, chicken droppings, and piggery dung, and 1:3 for plantain peels) and digested for 30 days. Parameters such as pH, ambient temperature, slurry temperature, and daily gas yield were monitored. Results showed that gas production commenced on the first day of digestion for all feedstocks, with cow dung exhibiting the highest cumulative biogas yield of 177.5 L, followed by chicken droppings (89.2 L), plantain peels (66.8 L), and piggery dung (59.4 L). The study concluded that cow dung was the highest-yielding feedstock among the substrates tested, on the basis of cumulative gas yield. The findings suggest that readily available agricultural and animal wastes could serve as renewable energy sources and help reduce environmental pollution and dependence on fossil fuels.

Keywords: Biogas, Plantain Peels, Cow Dung, Chicken Droppings, Piggery Dung, Anaerobic Digestion

Introduction

Biogas is a mixture of colourless, flammable gases obtained by the anaerobic digestion of organic waste materials [2]. Biogas is typically made up of methane (50−70%), carbon dioxide (30−40%) and other trace gases [10]. Energy consumption per capita is widely regarded as an index of a nation's development and standard of living (citation needed). The demand for fuel in terms of transportation and power generation in many nations including Nigeria has increased greatly. The demand has so far been met in Nigeria largely from the nation's stock of fossil fuels such as crude oil, which are finite. Fossil fuels are associated with greenhouse-gas emissions and environmental degradation, and their prices are volatile. The use of alternative and more environmentally friendly energy sources such as biogas has been advocated. Biogas is a renewable energy produced through the anaerobic digestion of organic materials, such as animal manure, agricultural residues, food waste, and sewage [19]. Biogas provides a sustainable energy source and can be used for cooking, heating, and electricity generation [11].

Organic waste, such as food scraps, manure, and sewage sludge, is one of the commonly used feedstocks for biogas production. These waste materials are abundant and readily available, making them a cost-effective option for biogas production. Organic waste can be easily collected from households and farms, providing a sustainable solution for waste management while producing renewable energy. Agricultural residues, including straw, stalks and animal by-products, are another important feedstock for biogas production. These materials have high biogas potential and can be utilized as feedstock in biogas digesters, contributing to decentralized energy production in rural areas [4, 5]. The terms "sewage gas" and "marsh gas" are common historical names for gases generated in anaerobic environments such as wetlands and sewage systems [7].

Statement of the problem

In Nigeria, about 1.4 million kilograms of cattle manure, 6.4 million kilograms of poultry manure and 5.2 million kilograms of piggery manure are produced per day [9], and these wastes pose a great threat to human health and constitute an environmental problem if not properly managed. Animal manure is rich in organic matter, which serves as the substrate for biogas production, and contains nitrogen (N) and phosphorus (P), which support microbial growth [1]. Studies have been carried out on the use of animal dung for the production of biogas, for example, [6] on cow dung, and [3, 13] on poultry droppings. However, comparative studies of animal wastes already exist [3, 9]. The gap addressed here is the side-by-side comparison of these animal wastes with plantain peels under the same digestion conditions. It is important to understand which feedstock yields the highest biogas production. Therefore, this comparative evaluation is needed to address this gap and to inform policy-makers, investors, and stakeholders on feedstock selection for biogas production.

Aim and objectives

The aim of this study was to compare the biogas production potential of plantain peels, cow dung, chicken droppings and piggery dung under anaerobic digestion. The specific objectives of this study were:

i. To produce biogas using different feedstocks (plantain peels, cow dung, chicken droppings and piggery dung);
ii. To analyse the cumulative and daily biogas yields of the feedstocks (plantain peels, cow dung, chicken droppings and piggery dung); and
iii. To identify the optimal feedstock for biogas production based on cumulative biogas yield.

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Methodology

Materials

The following materials were used for the experiment.

Four locally fabricated 60-litre biodigesters (A–D) from the National Centre for Energy Research and Development, University of Nigeria, Nsukka; ground plantain peels; fresh cow dung; chicken droppings; piggery dung; a hose pipe (about 2.7 m long); a large funnel (for easy feeding of the slurry); a calibrated bucket for measuring the volume of gas collected daily by water displacement; a digital pH meter (model PHS-3C); clean water (measured in litres); a rubber bowl; a thermometer; a weighing balance; and MATLAB (Matrix Laboratory) for plotting the data.

Method of experiment

Twenty kilograms of fresh plantain peels were washed with clean tap water and the water was allowed to drain for about 15 minutes. The washed plantain peels were ground into smaller particles. Then 11.25 kg of the ground plantain peels was mixed with 33.75 L of water in the ratio of 1:3 to form a slurry. The slurry (ground plantain peels and water) was fed into a digester labelled A. The quantity of the slurry was pre-determined by measuring it to make sure it occupied about 75% of the volume of digester A. During the charging of digester A, the waste was diluted with water. The purpose was to determine the volume of biogas produced daily by plantain peels only.

Then 15 kg of fresh cow dung was mixed with 30 L of water in a waste-to-water ratio of 1:2 (quantities measured using a weighing balance). The mixture of waste and water (cow dung slurry) was fed into a digester labelled B to determine the volume of biogas produced by cow dung alone.

For digester C, 15 kg of chicken droppings was mixed with 30 L of water in a waste-to-water ratio of 1:2 (quantities measured using a weighing balance). The mixture of waste and water (chicken droppings slurry) was fed into digester C to determine the volume of biogas produced by chicken droppings only.

Finally, 15 kg of fresh piggery dung was mixed with 30 L of water in a waste-to-water ratio of 1:2 (quantities measured using a weighing balance). The mixture of waste and water (piggery dung slurry) was fed into a digester labelled D to determine the volume of biogas produced by piggery dung alone.

The four set-ups used the same water-displacement method to determine the volume of gas produced. Biogas production was monitored and measured daily by the displacement method. All four digestion processes were observed for 30 days. The ambient temperature and the temperature of the digesting slurry were monitored daily with a thermometer for the 30 days. The ambient temperature was determined by measuring the air temperature in the place where the digesters were kept. The slurry temperature was determined by inserting the thermometer through the inlet of the digester to be in contact with the slurry for 3 min.

A digital pH meter (model PHS-3C) was used to determine the pH of the slurries. The pH electrode was rinsed with distilled water, dipped into the slurry and allowed to stabilize until a steady reading was obtained. The pH of the systems under digestion was recorded at 3-day intervals for the 30 days because biogas systems are very sensitive to pH.

Results and discussion

Table 1: Mass of the Wastes and Volume of Water (Mix Ratio) in Different Digesters

Wastes	Mass of Waste (kg)	Volume of Water (L)	Mix Ratio
Cow Dung	15	30	1:2
Plantain Peels	11.25	33.75	1:3
Chicken Droppings	15	30	1:2
Piggery Dung	15	30	1:2

Table 1 presents the masses of waste, the volumes of water and the resulting mix ratios used in the four digesters. Water was used to dilute the organic wastes during charging. The mixing ratios were chosen on the basis of the expected moisture content of each waste (no moisture-content measurement is reported). The ratio of waste to water was 1:2 (for cow dung), 1:3 (for plantain peels), 1:2 (for chicken droppings) and 1:2 (for piggery dung). However, the plantain peels contain less water than the animal dung. The volume of water added to the plantain peels was increased to arrive at the desired slurry consistency. This ratio is within what is expected in the charging of digesters [18]. The ability of a feedstock to digest was affected by slurry concentration. When the wastes were too diluted, the particles settled at the bottom of the digester, and when the wastes were too thick, the particles hindered the flow of the biogas formed at the lower part of the digester; in both cases, gas production was less than optimal.

Table 2: Summary of Results for the Four Wastes (Plantain Peels, Cow Dung, Piggery Dung, Chicken Droppings)

Items	Cow dung	Plantain peels	Chicken droppings	Piggery dung
Mass of waste used (kg)	15	11.25	15	15
Volume of water used (L)	30	33.75	30	30
Total volume of slurry (L)	45	45	45	45
No. of days of digestion	30	30	30	30
Total volume of gas generated (L)	177.5	66.8	89.2	59.4
Maximum ambient temperature (°C)	37.5	37.5	37	37
Maximum slurry temperature (°C)	46	45.9	47	46
Peak daily gas volume (L)	10.8	12.1	7.9	6.2
Specific gas yield (L per kg fresh waste)	11.8	5.9	5.9	4.0
Minimum pH	6.59	6.28	6.63	6.53
Maximum pH	7.20	6.98	6.90	6.96

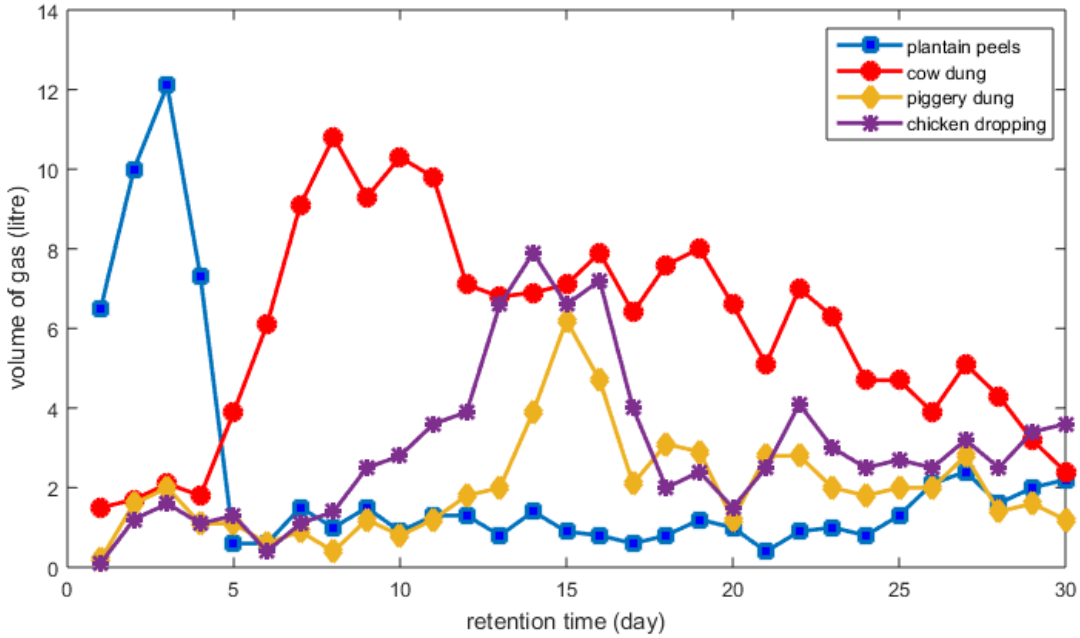


Figure 1: Daily biogas volumes from plantain peels, cow dung, piggery dung and chicken droppings against retention time

Figure 1 shows the comparison of the daily volumes of biogas produced from the four wastes (plantain peels, cow dung, piggery dung and chicken droppings). The blue curve represents plantain peels, the yellow curve piggery dung, the red curve cow dung and the purple curve chicken droppings. The results show that gas production started on the first day in all four digesters, with plantain peels recording a markedly higher initial volume than cow dung. However, it was observed that from the sixth day of anaerobic digestion onward, the volume of biogas produced from cow dung was generally higher than that from plantain peels, piggery dung and chicken droppings. Gas production from chicken droppings and piggery dung was slow at the start, peaking at 7.9 L on day 14 and 6.2 L on day 15, respectively, before declining; their cumulative yields were 89.2 L and 59.4 L. The sharp decline in gas production from plantain peels after the third day may have been due to inhibition, possibly through acid accumulation or cyanogenic compounds; this could not be confirmed because neither the pH profile nor the hydrocyanic acid content is reported. This is consistent with [17], who reported that cyanide inhibits methanogenesis; cyanogenic glycosides in plant materials can release cyanide, thereby reducing biogas production. Between the 16th and 30th days of the experiment, gas production generally declined in all the digesters. This might have been due to depletion of nutrients and a reduction in the population of methanogenic microorganisms in the digesting slurry [16], although neither was measured in this study. It can be concluded that the volume of biogas produced fluctuated over the 30-day anaerobic digestion period.

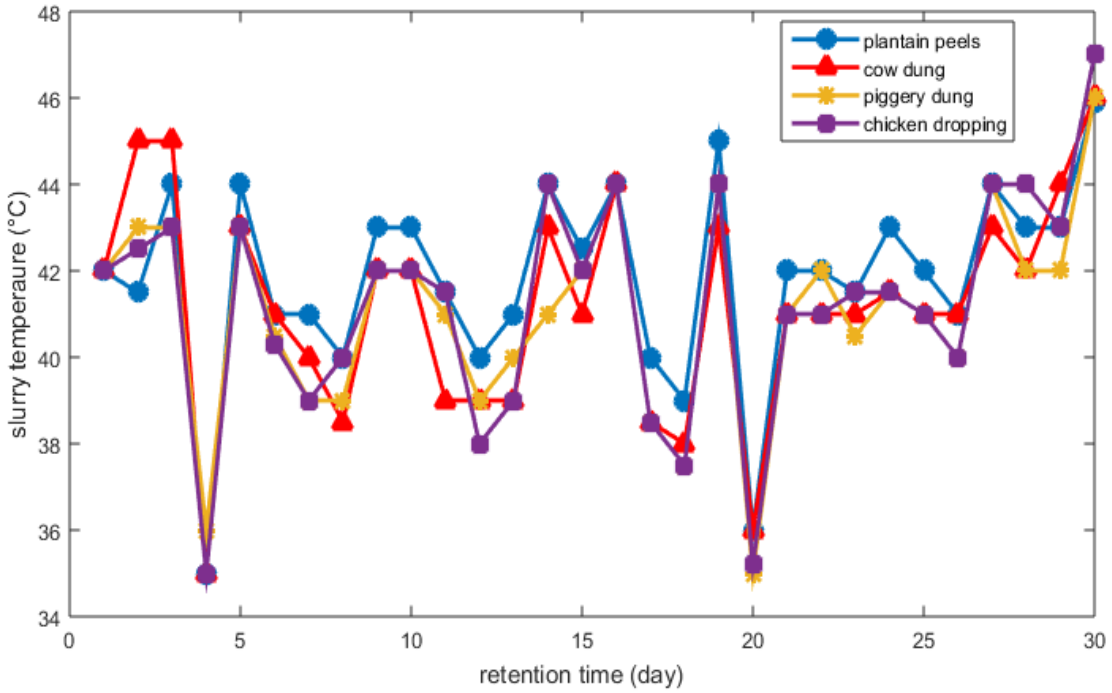


Figure 2: Daily slurry temperature from plantain peels, cow dung, piggery dung and chicken droppings against retention time

Figure 2, shows the comparison of the daily slurry temperature of cow dung, plantain peels, piggery dung and chicken droppings. The blue curve represents the slurry temperature of plantain peels; the red curve represents the slurry temperature of cow dung, the purple curve represents the slurry temperature of chicken droppings while the yellow curve represents the slurry temperature of piggery dung. The variation in temperature with retention time for the wastes, showed that the average temperature of the digesting slurry for plantain peel, cow dung, piggery dung and chicken droppings varied from 31°C to 47°C. The temperature range was within the mesophilic temperature range (20°C to 45 °C) which enabled microorganisms to attend a maximum performance for biogas production [8], hence, enhancing biogas production at this range. The fluctuating pattern of slurry temperature may be attributed to the fluctuating environmental temperature and to the energy generated during the biodegradation of the compounds that are present in the wastes.

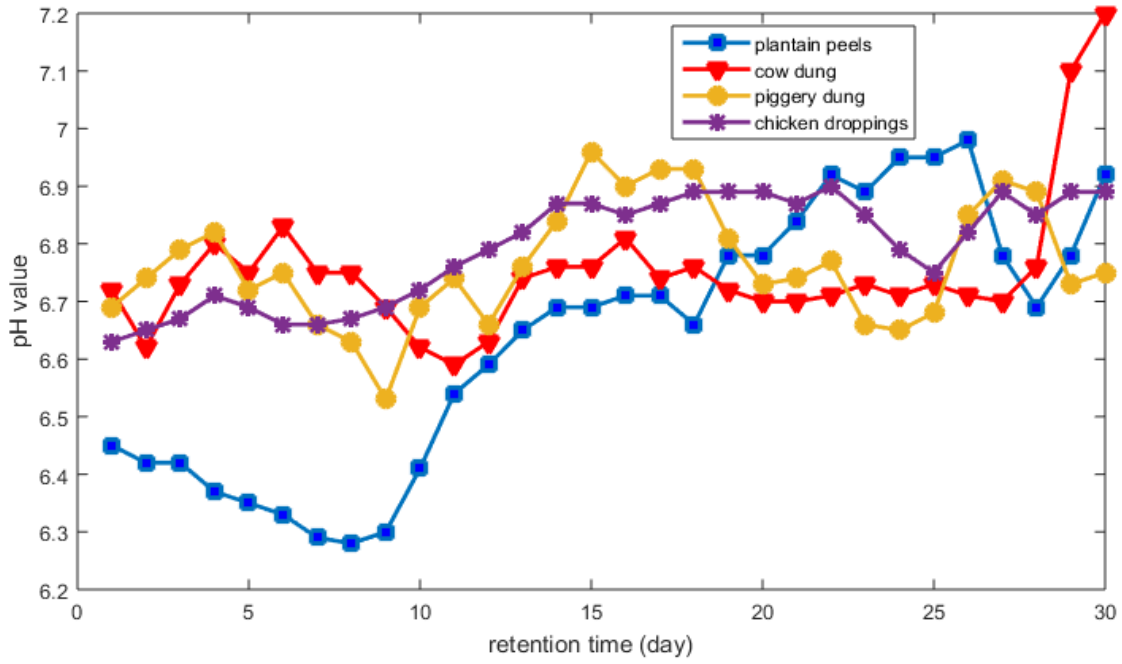


Figure 3: pH value of plantain peels, cow dung, piggery dung and chicken droppings against retention time

Figure 3 shows the pH variation pattern for the anaerobic digestion of cow dung, plantain peels, piggery dung and chicken droppings. The blue curve represents the pH of plantain peels; the red curve represents the pH value of cow dung, the purple curve represents the pH value of chicken droppings while the yellow curve represents the pH of piggery dung. The variation of the pH with retention time for the slurries was such that the pH values varied from 6.59 to 7.2 for cow dung, 6.28 to 6.95 for the plantain peels, 6.53 to 6.96 for piggery dung and 6.63 to 6.89 for chicken droppings. According to [12], pH range between 6.5 and 7.5 was required for optimum biogas production. The pH values were fluctuating within the 30 days of anaerobic digestion period The fluctuating pattern of the pH maybe attributed to the biodegradation of compounds that were present in the plantain peel, cow dung, piggery dung and chicken droppings [14]. The earlier decrease in pH value of the mixture (slurry) was probably due to the conversion of initial product to hydrolytic products such as glycerol, fatty acids, which includes acetic acids, propanoic acid and butyric acid and these acids depressed the pH values [15].

Conclusion

The experiment carried out showed that cow dung, plantain peels, chicken droppings and piggery dung can be used to produce biogas under the conditions tested. The study showed that cow dung produced the most biogas (177.5 L), followed by chicken droppings (89.2 L), plantain peels (66.8 L) and piggery dung (59.4 L) over the 30-day experiment. The differences may be related to the C/N ratio and other characteristics of the substrates, which were not determined in this study. It was also observed that plantain peels gave the highest daily volume of biogas (12.1 L) on day 3. Cow dung peaked at 10.8 L on day 8, chicken droppings peaked at 7.9 L on day 14 while piggery dung peaked at 6.2 L on day 15. Cow dung therefore gave the highest cumulative yield under the conditions tested. Replicated trials with total- and volatile-solids characterisation and methane analysis are recommended before feasibility is claimed.

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