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(Research Article)

Effects of slurry concentration and co-digestion on biogas yields from unseeded *Phaseolus vulgaris* (bean) peels chaff and unseeded *Musa paradisiaca* (plantain) peels chaff

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Abstract

This study explored converting agricultural wastes of Bean peel chaff (Bu) and Plantain peel chaff (Pu) into biogas, an eco-friendly biofuel, without cow rumen liquor. By digesting these wastes anaerobically in various combinations and slurry concentrations, the study assessed their individual and combined biogas yields. Bean and plantain peels were digested alone and in two mixtures: BP1u (bean-to-plantain ratio 0.691:1) and BP2u (1:1 ratio). Three waste-to-water slurry concentrations (1:6, 1:11, and 1:16) were used, with anaerobic digestion lasting 37 days in triplicate 1000ml mini digesters. Biogas production was measured via water displacement. The study found total solids percentages of 96.03% for Bu, 90.12% for Pu, 84.15% for BP1u, and 84.94% for BP2u. The carbon/nitrogen (C/N) ratios ranged from 9.04 to 15.3. Average biogas yields showed BP1u produced the highest (11.12 ml/day), followed by Bu (9.8 ml/day), BP2u (7.5 ml/day), and Pu (0.55 ml/day). Among slurry concentrations, 1:6 (C1) yielded the most biogas (17.45 ml/day), followed by 1:11 (C2) and 1:16 (C3). ANOVA indicated significant effects from both slurry concentration and co-digestion on biogas yield, along with a notable interaction between both factors. In conclusion, both bean and plantain peels can generate biogas effectively, especially when combined and digested in higher slurry concentrations for improved yield. This approach supports waste management and renewable energy goals by transforming agricultural residues into valuable biofuel.

Keywords: Bean peels; Plantain peels; Slurry concentration; Co-digestion; Biogas

1. Introduction

The world, as dynamic as it is, is in continuous need of energy to keep it going. However, in the search for this energy, conventional sources of energy such as fossil fuels, coal, oil and gas are not only getting depleted but also currently constitute an environmental concern with their negative impact on global warming. According to the UN (1), these fuels are the largest contributors to global warming, accounting for at least 75% of all greenhouse gas emissions and 90% of carbon dioxide emissions. Therefore, the emphasis has shifted to renewable energy sources. These are natural sources of energy that are comparatively more abundant, non-harmful, and are continuously replenished by nature. They include the Sun, wind, water, waste, tides, waves, and heat from the Earth (1–3). Among these, energy from wastes have been studied widely. Several wastes have been successfully converted into biodiesel and biogas, and several waste-to-wealth technologies are already in place today (4,5). The anaerobic digestion of wastes has received a special attention because, not only that biogas is produced, the digestate can be used to improve soil fertility (6).

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Greater attention has been given to animal manure and sewage sludge digested singly or in combinations (co-digestion) in the quest for sources of biogas production (4). This underscores the need to direct attention to agricultural wastes, food waste, and kitchen wastes. The latter wastes are more abundant in especially in urban areas where they constitute an environment hazard if not efficiently managed. Among these agro-wastes are food/fruit peels.

Phaseolus vulgaris, commonly known as beans, is a staple food in tropical regions. This legume thrives in fertile soils and serves as an essential protein source (7). Beans are typically consumed on their own or combined with other foods. In Southeast Nigeria, two popular bean dishes are fried bean cakes, called "akara," and steamed bean cakes, known as "moi-moi." During the preparation of these dishes, the outer seed coat of the bean is removed. While this seed coat is sometimes repurposed as animal feed, it often becomes waste in urban areas. Thus, converting it to biogas, whether singly or when combined with another waste, offers a valuable solution for waste management and energy production.

Musa paradisiaca, or plantain, is extensively grown and consumed throughout Nigeria. Its fruit and leaves have been dietary staples for centuries (8), commonly enjoyed as roasted unripe fruit or fried in both ripe and unripe forms. While plantain peels can serve as animal feed or natural fertilizer, in urban areas without livestock or farms, these peels often become waste. Therefore, it is essential to find productive ways to repurpose this waste.

Our aim is to evaluate the possible conversion of bean peels and plantain peels into biogas without the conventional addition of an inoculum, while studying the effects of slurry concentrations and co-digestion.

2. Material and methods

2.1. Collection and Preparation of Substrates

Fresh peels of *Phaseolus vulgaris* (beans) and *Musa paradisiaca* (plantain) were obtained from food vendors along Ikenegbu Road and Okigwe Road in Owerri, the capital of Imo State, Nigeria. The collected peels were then air-dried, ground into powder, stored in sterile containers, and labeled as Bu for bean peels and Pu for plantain peels.

2.2. Proximate analysis

The samples underwent proximate analysis to measure moisture content, total solids, protein and carbohydrate levels, and the carbon-nitrogen (C/N) ratio, following the 2003 guidelines of the Association of Official Agricultural Chemists (AOAC).

2.3. Preparation of Peel mixtures

A 1:1 mass ratio of Bu and Pu was combined to create BP2u. Based on the C/N ratios and moisture contents of Bu and Pu, an intermediate C/N ratio was calculated as per method (9) to form sample BP1u. All four samples—Bu, Pu, BP1u, and BP2u—were stored in pre-labeled sterile containers.

2.4. Preparation of slurries

Mini digesters of 1000 ml capacity were cleaned, dried, and sterilized at 121°C for 15 minutes before anaerobic digestion. Each digester was sealed, fitted with a gas outlet PVC hose that led to an inverted, water-filled, calibrated plastic cylinder for gas collection and daily measurement. The water displacement method was used to collect biogas, with each digester holding 753 cm^3 of slurry. Three slurry concentrations of the substrates—1:6 (C1), 1:11 (C2), and 1:16 (C3) substrate-to-water ratios—were prepared in triplicate and transferred aseptically into each digester. Biogas was measured daily over a 37-day retention period, with readings recorded regularly.

2.5. Experimental set-up and design

The randomized complete block design (RCBD) was used for the experiment. There were two factors: digestion mode/type (four levels of Bu, Pu, BP1u, and BP2u) and slurry concentration (three levels of C1, C2, and C3), with randomization.

2.6. Analysis of results

The daily biogas readings were recorded and later analysed using Microsoft Excel 365 Data Analysis Toolpak (two-way ANOVA with repetition).

3. Results and discussion

3.1. Proximate composition

The proximate composition of the substrates is presented in Table 1.

Table 1 Proximate composition of B, P, BP1u, and BP2u

SAMPLE	Code	Ash content (%)	Moisture content (%)	Percent Nitrogen	Percent Carbon	C/N ratio	Total solids (TS) (%)
Bean peel chaff	Bu	13.15	3.97	3.777	34.15	9.043	96.03
Plantain peel chaff	Pu	15.59	9.88	2.678	37.89	14.138	90.12
Mixed Bean/Plantain 1	BP1u	7.88	15.85	3.23	44.73	13.85	84.15
Mixed Bean/Plantain 2	BP2u	6.49	15.06	3.18	48.65	15.3	84.94

These findings align with those of Bashir *et al.* (10) and Meng *et al.* (11) , who opined that agricultural waste typically has high organic content and a C/N ratio within the optimal range. The high total solids in the substrates also support the findings of Kouame *et al.* (12) who asserted that high total solids facilitate methanization. However, we observed that the C/N ratios of Bu, Pu, and BP1u were below 15; despite this, the substrates generated considerable amounts of biogas. The C/N ratio of plantain peel chaff in this study was lower than that reported by Makinde and Odokuma (13), but closer to the recommended range for methanization.

3.2. Biogas yields of Bu, Pu, BP1u, and BP2u.

The mean biogas yields of the substrates are presented in Table 2.

Table 2 Mean biogas yields for Bu, Pu, BP1u, and BP2u

Substrates	C1 (1:6)	C2 (1:11)	C3 (1:16)	Total
Bu	4.4	5.06	0.34	9.8
Pu	0.55	0	0	0.55
BP1u	8.81	1.3	1.01	11.12
BP2u	3.69	1.95	1.86	7.5
Total	17.45	8.31	3.21	28.97

The substrates yielded varying amounts of biogas after digestion, with the BP1u combination showing the highest average yield and Pu the lowest. Co-digesting bean and plantain peels in a 0.691:1 ratio (BP1u) led to higher biogas production than either equal-proportion digestion (BP2u) or single-substrate digestion (Bu, Pu). This finding aligns with Latinwo and Agarry (14), as well as Olugbemide *et al.* (15) who reported increased biogas yields with co-digestion. The yield differences among substrates were also statistically significant.

In addition, slurry concentration significantly impacted biogas production in both single and combined digestions. Yields rose with higher slurry concentrations, with the 1:6 concentration (C1) producing the most biogas, followed by C2 and then C3 with the least. These results are consistent with the results of Mohamed *et al.* (16) and Deepanraj *et al.* (17) who found increased biogas yields at higher substrate concentrations. Table 3 presents a summary of the Analysis of Variance (ANOVA) results, showing that both slurry concentration and substrate type had highly significant effects on biogas yields, with a notable interaction between these two factors.

Table 3 Summary of two-way ANOVA (with replication)

Source of Variation	SS	df	MS	F	P-value	F crit
Substrate	819.48	3	273.16	11.93	1.61734 E-07	2.63
Slurry Concentration	964.58	2	482.29	21.06	1.87452 E-09	3.02
Interaction	1053.58	6	175.60	7.67	7.67804 E-08	2.12
Within	9893.41	432	22.90			
Total	12731.05	443				

4. Conclusion

We conclude that both slurry concentration and co-digestion significantly affected biogas production from the agricultural wastes of bean peels and plantain peels. This implies that, whether the substrates are digested alone or in combination with each other, a very important attention must be given to the final slurry concentration: higher slurry concentrations generate more biogas than dilute slurry concentrations. We recommend that more agricultural substrates should be explored for their potential to produce biogas, to sanitize the environment while augmenting energy needs.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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