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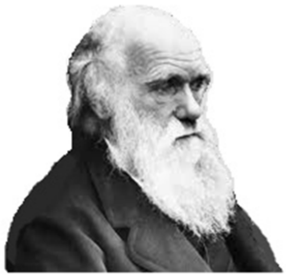

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Anaerobic Digestion of Organic Waste for the Production of Biogas in Calabar, Cross River State, Nigeria

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ABSTRACT

The quest for environment friendly means of waste management has prompted studies on technologies for treatment of municipal organic wastes. Among these is anaerobic digestion. This research was thus conducted to assess the potential of fruit wastes; Watermelon (*Citrus lanatus*) peel (W), Pawpaw (*Carica papaya*) peel (P), Banana (*Musa acuminata* Cv. AAA group) peel (B) and Cow dung (C) for the production of biogas through anaerobic digestion processes. The production of biogas was carried out in single, double and multiple substrates combinations at 13 kg, 6.5kg and 3.25 kg, respectively, per substrate. The substrates were digested anaerobically in 60-liter digesters for 45 days. The treatment comprised of 11 substrates and water as control. The result indicated that the moisture content ranged from 82.0 to 93.0% and the pH of wastes ranged from 4.9-8.3, with a majority of the substrates falling between 6.0-7.1. Treatment W+C+P+B produced the highest biogas (49.4 ml) at 45 days of digestion. This was followed by treatment W+C and W+B - which were 24 and 23.4 ml, respectively. Treatment B and C+B had the lowest methane yield of 2.2 and 7.6 ml, respectively. The combination of W+C+P+B (8.4) and C+B (6.7%) had the highest values of nitrogen content, while W+C (11%) and C+P (1.4%) had the lowest values. The mineral contents of N, P, K, Ca and Mg in most cases were higher than those obtained before digestion. Hence, Fruit waste (W+C+P+B) was the most suitable substrate for producing biogas and bio-fertilizer. Moreover, the values of nitrogen, phosphorus and potassium in the digestate indicate that it will be a good source of fertilizer for crop production.

***Keywords*:** Biogas, anaerobic digester, bio-fertilizer, total solid and waste management

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1. INTRODUCTION

Globally, human population is on the increase and this has resulted to reduction in available space within urban centers and increased generation of domestic and industrial wastes on daily basis. Large proportions of the wastes generated are usually taken to landfills. The issue of great concern now is the continuously reducing spacing for land filling as well as the continuous emission of landfill gas containing mostly methane which is a potential greenhouse gas to the environment[1]. Thus the quest for environment friendly means of waste management and clean energy alternatives instead of the traditional fossil fuel has prompted studies on technologies for treatment of municipal organic wastes all aiming at protecting the environment in Cross River State, Nigeria.

Nigeria generates about 542.5 million tons of municipal solid waste (MSW) per-annum. This alone has the potential of yielding about 25.53 billion m^3 of biogas (about 169,541.66 MWh) and 88.19 million tons of biofertilizer per annum[2]. Biogas was produced from fruit and vegetable waste with cow dung in a study conducted by Deressa *et al.*[3] and Abebe[4]. Biogas yield in Nigeria will be able to completely replace the use of kerosene and cool for domestic cooking and also reduced the consumption of wood fuel by 66%.

The process that results in the production of bio-gas is anaerobic digestion. Anaerobic digestion is an established technology for the treatment of wastes[2], of which the final product is biogas; a mixture of methane (55-75 vol %), carbon (iv) oxide (30-50 vol %), hydrogen (5-10 vol %) and nitrogen (0-3 vol %) that can be used for heating and the residue to be disposed can be used as bio-fertilizer[5]. Anaerobic digestion is a biological process that converts complex organic substrates into biogas and digestate (biofertilizer) by microbial action in the absence of oxygen through four main steps; hydrolysis, acetogenesis, acidogenesis and methanogenesis[1,6]

There is an urgent need for appropriate management of municipal solid waste (MSW) in Calabar metropolis, since thousands of tons of wastes are generated on daily basis. Hence, left over foods, fruits peels, vegetable wastes and animal manures including cow dung manure may be subjected to anaerobic digestion for the production of biogas and bio fertilizer[7]. Conversely, anaerobic digestion appears to be a promising alternative for the treatment of organic solid waste due to its benefit of creating a stable by-product in the form of bio-fertilizer and producing biogas with 40-65% methane[3,5].

This study justifiably will explore the conventional use of anaerobic digestion to facilitate the production of biogas from organic waste like Cowdung, Banana (*Musa acuminata* Cv. AAA group) peels, Water melon (*Citrullus lanatus*) peel and Paw-paw (*Carica papaya*) peel which could serve as alternative energy sources.

Despite the benefit of anaerobic digestion, its application for domestic and industrial organic waste treatment in Cross River State is not widely spread into practice due to lack of awareness, inappropriate treatment system configuration and longer time required for the biostabilization.

2. MATERIALS AND METHODS

2. 1. Description of the study area

This research was conducted in Greenhouse, University of Calabar, Teaching and Research Farm, Calabar, Cross River State. The farm is located between latitudes 04º45' and

04º57' north of the equator and longitudes 08º21' and 08º37' east of the Greenwich Meridian. The area is characterized by two district tropical moist climates - the rainy and dry season. The rainy, season usually starts from March and ends in early Novermber with a peak usually in July and September. The mean annual air temperatures and relative humidity are 26.7 ºC and 87 % respectively.

2. 2. Substrates types used for the experiment and preparation of the feedstock

Four different municipal soil wastes (MSW) were used as substrates; Water melon (*Citrullus lanatus)* peel, Paw-paw (*Carica papaya*) peel, Banana (*Musa acuminata*) peel and Cowdung. Forty (40) kg of each fruit substrates were collected from Fruits retailer within Calabar Metropolis while the animal manure was obtained from Abattoir at Atimbo Slaughter in Calabar Metropolis.

2. 3. Use of single substrate

Water melon peel (W), Paw-Paw peel (P) and Banana peel (B) were sorted and put into different mortar and pounded into pulp except cow dung (C) which was cured and sterilized for 2 weeks before used. The digestion was operated using the principle of anaerobic digestion by mixing the substrates at a ratio of 1:3 (substrates weighed 13 kg and water 39 kg (w/w) which gave 36 litres and placed in different digester as shown in Photo 1.

Photo 1. Anaerobic digestion in progress.

2. 4. Use of two substrates combination

This involved the combination of W+C, W+P, W+B, C+P, C+B and P+B. Each of the substrate weighed 6.5 kg per combination to give a total of 13 kg. The same principle was applied as in single substrate preparation.

2. 5. Use of multiple substrates combination

This involved the combination of Water melon peel (W) + Cowdung (C) + Paw-paw (P) + Banana (B) at 3.25 kg each to give a total of 13 kg. The same principle was also applied as in single substrate preparation. The principle of Asikong *et al.*[8] was adopted for the monitoring of daily gas production through the use of gasometric chamber.

2. 6. Chemical and biological Analysis

The pH within the digesters during the digestion process was determined using a pH meter at 5 days interval[9]. The bioslurry produced from each of the substrate and their combinations were sampled and analyzed for pH, available phosphorus, organic carbon, calcium, potassium, sodium and magnesium in accordance within the standard procedures as described by IITA[10]. The bacterial population and identification was analyzed using the principle described by Zuberer[11]. The identification of hydrolytic fermentative bacteria in pure culture and totals viable anaerobic bacteria were determined by AOAC [12] and Olukemi and Ugoji [9] respectively.

2. 7. Measurement of biogas, moisture content and temperature in the digester

The method of Itodo *et al.*[13] and Olukemi and Ugoji[9] were used for the measurement of biogas produced. Biogas production was measured on volume base in a gasometric chamber by displacement of paraffin oil every 5 days interval for 45 days. The moisture content of the sample was determined by weighing 100g of the fresh grounded sample into porcelain crucible and drying in an oven at 105 ºC for 24 hrs. Thereafter, the crucible and its content were re-weighed and the difference in weight was calculated for percentage moisture content and total solid. The measurement of temperature was carried out by inserting the thermometers into different anaerobic digester and readings were monitored at 5 days interval at a fixed time for 45 days[9].

3. RESULTS

Table 1. Moisture content and total solid of different substrate.

Substrates	MC (%)	TS (%)
B	89.0	11.0
P	92.0	8.0
C	82.0	18.0
W	93.0	7.0

W+B	93.0	7.0
W+P	93.0	7.0
C+P	85.0	15.0
W+C	89.0	11.0
C+B	86.0	14.0
P+B	91.0	9.0
W+E+P+B	91.0	9.0

MC = moisture content, TS = Total solid, B = Banana peel, P = paw-paw peel, W = water melon peel, cow dung.

The moisture content and total solid of undigested substrates were determined before digestion as shown in Table 1. The result revealed that the materials used as treatment had high moisture content which ranged from 82.0 to 93.0 %. The substrates with the highest moisture content 93 % were W, W+B and W+P. Conversely, the substrate that had the lowest moisture content (82.0%) among the treatment used was cow dung (C). The result indicated that only cow dung (C) had the highest total solid (18%) among the treatment used for the experiment whereas W, W+B and W+P had recorded the lowest percent total solid.

3. 1. Total bacterial and fungal isolates from substrates before and after digestion (45 days).

Total viable bacterial population on the first day before digestion ranged from 3.0×10^6 to 9.3×10^6 cfu/g with the substrate W+C+P+B having the highest count. However, 45 days after digestion it ranged from 2.5×10^6 to 6.3×10^6 cfu/g with the substrate W+C+P+B having the highest count (Table 2. Similarly, total viable fungi count at first day before digestion ranged from 1.9×10^5 to 4.7×10^5 cfu/g and after 45 days of digestion it ranged from 1.5×10^5 to 3.9×10^5 cfu/g. The highest fungal count at first day before digestion and after 45 days of digestion was associated with W+C+P+B. Bacterial and fungal count were higher in the substrate utilized than the control before and after digestion.

Table 2. Total viable bacterial and fungal counts (cfu/g) before and after digestion for 45 days.

Substrates	Bacterial count (cfu/g) before digestion	Bacterial count cfu/g) 45 days after digestion	Fungal count (cfu/g) before digestion	Fungal count (cfu/g) 45 days after digestion
B	4.2×10^6	3.1×10^6	2.3×10^5	1.5×10^5
P	5.6×10^6	3.9×10^6	3.6×10^5	2.8×10^5
W	3.8×10^6	2.4×10^6	2.7×10^5	2.0×10^5

C	6.6×10^6	5.4×10^6	4.1×10^5	3.2×10^5
W+B	5.5×10^6	3.7×10^6	3.6×10^5	1.9×10^5
W+P	5.7×10^6	4.1×10^6	3.4×10^5	1.6×10^5
C+P	7.4×10^6	5.8×10^6	4.2×10^5	2.8×10^5
W+C	7.9×10^6	5.9×10^6	3.9×10^5	2.5×10^5
P+B	8.3×10^6	6.0×10^6	4.0×10^5	2.7×10^5
C+B	7.3×10^6	5.7×10^6	3.4×10^5	1.8×10^5
W+C+P+B	9.3×10^6	6.3×10^6	4.7×10^5	3.9×10^5
O	3.0×10^6	2.5×10^6	1.9×10^5	1.5×10^5

B = Banana peels, P = Paw-paw peels, W = water melon peels, C = Cowdung, W+ B = Water melon peel + Banana peel, W+P = Water peel + Paw - paw peel, C+ P = Cow dung + Paw – paw peel, W+C = Water melon peel + cow dung, P+B= Paw-paw peel + Banana peel, C+B = Cow dung +Banana peel, W+ C+P+B = Water melon peel + Cow dung + Paw- paw peel + Banana peel and O = control.

3. 2. Mineral content of the substrate, pH and temperature during the digestion process

The substrate formulations have the chemical composition as shown in Table 3. The results showed that nitrogen and pH were consistently higher after 45 days of digestion than they were in their initial form. The highest value obtained for nitrogen after 45 days of digestion was associated with W+ C+ P+B (8.4 %) and C+B (6.7 %) whereas W+B (1.1 %) had the lowest nitrogen content. However, the mineral contents of P, K, Na, Ca and Mg did not follow a regular trend but before digestion the lowest value of phosphorus content (2.1 mg/kg) was obtained for substrate P while the highest value (6.3 mg/kg) was obtained for the combination of W+ C+P+B whereas 45 days of digestion the lowest value (3.1 mg/kg) were obtained from B, P and W+C while the highest value (6.9 mg/kg) was obtained from P+B. Before digestion the least potassium content (0.7 cmol/kg) was obtained from C+P while the highest value (2.5 cmol/kg) was obtained from B whereas after 45 days of digestion the least value (0.1 cmol/kg) was obtained from W+P while the highest value (2.2 cmol/kg) was obtained from P+B.

Table 3. Mineral content and pH of the substrates used for the experiment

Substrates	Initial properties of substrate							Properties at 45 days after digestion						
	N (%)	P mg/kg	K (cmol/kg)	Na (cmol/kg)	Ca (cmol/kg)	Mg (cmol/kg)	pH	N (%)	P mg/kg	K (cmol/kg)	Na (cmol/kg)	Ca (cmol/kg)	Mg (cmol/kg)	pH
B	0.3	3.1	2.5	0.9	0.5	0.3	4.9	1.7	3.1	0.7	0.9	0.8	0.2	6.0

P	0.6	2.1	1.1	0.6	0.6	0.3	3.0	3.4	3.1	0.5	0.7	0.2	0.9	5.9
W	0.3	3.2	1.2	0.3	0.5	0.2	4.3	1.7	4.3	0.6	0.4	0.2	0.9	6.0
C	0.7	5.2	0.9	0.4	1.2	0.4	7.3	5.6	5.4	1.3	0.5	1.2	0.5	8.3
W+B	0.3	3.8	1.5	0.6	0.4	0.2	4.0	1.1	6.3	0.6	0.7	0.3	0.8	6.4
W+P	0.4	3.7	1.0	0.4	0.6	0.2	3.0	1.7	3.2	0.1	0.5	0.4	0.5	6.5
C+P	0.5	3.7	0.7	0.3	0.8	0.1	3.5	4.5	3.2	0.6	0.4	0.7	0.5	6.2
W+C	0.6	4.2	1.4	0.4	0.7	0.2	4.8	1.8	3.1	1.0	0.5	1.2	1.2	6.6
P+B	0.6	3.8	1.6	0.8	0.4	0.2	3.4	3.4	6.9	2.2	0.9	0.2	0.2	5.8
C+B	0.6	4.6	1.9	0.7	1.0	0.4	6.2	6.7	4.4	0.6	0.8	1.2	1.2	7.6
W+C+P+B	0.6	6.3	1.4	0.7	0.8	0.2	3.6	8.4	5.1	1.6	0.8	1.3	1.3	6.8

Note: B = Banana peel, P = Paw-Paw peel, W = Water melon peel, Cow dung; W+B = Water melon +Banana peel, W+P = water melon + Paw-paw peel, C+P = Cow dung + Paw-paw peel, W+C =Water melon peel +Cow dung; P+B = Paw-paw peel + Banana peel, C+B = Cow dung + Banana peel, W+C+P+B = Water melon peel + Cow dung + Paw-paw peel + Banana peel and OC = organic carbon.

The pH and temperature were monitored at five days internal for 45 days (Table 4 and 5 respectively). The initial pH of the substrate was acidic in reaction except those of C and C+B. Generally, pH of the substrates in the digester increase with days of digestion and some even increase to alkaline pH. Generally, the pH of the substrates ranged from 4.9-8.3 with majority of the substrates falling between 6.0-7.1.

Table 4. pH variation within the anaerobic digesters at different time intervals.

Substrates	Duration (days)									
	0	5	10	15	20	25	30	35	40	45
B	4.9	6.4	6.4	5.7	5.8	5.8	6.0	6.1	6.3	6.3
P	3.0	4.9	5.9	5.9	5.9	5.7	5.9	6.0	6.0	6.1
W	4.3	7.1	7.1	6.9	6.1	6.2	6.0	6.0	6.1	6.6
C	7.3	6.9	6.7	6.8	6.5	6.6	8.2	7.0	6.8	6.9
W+B	4.0	5.8	5.1	6.0	6.0	5.8	6.4	7.3	5.9	7.8
W+P	3.0	5.6	5.5	5.9	6.0	5.7	6.5	6.2	7.2	5.9

C+P	3.5	7.6	7.6	7.0	7.3	6.9	6.2	6.1	7.0	7.1
W+C	5.5	7.7	7.8	7.4	7.2	6.8	7.2	6.2	6.9	6.8
P+B	3.4	5.3	5.4	5.2	5.6	6.0	5.9	5.8	5.6	6.1
C+B	6.2	7.0	6.8	6.1	6.5	6.5	7.9	7.8	6.2	6.1
W+C+P+B	3.6	7.0	6.8	8.3	7.9	7.8	6.9	6.8	5.8	7.1
0	6.9	7.0	7.0	6.9	7.0	7.1	7.2	6.8	7.0	7.1

Note: B = Banana peel, P = Paw-Paw peel, W = Water melon peel, Cow dung; W+B = Water melon + Banana peel, W+P = water melon + paw-paw peel, C+P = Cow dung+ Paw-paw peel, W+C =Water melon +Cow dung; P+B = Paw-paw + Banana peel, C+B = Cow dung + Banana peel, W+C+P+B = Water melon peel + Cow dung + Paw-paw peel + Banana peel and is 0 control.

The temperature ranged between 28-30 ºC from the first to twentieth day of digestion except for the control which had temperature which ranged between 27º to 28 ºC. Then from 25 to 45 day of digestion the temperature ranged was from 23 to 34 ºC (Table 5).

Table 5. Temperature variation (ºC) within the anaerobic digesters at different time intervals.

Substrates	Duration (days)									
	1	5	10	15	20	25	30	35	40	45
B	28	28	28	28	29	30	30	30	30	30
P	28	28	30	30	30	30	30	29	30	31
W	28	28	29	29	30	30	30	30	30	30
C	29	30	29	29	28	30	30	30	30	29
W+B	28	29	30	30	30	29	30	30	30	29
W+P	28	29	29	29	30	29	30	31	29	28
C+P	29	29	29	29	28	30	31	30	31	30
W+C	29	30	30	28	29	31	31	29	30	30
P+B	28	28	29	30	30	30	30	30	30	30
C+B	29	29	28	29	29	30	31	30	31	31
W+C+P+B	29	29	29	30	30	31	30	32	35	34
0	28	27	28	29	28	28	28	28	28	29

Note: B = Banana peels, P = Paw-Paw peels, W = water melon peels, cow dung; W+B = Water melon +Banana peel, W+P = water melon + paw-paw peels, C+P = Cow dung + Paw-paw peels, W+C = water melon +cow dung; P+B = Paw-paw + banana peels, C+B = cow dung+ banana peels, W+C+P+B = Water melon peels + Cow dung + Paw-paw peel + Banana peel and is 0 control.

3. 3. Biogas yield in anaerobic digester during digestion

Treatment W+C+P+B had the highest methane yield by volume with 49. 4 ml (32.4%) at 45th day. Treatment B had the lowest methane yield of 2.2 ml (1.4%) whereas treatment W, C and W+P did not produce any gas (Table 6). Biogas production increased with time and the maximum biogas yield was obtained between 44th to 45th day of digestion. The graph on Fig. 1 showed the variations in the biogas produced for all 11 substrates including the control at 5 days interval over 45 days. The maximum biogas production (49.4 ml) was observed for W+C+P+B at 45th day with mean value of 28.52 ml.

Table 6. Biogas yield (ml) from the substrates in anaerobic digesters at different time intervals.

Substrates	Duration in Days									
	0	5	10	15	20	25	30	35	40	45
B	0	0	0	0	0	0	0	0	2	2.2
P	0	1.2	3	4.2	5.6	8.8	11.4	11.8	12.1	12.4
W	0	0	0	0	0	0	0	0	0	0
C	0	0	0	0	0	0	0	0	0	0
W+B	0	2	5	11	14.3	15.7	17.0	18.6	19.4	23.4
W+P	0	0	0	0	0	0	0	0	0	0
C+P	0	0	0	0	2.1	3.3	4.8	6.0	7.4	7.6
W+C	0	2	9	9	11.4	14.1	16.5	20.8	23.6	24.0
P+B	0	2	4	6.4	8.6	11.8	16.0	16.9	18.2	18.4
C+B	0	2	4	5.2	6.1	7.2	9.0	11.0	11.4	12.6
W+C+P+B	0	7	11	30.0	34.0	36.8	39.0	43.0	46.0	49.4
0	0	0	0	0	0	2.0	2.1	2.4	2.4	2.5

B = Banana peel; P = Paw-Paw peel, W = Water melon peel; Cow dung; W+B = Water melon peel + Banana peel, W+P = Water melon + Paw-paw peel, C+P = Cow dung + Paw-paw peel, W+C = Water melon peel +Cow dung; P+B = Paw-paw peel + Banana peel; C+B = Cow dung

+ Banana peel W+C+P+B = Water melon peels, + Cow dung + Paw-Paw peel + Banana peel and O = Control.

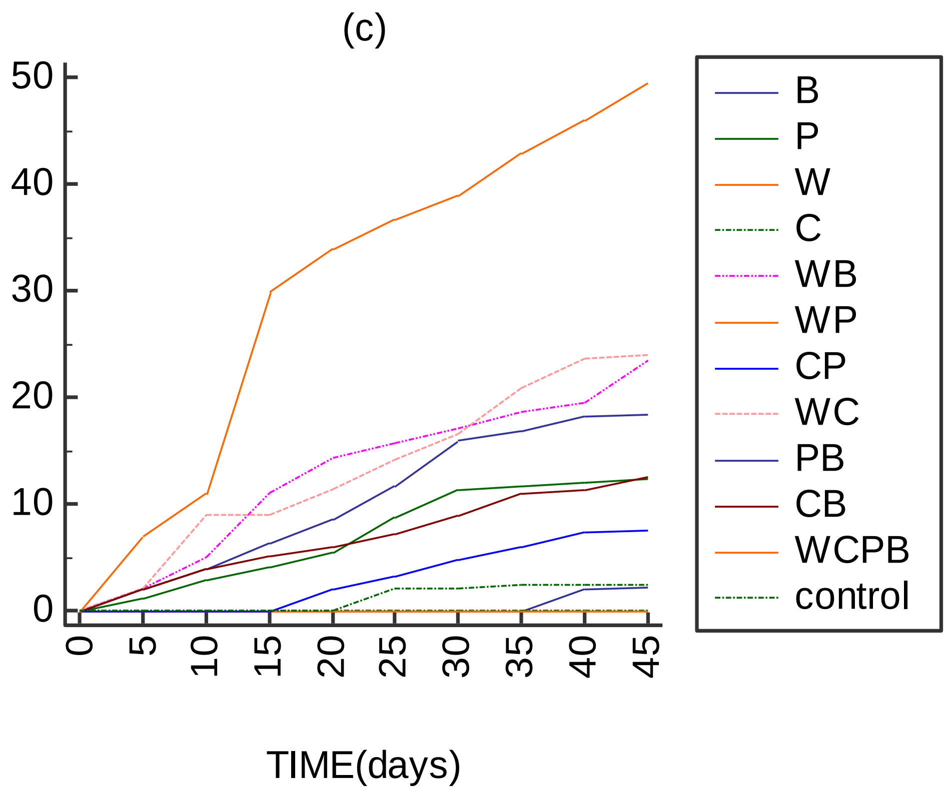

Fig. 1. Biogas variation in the anaerobic digester during digestion.

WB = Water melon + Banana peel; WP = water melon + Paw-paw; CP = Cow dung + Paw-paw; WC = Water melon + Cow dung; PB = Paw-paw + Banana; CB = Cow dung + Banana; W+C+P+B = Water melon + Cow dung + Paw-paw + Cow dung.

4. DISCUSSION

Among the substrates utilized in this study, cow dung (C) had the highest total solid while W, W+B and W+P recorded the lowest percent total solid. From this result, it can be infer that the substrates constituted of biodegradable portion that could be digested for the release of biogas by the microorganisms and the digestate that can be effectively utilized as bio-fertilizer. Research by Deressa *et al.*[3] reported 19 % TS from banana peel and this value was quite higher than 11 % recorded for this study. However, the value recorded for cow-dung (18 %) was comparable to 16.28 and 20.25 % reported by Jha *et al.*[14] and Deressa *et al.*[3] respectively, and lower than 9.6 % TS obtained by Raji *et al.*[15]. The total viable bacterial and fungal count at 45 day after digestion was higher than those obtained on the first day of digestion. This result is in line with the findings of Akpan *et al.*[5], who reported that there was a decrease in microbial population after anaerobic digestion. The mineral contents (i.e. P, K, Na, Ca and Mg) did not follow a regular trend but the values obtained for most nutrients after digestion was higher than those recorded before digestion. For example, before digestion the lowest value of phosphorus content (2.1 mg/kg) was obtained for substrate P while the highest value (6.3 mg/kg) was obtained for the combination of W+ C+P+B. However, 45 days after digestion the lowest value (3.1 mg/kg) were obtained from B, P and W+C while the highest value (6.9 mg/kg) was obtained from P+B. This result is also in line with reports of Berova *et al.*[1] who had inconsistent but increased in nutrient content after digestion.

According to Cioabla *et al.*[16] and Manyi-Loh *et al.*[17], the performance of an anaerobic digester is strongly influenced by the pH and temperature of digesting substrate. The initial pH of the substrate was acidic in reaction except for those of C and C+B. However, the result obtained for this study indicated that the pH of the substrates in the digester increase with days of digestion and some even increase to alkaline pH. This result corroborates with the report of Manyi-Loh *et al.*[17] who stated that organic materials including diary manure have high buffering capacity producing alkalinity when degraded upon by the microorganism. The pH ranged (6.0-7.1) of majority of the digester in this study was similar to the range (6.0-6.9) obtained by Aliyu, (2017) and also in conformity with the optimum pH range for biogas production[18,19]. The temperature range of 23 ºC to 34 ºC obtained from 25^{th} to 45^{th} day of digestion agrees with the result of Bouallagui *et al.* [20] and standard range of 25-35 ºC, and also happens to be in the range of mesophilic 25-45 ºC which is allowed for production of biogas. Cioabla *et al.*[16] and Manyi-Loh *et al.*[17] had reported the effect of temperature on microbial properties during anaerobic digestion and estimated the value to be within the range of 25-35 ºC. Biogas produced in this study increased with increase in days of digestion and the maximum biogas yield of 49.4 ml was obtained between 44^{th} to 45^{th} days of digestion. This result was not in agreement with the results of Aliyu[21] who obtained biogas yield of 98.64 ml for pineapple peel. However, the result was comparable with those obtained by Sambo *et al* [22], Deressa *et al*.[3] and Eleri *et al*.[23] from anaerobic digestion of kitchen waste using cow dung as innocula.

5. CONCLUSION

It is evident from the result that substrate W+C+P+B and P+B used in this investigation are good materials (substrate) for biogas production. However, the volume of gas produce from these substrates is dependent on pH, temperature and substrate combinations. However, it could be concluded that digestion of fruit waste and cow dung to generate biogas and biofertilizer offers an alternative and efficient methods of energy production and fertilizer for high productivity of crops for the farmers and entire country. The values of nitrogen, phosphorus and potassium in the digestates indicate that the substrate could serve as alternative to chemical fertilizer.

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