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Evaluation of Biogas Production from Food Waste

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ABSTRACT

A comparative study on anaerobic digestion of some common food wastes (yam peels, plantain peels, orange rind and fish waste) and mixtures of these wastes were carried out in batch type digesters for 70 days digestion period. During the experiment, the digestion temperature and volume of biogas produced were monitored daily while the pH of the slurry was monitored weekly. The digestion was carried out in mesophilic temperature range of 30 ˚C to 37 ˚C with a total solid concentration of 8%. The results of study showed that the food waste type had significant (P≤0.05) effect on substrate temperature and pH but had no significant (P>0.05) effect on biogas production. The mean values showed that biogas production was in the range of 1090 ml/day and 8016.67 ml/day. The study concluded that anaerobic digestion of the mixture of the food wastes enhanced biogas production although not significantly (P>0.05).

Keywords–*Biogas Production, Anaerobic digestion, Food waste, pH*

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I. INTRODUCTION

Biogas is a clean-burning, "green" fuel used for heating and cooking, transport and power generation. Biogas usually contains about 55-65% methane, 30-35% carbon dioxide, and traces of hydrogen, nitrogen and other impurities. Its heating value is around 600 BTU per cubic foot (21 BTU per liter). Biogas typically refers to a gas produced by the biological breakdown of organic matter such as dead plant, animal material, animal faeces, and kitchen waste in the absence of oxygen. Biogas can be used as a fuel in any country for any heating purpose, such as cooking, electricity and when compressed like natural gas can be used as vehicle fuel to power motor vehicles [1]. Biogas is a renewable fuel, so it qualifies for sustainable energy subsidies in some parts of the world. Biogas can also be cleaned and upgraded to natural gas standards when it becomes bio methane.

Coker et al. [2]was carried out a study on the quantity and nature of food wastes produced in a typical Yoruba household in Ibadan, Nigeria by with a population size of seven to eight. Most of the foods processed and prepared in the household generate varying amounts of waste, up to 62%. If portions of food waste are diverted from landfills it will provide a significant contribution toward achieving mandated solid waste diversion goals. In addition, diverting food waste from landfills will prevent uncontrolled emissions of its breakdown products, including methane—a potent greenhouse gas.

Kitchen waste with its high water content is an ideal carrier of disease and odor but these problems can be solved by converting food waste to energy in the form of biogas. According to Schnepf[3], food waste produces two clean energy gases — hydrogen and methane (other waste materials just produces methane gas), which can be burned to produce electricity and heat, or to propel vehicles. Even though these seem to be more productive, much work has not been done in the evaluation of biogas production from food waste.

This research was carried out to evaluate biogas production from some common food wastes and to determine the food waste component that produces the highest biogas quantity. These food wastes were then co-digested to evaluate the biogas production. The following food wastes were used: fish parts, orange rind, yam peels and plantain peels. The digestion was carried out in batch type anaerobic digesters. The experiment is completed within ten weeks i.e. seventy days retention period.

II. MATERIALS AND METHODS

The study was carried out in a laboratory at the Department of Agricultural and Environmental Engineering, Obafemi Awolowo University (OAU), Nigeria.

2.1 Materials

The waste materials used for the study were: Fish parts, plantain peels, and yam peels collected from Forks and Fingers eatery in OAU; Orange rind from a local fruit seller in OAU and cow dung from the OAU Teaching and Research Farm.

The following equipment was used in the study.

i. **Weighing balance:** to determine the weight of food waste samples.
ii. **PH meter:** to measure the pH of the digested materials.
iii. **Measuring Cylinder:** to measure the volume of water displaced by the biogas generated.
iv. **Mixing Tank:** a big plastic container for mixing the food waste.

2.2 Anaerobic Digester Set-Up

The batch type anaerobic digesters used for the study were made up of the following materials and specifications:

i. **Digester:** A 25 litre (base: 400 mm x 230 mm; height: 275 mm) plastic keg serves as the digester.
ii. **Water collector:** A 5 litre transparent plastic (base: 170 mm x 130 mm; height: 240 mm).
iii. **Rubber Hoses:** The hose is about 1 meter in length and 7 mm inner diameter. It was used to convey gas from the digester to the water tank and to the water collector.
iv. **Digital Thermometer with thermocouple probe:** to read temperatures. The thermometer was in the range of 0 °C to 100 °C.
v. **Water tank:** A 10 litre plastic keg (base: 180 mm x 180 mm; height: 215 mm). The method that was used for gas collection was water displacement method. Two holes were cut on the cover of the keg to fit in two hoses as shown in Figure 1. Water was introduced to fill the keg to the brim.

2.3 Methods

2.3.1 Determination of moisture content

The moisture content of the samples was determined using the oven–drying method. Pre–weighed samples were dried in the oven at 150 °C for 24 hours. Moisture content was calculated using equation 1:

- (1)

Where $M_{initial}$ is the mass of the sample before drying and M_{final} is the mass of the sample after drying.

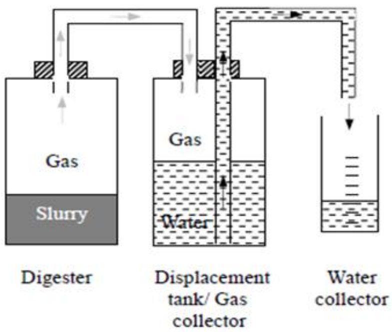

Figure 1: Schematic Diagram of the Experimental Set-up for Anaerobic Digestion
Source: Salman et al. [4]

2.3.2 Determination of carbon content

The oven dried samples were analyzed for the initial carbon concentration using the ash method. The ash was determined by burning the pre-dried sample in a muffle-furnace at 650 °C for 6 hours. The equation 2 [5] was employed to calculate the ash content while equation 3 was used to calculate the carbon content.

(2)

(3)

2.3.3 Determination of nitrogen content

The nitrogen content of the food waste samples was determined using the Kjeldahl method. The Kjeldahl method or Kjeldahl digestion in analytical chemistry is a method for the quantitative determination of nitrogen in chemical substances [6]

2.3.4 Determination of the quantity of water added to the mixture (solid concentration)

The amount of fermentable material of feed in a unity volume of slurry is defined as solid concentration, 7 – 9% solids concentration is best suited. A calculated amount of water was mixed with the mixture to maintain an acceptable total solid concentration that was required for anaerobic bacteria performance. The procedure is described as follows:

(4)

Where:

WWCD = Wet Weight of Cow Dung (kg)

$WW_{foodwaste}$ = Wet Weight of food waste (kg)

MC (%) = Percentage Moisture Content

T_{WW} = Total Wet Weight (kg)

Y = Quantity of water added (kg)

The properties of food waste and cow dung used is shown in Table 1

Table 1: Quantity of Food Waste Added to the Digester

Sample	**Quantity in dry weight (kg)**
Yam Peels	2.2
Orange Rind	1.8
Plantain Peel	3.3
Fish waste	2.7

2.4 Experimental Procedure

The yam peels, plantain peels and orange rind were chopped into smaller sizes (< 4 mm sieve size) to facilitate digestion. Each of the food waste was measured and poured into the mixing tank which contained cow dung (about 60% of the digester volume) and then stirred to ensure homogeneity.The homogenous mixture of food waste and cow dung slurry was then introduced into the digesters and hermetically sealed. Manual agitation was performed on the digester on a daily basis in order to ensure intimate contact between the micro-organisms and the substrate for effective biogas production. The schematic diagram of the set-up is as shown in Figure 1. The water tank was filled with water to its brim. The gas produced by the substrates inside the anaerobic digester was channeled to the water tank on which two separate holes were drilled at the top, two rubber hoses were inserted in the holes, the first one (1000 mm in length and 7 mm in diameter) was used to connect the digester while the second (800 mm in length and 7 mm in diameter) was used to connect the water collector. The weight of gas produced was equivalent to the amount of water displaced in the water chamber (Archimedes' principle of floatation). The displaced water was collected in the water collector. The volume of water displaced in the water collector was measured daily (between 2 pm and 3 pm) using a measuring cylinder. A hole was bored at the bottom of the digester where the thermometer probe was fitted tightly with a rubber cork. The temperature reading was taken between 2 pm and 4 pm daily throughout the period of the experiment. The pH was measured weekly using a digital pH meter. The sample analyzed was collected in a dry bottle from the digester and then analyzed. The probe of the pH meter was immersed into the sample to be analyzed and the meter was allowed to stabilize before the reading was taken. Each treatment was replicated three times. Figure 2 shows a cross-section of the experimental set-up.

2.5 Statistical Analysis

In order to determine the effect of the waste materials on biogas production, data collected was subjected to statistical analysis using Statistical Analysis System software [7]. One-way analysis of variance (ANOVA) was performed to compare variations in pH, temperature and biogas production. Where significance was indicated, Duncan's multiple range tests was used to establish which treatment was significantly different.

Figure 2: Cross-section of the Experimental Set-up

3. RESULTS

3.1 Physico-chemical Properties

The initial physical and chemical properties analysis were carried out on each sample and the results were summarized in Table 2. Optimum carbon to nitrogen ratios in anaerobic digesters are between 20 and 30. A high C:N ratio is an indication of a rapid consumption of nitrogen by the methanogens and results in a lower gas production. On the other hand, a lower C:N ratio causes ammonia accumulation and pH values exceeding 8.5, which is toxic to methano-genic bacteria. Optimum C:N of the feedstock materials can be achieved by mixing waste of low and high C:N, such as organic solid waste mixed with sewage or animal manure [8].

Table 2: Properties of food waste and cow dung used

Sample	MC (%)	Ash (%)	Carbon (%)	Nitrogen (%)	C:N ratio
Yam Peel	77.27	1.14	54.92	1.26	43.59
Orange Rind	52.35	1.74	54.59	1.26	43.33
Plantain Peel	84.65	1.84	54.53	1.47	37.10
Fish	81.43	2.14	54.37	10.85	5.01
Cow Dung	57.21	4.312	53.16	1.15	46.23

3.1.1 Temperature variation

The results of the ANOVA (Table 3) showed that the food waste type had significant ($P \leq 0.05$) effect on the temperature. The Duncan's multiple range tests on the effect of food waste type on temperature (Table 4) showed that temperature variation for fish waste, yam peels and mixture were not different significantly ($P>0.05$). The orange rind and plantain were also not different significantly ($P>0.05$). Figure 3 showed the variation of digester temperature with digestion time. It showed that digestion temperature variation was higher in fish waste and lower in plantain. The internal temperature of the digester fluctuated between 27 ˚C and 31 ˚C.

Table 3: ANOVA Results Showing the Effects of Food Waste Type on Temperature, pH and Biogas Production

Source	DF	Squares	Sum ofMean Square	F Value	Pr> F
Dependent Variable: Temperature					
Model	4	2.62933333	0.65733333	14.29	0.0004
Error	10	0.46000000	0.04600000		
Corrected Total	14	3.08933333			
Dependent Variable: pH					
Model	4	13.25776000	3.31444000	116.82	<.0001
Error	10	0.28373333	0.02837333		
Corrected Total	14	13.54149333			
Dependent Variable: Gas					
Model	4	97881.8133	24470.4533	1.51	0.2713
Error	10	161986.7800	16198.6780		
Corrected Total	14	259868.5933			

DF = Degree of Freedom SS = Sum of Square

Table 4: Duncan's Multiple Range Tests on the Effect of Food Waste Type on Temperature, pH and Biogas Production

Treatment	Temperature (˚C)	pH	Biogas (ml)
Fish	29.6000[a]	7.0367[a]	137.8[a]
Yam peel	29.4000[a]	4.6300[c,d]	149.8[a]
Orange rind	28.6667[b]	4.4500[d]	217.6[a]
Plantain peel	28.5333[b]	4.8700[b,c]	130.9[a]
Mixture	29.2667[a]	4.9767[b]	345.7[a]

Means with the same alphabets (superscript) are not significantly different at P≤0.05

3.1.2 PH variation

The results of the ANOVA (Table 3) showed that the food waste type had significant (P≤0.05) effect on pH. The Duncan multiple range test result (Table 4) showed that the mean pH were significantly (P≤0.05) different in all the treatments. Figure 3showed that pH of fish waste was quite higher than every other food waste type and lowest in the mixture. It confirms that during acidogenesis when acetic, lactic and propionic acids are formed, the pH dropped. It was observed that the pH of the treatment ranged between 4.2 and 8.0.

3.1.3Biogas production

The results of ANOVA (Table 3) showed that the food waste type did not have significant (P>0.05) effect on the biogas production. The Duncan's multiple range test on the effect of food waste on biogas production (Table 4) showed that each food waste produced the same (P>0.05) quantity of biogas. The variation of biogas yield shown in Figure 5 revealed that the mixture treatment produced the highest biogas in the first week followed by orange rind, plantain peels, yam peels, and fish waste both daily and weekly. It showed that variation of biogas production was at its peak within the first five days in all the treatments.

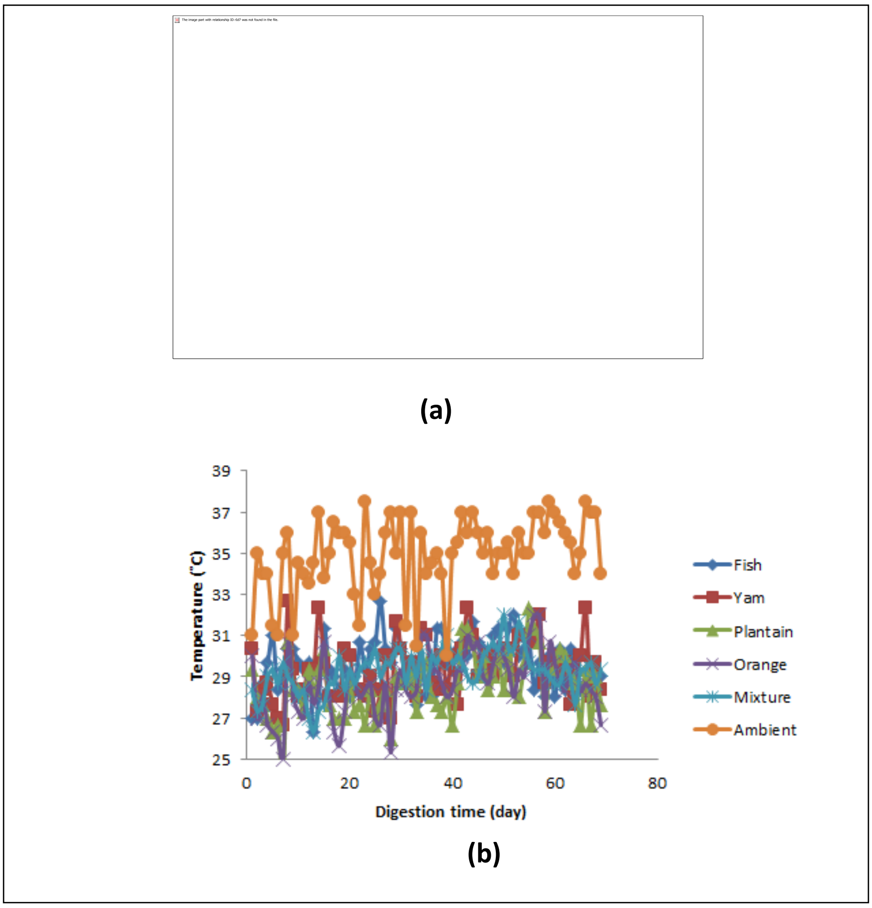

Figure 3: Variation of Substrate Temperature (a) Daily (b) Weekly

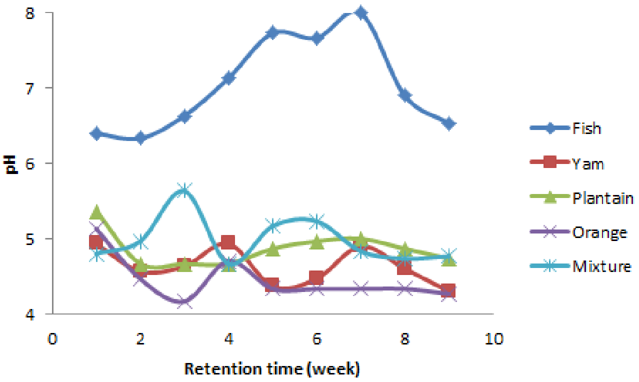

Figure 4: Variation of Substrate pH with Digestion Time

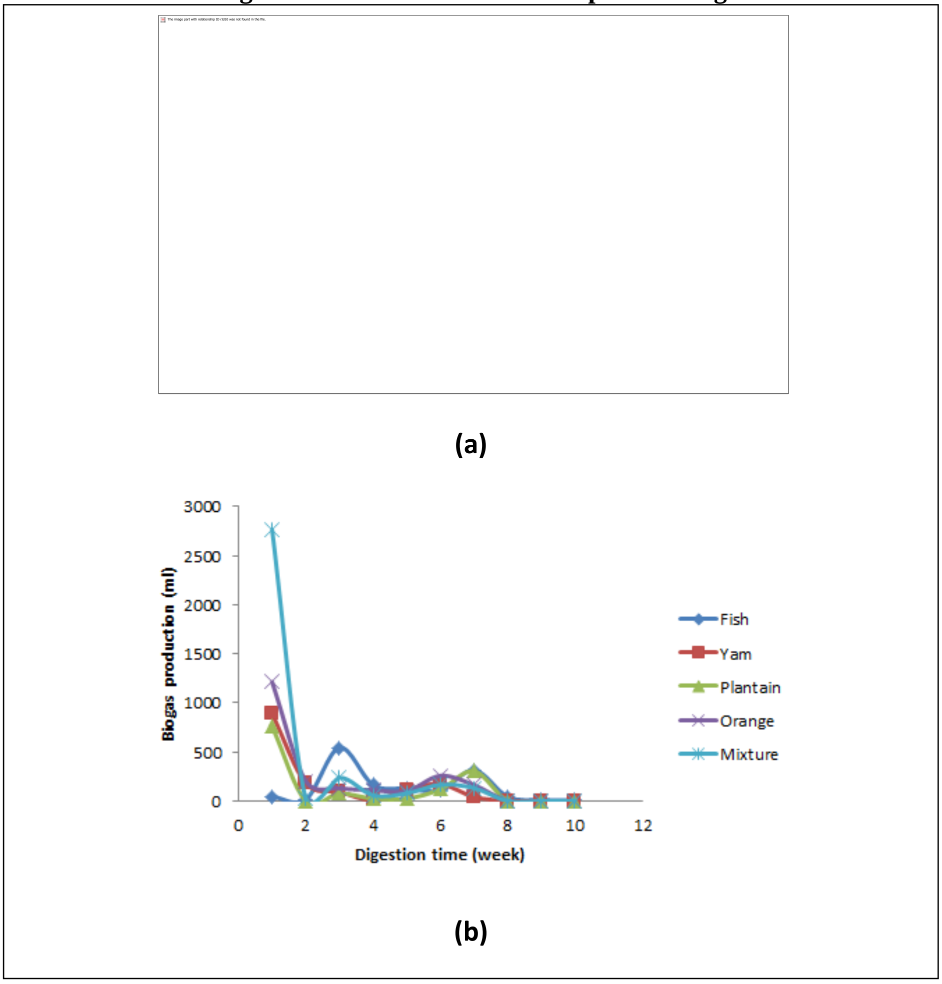

Figure 5: Variation of biogas production (a) Daily (b) Weekly

III. CONCLUSION

The results of the study showed that the food waste type had significant ($P \leq 0.05$) effect on the substrate temperature and pH but had no significant ($P > 0.05$) effect on biogas production. From the result of the study, each of the food waste type produced the same quantity ($P > 0.05$) of biogas although the mixture treatment had the highest quantity (8016.67 ml/day). The least production was from fish waste with mean volume of 1090 ml/day.

IV. RECOMMENDATIONS

The following recommendations are made so as to increase the quality and quantity of biogas production:

i. Orange rind should be pre-treated by removing D-Limonene oil which is a well-known antimicrobial agent that may cause upset or failure of anaerobic digesters [9]
ii. If possible the plastic digesters should have equal thickness to obtain even pressure on gas to be delivered.

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