

BIOGAS PRODUCTION FROM CO-DIGESTION OF RICE HUSK, CASSAVA PEEL, AND POTATO PEEL IN LAFIA, NASARAWA STATE, NIGERIA

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ABSTRACT

0.5 kg of agricultural waste samples (cassava peel and rice husk, CP/RH; rice husk and potatoes peel, RH/PP; and potatoes peel and cassava peel, PP/CP) were mixed in a ratio of 1:1 and co-digested in 5 L capacity of fabricated digester. The experiment was carried out for a period of 7 weeks at room temperature and evaluated for mineral content in the undigested and digested waste materials, biogas generation, and proximate compositions. The mineral compositions of the undigested and digested waste samples after Flame Photometry and Atomic Absorption Spectrophotometer (AAS) show that the digested samples contain a higher concentration. The elemental concentrations of the waste samples ranged from 0.5532 mg/g of Sodium in undigested RH to 18.2412 mg/g in the digested sample of CP. The weekly cumulative generation of biogas after 7 weeks at a room temperature range of 29 – 34 °C shows that the PP/CP has the highest yield of 18.81 mL/g VS, followed by the RH/PP 16.79 mL/g VS, and the CP/RH sample 15.40 mL/g VS, respectively. The volume of the biogas generated for CP/RH, RH/PP, and PP/CP samples decreases at week 7 from 2.76 mL/g VS to 2.49 mL/g VS, 2.92 mL/g VS to 2.76 mL/g VS, and 3.44 mL/g VS to 3.23 mL/g VS. The proximate composition of the waste shows that rice husk had the highest percentage of volatile solids (19 %), ash, and crude protein (6.91 %), potatoes peel had highest moisture content (54 %), while RH had the highest C/N ratio of 82:1.

Keywords: Biogas, Digester, Methane, Agricultural waste

INTRODUCTION

Man has search different sources of energy such as petroleum, coal, wind, electricity, water, and the sun in the forms of fuel wood over the century to meet-up with his daily requirements for basic energy. The main primary sources of energy worldwide that provide the required energy for daily needs are fossil fuels (Grando *et al.*, 2017; Sambo *et al.*, 2015).

In Nigeria, the high cost of renewable energy technology has prompted the search for an alternative source of clean energy, one of which is the production of biogas. Biogas is a renewable fuel produced through anaerobic digestion, typically composed of 50–75 % methane (CH₄) and 25–50 % carbon dioxide (CO₂). It also contains smaller amounts of water vapor (H₂O), nitrogen (N₂), and trace impurities like hydrogen sulfide (H₂S). This mixture is used for heat, electricity, or refined into biofuel. Furthermore, biogas can be used to power motor vehicles when compressed, much like natural gas (Eze & Ezeokonkwo, 2018).

Nigeria is an energy-rich country in relation to both renewable energy resources, like biomass, wind, solar, and fossil fuels such as coal, crude oil, and natural gas. Despite the abundant energy resources, the rural and poor urban households still depend on biomass to meet their daily needs for energy. Feedstock substrates identified in Nigeria for economically feasible

production of biogas include sewage, agricultural residues, processing waste, water lettuce, dung, water hyacinth, cassava leaves, and rice husk (Adamu *et al.*, 2017; Akinbami *et al.*, 2001; Olugasa *et al.*, 2014).

Some Nigerian scientists carried out important research on reactor design that might lead to optimization in the development of anaerobic digesters. For example, an economic evaluation and engineering design were carried out at the Technology Planning and Development Unit, Obafemi Awolowo University, Ile-Ife, of a family-sized digester plant (Adeoti *et al.*, 2000). The design and construction of a plastic biodigester used to generate biogas from a mixture of rice husk and spent grains were carried out by Ezekoye and Okeke (2006). Similarly, a simple biogas plant (with an additional gas storage system) that could produce 425 L of biogas per day was designed at Usman Danfodiyo University, Sokoto, which could be enough for household meals (Dangogo & Fernando, 1986). Analyses and synthesis of the key issues regarding the design of a high-performance anaerobic digester were carried out by Igoni *et al.* (2007). A good biogas production was reported after the digestion (fermentation) of the slurries was carried out in a batch operation.



Figure 1: Images of (A) Cassava peel (CP); (B) Potato peel (PP); and (C) Rice husk (RH)

Nigeria's major food crops are cassava, sweet potatoes, and rice; as a result, large quantities of waste are often produced from husks and peels. These wastes are dumped indiscriminately and decompose at the same time, which frequently releases harmful gases like ammonia and hydrogen sulfide, which are extremely dangerous to the environment. Channeling these husks and peels to produce biogas could be an effective approach to manage the waste, and the biogas produced could be used as a source of energy for people's cooking and lighting (Ismail *et al.*, 2022; Matin *et al.*, 2024; Nugraha *et al.*, 2018).

The aim of this research study is to determine the biogas generation from three different sources of agricultural waste (Rice husks, sweet potato peel, and cassava peel) for possible commercial exploitation for industrial application in both urban and rural areas using biogas digester. This study is expected to reduce agricultural wastes in the environment by harnessing rice husk, potatoes peels, and cassava peels into useful energy. Furthermore, this study determines the concentration of the mineral content (Na, K, Mg, Ca, P, and N) in the digested and undigested waste materials which might be used as bio-fertilizer to substitute chemical fertilizers.

MATERIALS METHODS

Samples Collection and Pre-treatment

Potatoes were purchased in large quantities from the tomato market in Lafia metropolis, while cassava peels were obtained in bulk from the Shabu cassava processing plant in Lafia North Development Area, Nasarawa State, Nigeria; while 3.0 kg of rice husk was obtained from a rice-producing community in Kwandare, Northern part of Lafia, and was pulverized using a mortar and pestle. The samples were separately homogenized using an electric blender and thereafter allowed to undergo an initial fermentation in a plastic container (10 L capacity) and agitated with a Corning agitator for fourteen days.

Fabrication of the Biogas Digesters (Reactors)

Three laboratory type anaerobic digesters (5 L capacity), labeled A, B and C were fabricated at the Vocational and Skill Acquisition Centre relevant technology Government Science School Lafia, Nasarawa State, Nigeria. The digesters were made of iron (20 cm in diameter and 35 cm high) with gas

holder, slurry/sample inlet, gas outlet, and beam. The slurry/sample inlet of each digester prior to sealing was flushed with nitrogen gas for 2 min to ensure anaerobic conditions. Similarly, pressure was applied to check for the potential gas leakage within the digesters before the commencement of the experiment. The temperature was monitored at ambient room temperature range of 29 – 34 °C throughout the digestion period. Temperature was measured daily using a calibrated thermometer. The gas produced was collected by the downward displacement of water. Regular inspections were performed on the digesters to ensure optimal performance and the absence of leaks.

Preparation of the Feedstock

The digesters were operated using 0.5 kg mixture of the different feed stocks in 1:1 ratio (Rice husks, sweet potatoes peels, and cassava peels). Digester A contains rice husk powder and potatoes peels powder; Digester B contains sweet potatoes powder and cassava peels powder; Digester C contained rice husk powder and cassava peels powder. These feedstock formulations were mixed thoroughly in separate containers with 2.0 L of distilled water before transferring into the digesters. The digesters were allowed to run for 49 days during which the volume of gas produced (Methane) was recorded daily. The entire experiment was repeated in duplicate for reproducibility. No external inoculum was used in this study. The anaerobic digestion process relied on the indigenous microbial population naturally present in the substrate to initiate and sustain biogas production. This approach was adopted to evaluate the inherent biodegradability and biogas potential of the substrate without external microbial enhancement.

Proximate Analysis

Moisture and ash contents were determined using the standard procedures of Helrich (1990), while organic matter content was calculated by difference.

Moisture Content (%) = $(w_2 - w_3) / (w_2 - w_1) \times 100$ ----- (1)
Where: w_1 = weight of empty crucible; w_2 = weight of empty crucible + weight of sample before heating w_3 = Final weight after drying.

Total solids were calculated as:

% Volatile solids = $\frac{\text{weight of Sample after ignition}}{\text{weight of original Sample}} \times 100$ ----- (2)

Crude nitrogen was determined in both the digested and undigested samples by the Kjeldahl method. The nitrogen content of the sample was calculated using the formula:

$$N = \frac{V_1 \times M \times 0.014 \times T}{V_2 \times g} \times 100 \text{ ----- (3)}$$

Where: T = titre value of HCl, M = concentration of HCl = 0.01M V₁ = volume of water used for dilution of digest, g = weight of sample in g V₂ = volume of the aliquot used = 20 cm³

Mineral Analysis of the Digested and Undigested Slurry

The ash obtained from ashing was analyzed for mineral composition (Ca, Mg, K, Na, Fe, Zn) using Atomic Absorption Spectrophotometry (AAS) and flame photometry, as described by Audino *et al.* (2017).

Carbon-to-Nitrogen (C/N) Ratio (Walkley Black method)

0.5 g of each dried sample was treated to 1.0 molar of K₂Cr₂O₇ solution and 20 ml of concentrated H₂SO₄ was left for 30 min. 200 ml of distilled water was added followed by titration with 0.5 molar ferrous ammonium sulfate (FAS) using 2-3 drops of diphenylamine indicator.

$$C/N \text{ Ratio} = \frac{\text{Total Carbon (\%)}}{\text{Total Nitrogen (\%)}} \text{ ----- (4)}$$

RESULTS AND DISCUSSION

Weekly and Cumulative Biogas Generation

The weekly biogas generation over 7 weeks at room temperature is shown in Table 1. The results show that the PP/CP sample has the highest yield of 3.23 mL/g VS followed by the RH/PP sample at 2.76 mL/g VS, and the CP/RH sample at 2.49 mL/g VS. The initial volumes of the gas were generally low; however, they increased as experimental weeks increased. This might be because of the increasing rate of fermentation as the week increases, thus leading to a proportional increase in volume of the biogas produced. These results correspond with the results obtained by Sambo *et al.* (2015) and Li *et al.* (2011). Furthermore, the volume of the gas produced slightly decreased in week 7. This decrease in the volume of the biogas generated could be a result of a decrease in the substrate concentrations as the reaction continued with an increase in the number of weeks.

In biogas production, the anaerobic digestion process is initiated and stabilized by the presence of inoculum. It accelerates the degradation of organic waste, significantly enhances biogas volume and methane content, and provides buffering capacity to manage acidity, ultimately leading to faster and more efficient energy production. However, the absence of inoculum in this research is likely contributed to the relatively low biogas yield observed. Without a pre-established community of active methanogenic microorganisms, the system may have experienced an extended lag phase, during which microbial populations gradually adapted to anaerobic conditions. This delay in

microbial establishment can reduce the overall rate and efficiency of biogas production. Additionally, the initial microbial load in the substrate may have been insufficient to rapidly initiate methanogenesis (Kabeyi, Olanrewaju & Akpan, 2024).

The cumulative biogas yields obtained in this study after 7 weeks were 15.40 mL/g VS(CP/RH), 16.79 mL/g VS(RH/PP), and 18.80 mL/g VS(PP/CP). These values are considerably lower than those reported in previous studies, where lignocellulosic and mixed organic wastes typically produce 200–600 mL/g VS or several liters of biogas under optimized conditions by Ismail *et al.* (2022) and Matin *et al.* (2024).

Table 1: Weekly and cumulative production of biogas from waste samples (mL/g VS)

No. of Weeks	Weekly samples production of biogas			Cumulative sample biogas production		
	CP/RH	RH/PP	PP/PC	CP/RH	RH/PP	PP/PC
1	1.16	1.33	1.14	1.16	1.33	1.14
2	1.65	1.80	1.92	2.81	3.13	3.06
3	2.20	2.43	2.65	5.00	5.56	5.71
4	2.49	2.69	3.08	7.50	8.25	8.79
5	2.66	2.85	3.35	10.16	11.10	12.14
6	2.76	2.92	3.44	12.91	14.03	15.58
7	2.49	2.76	3.23	15.40	16.79	18.81

Table 2: Proximate composition of solid waste samples (%)

Samples	Moisture	Ash	Crude Protein	Volatile Solids	C/N Ratio
CP	49	42	5.09	9	47:1
RH	18	63	6.91	19	82:1
PP	54	36	3.88	10	43.2:1

CP = Cassava Peel; RH = Rice Husk; PP = Potatoes Peel; % Crude protein = % N x 6.25

Proximate Composition of the Agricultural Waste Samples

Table 2 shows the proximate composition of the waste samples with rice husk had the highest percentage of volatile solid, ash, and crude protein, potatoes peel was highest in moisture content (54 %). The rice husk sample contains a high crude protein content of 6.91 %, this might be because of application of rice farmland with nitrogenous fertilizer. The microorganisms act on organic matter constituents to produce biogas during anaerobic digestion (Sambo *et al.*, 2015). This shows that the amount of biogas production is influenced by the relative volatile solids, moisture, and ash content in each plant. The higher the ash and moisture content the lower the organic matter content and the amount of biogas that will be produced (Mata-Alvarez *et al.*, 2014). On the other hand, high organic matter content due to low ash and moisture content will result in high yield of biogas. Combination of PP/CP produced lower volume of biogas possibly due to lower organic matter content of waste samples.

Table 2 shows result of Carbon to Nitrogen (C/N) ratio of the waste samples, with all samples having much higher Carbon to Nitrogen ratio, consequently, making it difficult for biogas digestion processes aerobically.

However, co-digestion of these waste samples, especially RH/PP, produced volume of biogas of 2.92 mL/g VS this might be because of high nitrogen content of RH due fertilizer application of the farmland. Too much nitrogen slows down digestion of substrates and can cause ammonia inhibition. Microbial digestion of organic matter required a balanced carbon to nitrogen ratio (Matin *et al.*, 2024).

Organic Fertilizer Potential of Undigested and Digested Waste Samples (mg/g)

The nutritional mineral concentrations of the undigested and digested of the waste samples after Flame Photometry and AAS are shown in Table 3. From the results, it shows that the digested waste samples contained higher concentration of elemental concentration than the undigested samples. The elemental concentrations of the waste samples ranged from 0.5532 mg/g of Sodium in undigested RH to 18.2412 mg/g in the digested sample of CP.

Table 3: Mineral composition of the waste samples (mg/g)

Samples	Undigested						Digested					
	Na	K	Ca	Mg	P	N	Na	K	Ca	Mg	P	N
RH	0.5532	0.637	1.0991	1.2453	0.6241	1.172	3.251	3.314	14.7234	13.571	3.231	1.057
PP	1.2051	1.204	1.4661	1.2536	0.2104	1.352	13.126	14.623	12.9341	14.136	2.463	1.845
CP	1.4533	0.891	1.9152	1.5886	0.5752	1.721	15.645	10.325	18.2412	17.332	1.573	1.954

RH = Rice husk; PP = Potatoes peel; CP = Cassava peel

Mineral concentrations (Na, K, Ca, Mg, P, and N) of biogas wastes are important and serve as organic fertilizer for plants growth. Nitrogen, Phosphorus, and Potassium (NPK) improved circular farming by recycling waste into valuable soil conditioner, retention of water, boosting plant resilience, and reducing chemical fertilizer reliance. It improved healthier productive crops while minimizing pollution by adding organic matter and important microbes into the soil (Mgxaji *et al.*, 2025). Comparing the undigested and digested samples is important to determine environmentally safe and sound management of the process and its byproducts, optimizing the anaerobic digestion process, and assessing the quality and value of the resulting biofertilizer (Mwakidoshi *et al.*, 2023). The concentration of these elements in biogas slurry differs depending on the substrates. Manure is formed because of the fermentation of the biogas substrate, thus producing effluent and sludge. The relationship between nutritional concentrations of elements in digested and undigested waste samples in biogas indicates that anaerobic digestion increases the concentration and availability of mineral nutrients (such as nitrogen, phosphorus, and potassium) in the digested waste compared to the initial feedstock. Even though the overall amount of nutrients remains largely unchanged because digestion mainly converts carbon into gas, the reduction of organic matter and water results in a more concentrated nutrient-rich slurry, often with higher concentrations of mineral elements like K and Ca. Most of the organic matter and nutritional elements are present in the sludge. Furthermore, increased organic matter in the digested waste sample as compared to the undigested substrate is an indicator of the conversion of organic matter into biogas efficiency (He *et al.*, 2024; Mgxaji *et al.*, 2025).

CONCLUSION

This study shows that:

- i) Biogas is generated via co-digestion of some agricultural wastes through anaerobic digestion.
- ii) Combination of potato peel and cassava peel produced the highest volume of biogas.
- iii) The slurry of the digested waste sample contains high concentrations of nutritional elements for the plants growth that can substitute chemical fertilizers.

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

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