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# EXPLORING THE BIOGAS GENERATION POTENTIAL OF AGRICULTURAL RESIDUES IN NIGERIA

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***Abstract:*** **This study explores the utilization of agricultural residues, specifically lettuce, pineapple, and tomato wastes, for biogas production through anaerobic digestion. Employing smaller digesters (1L for tomato and lettuce, 2L for pineapple), the biogas generation setup spans five weeks. Results show varying biogas yields: lettuce at 0.029 $m^3$/Kg, pineapple peel at 0.037 $m^3$/Kg, and tomato at 0.027 $m^3$/Kg. Discrepancies in yield are attributed to differences in chemical compositions, microbial content, and operational parameters. This research contributes valuable insights into biogas and green chemistry, benefiting students and researchers interested in environmental sustainability. The findings support the efficient recycling of agricultural residues, showcasing biogas as an ancient yet effective method for global renewable resource recycling and greenhouse gas removal.**

***Keywords:*** **Biogas, biomass, agricultural residue, anaerobic digestion, biogas yield.**

## 1. INTRODUCTION

The utilization of waste for biogas generation stands as an effective and sustainable avenue for renewable energy production. Various waste materials, encompassing food waste, agricultural residues, animal manure, sewage sludge, and lignocellulosic biomass, have been explored for biogas production through anaerobic digestion [1]–[4]. This study focuses on the potential of lettuce waste, similar to other organic materials, to contribute to biogas generation through anaerobic digestion. Lettuce waste, comprising leaves, stems, and trimmings, contains organic compounds like cellulose, hemicellulose, and sugars that can be converted into biogas during anaerobic digestion [5]. While specific studies on lettuce waste are limited, insights from analogous agricultural waste and co-digestion scenarios suggest its promising potential [6]. Similarly, pineapple waste, predominantly consisting of peels, cores, and other residual parts, is examined for its viability in biogas production. The anaerobic digestion process breaks down the organic matter in pineapple waste, rich in carbohydrates like cellulose and hemicellulose, producing valuable biogas byproducts [7]. Studies on the biogas potential of pineapple waste further support its consideration. Additionally, this research explores the biogas potential of tomato waste, emphasizing the anaerobic digestion process and the composition of tomato waste rich in carbohydrates. The produced biogas, primarily methane and carbon dioxide, holds significance as a renewable fuel [5], [8], [9]. Beyond energy applications, biogas research extends to environmental sanitation and greenhouse gas removal. This study aims to exploit lettuce, pineapple peel, and tomato biomasses for biogas production through anaerobic digestion, utilizing batch reactors for a straightforward evaluation and analysis. The purpose of this study therefore, is to exploit lettuce, pineapple peel and tomato biomasses for biogas production through anaerobic digestion. The study utilizes a batch reactor for each type of residue used for easy evaluation and analysis. The types of agricultural residues utilized in the present study are presented in **Figure 1**.

| LETTUCE | PINEAPLLE PEEL | TOMATO |
|---|---|---|
|  |  |  |

**Figure 1: Pictures of the Agricultural Residues Utilized in the Digestion Process.**

## 2. MATERIALS AND METHODS

### 2.1 Method of Biogas Production

This study employs wet anaerobic digestion for biogas generation. The biodigester capacities vary, with 1 L for Tomato and Lettuce residues and 2 L for Pineapple residue. For Tomato residue, 350 g is crushed and mixed with 450 ml tap water (1:1) to create a tomato slurry. After sealing the biodigester with a glue gun and allowing it to dry, a gas passage hole is made in the center of the cover for biogas analysis. Likewise, 250 g of Lettuce residue is crushed, combined with 850 ml tap water (1:3), and prepared similarly. Pineapple residue (500 g) is crushed, mixed with 1.5 L tap water (1:3), and processed using the same method. Both Lettuce and Pineapple residues are prepared as per the Tomato residue procedure. The setups undergo a 5-week anaerobic incubation period for biogas generation. The biodigester setup details are illustrated in **Figure 2**.

To assess the generated biogas volume, a pressure gauge was affixed to the digester, employing the ideal gas equation within a pressure range of 10,000 – 100,000 Pa. The volume of gas produced for each pressure reading was estimated using the ideal gas equation as sown below.

**PV = nRT**

*Where* $T=30°C\ (30 + 273)\ K$, $n = 1$ *mole*, $R = 8.314\ J/mol^{-1}\ K^{-1}$, $V = nRT/P$.

Daily pressure measurements were recorded throughout the entire hydraulic retention period designated for the study.

**Figure 2: A Set-up for the Bio-digestion**

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## 3. RESULTS AND DISCUSSION

### 3.1 Results

#### 3.1.1. Chemical Composition of Biomass

The chemical composition of various biomasses exhibits variations influenced by factors like variety, maturity stage, and growing conditions. The following approximate ranges of major components in lettuce, pineapple, and tomatoes, derived from literature sources, are presented in the table below [5], [10], [11].

**Table 1: Comparison of Chemical Composition of Different Biomass**

| Lettuce | | Pineapple peel | | Tomato | | Cow dung | |
|---|---|---|---|---|---|---|---|
| **Component** | **Percent (%)** | **Component** | **Percent (%)** | **Component** | **Percent (%)** | **Component** | **Percent (%)** |
| Moisture Content | 90-95% | Moisture Content | 80-90% | Moisture Content | 90-95% | Moisture Content | 75-85% |
| Carbohydrates | 2-3% | Carbohydrates | 7-12% | Carbohydrates | 3-4% | Organic Matter | 45-55% |
| Proteins | 1-1.5% | Proteins | 0.5-1% | Proteins | 0.9-1.2% | Total Solids | 15-25% |
| Fats | 0.2-0.3% | Fats | 0.1-0.5% | Fats | 0.1-0.2% | Volatile Solids | 65-75% |
| Fiber | 1-2% | Fiber | 10-15% | Fiber | 1-2% | Fixed Carbon | 15-25% |
| Ash | 0.8-1% | Ash | 2-4% | Ash | 0.5-0.8% | Nitrogen | 0.5-1.5% |
| Vitamin C | 2-10 mg/100 g | Vitamin C | 10-30 mg/100 g | Vitamin C | 15-30 mg/100 g | Carbon | 25-35% |
| Vitamin A | 700-1000 µg/100 g | Vitamin A | 10-50 µg/100 g | Vitamin A | 100-300 µg/100 g | Phosphorus (as $P_2O_5$) | 0.2-0.5% |
| Potassium | 150-250 mg/100 g | Potassium | 150-300 mg/100 g | Potassium | 200-400 mg/100 g | Potassium (as $K_2O$) | 0.5-1.5% |
| Calcium | 20-40 mg/100 g | Calcium | 10-30 mg/100 g | Lycopene | 1-10 mg/100 g | Calcium (as CaO) | 0.5-1.5% |

#### 3.1.2. Biogas Yield

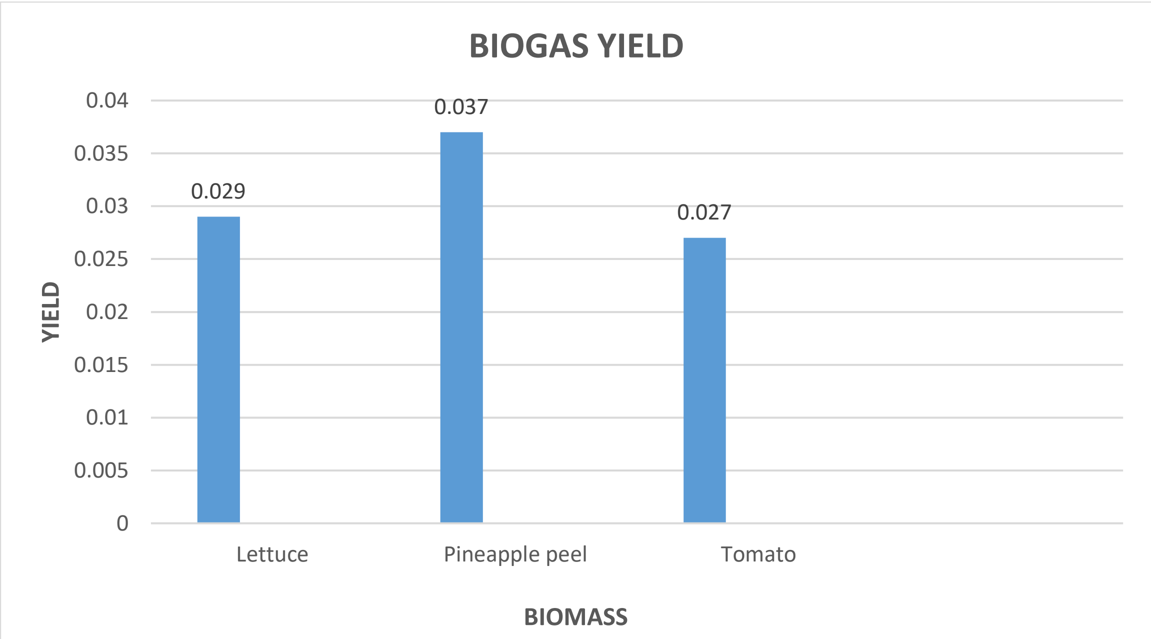


**Figure 3: Biogas Yield for the Lettuce, Pineapple Peel and Tomato Residues**

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### 3.2. Discussion

The presented table offers an overview of the chemical compositions of four distinct biomasses (lettuce, pineapple peel, tomato, and cow dung), providing insights into operational parameters and processes involved in biogas generation. **Figure 3** supplements this information by illustrating the biogas yields for each biomass. The biogas generation capacity of lettuce waste, detailed in the table, can vary based on factors like waste composition, process conditions, and anaerobic digestion system specifics. Limited specific research on lettuce waste biogas generation in terms of cubic meters per kilogram ($m^3/kg$) is available. A recent study reported a range of 0.06-0.12 $m^3/kg$, while our study produced a slightly lower value of 0.029 $m^3/kg$, potentially influenced by reaction conditions and lettuce material characteristics [5].

Similarly, pineapple peel's biogas generation capacity, outlined in the table, depends on various factors. Limited specific research on pineapple peel is available, and our study yielded approximately 0.037 $m^3/kg$, slightly below reported values [12]. This discrepancy may be attributed to the higher carbohydrate and fiber contents in pineapple peel. Tomato waste's biogas generation, described in the table, is influenced by waste composition, process conditions, and anaerobic digestion system specifics. Recent studies reported ranges of 0.05-0.15 $m^3/kg$ and 0.03-0.35 $m^3/kg$ [9], [12]. Our study revealed a value of 0.027 $m^3/kg$, slightly below the reported range, potentially due to low fat, fiber, and ash content in tomatoes.

Comparing the chemical composition of cow dung with the substrates used, cow dung exhibits higher chemical nutrients. This abundance contributes to cow dung's higher biogas yield compared to most biomasses [4], [8]. The order of biogas yield from lettuce, pineapple peel, and tomato wastes is 0.029, 0.068, and 0.027 $m^3/kg$, respectively (**Figure 3**). The decreasing order of biogas yield in the studied biomasses appears to be lettuce > tomato > pineapple $m^3/kg$ due to both lettuce and tomato wastes utilizing 1 L digesters. Biogas generation involves hydrolysis, acidogenesis, acetogenesis, and methanogenesis stages. Hydrolysis breaks down complex organic compounds, followed by acidogenesis converting monomers into volatile fatty acids. Acetogenesis transforms VFAs into acetic acid, and methanogenesis produces methane using acetic acid, hydrogen, and intermediate compounds. The main gases involved in biogas generation are methane ($CH_4$), carbon dioxide ($CO_2$), hydrogen sulfide ($H_2S$), and trace gases [1], [6], [10], [13]. The presence of trace gases depends on feedstock and process conditions. Hence, this study is poised to serve as a comprehensive guide for researchers, students, and government entities, offering insights into the efficient utilization of agricultural residues for biogas generation. By advocating for a shift from conventional practices involving expenditure on transportation, logistics, and the subsequent incineration of waste, the study aims to potentially alleviate the financial burden on the country's budget related to environmental management and pollution control.

### 3.3 Anaerobic Digestion Process

Anaerobic digestion is a natural biological process that decomposes organic matter in the absence of oxygen, yielding biogas primarily composed of methane ($CH_4$) and carbon dioxide ($CO_2$). Widely employed for treating organic waste like sewage sludge, agricultural residues, food waste, and animal manure, anaerobic digestion simultaneously taps into the energy potential of the generated biogas. This process involves crucial parameters, encompassing substrate preparation, digester loading, microbial activity, gas production, retention time, digestate handling, biogas utilization, and monitoring/control [14]. Organic waste, referred to as substrates or feedstock, undergoes preparation involving shredding, chopping, or grinding to enhance surface area for microbial accessibility. Loaded into anaerobic digesters—available in batch, continuous, plug flow, and complete-mix systems—the substrate encounters diverse anaerobic microorganisms, including bacteria, archaea, and methanogens. Acidogenic bacteria initiate breakdown, yielding organic acids and volatile fatty acids (VFAs). Acetogenic bacteria transform VFAs into acetic acid, hydrogen ($H_2$), and carbon dioxide ($CO_2$), while methanogens convert these products into methane ($CH_4$) and $CO_2$. Methane, the primary biogas component, holds the energy value. Biogas composition typically comprises 50-75% methane, along with carbon dioxide, trace gases like hydrogen sulfide ($H_2S$), and water vapor. Retention time, varying with digester type and waste treated, influences digestion completeness and gas yields. Post-digestion, nutrient-rich digestate, separated from biogas, serves as organic fertilizer or soil conditioner. Biogas finds diverse applications: electricity and heat generation via combined heat and power (CHP) or gas engines, cooking fuel, injection into natural gas pipelines, vehicle fuel (biomethane), and renewable energy for industrial processes [15]. To maintain stable anaerobic digestion efficiency, continuous monitoring and control of parameters like temperature, pH, and organic loading rates are imperative [3], [5], [11], [15]–[17].

## 4. CONCLUSION

This research has successfully explored the biogas generation potential of diverse agricultural residues, including lettuce, pineapple peel and tomato, employing the anaerobic digestion process. The wastes demonstrated appreciable biogas yields, underlining their viability for sustainable energy production. The high mineral compositions present in all biomasses further support their suitability for anaerobic digestion. Notably, the study utilized a low biomass loading, which, although yielding promising results, indicates the potential for enhanced biogas production through the use of larger digesters. The order of decreasing biogas yield among the biomasses was found to be lettuce > pineapple peel > tomato, highlighting the varying capabilities of these feedstocks in biogas generation. Comparative analysis with cow dung, which exhibited higher chemical nutrients, emphasizes the need to consider substrate characteristics in optimizing biogas yields. The anaerobic digestion process, a vital component of this study, involves complex biochemical stages mediated by diverse microorganisms. These stages include hydrolysis, acidogenesis, acetogenesis, and methanogenesis, ultimately leading to the production of methane-rich biogas. The composition of biogas aligns with established ranges, primarily comprising methane and carbon dioxide, alongside trace gases like hydrogen sulfide. The generated biogas holds potential for versatile applications, from electricity and heat generation to cooking fuel and biomethane for vehicles, contributing to sustainable energy solutions. The study underscores the importance of continuous monitoring and control of critical parameters for maintaining stable and efficient anaerobic digestion processes. In future endeavors, employing larger digesters and further optimizing operational parameters will likely enhance biogas yields, advancing the practicality and efficiency of utilizing these biomasses for renewable energy production. Overall, this research contributes valuable insights to the field of anaerobic digestion and offers a foundation for continued exploration and refinement of biogas generation from diverse organic waste sources.

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