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INVESTIGATING THE EFFECTS OF PRE-TREATMENT WITH GRANULATED PLANTAIN PEEL ON BIOGAS PRODUCTION FROM POULTRY WASTE

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ABSTRACT
The continued reliance on wood and fossil fuels has demonstrably negative environmental and economic consequences. These include significant contributions to carbon emissions and global warming, as well as economic instability driven by volatile energy markets, as evidenced by recent price surges in petroleum products in regions such as Nigeria. Thus, there is a pressing need to develop energy sources that are both protective and restorative to the environment. This study investigates the pre-treatment of poultry waste with granulated plantain peels (GPP) as a pre-treatment agent to enhance both the yield and quality of biogas. Conducted over 53 days using two laboratory-scale bio-digesters, one fed a mixture of poultry waste and GPP and a control bio-digester receiving only poultry waste, gas production was measured at five-day intervals. The pre-treated substrate yielded a cumulative 52,650.6 cm^3 of biogas, a 140 % increase over the 21,928.6 cm^3 from the untreated control. Flammability testing indicated an accelerated production onset, with biogas from the pre-treated mixture igniting from the first day and exhibiting appreciable methane content by days 3–4, whereas the control began production on day 3, with significant methane observed only by days 4–5. Furthermore, a compression test demonstrated the technical feasibility of storing the biogas, showing a minimal temperature increase of 0.19 °C per psi during pressurization.

Keywords: Biogas production, Granulated plantain peel, Pre-treatment, anaerobic, methane yield

INTRODUCTION
The escalating economic and environmental limitations associated with fossil fuel dependence, including price volatility and significant greenhouse gas emissions, have catalysed extensive scientific inquiry into sustainable and cleaner energy alternatives over recent decades (Odejobi & Odetoye, 2024; Shobajo *et al.*, 2025). Among these, the biological conversion of organic wastes such as agricultural residues, municipal solid waste, and industrial effluents via anaerobic digestion (AD) has emerged as a viable pathway for biofuel production, notably biogas (Aliyu, 2019; Godfrey, 2024). This technology offers a dual benefit: it generates a renewable energy carrier suitable for heat and power generation while providing an effective waste management solution that mitigates pollution (Egwu, 2019). Furthermore, the nutrient-rich digestate produced can be repurposed as a valuable bio-fertilizer, enhancing the process's circular economy potential (EnviroNews Nigeria, 2026; Godfrey, 2024).
Anaerobic digestion (AD) is a microbial process wherein consortiums of bacteria, including methanogenic archaea and hydrolytic species, metabolize organic substrates in an oxygen-free environment (bio-digester) (Aliyu, 2019; Egwu, 2019). The resulting biogas is primarily composed of methane (CH_4) and carbon dioxide (CO_2), with trace amounts of other gases; its precise composition and yield are heavily influenced by the physicochemical characteristics of the feedstock used (Akinfemi *et al.*, 2025; Shobajo *et al.*, 2025). Research indicates that co-digestion, the simultaneous processing of multiple organic wastes, can synergistically enhance biogas production compared to mono-digestion, often by improving the nutrient balance and buffering capacity within the digester (Egwu, 2019; Shobajo *et al.*, 2025).
Plantain (*Musa paradisiaca*), a starch-rich staple in tropical regions like Nigeria, generates substantial peel waste, constituting approximately 30-40 % of the fruit's mass (Akinfemi *et al.*, 2025; Nweke & Nwabanne, 2020). In regions with underdeveloped waste management infrastructure, the disposal of this nitrogen- and phosphorus-rich residue presents a significant environmental challenge due to its rapid microbial degradation and leachate potential (Akinfemi *et al.*, 2025). Valorising plantain peel (PP) as an AD feedstock therefore represents a strategic opportunity to concurrently address waste disposal and energy access issues (Egwu, 2019; Nweke & Nwabanne, 2020). Notably, PP exhibits a highly basic pH (≈8.5-9.5) and significant alkaline mineral content, properties which suggest its potential utility as a natural alkaline additive in AD to facilitate the breakdown of recalcitrant lignocellulosic structures in other co-substrates (Egwu, 2019; Akinfemi *et al.*, 2025).
A critical determinant of AD system performance is feedstock selection, as the process is applicable to a broad spectrum of organic materials, from simple wastewater to complex solid wastes (Odejobi & Odetoye, 2024; Godfrey, 2024). The term “feedstock” in this context encompasses any substrate convertible to methane via anaerobic metabolism, including materials

containing compounds otherwise considered toxic (Shobajo *et al.*, 2025). Consequently, diverse feedstocks including the aforementioned industrial wastewater, agricultural by-products, food waste, and sewage sludge serve as foundational resources for renewable biogas energy systems (Adeleke *et al.*, 2023).

Several researchers have explored either the co-digestion of substrates or alkaline pre-treatment of substrates prior to anaerobic digestion. For instance, Adeniran *et al*. (2018) co-digested poultry droppings with banana peels, while Aderinlewo and Layode (2018) investigated the pre-treatment of cow dung with plantain peel ash. Aderinlewo *et al*. (2021) co-digested poultry wastes with cocoa pod husk ash and cassava peel ash, and more recently, Aderinlewo *et al*. (2024) applied alkaline pretreatment to cattle dung using GPP. In a related study, Hu *et al*. (2019) co-digested chicken manure with corn straw. Despite these efforts, the application of GPP as a pretreatment agent specifically for poultry waste has not been investigated. To address this gap, the present study examines the alkaline pretreatment of poultry waste using GPP as a means of modifying the substrate prior to anaerobic digestion, with the aim of enhancing its biodegradability.

This research explored the impact of pre-treating poultry waste with granulated plantain peels on biogas yield, utilizing granulated plantain peel as a pre-treatment agent.

MATERIALS AND METHODS

Materials

The equipment and resources utilized for biogas generation included: floating drum bio-digester, granulated plantain peels (GPP), poultry waste, digital scale (capacity: 5000 g; sensitivity: 1 g), mercury-in-glass thermometer, pH meter, infrared thermometer and compression machine (powered by a 1.5 hp gasoline engine, fitted with an electronic pressure gauge).

Feedstock Preparation

Fresh poultry droppings were collected from broiler chicken farms within the Federal University of Agriculture, Abeokuta (FUNAAB) one day prior to the start of the retention period to minimize decomposition. Plantain peels were sourced from campus food vendors. These peels were sun-dried for approximately twenty-one days until brittle, then ground into granules using a hammer mill and stored in polythene bags.

The poultry waste was equally divided between two digesters. Digester A was loaded with a mixture of poultry waste and Granulated Plantain Peels (GPP), while Digester B, serving as the control, contained only poultry waste. All substrates were cleaned of impurities, mixed to a uniform consistency, and loaded into the digesters in pre-measured volumes. The mass of the poultry waste in each digester was calculated. For Digester A, GPP was added at a rate of 4 % of the poultry waste's mass (Aderinlewo & Layode, 2018), measured using a Camry digital balance (model TCS-150-ZE11) with a 50 g accuracy. The contents of the two bio-digesters were maintained at mesophilic conditions (around 37 ^{o}C) to optimise microbial activity (Mupambwa *et al.*, 2019). This methodological framework aims to provide insights into optimising biogas production from poultry waste and plantain peels, contributing to sustainable waste management practices (Hu *et al.*, 2019).

Experimental Setup

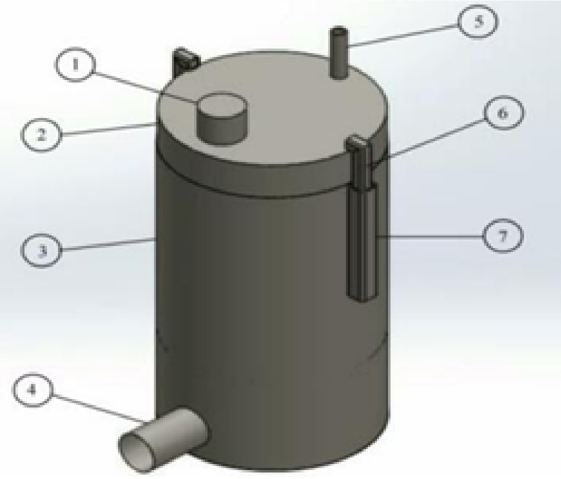
The experiment was conducted at the designated experimental site of the Department of Agricultural and Bio-Resources Engineering, College of Engineering, Federal University of Agriculture, Abeokuta. Biogas generation took place at a pre-determined location on this site, while the assembly and integration of the compression system were completed in the department's workshop. A retention period of 53 days was used. Biogas production was quantitatively assessed using gas collection systems. The study rigorously adheres to safety precautions for handling organic waste and biogas, with ethical considerations ensuring compliance with relevant waste management and research regulations.

The Description of the Bio-digester

A floating drum bio-digester was constructed with an inverted, smaller steel drum (the gas holder) placed inside a larger fixed drum (the digester tank). In this system, the produced biogas collects in the gas holder, displacing it upward above the slurry. As gas is produced or consumed, the gas holder rises or sinks respectively. Two external guide frames prevent lateral tipping during this vertical movement, allowing biogas volume to be calculated from the change in the holder's height.

Figure 1 provides an isometric view of the floating drum assembly, detailing the primary apertures: a substrate inlet at the top for feeding feedstock, a gas outlet for biogas collection, and a digestate outlet. Plate 1 illustrates the complete experimental setup of the digesters.

Plate 1: Floating drum bio-digesters experimental setup



KEY

S/N	Parts Description	Material
1	Substrate inlet	Stainless steel
2	Gas storage tank	Mild steel
3	Digester tank	Mild steel
4	Slurry outlet	Stainless steel
5	Gas outlet	Mild steel
6	Guard bars	Iron
7	Guard frame	Mild steel

Figure 1: Isometric view of floating drum bio-digester (Aderinlewo & Layode, 2018)

Bio-digester Tank Design Volume

The volumes of bio-digester tank, gas tank and substrate were determined as follows:

i. **Bio-digester tank volume:** The digester tank is a cylindrical shaped compartment and its volume is determined by the Equation (1) as used by Aderinlewo (2024).

$$V_d = \pi R_d^2 H_d \qquad (1)$$

Where: V_d is the volume of digester tank, cm^3; R_d is the radius of the digester tank, 15.6 cm; H_d is the height of the digester, 50 cm.

$$V_d = \pi \times 15.6^2 \times 50 = 38{,}227 \text{ cm}^3$$

Therefore, the volume of the bio-digester is 38,227 cm^3.

ii. **Gas tank volume:** The gas tank volume was calculated using the Equation (2) as used by Aderinlewo (2024).

$$V_{gt} = \pi r_{gt}^2 h_{gt} \qquad (2)$$

Where: V_{gt} is the volume of gas produced at a 5-day interval, cm^3; r_{gt} is the radius of the gas tank, 40 cm; h_{gt} is the height of the gas tank, 14 cm.

$$V_{gt} = \pi \times 14^2 \times 40 = 24{,}630 \text{ cm}^3$$

Therefore, the volume of the gas tank is 24,630 cm^3.

iii. **Volume of substrate:** The substrate was loaded to fill averagely two-third of the bio-digester tank and the corresponding mass of poultry droppings and that of the granulated plantain peel were determined by the Equation (3) as used by Aderinlewo (2024). The substrate was a mixture of poultry droppings and water in 1:1 by volume. Therefore, the two-third volume of the bio-digester tank was made up of both the volume of pre-treated poultry droppings with GPP and water in the same ratio.

$$V_{pw} = V_w = \frac{V_d}{3} \qquad (3)$$

Where: V_{pw} is the volume of poultry waste, cm^3; V_w is the volume of water, cm^3; V_d is the volume of bio-digester, 38,227 cm^3.

$$V_{pw} = V_w = \frac{38{,}227 \text{ cm}^3}{3} = 12{,}740 \text{ cm}^3$$

Therefore, the volume of poultry waste is 12,740 cm^3.

iv. **Mass of poultry waste:** The mass of poultry waste used in the substrate was calculated through the calculated volume of poultry waste by using the Equation (4) as used by Aderinlewo (2024).

$$M_{pw} = \rho \times V_{pw} \qquad (4)$$

Where: ρ is density of poultry waste, 1.7 g/cm^3 (Aderinlewo *et al.*, 2024); M_{pw} is the mass of poultry waste, g; V_{pw} is the volume of poultry waste; cm^3.

$$M_{pw} = 1.7 \times 12{,}740 = 21{,}658\ g$$

Therefore, the mass of poultry waste is 21,658 g.

v. **Mass of granulated plantain peel:** The mass of granulated plantain peel, M_{gpp}, used was 4% of the mass of poultry waste (Aderinlewo & Layode, 2018).

$$M_{gpp} = 0.04 \times 21{,}658 = 866\ g$$

Therefore, mass of granulated plantain peel is 866 g. The substrate loaded in the bio-digester was retained for 53 days.

Performance Evaluation of the Bio-digester

i. **Data collection for biogas production:** The data collected were the pH of the substrates before and after loading, the daily temperature at the retention site and the height of the rising gas tank. The pH of the substrate was measured with the pH meter before loading and after retention. The daily temperature at the site was measured using mercury in glass thermometer. The change in the height of gas tank was measured with the meter tape at a 5 days interval.

ii. **Volume of gas produced:** The volume of gas produced at any interval of 5 days was computed from the change in the height of the gas tank using the Equation (5) as used by Aderinlewo (2024).

$$V_g = \pi r_{gt}^{\ 2} \Delta h_{gt} \qquad (5)$$

Where: V_g is volume of gas produced at a 5 days interval, cm^3; r is radius of the gas tank, cm; Δh is change in the height of gas tank, cm.

iii. **Gas compression:** The compression system is made up components to fill the biogas into a cylinder and to also measure the changes in temperature, mass and pressure as the cylinder is being filled. After correct fitting of all components, the mass of the cylinder without and with the filling-head was measure and recorded. The petrol engine was started for the filling. After the filling the gas, control valve to the pressure gauge was closed. The following parameters were taken before, during and after filling the gas which were mass, temperature and pressure. The cylinder was left on the scale during filling and mass readings were recorded at intervals of 30 seconds. An infrared thermometer was used to measure the temperature of the cylinder as it was being filled at the same intervals of 30 seconds and the readings of the pressure gauge were also noted at the same interval.

iv. **Flammability test:** To assess the qualitative indication of combustible gas of the biogas produced, a flammability test was conducted. The biogas, collected from the digesters in tire tubes, was connected via a hose and valve to a modified camping burner fitted with a filling head. All connections were sealed to prevent air from entering and diluting the gas sample. The biogas was then released toward the flame of a lighter. Observations were made to determine whether the gas ignited and sustained a flame or extinguished the lighter's flame. When combustion occurred, the resulting flame color was also recorded, as it provides an indication of the combustible gas concentration in the biogas.

Data Analysis

Data obtained for the volume of gas obtained from bio-digester A (mixture of poultry waste and granulated plantain peels) and bio-digester B (poultry waste only) were analysed using descriptive statistics.

Results and Discussion

Measurement of Gas Production

For bio-digester A, which contained a mixture of poultry waste and granulated plantain peels, biogas production commenced on the first day of the retention period; the initial 5-day interval yielded a gas volume of 20,446.90 cm³. Production declined sharply in the second 5-day interval to 7,521.5 cm³, representing a 63.2 % decrease. A slight recovery followed in the third interval, with an output of 8,032.7 cm³, which was 6.8 % higher than the preceding interval (Table 1).

Beginning on day 18, a sustained reduction in production was observed. The fourth 5-day interval produced 4,673.6 cm³, a 41.8 % drop from the third interval. This downward trend continued through the subsequent intervals, with volumes of 4,454.5, 3,067.0, 1,898.6, 1,606.5, and 949.3 cm³ for the fifth through ninth intervals, respectively. The corresponding percentage decreases from one interval to the next were 4.7, 31.1, 38.1, 15.4, and 40.9 %. Significant gas production ceased between days 48 and 53. The cumulative biogas volume generated by bio-digester A over the entire retention period was 52,650.6 cm³ (Table 1).

Table 1: Biogas measurement in bio-digester A-poultry waste with GPP

Days	Gas tank Height (cm)	Change in tank height (cm)	Volume of gas produced (cm^3)
1 - 5	28.0	28.0	20,446.9
6 - 11	38.3	10.3	7,521.5
12 - 17	49.3	11.0	8,032.7
18 - 23	55.7	6.4	4,673.6
24 - 29	61.8	6.1	4,454.5
30 - 35	66.0	4.2	3,067.0
36 - 41	68.6	2.6	1,898.6
42 - 47	70.8	2.2	1,606.5
48 - 53	72.1	1.3	949.3
	Cumulative biogas volume		**52,650.6**

Table 2: Biogas measurement in biodigester B-poultry waste alone

Days	Gas tank Height (cm)	Change in tank height (cm)	Volume of gas produced (cm^3)
1 - 5	4.3	4.3	2937.3
6 - 11	11.1	6.8	4645.4
12 - 17	18.6	7.5	5123.6
18 - 23	24.2	5.6	3825.6
24 - 29	27.9	3.7	2527.6
30 - 35	29.5	1.6	1093.0
36 - 41	31.1	1.6	1093.0
42 - 47	32.1	1.0	683.1
48 - 53	–	–	–
	Cumulative biogas volume		**21,928.6**

For bio-digester B (the control unit), biogas production began on the third day of the retention period (Table 2). The initial 5-day interval yielded 2,937.5 cm³. Production rose in the second interval, increasing by 58.1 % to 4,645.4 cm³, and further increased by 10.3 % in the third interval to 5,123.6 cm³. A decline commenced from day 18 to day 23, with the fourth interval showing a 25.3 % reduction to 3,825.6 cm³. This downward trend persisted over the next twenty days. The fifth, sixth, seventh, and eighth 5-day intervals produced 2,527.6, 1,093.0, 1,093.0, and 683.1 cm³, respectively. These volumes represent successive reductions of 33.9, 56.8, 0, and 37.5 % compared to the preceding interval. Significant gas production concluded between days 42 and 47. The cumulative biogas volume generated by bio-digester B throughout the retention period was 21,928.6 cm³ (Table 2).

The data trends presented in Tables 1 and 2 are fully detailed in Fig. 2. Of the two digesters, Digester A demonstrated superior biogas production in both total and average output. It generated an average of 993.41 cm³ daily over 53 days, culminating in a total yield of 52,650.6 cm³. In contrast, Digester B produced an average of 413.75 cm³ per day, resulting in a total of 21,928.6 cm³ for the same period. This represents a substantial difference of 30,721.8 cm³, or a 140 % increase in total biogas yield attributable to the inclusion of granulated plantain peel in Digester A. Notably, the bulk of Digester A's production occurred within its initial 5-day interval, which yielded 20,446.9 cm^3 and accounted for 38.8 % of its total output.

A key observation is the significant rise in biogas yield from Digester A, which contained poultry waste mixed with granulated plantain peel (GPP), compared to Digester B containing only poultry waste. This finding aligns with previous researches by Aderinlewo *et al.* (2024, 2021), Aderinlewo and Layode (2018), which established that pre-treating animal waste with alkaline materials enhances waste digestion and increases biogas production. Consequently, the pre-treatment of poultry waste with GPP demonstrates a positive effect on anaerobic digestion, thereby confirming the earlier statements by these researchers. This outcome is attributable to the alkaline properties of granulated plantain peel.

Comparatively, studies such as those by Muscolo *et al.* (2017) and Hu *et al.* (2019) have also reported increased biogas yields by utilising diverse substrates, underlining the critical role of substrate composition in optimising biogas production.

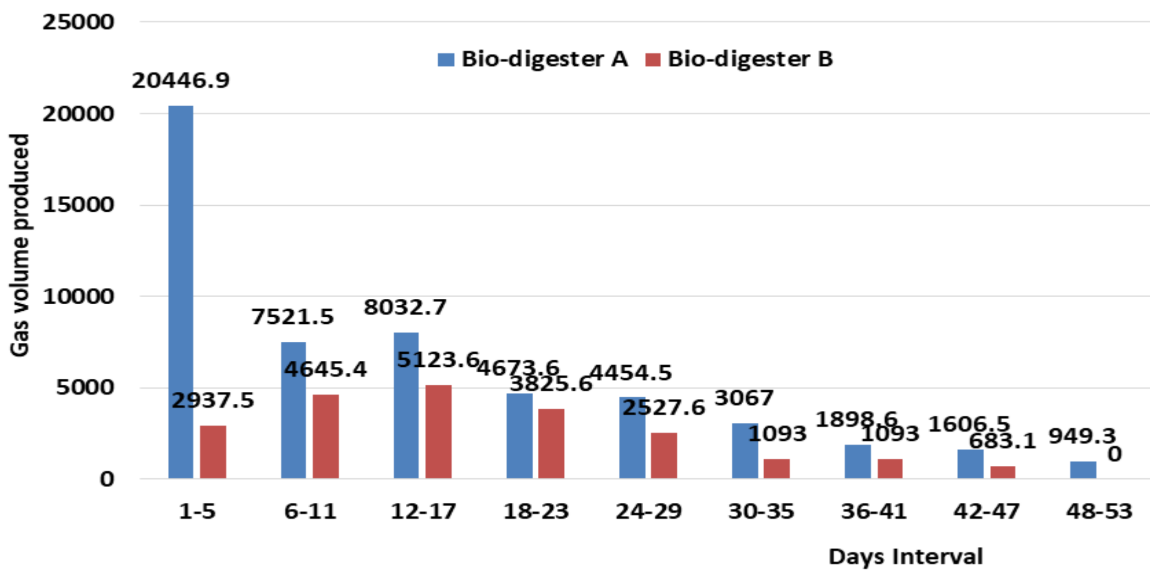


Figure 2: Comparison of biogas produced from bio-digester A and bio-digester B

Measurement of Ambient Temperature

Ambient temperature was recorded with a mercury-in-glass thermometer, yielding a range of 28 to 40 °C and an average of 35.2 °C (Fig. 3). This average falls within the mesophilic temperature range defined by Schiraldi and Rosa (2014) as 20–45 °C, with an optimum between 30–39 °C.

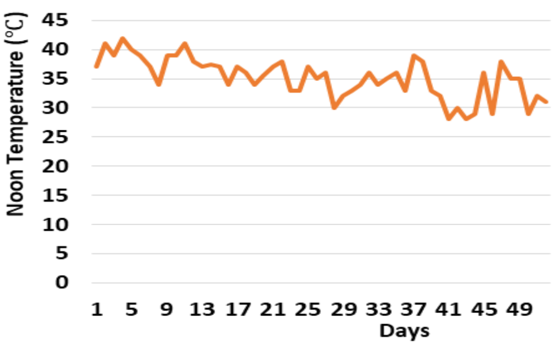


Figure 3: Daily ambient temperature

pH Measurement

The pH values of the bio-digester contents, measured before and after the retention period, are presented in Table 3. The substrate in bio-digester A (poultry waste with GPP) shifted from an initial pH of 6.5 to a final pH of 8.1. Conversely, the substrate in Digester B (poultry waste only) changed from pH 6.3 to pH 7.5. Both bio-digesters functioned within the optimal pH range for biogas generation, with a clear increase toward more basic conditions observed post-digestion. This alkalinization was more substantial in digester A, attributable to the inclusion of alkaline granulated plantain peels. This result aligns with findings by Aderinlewo *et al*. (2024, 2021) on using alkaline materials for animal waste pre-treatment.

Table 3: pH of the substrates

Bio-digester	pH before retention	pH after retention
A- Poultry waste with GPP	6.5	8.1
B- Poultry waste alone	6.3	7.5

Table 4: Measurement of mass, temperature and pressure during compression

S/N	Mass (g)	Accumulated Biogas Mass (g)	Temperature (℃)	Pressure (Psi)
1	3280	-	33.4	0.00
2	3346	66	33.8	12.7
3	3416	136	34.3	22.1
4	3494	214	34.6	33.5

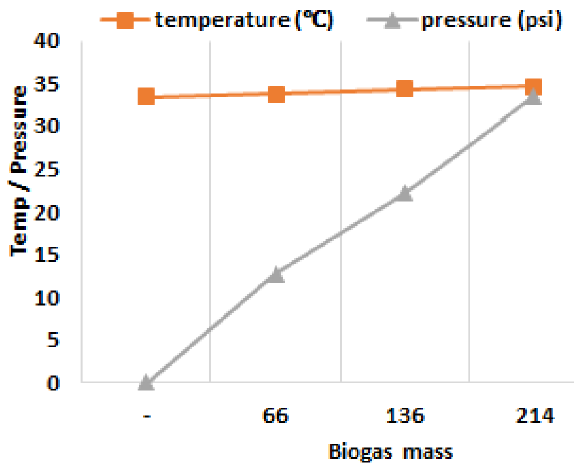


Figure 4: Response of parameters to biogas compression

Gas Compression Measurement

Before compression began, the initial mass of the cylinder and filling head on the scale was 3,280 g, with an ambient temperature of 33.4°C and a pressure reading of 0 psi. The filling process lasted approximately 120 seconds, with parameters recorded at roughly 30-second intervals. At the second measurement, the cylinder mass was 3,346 g, representing a biogas mass of 66 g, at a temperature of 33.8 °C and a pressure of 12.7 psi. By the third measurement, the biogas mass had increased to 136 g, accompanied by a temperature of 34.3 °C and a pressure of 22.1 psi. For the fourth and final measurement, the cylinder mass reached 3,494 g, corresponding to a biogas mass of 214 g. The temperature had risen to 34.6 °C, and the pressure attained was 33.5 psi (Table 4). The responses of both temperature and pressure are shown in the Figure 4 during gas compression.

The successful compression of biogas into storage cylinders confirms its viability for transport and storage, a pivotal advancement for commercial scalability. This development decouples biogas use from its production site, significantly expanding its practical utility. By facilitating distribution and on-demand use, the research directly supports the integration of biogas into broader renewable energy and sustainable waste management systems, a goal underscored by its documented environmental and economic merits (Couch *et al*., 2019).

Flammability Test

The observations and inference made on the flammability tests carried out on the gas generated during the early days of retention and after retention are shown in Table (5). The gas generated in bio-digester A was collected and a flammability test was carried out on days 1, 2, 3, 4 and 53, while the gas generated in bio-digester B was collected for a flammability test on days 3, 4, 5 and 53. In bio-digester A, the gas produced on day 1 and day 2, quenched the flames they were exposed to. The gas of day 3 attracted the flame with a faint flickering blue flame. On day 4, the faint blue flame was steady. The gas at day 5 had blue outer layer. In bio-digester B, gas produced at Day 3 extinguished the flame it was exposed to, while that of days 4 and 5 burnt with a faint blue and blue flame, respectively.

Pre-treatment also speeds up output since gas production began on Day 1 after retention in the bio-digester with the treated substrate as opposed to Day 3 in the bio-digester using only poultry waste. From the flammability test, gas production in digester A started from Day 1 after retention with the gas of Days 1 and 2 extinguishing flames exposed to it. This can be said to be that the gas has very little or no combustible gas and is made mainly of CO_2. In Digester B, production did not start until Day 3, and the flammability test showed that there was qualitative indication of combustible gas produced on Day 4.

At day 53, the gas from both bio-digesters A and B burnt with an obvious bluish yellow flame when exposed to a naked flame.

Table 5: Flammability test results

Days	Bio-digester A (gas)	Flame Colour	Inference (Combustible gas)	Digester B (gas)	Flame Colour	Inference (Combustible gas)
1	Yes	–	No	No	–	–
2	Yes	–	No	No	–	–
3	Yes	Flickering faint blue	Low	Yes	–	No
4	Yes	Flickering faint blue	Low	Yes	Flickering faint blue	Low
5	Yes	Blue	Appreciable	Yes	Blue	Appreciable
53	Yes	Bluish yellow	High	Yes	Bluish yellow	High

The flammability of the biogas from both bio-digesters verifies combustible gas production. Notably, the more vigorous flame from the GPP amended bio-digester points to a greater combustible gas yield, a key quality for its use in power, heat, and fuel. This enhancement likely stems from the improved carbon-to-nitrogen balance created by adding GPP to the poultry waste, which favours combustible gas producing microbes. These results are consistent with the earlier work of Adeniran *et al*. (2018), Aderinlewo and Layode (2018), Aderinlewo *et al*. (2021), Aderinlewo *et al*. (2024).

CONCLUSION

The experimental data reveal a substantial enhancement in biogas yield from poultry waste when pre-treated with granulated plantain peels (GPP). The cumulative production from GPP-treated waste reached 52,650.6 cm³, representing a 140 % increase over the 21,928.6

cm³ generated by the untreated control. This marked improvement confirms the efficacy of GPP as a pre-treatment agent and underscores its potential for significantly optimizing substrate conversion in biogas production systems.

Recommendations

Further studies should focus on optimizing the ratio of poultry waste to granulated plantain peels (GPP) to enhance biogas yield, assessing the scalability of the pre-treatment process, and evaluating the economic feasibility of large-scale biogas production and compression. Additionally, long-term monitoring of bio-digester efficiency and an analysis of digestate quality as a biofertilizer would offer deeper insights into the sustainability and practical applications of this biogas generation approach.

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

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