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Impact of Co-digestion and Slurry concentration on biogas production from Kitchen wastes of *Musa paradisiaca* (Unripe plantain fruit peels) and *Phaseolus vulgaris* (Bean peels).

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Abstract

The efficient and useful conversion of kitchen waste into biogas will mitigate the health and environmental challenges caused by their indiscriminate disposal. This study compared the potential yields of biogas from plantain peels chaff (P) and bean peels chaff (B) when anaerobically digested in singles and when combined, and when digested in different slurry concentrations. Two combinations of the substrates were used; PB1 consisted of P and B combined in the ratio of 1:0.691 respectively, while PB2 had an equal ratio (1:1) of P and B. The substrates were digested anaerobically in three slurry concentrations representing substrate/water mixing ratios of 1:5 (S1), 1:10 (S2) and 1:15 (S3). The substrates were digested for thirty-seven days after augmentation with cow rumen liquor. Proximate analysis of the substrates was also done. Biogas was collected using the water displacement method. Results revealed that the total solids (%) of the substrates were 90.12 (P), 96.03 (B), 84.15 (PB1), and 84.94 (PB2). The carbon/nitrogen (C/N) ratios ranged from 9.04 to 15.3. PB1 yielded the highest mean volume of biogas per day (10.8 cm^3/day) while P yielded the least (8.07 cm^3/day). Results revealed that biogas yields increased as slurry concentration increased. The difference in yields with respect to co-digestion was not significant, whereas the difference with respect to slurry concentration was highly significant. We conclude that the peels of *Musa paradisiaca* and *Phaseolus vulgaris* could be converted into biogas whether digested individually or combined, and that higher slurry concentrations are recommended for a higher production of biogas.

Keywords: Kitchen waste; Slurry concentration; Anaerobic digestion; Co-digestion; Biogas

1. Introduction

Food waste or kitchen wastes are organic fractions of municipal solid wastes that come from left-over food or by-products of food processing. They are mainly sourced from restaurants, canteens, eateries, household kitchens, roadside food vendors and food hawkers (1,2). In most urban cities of developing countries, the indiscriminate disposal of kitchen waste from homes, street food vendors and travelers is worrisome. These wastes deface and pollute major streets and suburbs, and threaten public health, environmental health and safety (3).

Musa paradisiaca (Plantain) is widely cultivated and consumed in various parts of Nigeria. Its fruit and leaves have been used as food for centuries (4). The most popular forms are the roasted unripe fruit and the fried (ripe and unripe) fruit. The peels of this fruit can be used as animal feed or as manure. However, in the urban cities where there may not be livestock to feed nor farms to manure, the peels constitute a waste. This waste needs to be put to a productive use.

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Phaseolus vulgaris (Beans) is another important food in the tropics. It is a legume that is easily grown in fertile soils, and a very important source of protein (5). Beans is popularly eaten alone or in combination with other foods. The more common preparation of beans is the fried bean cake popularly known as “akara”, and the cooked bean cake known as “moi-moi” in Southeast Nigeria. During the preparation of “akara” and/or “moi-moi”, the outer seed coat of the bean is washed off. This seed coat which is normally used as animal feed where applicable constitutes a waste in urban cities. It therefore needs to be converted to biogas.

Kitchen waste being organic, can be collected and converted through anaerobic digestion (6,7) into biogas (8–10). Biogas is a renewable energy source that can be used for cooking, lighting, and various other uses (11). The potential of converting kitchen waste into biogas is enormous as kitchen waste has high organic content (90-95%), high moisture content (70-90%), and carbon/nitrogen ratio within the required range of 15 to 30 (1). The various forms of kitchen waste can also be combined in a process known as co-digestion (12,13).

The primary purpose of co-digestion is to enhance the carbon/nitrogen (C/N) ratio of the final mixture of the waste for optimal biogas production. Co-digestion may also enhance the faster removal of wastes from the environment, thereby ameliorating the burden of morbidity. Various wastes have been successfully co-digested into biogas [8,10,11].

Another factor of concern in anaerobic digestion is the slurry concentration or substrate-water mixing ratio. If the final mixture is too thick, it might impede biogas flow; if the mixture is too thin, less biogas is produced (14). Therefore, an investigation into the impact of slurry concentration on the efficiency of biogas production is necessary.

Our focus in this work was to first determine if plantain peels and bean peels can be converted into biogas, and then to know the impacts of co-digestion and mixing ratio as it affects biogas production from the substrates during their anaerobic digestion.

2. Materials and Methods

2.1. Collection and Preparation of Samples

Peels of unripe *Musa paradisiaca* (Plantain) and *Phaseolus vulgaris* (Beans) were collected from food vendors at Eziobodo (Owerri-West Local Government Area) and Amakohia-Uratta (Owerri-North Local Government Area) all in Imo State, Nigeria. The peels were air-dried, pulverized, stored in sterile containers, and labeled P and B respectively.

2.2. Proximate analysis

The samples were subjected to proximate analysis to determine moisture content, total solids, protein and carbohydrate content, and carbon-nitrogen (C/N) ratio according to Association of Official Agricultural Chemists (AOAC) 2003 guidelines.

2.3. Preparation of secondary samples

An equal ratio (1:1) of P and B by mass was used to derive PB2. Given the C/N ratios and moisture contents of P and B, a C/N ratio that lies between that of P and B was derived according to (15) to form the sample PB1. The four samples of P, B, PB1, and PB2 were stored in sterile pre-labelled containers.

2.4. Preparation of slurries

One-litre-capacity mini digesters were washed, dried and sterilized at 121 ^{o} C for 15 minutes prior to anaerobic digestion. Each digester was air-tight and equipped with a gas outlet hose. The gas outlet opens into a column of water inside an inverted, calibrated plastic measuring cylinder. The measuring cylinder served for both gas storage and daily gas measurement. Biogas was collected using the water displacement method. The total working volume of each digester was 753 cm^3. Three slurry concentrations of 1:5 (S1), 1:10 (S2), and 1:15 (S3) substrate-water mixture were prepared in triplicates and aseptically transferred into each digester. To each substrate-water mixture inside a digester, an inoculum of 251 cm^3 of freshly strained cow rumen liquor obtained from Obinze abattoir was added, and the final mixture was stirred using a sterile rod. The inoculum represents 33% of the digester volume (16,17). Biogas was measured once a day in repeated measurements for thirty-seven (37) days hydraulic retention time and readings recorded.

2.5. Experimental set-up and design

A randomized complete block design (RCBD) was used as the experimental design.

2.6. Analysis of results

The daily biogas readings were recorded and subsequently analysed using Microsoft Excel 365 Data Analysis Toolpak.

3. Results and Discussion

3.1. Proximate composition of the samples.

The proximate composition of the four samples is presented in Table 1.

Table 1 Proximate composition of P, B, PB1, and PB2

SAMPLE	Code	Moisture content (%)	Ash content (%)	Percent Carbon	Percent Nitrogen	C/N ratio	Total solids (TS) (%)
Plantain	P	9.88	15.59	37.89	2.678	14.138	90.12
Beans	B	3.97	13.15	34.15	3.777	9.043	96.03
Plantain/Beans 1	PB1	15.85	7.88	44.73	3.23	13.85	84.15
Plantain/Beans 2	PB2	15.06	6.49	48.65	3.18	15.3	84.94

The above data agrees with the findings of Meng et al. (1) and Bashir *et al.* (18) which suggested that kitchen waste has a high organic content and C/N ratio within the required range. The high total solids of the substrates also agrees with the findings of Kouame *et al.*, (19) in having high total solids which favours methanization. However, we discovered that P, B, and PB1 had C/N ratios lower than 15, but the substrates produced appreciable quantities of biogas as will be seen in subsequent tables. The C/N ratio of plantain peels chaff as observed in this work was lower than that of the work of Makinde and Odokuma (20) and lies closer to the range recommended for methanization.

3.2. Biogas yields of P, B, PB1, and PB2.

Table 2 presents the mean biogas yields for all the substrates.

Table 2 Mean biogas yields for P, B, PB1, and PB2

Slurry Concentrations	S1 (1:6)	S2 (1:11)	S3 (1:16)	Total
P (ml/day)	4.46	1.88	1.73	8.07
B (ml/day)	4.76	3.67	1.41	9.84
PB1 (ml/day)	7.44	1.84	1.52	10.8
PB2 (ml/day)	4.45	2.27	1.49	8.21
Total (ml/day)	21.11	9.66	6.15	36.92

The substrates produced different quantities of biogas after digestion. The substrate combination of PB1 produced the highest mean yield while P had the least mean yield. The co-digestion of plantain and beans peels in the ratio 1:0.691 boosted its biogas yield better than when the substrates were digested in equal proportions or digested alone. This agrees with the findings of Latinwo & Agarry (21) and Olugbemide *et al.* (22) which suggested that co-digestion of substrates produced better yields of biogas. However, there was no significant difference in the yields of the substrates.

In contrast, slurry concentration significantly affected biogas yields from the substrates, whether digested singly or combined (Table 2). The biogas yields increased as substrate concentration increased. The slurry concentrations having one part of the substrate in five parts of water (S1) produced the highest quantities of biogas, followed accordingly by S2 and S3 which produced the least. This result agrees with the findings of Mohamed *et al.* and Deepanraj *et al* (14,23,24) in having more biogas yields when substrate concentration increases. The summary of Analysis of Variance (ANOVA) for the substrates is presented in Table 3. The yield differences pertaining to substrates were not significant, while that pertaining to slurry concentration were highly significant. In addition, there was interaction between substrate type and slurry concentration.

Table 3 Summary of two-way ANOVA between P, B, PB1, and PB2

Source of Variation	SS	df	MS	F	P-value	F crit
Substrate (P, B, PB1, PB2)	64.96	3	21.65	0.46	0.71	2.63
Columns (S1, S2, S3)	1131.68	2	565.84	11.99	8.58215E-06	3.02
Interaction	252.42	6	42.07	0.89	0.50	2.12
Within	20392.97	432	47.21			
Total	21842.02	443				

4. Conclusion

We conclude that the co-digestion of plantain and beans chaff has no significant effect on the yield of biogas from kitchen waste, but that slurry concentration significantly affected the yield. Therefore, attention should focus the more on substrate and water mixing ratio to get the best results during anaerobic digestion of kitchen wastes.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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