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Comparative Analysis of Biogas Production from Agricultural Wastes

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ABSTRACT

Wastes from Agriculture have served and will continue to serve as a remarkable energy source for rural and urban inhabitants due to their accessibility and affordability. It can also provide bioenergy and biomaterial products that have contributed immensely to reducing greenhouse gas (GHG) emissions and their associated global warming. In this research, onion leaves and cow dung were poured into two 25-litre digesters in equal proportions for experimental analysis. The result revealed that cow dung has a high cumulative biogas production of 13,422 ml/week in 90 days of retention time compared to onion leaves, demonstrating the efficiency of our research. The biogas observed a high calorific value of 9.41kcal/m^3 from cow dung with 0% carbon monoxide and 10.97% methane content. Onion leaves obtained a pH value of 6.97 before anaerobic digestion at 30^{o}C, while cow dung was measured to be 6.61 at a temperature of 29^{o}C. All these parameters show that cow dung and onion leaves are suitable substrates for biogas production. However, in this regard, cow dung has outstanding potential and merit in methane production, which is explosive over onion leaves to replace kerosene and coal for domestic application.

Keywords: anaerobic digestion, bioenergy, biogas, cow dung, onion leaves

1.0 INTRODUCTION

The use of biogas as a sustainable energy resource has been on the rise due to its abundant, low-cost feedstock and versatile applications in fuel, heating, power generation, and the production of valuable chemicals (Kabeyi & Olanrewaju, 2022). The global biogas-based electricity generation capacity has increased significantly over the past decade, reaching 120 GW in 2019 from 65 GW in 2010 (Pavičić et al., 2022).

Agricultural waste plays a significant role in providing bioenergy and biomaterials, reducing greenhouse gas emissions (Kumar et al., 2023; Mengqi et al., 2021). Anaerobic digestion technology has effectively converted organic wastes into biogas for heating and electricity generation (Lenzuni et al., 2024).

In many rural areas, traditional methods of generating heat from plant materials pose risks to health and the environment (Pandiyan et al., 2022). To address this issue, the study aims to produce biogas from cow dung and onion leaves as a safer and more sustainable alternative.

Anaerobic digestion of organic wastes, including animal and plant origin, has shown promise in yielding substantial biogas (Atelge et al., 2020). Co-digestion of animal wastes with fruit and vegetable wastes in the correct ratio has demonstrated a high biogas yield (Miramontes-Martínez et al., 2023). Carbon dioxide (CO_2) generated during the anaerobic process in the digester constitutes a significant impurity in biogas composition. Aryal et al. (2020) reported a technology that not only boosted the yield of CH_4 but also offered the potential to significantly enhance biogas production. This was achieved through the in situ conversion of CO_2 into CH_4 by coupling an anaerobic digester with a microbial electrolytic cell in a single chamber.

Animals and vegetable wastes are primarily organic materials that can be smashed into simpler compounds that serve as feedstock for many industrial processes (Chavan et al., 2022). Most vegetable wastes are lignocellulosic and can be aerobically or anaerobically digested into value-added products using specialized microbes (Dutta et al., 2023). Research has shown that the rapid acidification of vegetable waste during digestion tends to operate digesters at a low organic loading rate (ORL), reducing efficiency (Nkuna et al., 2021). However, the utilization of protein-rich substrates as buffers has resulted in excellent outcomes (Qiao et al., 2023); hence, co-digesting high nitrogenous wastes with vegetable wastes increases the stability of the digester with a consequent increase in biogas production (Chow et al., 2020).

Bumharter et al. (2023) studied the primary raw

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materials used in agriculture to determine the most effective performance measure and gain insights into process optimization. An analysis of 65 separate studies involving the co-digestion of manure and lignocellulosic biomass revealed that the carbon-nitrogen ratio (C/N) is the most crucial factor in generating a high proportion of biomethane in biogas. This ratio also significantly impacts the quantity of biogas produced, as even slight deviations can lead to pH changes and the accumulation of volatile fatty acids or ammonia.

Biomass and waste are increasingly used as significant energy sources in Nigeria and worldwide. Several researchers have used different waste/biomass energy technologies in the past. However, anaerobic digestion, with its eco-friendliness and reassuring simplicity of design, is the best option. Much waste is generated from agriculture, municipalities, and industries in rural Nigeria and urban areas. This waste, currently underutilized, can be harnessed for biogas production, thanks to the straightforward process of anaerobic digestion (Odejobi *et al.*, 2024).

Gohain et al. (2023) in the study mentioned that Agricultural waste is not just a problem; it is an urgent issue causing ecological problems and expressing concerns about public health and the environment. However, nature has a powerful ally in the form of the microbial community, which can help manage this waste by producing methane and nutrient-rich fertilizers. This natural process, combined with the use of anaerobic digestion (AD), an old technology that has existed since 1859 when a digestion plant was implemented in Bombay, offers a promising solution to the agricultural waste problem.

Organic waste is a major byproduct of the agricultural sector, and addressing this issue is crucial for sustainable development. Finding an effective method for disposing of this highly biodegradable solid waste can be challenging. Anaerobic digestion offers a promising technological solution for producing renewable energy (biogas) and treating waste (Sihlangu *et al.*, 2024).

1.1 Objective of the study

Zamfara state operates large cattle and other domestic animal farms and harvests enormous amounts of onion. The vast economic benefits of waste from these farms should be utilized more, as the rate of conversion of these wastes to value-added products is relatively low. Bearing in mind the adverse impact of the unceasing utilization of fossil fuels as a significant source of energy on the environment, specific interest in developing alternative renewable fuels becomes relevant. This study proposes the conversion of cow-dungs and onion leaves in a modified continuous flow reactor to produce biogas that will serve as an alternative renewable energy source. The study postulated that converting these abundant and completely underutilized wastes into biogas will not only meet the populace's energy demand but also significantly reduce environmental pollution caused by the indiscriminate dumping of these wastes, thereby contributing to environmental sustainability.

2.0 MATERIALS AND METHOD

2.1 Materials

The basic materials used to construct biogas digesters in this research are shown in Table 1.

Table 1: List of materials to be used

S/no.	Material	Quantity
1	Jerrican	Two 25 Litre
2	Onion Leaves	15 kg
3	Cow dung	15 kg
4	PVC Pipe/Hose	1/2 inches, 2 meter
5	Water	10 Litres
6	Sandpaper	1/2 meter

2.2 Method

2.2.1 Construction of Biogas Digesters

Two 25-litres of plastic Jerrican were used for biogas digester constructions. Digesters were constructed by first making half (1/2) inch holes on the lids (cover) of the two twenty-five (25) litres of Jerrican, each using a soldering iron. Two PVC hoses, two meters and a half (1/2) inches, were cut and inserted into the Jerrican through the holes on the lids. The holes on the lids were sealed tightly using four-minute super glue, red and blue Araldite mixed with sand to prevent the entry of oxygen and loss of biogas. The pipes from the digesters were connected to the measuring cylinders in a plastic water bath (Container). The two set-ups of constructed digesters are shown in Plate 1

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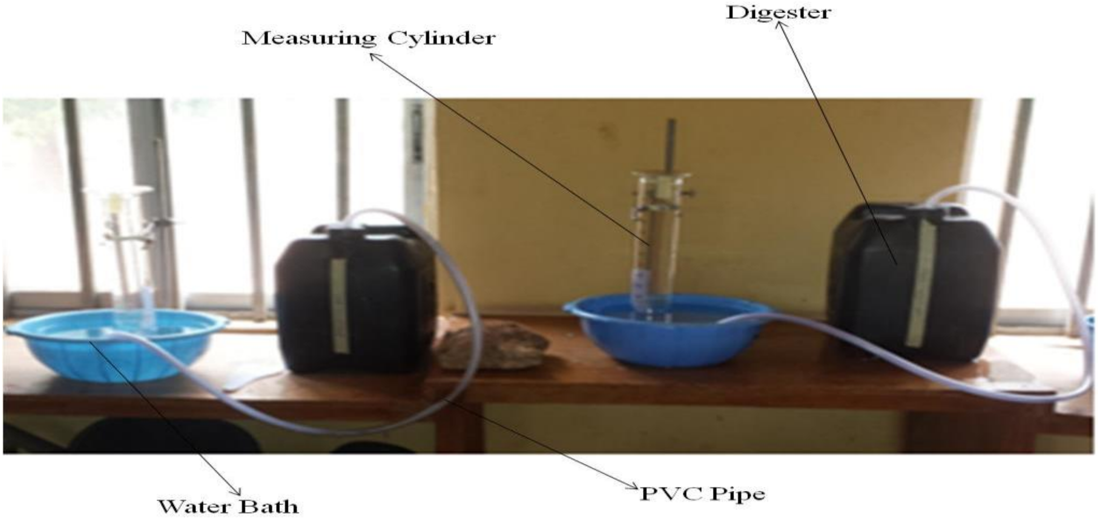

Plate 1 shows the two Constructed biogas digesters.

2.2.2 Sample Collection

15 kg of Fresh cow dung was collected from local breeds in Yankaba village, in Kaura Namoda, and was dried under sun radiation for seven days, after which it was ground using a grinding machine. 15 kg of fresh Onion leaves were also collected from the Kaura Namoda market, and the leaves were crushed into pieces using mortar and pestle, as shown in Plates 2 and 3.

Plate 2: Fresh Cow Dung

Plate 3: Dump Onion Leaves

2.2.3 Experimental Set-up: The reactor was filled with the right amount of starter material and fresh cow dung in a systematic way to ensure consistency in the experiment. We started by feeding only cow dung for the first 90 days as a reference period (control). Then we repeated the process using onion leaves separately. We made sure to maintain at least one hydraulic retention time (HRT) during each run, and adjusted the organic loading rate (OLR) once a steady gas production rate was achieved. As the produced gasses start rising, the gas flows through the PVC pipe to the inverted measuring cylinder in a water bath; as the gasses get into the inverted measuring cylinder, they gradually depress the water level, and the gas bubble occupies the Vacuum. The volume of produced biogas was recorded at the water level in a calibrated measuring cylinder in a millilitre. The daily yield of biogas production in millilitres was recorded from each digester. The pH values of the slurry were measured at the end of the experiments. However, the ambient and room temperature at 20-minute intervals were recorded.

3.0 RESULTS

3.1 Component Composition of the Cumulative Biogas Produced

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The results of the investigated component composition of the produced biogas and their respective calorific values of each sample are presented in Table 2 for (Onion leaves and Cow dung)

Table 2: Cumulative biogas production Yield

Samples	A	B
First Month Cum. biogas Yield	6482 ml	6551 ml
Second Month Cum. biogas Yield	628 ml	4780 ml
Third Month Cum. biogas Yield	Retention Time	2091 ml
Fourth Month cum. biogas Yield	Retention Time	Retention Time
Total cum. biogas Yield	7,110 ml	13,422 ml

Key: Sample A = Onion Leaves; Sample B = Cow dung

The results in Table 2 reveal that sample A had cumulative biogas production of 6482 ml in November 2023, which is in the summer season. A tremendous drop was observed in December 2023, the winter season, with 628 ml of biogas yield. Finally, retention time was observed in the third and fourth months, January 2024 and February 2024. Sample B produced 6551 ml in the first month, November 2023. It continues up to the third month with a cumulative biogas production of 2,091 ml; the production of biogas, however, stopped in the fourth month, February 2024. The results also showed that sample B (Cow dung) has an overall cumulative biogas production of 13,422 ml, followed by onion leaves with a cumulative biogas production of 7,110 ml.

3.2 Component Composition of the Percentage Biogas Produced and Calorific Values

The results of the investigated component composition of the produced biogas and their respective calorific values for each sample are presented in Table 3 for (Onion leaves and Cow dung)

Table 3: Substrate composition and calorific values

Samples	Composition					Caloric Value ($kcal/m^3$)
	CO (%)	CO_2 (%)	CH_4 (%)	H_2 (%)	O_2 (%)	
A	0.03	0.21	0.04	0.00	20.86	0.03
B	0.00	1.05	10.97	0.28	18.48	9.41

The results from Table 3 show that biogas produced from Onion leaves have a high percentage composition of carbon monoxide (CO), 0.03%. A high percentage of carbon dioxide (CO_2) in the biogas was observed at 1.05% from cow dung, which is 80% greater than onion leaves. However, the percentage composition of methane gas (CH_4) is high in Cow dung, at 10.97%. Furthermore, cow dung has a high percentage composition of 0.28% hydrogen gas (H_2) but a shallow percentage composition of oxygen gas (O_2) of 18.48% compared to onion leaves. However, the gas analysis identified in Table 3 indicated that cow dung possessed a high calorific value of 9.41 $kcal/m^3$ compared to onion leaves with 0.03 $kcal/m^3$.

3.3 pH values and Temperature readings on biogas production

Table 4 presents the pH values of biogas samples A and B for biogas produced from onion leaves and cow dung with corresponding temperatures measured before the anaerobic digestion and after the experiment.

Table 4: pH values from biogas samples

Sample	pH Before Anaerobic Digestion	Temp. Before Anaerobic Digestion
A	6.97	30
B	6.61	29

The result from Table 4 indicates that sample A obtained a pH value of 6.97 before anaerobic digestion at 30ºC. The pH value of this sample decreased to 4.22 at a temperature of 30ºC after the experiment. This indicated that sample A was Neutral before anaerobic digestion, but it became highly acidic after the experiment had taken place following pH scales. The pH values of sample B were measured to be 6.61 at a temperature of 29°C before digestion, which is slightly acidic. However, after the experiment, the pH reduced to 6.43 at 29°C, slightly acidic according to pH scales.

4.0 DISCUSSION

Furthermore, Table 2 showed that onion leaves and cow dung had obtained cumulative biogas production of 7,110 ml and 13,422 ml. However, the biogas production in onion leaves was high in the first week due to the quick action of microbes due to temperature and pH. Onion leave had a retention time of 56 days, while cow dung continued production for up to 90 days' retention time. Cow dung assumed higher biogas yield with the highest cumulative biogas production of 13,422 ml compared to onion leaves, agreeing with Rahmani et al. (2022). This implies that cow dung can serve as an essential feedstock for biogas production if digested alone, which was also reported by Alfa et al. (2021). However, the non-production of cow dung in the first week has been linked to the acidic pH of 6.61, which is slightly acidic.

Moreover, no production occurs under such a pH scale because methanogens that produce biogas are responsive to pH (Induchoodan *et al.,* 2022). Furthermore, the retention time for onion leaves and cow dung substrates was in the fifth and eighth weeks. Onion leaves had their retention time in the eighth week at a room temperature of 33^{0}C, which falls under the mesophilic temperature range. The substrate stopped production in the eighth week because its pH changed to 4.22, which showed highly acidic at this pH value. The bacteria responsible for biogas production could not act on the substrate.

Furthermore, the cow dung reached its retention time in the 13th week at room temperature of 29°C, the psychrophilic temperature (<30°C); range biogas could not be produced at this temperature. This is because the bacteria responsible for biogas production could not act at this temperature condition, which is in line with the work of Amin et al. (2021). The pH of the substrate had changed to 6.43 after the experiment, which is slightly acidic, and in this pH value, the microbe could not act on the substrate.

The result presented in Table 3 indicates that biogas from onion leaves have a low calorific value of 0.03 kcal/m^3. This was because it has 0.00% hydrogen gas and a shallow percentage composition of 0.04% methane gas, a combustible fuel. However, onion leaves had low methane gas yield in the vegetable waste class with high fibre, cellulose, and low glucose content (Ganesh *et al.*, 2022). In addition, biogas from onion leaves has a percentage composition of 0.03% of carbon monoxide, which is toxic to the environment. Poisonous gas in onion leaves contributed to the low calorific value, in agreement with Velusamy et al. (2022). The biogas produced from cow dung obtained a high calorific value of 9.41kcal/m^3. This results from the high percentage composition of 10.97% of methane gas and 0.28% of hydrogen gas, which are combustible fuels. Also, it has the advantage of 0.00% of carbon monoxide, which is toxic in the environment and follows Katsaros (2021).

5.0 CONCLUSION

The high yield and the total cumulative biogas production of 13,422 ml were observed by cow dung. However, the onion leaves and mixture have early production at a mesophilic temperature range of 30°C - 40°C. It has been found that the biogas yield depends on the pH value and the room temperature. Biogas from cow dung obtained a high calorific value of 9.41 kcal/m^3. The calorific value depends on the high percentage composition of methane (CH_4) and hydrogen gasses (H_2). Onion leaves obtained a pH value of 6.97 before anaerobic digestion at 30°C, while cow dung was measured to be 6.61 at a temperature of 29°C. All these parameters show that cow dung and onion leaves are suitable substrates for biogas production. However, in this regard, cow dung has outstanding potential and merit in methane production, which is explosive over onion leaves to replace kerosene and coal for domestic application.

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