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The potential of biogas production from fruit wastes (Watermelon, Mango and Pawpaw)

Anika Ogemdi Chinwendu [1, 2, *], Akin-Osanaiye Bukola Catherine [2], Asikong Ernest Bassey [1] and Edet Uwem Okon [1, 3]

[1] Department of Microbiology, Faculty of Biological Sciences, University of Calabar, PMB 1115, Calabar, Cross River State, Nigeria.
[2] Department of Microbiology, Faculty of Science, University of Abuja, PMB 117, Abuja, Nigeria
[3] Obong University, Faculty of Natural and Applied Sciences, Department of Microbiology, Obong Ntak, Etim Ekpo, Akwa Ibom State, Nigeria.

Abstract

The study determined the potential of biogas production from fruit wastes: mango, pawpaw and watermelon and their combinations. Fixed batch type anaerobic digesters were locally fabricated and used for the study. Retention time was for 45 days. The different substrates were prepared into slurry treatments by grinding and mixing with water in the ratio of 1:3, and 1:2 for only watermelon treatment because of its high moisture content. Determination of process pH, temperature and viable anaerobic counts were carried out to monitor how their variations in the anaerobic digesters affected the biogas production process, using pH meter, mercury in glass thermometer and a locally designed anaerobic glove box. Quantification of biogas yield was by liquid displacement. The pH, temperature and anaerobic counts varied over the 45 days retention time. The total volume of biogas produced from each digester at the end of the digestion was 2971 cm^3, 1577 cm^3, 83 cm^3, 5103 cm^3, 1630 cm^3, 916 cm^3, and 4348 cm^3, from watermelon (W), mango (M), pawpaw (P), watermelon + melon (WM), pawpaw + water melon (PW), mango and pawpaw (MP) and mango, watermelon, and pawpaw (MWP), respectively. The excellent biodegradability potential displayed by watermelon waste and to a lesser extent mango waste is of great importance in waste management and the energy transition vision of Nigeria.

Keywords: Biogas production; Fruit wastes; Biodegradability potential; Waste management; Energy transition

1. Introduction

In a rapidly developing economy country like Nigeria, there is a corresponding increase in energy consumption demand [1-2]. At the moment, Nigeria has an installed capacity of 12,522MW; however, it is operating at a capacity of 3,879MW. Our estimated energy need is placed between 98,000MW and 160,000MW leaving behind a huge generation gap [1-2]. In order to bridge the energy gap, the country has been investing in the construction of various dams and even solar energy projects. Furthermore, there are resources and potentials such as natural gas and coal, and nuclear power exist, but these are not utilized at the moment due the absence of proper technologies and/or the political will.

Biogas is a readily combustible anaerobically generated gas via the activities of a consortium of anaerobic microbes decomposing organic wastes such as solid wastes, fruit wastes, industrial effluent, cattle manure and discarded vegetables [3]. It has been suggested that the Nigeria's energy demands can be met sustainably via the use of renewable energy such as biogas [1] for a number of reasons. Renewable energy sources are readily available, cheap, does not require elaborate technology to use and most importantly, the fuel that they generate is environmentally friendly. Amongst the aforementioned sources/raw materials, fruit wastes stands out due to its availability, not affected by

seasonality and low cost. Furthermore, due to increasing awareness of the health benefits of fruits, the consumption of fruits has dramatically increased in major cities in Nigeria leaving behind huge amount of fruit wastes [4-5]. These fruits wastes are usually not well managed just like other solid and liquid wastes across the country. This improperly managed wastes bring with it a number of health concerns [6-7].

Biogas production technology is an easy to adopt dual technology that converts wastes to energy and also helps in the management of organic wastes such as fruit waste [8-9]. In addition to the management of the waste, the generated organic residue can serve as organic manure [8]. Biogas has as its main components, methane and carbon dioxide with trace amounts of hydrogen sulphide, hydrogen and nitrogen gases. The production of biogas via anaerobic degradation of organic wastes depends on a number of factors. Some of these factors include the amount and kind of fruits waste or inorganic wastes utilized, operating conditions of the digester such as pH and temperature, and design of the bioreactor [10-11]. The common bioreactor designs include single-phase digestion, two phase digestion and co-digestions amongst others. Attractively, co-digestion allows for the utilization of co-substrates or a combination of the fruit wastes [8].

In this study, co-substrate strategy was utilized. The fruit wastes used were those of watermelon, mango and pawpaw. The wastes of these fruits are usually disposed indiscriminately in open dumpsites in public places such as markets. There is a dearth of information of the biogas production potentials of the wastes of these commonly consumed fruits in Southern Nigeria. Thus, the primary aim of this research was to examine the biogas production potentials of wastes generated from these commonly consumed fruits using co-digestion strategy.

2. Material and methods

2.1. Substrate collection

Exactly 10 kg of each of the fruit wastes samples (Watermelon-W, Mango-M and Pawpaw-P) were collected in polythene bags from the two main markets (Marian and Watt markets) in Calabar Metropolis, Calabar, Cross River State, Nigeria. Samples were then immediately transported to the laboratory for further analysis. Similar quantity of cow dung used as positive control in the anaerobic digestion process was collected from the animal farm of the University of Calabar, Calabar, Cross River State.

2.2. Inoculum collection and preparation

Slurry collected from an old but active cow dung digester obtained from the University of Calabar anaerobic digestion plant were prepared according to the following method of Asikong *et al*[12]. Activated carbon (charcoal) used as microbial support was washed using acetate buffer pH (4-5) five times and was re-suspended overnight in the buffer. Twenty gram (20 g) weight of the cow dung digester slurry (residue w/v) was blended with 20 kg weight of the pre-treated activated carbon and incubated at room temperature in anaerobic condition for 40 days. The adsorbed cells thus served as crude starter culture for all the digesting blends.

2.3. Preparation of slurry and loading of digesters

Preparation of substrates used for biogas generation in this study was carried out according to the methods described previously and each preparation was done in triplicates [12-13]. Single substrates preparations were done as briefly explained below. One kilogram each of freshly ground fruit wastes was mixed with distilled water in a ratio of 1:3 with the exception of watermelon waste which was mixed in a ratio of 1:2 because of it high moisture content. Also, 1kg of cow dung used a positive control was prepared similarly. The mixture was agitated thoroughly and transferred into the digesters, seeded with 10 % inoculum and tightly corked with stopper to create anaerobic condition. On the other hand, preparations for combination of substrates was carried out in the order as explained briefly. The combinations were Watermelon waste + Mango waste (WM), Pawpaw waste +Watermelon waste (PW), Mango waste + Pawpaw waste (MP) and Mango waste + Watermelon waste + Pawpaw waste (MWP) and in the ratio of 1:1(for WM, PW and MP) and 1:1:1 (for MWP). Each mixture was loaded into the digesters by mixing with distilled water in the ratio of 1:3 along with 10% inoculum and tightly corked with stopper to create anaerobic condition. Blending in the proportion 10:1 (that is, 10% inoculum) of substrate to inoculum previously described was employed [14].

2.4. Anaerobic digester design

Anaerobic digesters (a batch-type) of about 20 litters each used for the digestion of substrates for biogas generation were fabricated locally according to the method described by Asikong *et al* [12]. Twenty-four (24) empty gas cylinders consisting of an opening through which the substrates were introduced into the digester and an outlet tap from where samples were collected for analysis were used.

2.5. Microbiological analysis

Total anaerobic counts were carried out using viable plate count method under strict anaerobic condition. Complete anaerobiosis was achieved with the aid of anaerobic media, anaerobic jar provided with hydrogen gas generator envelop (anaerobic gasPak), palladium pellets (serving as catalyst), and a locally designed anaerobic glove box were all culturing was carried out.

2.6. Media preparation

The anaerobic medium of Batch *et al.* (1979) as described in the handbook of media and stains and reagents in Microbiology [16]. Media preparations were carried out under an oxygen free atmosphere as described by Atlas [17]. Exactly 919 ml of basal solution was boiled with 10 ml of redox indicator solution and 1 ml trace element solution in a side arm flask while streams of N_2-CO_2 (80:20) gases were simultaneously bubbled through the side arm. The mixture was cooled to room temperature, then 10 ml reducing agent, 50 ml of carbonated buffer and 10ml of enrichment solutions added. The pH was adjusted to 6.8 and autoclaved at 121 ℃ for 20 minutes, cooled and transferred to the anaerobic glove box for dispensing. For agar medium, 2% agar was added before autoclaving and just before dispensing, 10 ml of membrane filter sterilized vitamin solution was added.

2.7. Anaerobic glove box design

A novel anaerobic glove box was fabricated locally. It was constructed with a large transparent square-shaped glass plastic box (about 60 by 80 cm in size), with two attached gloves ports and an opening with airtight locks at the top through which material are inserted into the box. The box is fitted with two valves, one leading to the outside and the other (gassing valve) to the inside of the box through which the box is evacuated and replaced with oxygen free gas and an electrical heating mantle (made of spiral heating spring and operated by a foot switch) where materials was sterilized. Once materials for anaerobic work are placed in the glove box, it is locked airtight, then the valve at the top of the box was opened while the valve at the side of the box was connected via a rubber tube to a vacuum pump to evacuate air from the box, afterwards oxygen in the box was flushed out with nitrogen gas, then the top valve was then closed. Any residual oxygen left in the box is converted into water by a reaction catalyzed by palladium pellets in the presence of hydrogen gas generator envelop (anaerobic GasPak). The water formed was absorbed by calcium oxide in the box. Anaerobic work in the glove box began once the anaerobic indicator strip turns colourless indicating an absence of oxygen. All manipulations of culturing were done with the hands inserted through the glove ports. See Figure 1.
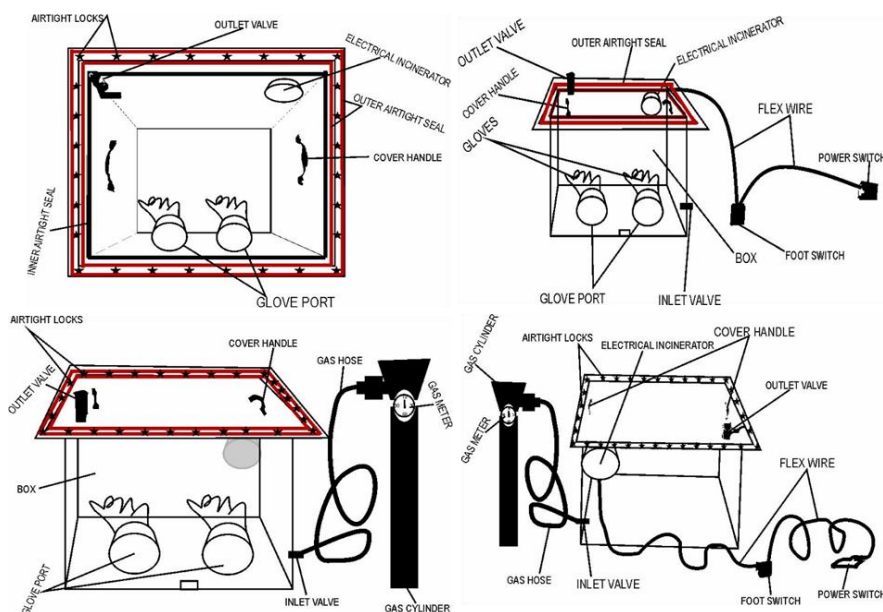

Figure 1 Schematic diagram of the anaerobic glove box design

2.8. Sampling of digester content for microbiological analysis

During the digestion period, samples from the digesters were collected for the screening of anaerobic microbial population of the digester after shaking to achieve a uniform mixture. The samples from the digester were collected from the outlet tap in sterile capped bottles. The bottles were filled almost to the brim to prevent oxygen inhibition during sampling, and transferred into the anaerobic glove box for immediate analysis.

2.9. Total viable anaerobic counts

To monitor the microbial population of the anaerobic digester during the 45 days retention time, the total viable anaerobic counts of the waste and digesting slurry samples were determined at five (5) days interval. As described by Wensinck and Embden [18] and Okore [19], 1 ml of each sample was inoculated anaerobically into tubes containing 9ml liquid anaerobic medium (constituting the 10^{-1} dilution) in the anaerobic glove box, and incubated anaerobically in anaerobic jar at 35 ℃ for 12 hours to enrich the culture. The 12 hour old enriched cultures were then serially diluted in ten-fold steps up to the 10^{-5} dilution and 1ml aliquot of the 10^{-5} dilutions was pour plated in triplicate. The plates were incubated anaerobically at 35 ℃ for 72 hours using an anaerobic jar provided with sachets of gas generating kit (GasPak). Resulting colonies were then reported as CFU/g. See Table 3.

2.10. Measurement of biogas production

The method described by Olukemi and Ugoji [20] was used. Biogas generation was monitored and measured daily on volume basis in a gasometric chamber by displacement of paraffin oil. The gasometric chamber consists of a graduated burette with the upper-end connected to the anaerobic digesters and the lower-end to a glass funnel with paraffin oil, see (Figure 5). The evidence of biogas production and flammability was determined by the displacement of the paraffin oil in the graduated burette downward, when the outlet tap of the anaerobic digester and the inlet tap of the graduated burette were opened.

2.11. Statistical analysis

Replicates readings from the study were subjected to analysis of variance (ANOVA) to compare variations in pH, temperature, anaerobic counts, and biogas production across the digestion days and in all the treatments. Where significance was indicated, Duncan multiple range test at 5% significant level was used to show which treatment was notably different and results presented as mean ± standard deviation. This was done using the trail version of NCSS statistical software.

3. Results and discussion

The process pH, operating temperature in the different digesters as well as the retention time and substrates were among the major factors that influenced the rate of biogas production in this study. Table 1 shows the variation in the pH of the different treatments before and during digestion. Mean pH ranges of 6.5-7.3 (Control), 5.5-7.2 (W), 5.0-7.1 (M), 5.6-8.3 (P), 6.3-7.2 (WM), 6.0-7.5 (PW), 5.3-7.5 (MP) and 6.0-8.0 (MWP) were observed within the 45 days of digestion. The result showed that the digestion began at an acidic range and later varied as the anaerobic digestion of the different substrate treatments advanced. The mean pH values were generally significantly different (p <0.05) in all the treatments and across the digestion days except as seen in pawpaw and mango treatments. In addition, the pH recorded for the single pawpaw waste treatment recorded the highest value.

According to Ciobla *et al.* [21] pH is an influential factor that affects anaerobic digestion process of biogas generation. In this study the pH varied significantly (p<0.05) before digestion and across the digestion days with a notable significant difference (p<0.05) observed on the 25th day of digestion in all the treatments (Table 1). Moreover, the pH recorded for the single pawpaw waste treatment was higher than the rest. The process pH was observed to fluctuate. At the start of digestion, pH range of 5.0-7.2 was recorded, while at the end it was between 6.7-8.3. This observation was not surprising as similar study by Sitorus *et al.* [22] on anaerobic digestion of mixed organic wastes for biogas generation, also reported a fluctuation in the anaerobic process pH. The drop of pH observed at various points in this study could have been as a result of the production of volatile fatty acids such as propionic and butyric acid by acid forming bacteria while acting on the substrates in the digesters [23].

Table 2 shows the temperature variation of the substrates before and during the digestion process. The temperature ranged between 27-29 ℃ (Control), 27-38 ℃ (W), 25-34 ℃ (M), 25-38 ℃ (P), 24-39 ℃ (WM), 29-38 ℃ (PW), 24-32 ℃ (MP) and 30-39 ℃ (MWP) within the 45 days of digestion. The result showed that at the start of the digestion process, the temperatures measured were ambient but showed marked fluctuation as the anaerobic digestion progressed in the different substrate treatments. Significant (p<0.05) variations in temperature was observed between the different substrate treatments before and during the anaerobic digestion process. Peak biogas generation was observed when temperatures of the anaerobic digestion process were in the range of 28 to 35 ℃ (Table 2). This correlates with the findings of Astuti *et al.* [24]. During the anaerobic digestion process, the mean temperatures within the digesters ranged between 25 ℃ and 39 ℃ compared to the ambient (temperature before digestion) temperature which ranged between 28 ℃ to 30 ℃ This observation is in agreement with similar studies by Sunarso *et al* [23].

Table 1 pH variation during anaerobic digestion

Fruit waste	pH/Digestion(days)									
	BD	5	10	15	20	25	30	35	40	45
Mango	$5.00^e\pm0.00$	$5.32^f\pm0.01$	$6.70^c\pm0.00$	$6.95^a\pm0.01$	$6.50^d\pm0.01$	$6.66^g\pm0.02$	$6.72^f\pm0.02$	$6.94^c\pm0.01$	$6.52^e\pm0.01$	$7.10^c\pm0.00$
Mp	$5.50^d\pm0.30$	$6.18^e\pm0.01$	$6.62^d\pm0.00$	$5.78^d\pm0.01$	$6.56^d\pm0.01$	$7.19^b\pm0.01$	$7.13^b\pm0.01$	$7.12^b\pm0.01$	$6.86^d\pm0.00$	$7.29^b\pm0.01$
Mwp	$5.10^e\pm0.14$	$6.86^c\pm0.01$	$7.40^a\pm0.01$	$6.38^f\pm0.01$	$6.72^c\pm0.00$	$6.76^e\pm0.01$	$6.94^c\pm0.00$	$6.80^e\pm0.01$	$6.98^c\pm0.01$	$6.82^f\pm0.01$
Pawpaw	$5.61^c\pm0.01$	$5.94^g\pm0.00$	$6.82^b\pm0.01$	$6.94^b\pm0.00$	$7.05^a\pm0.16$	$7.34^a\pm0.00$	$7.78^a\pm0.04$	$7.76^a\pm0.01$	$7.72^a\pm0.01$	$8.10^a\pm0.01$
Pw	$6.70^b\pm0.01$	$6.98^b\pm0.01$	$6.70^c\pm0.01$	$6.32^g\pm0.01$	$6.50^d\pm0.00$	$6.72^f\pm0.01$	$6.72^f\pm0.01$	$6.66^f\pm0.03$	$6.06^f\pm0.72$	$6.62^g\pm0.01$
Watermelon	$7.20^a\pm0.01$	$6.94^b\pm0.00$	$6.70^c\pm0.00$	$6.26^h\pm0.03$	$5.86^b\pm0.03$	$6.57^h\pm0.01$	$6.57^g\pm0.01$	$6.80^e\pm0.00$	$6.82^d\pm0.00$	$6.94^d\pm0.01$
Wm	$6.50^b\pm0.01$	$6.42^d\pm0.01$	$6.56^e\pm0.01$	$6.66^e\pm0.03$	$6.82^b\pm0.01$	$6.80^d\pm0.03$	$6.80^e\pm0.01$	$6.66^f\pm0.01$	$7.02^b\pm0.01$	$6.92^e\pm0.01$
Control	$7.00^a\pm0.00$	$7.00^a\pm0.01$	$6.70^c\pm0.01$	$6.90^c\pm0.01$	$6.78^c\pm0.03$	$6.93^c\pm0.02$	$6.93^d\pm0.01$	$6.91^d\pm0.01$	$6.52^e\pm0.01$	$6.52^h\pm0.01$

Values are means of triplicates ± standard deviation (SD). Values bearing the same superscripts along the columns were similar and no significant statistical difference (p <0.05) was observed for them, while those with different superscripts differed significantly. Key: W = Watermelon waste, M = Mango waste, P = Pawpaw waste, WM = Watermelon waste + Mango waste, PW = Pawpaw waste + Watermelon waste, MP= Mango waste + Pawpaw waste, MWP = Mango waste + Watermelon waste+ Pawpaw waste BD = before digestion

Table 2 Temperature variation during anaerobic digestion

Fruit waste	Temperature (℃)/Digestion (days)									
	BD	5	10	15	20	25	30	35	40	45
Mango	29.02^c±0.01	30.21^c±0.01	27.61^h±0.01	28.81^g±0.01	29.81^f±0.01	32.21^c±0.01	31.81^d±0.01	29.01^f±0.01	26.41^g±0.01	33.61^a±0.01
Mp	29.52^b±0.01	29.81^e±0.01	28.21^g±0.01	27.61^h±0.01	30.41^d±0.01	28.21^g±0.01	28.41^f±0.01	28.61^g±0.01	27.81^f±0.01	26.81^b±0.01
Mwp	29.52^b±0.01	33.01^b±0.01	31.21^d±0.01	31.01^d±0.01	34.21^b±0.01	35.01^a±0.01	34.41^a±0.01	35.21^c±0.01	37.01^a±0.01	33.41^a±0.01
Pawpaw	25.81^e±0.01	29.21^f±0.01	29.81^f±0.01	29.81^f±0.01	30.22^e±0.01	29.41^e±0.01	29.41^e±0.01	28.61^g±0.01	29.01^e±0.01	26.81^b±0.01
Pw	29.02^c±0.01	29.81^e±0.01	31.61^c±0.01	31.61^c±0.01	30.81^c±0.01	31.01^d±0.01	34.41^a±0.01	34.21^d±0.01	33.81^d±0.01	35.01^a±0.01
Watermelon	28.02^d±0.01	30.01^d±0.01	30.81^e±0.01	30.81^e±0.01	29.81^f±0.01	29.01^f±0.01	33.41^c±0.01	35.61^b±0.01	36.81^b±0.01	35.61^a±0.01
Wm	29.52^b±0.01	30.01^d±0.01	32.41^b±0.01	32.41^b±0.01	30.21^e±0.01	34.01^b±0.01	34.01^b±0.01	32.01^a±0.01	37.01^a±0.01	35.01^a±0.01
Control	30.02^a±0.01	33.40^a±0.00	37.01^a±0.01	37.01^a±0.01	35.21^a±0.01	35.01^a±0.01	31.81^d±0.01	33.21^e±0.01	34.41^c±0.01	29.41^b±0.01

Values are means of triplicates ± standard deviation (SD). Values bearing the same superscripts along the columns were similar and no significant statistical difference ($p < 0.05$) was observed for them, while those with different superscripts differed significantly. Key: W = Watermelon waste, M = Mango waste, P = Pawpaw waste, WM = Watermelon waste + Mango waste, PW = Pawpaw waste + Watermelon waste, MP= Mango waste + Pawpaw waste, MWP = Mango waste + Watermelon waste+ Pawpaw waste BD = before digestion

Table 3 Total anaerobic counts ($\times 10^7$cfu/g) before digestion and during anaerobic digestion

Fruit waste	Anaerobic count/Digestion(days)									
	BD	5	10	15	20	25	30	35	40	45
Mango	1.41[h]±0.00	1.40[g]±0.01	1.23[f]±0.01	1.55[g]±0.00	1.45[f]±0.01	1.43[f]±0.01	1.22[g]±0.01	1.20[e]±0.00	1.16[e]±0.00	1.22[d]±0.01
Mp	1.93[e]±0.00	1.90[e]±0.01	1.89[d]±0.01	1.79[d]±0.01	1.61[e]±0.01	1.50[e]±0.01	1.41[f]±0.01	1.21[e]±0.00	1.08[g]±0.01	1.07[e]±0.01
Mwp	2.90[a]±0.01	2.90[a]±0.01	2.89[a]±0.01	2.89[a]±0.00	2.67[a]±0.01	2.51[a]±0.00	2.70[a]±0.01	2.67[a]±0.00	2.54[a]±0.01	2.21[a]±0.01
Pawpaw	1.56[g]±0.01	1.03[h]±0.01	1.23[f]±0.01	1.23[h]±0.01	1.08[h]±0.01	1.05[g]±0.01	1.01[h]±0.01	0.92[f]±0.00	1.01[h]±0.01	0.93[g]±0.01
Pw	2.04[d]±0.01	1.92[d]±0.01	1.90[d]±0.00	1.63[f]±0.00	1.67[d]±0.01	2.01[d]±0.01	2.11[c]±0.00	2.09[b]±0.01	1.87[c]±0.01	1.50[c]±0.01
Watermelon	1.86[f]±0.01	1.73[f]±0.01	1.72[e]±0.00	1.66[e]±0.00	1.36[g]±0.00	1.48[e]±0.01	1.46[e]±0.01	1.21[e]±0.00	1.11[f]±0.01	1.04[f]±0.01
Wm	2.30[c]±0.01	2.27[c]±0.00	2.17[c]±0.01	2.08[c]±0.01	2.08[c]±0.01	2.20[b]±0.01	2.20[b]±0.01	1.97[c]±0.01	1.83[d]±0.00	1.82[b]±0.00
Control	2.70[b]	2.71[b]±0.01	2.50[b]±0.01	2.65[b]±0.00	2.35[b]±0.00	2.08[c]±0.01	1.95[d]±0.00	1.91[d]±0.01	1.95[b]±0.00	1.80[b]±0.00

Values are means of triplicates ± standard deviation (SD). Values bearing the same superscripts along the columns were similar and no significant statistical difference ($p < 0.05$) was observed for them, while those with different superscripts differed significantly. Key: W = Watermelon waste, M = Mango waste, P = Pawpaw waste, WM = Watermelon waste + Mango waste, PW = Pawpaw waste + Watermelon waste, MP= Mango waste + Pawpaw waste, MWP = Mango waste + Watermelon waste+ Pawpaw waste BD = before digestion

Table 4 Biogas yield during anaerobic digestion

Fruit waste	Biogas yield (%)/Digestion(days)									
	BD	5	10	15	20	25	30	35	40	45
Mango	$0.00^a\pm0.00$	$0.00^b\pm0.00$	$0.00^e\pm0.00$	$8.61^e\pm0.01$	$52.81^d\pm0.01$	$80.20^d\pm0.00$	$84.22^d\pm0.01$	$35.01^g\pm0.02$	$6.00^h\pm0.00$	$43.81^e\pm0.01$
Mp	$0.00^a\pm0.00$	$0.00^b\pm0.00$	$0.00^e\pm0.00$	$2.00^g\pm0.00$	$24.40^e\pm0.00$	$28.80^f\pm0.00$	$40.81^g\pm0.01$	$39.01^f\pm0.02$	$29.61^f\pm0.01$	$18.81^f\pm0.00$
Mwp	$0.00^a\pm0.00$	$0.00^b\pm0.00$	$17.00^b\pm0.00$	$26.01^c\pm0.01$	$130.81^a\pm0.01$	$285.80^a\pm0.00$	$160.21^b\pm0.01$	$94.41^c\pm0.01$	$70.80^c\pm0.00$	$84.60^c\pm0.00$
Pawpaw	$0.00^a\pm0.00$	$0.00^b\pm0.00$	$0.00^e\pm0.00$	$0.00^h\pm0.00$	$2.06^h\pm0.01$	$2.01^h\pm0.00$	$1.60^h\pm0.00$	$4.01^h\pm0.01$	$6.86^g\pm0.08$	$0.00^h\pm0.00$
Pw	$0.00^a\pm0.00$	$0.00^b\pm0.00$	$0.00^e\pm0.00$	$6.60^f\pm0.00$	$10.01^g\pm0.01$	$53.81^e\pm0.01$	$80.40^e\pm0.01$	$89.40^d\pm0.00$	$39.01^d\pm0.01$	$46.81^d\pm0.02$
Watermelon	$0.00^a\pm0.00$	$1.00^b\pm0.00$	$36.61^a\pm0.00$	$19.00^d\pm0.00$	$16.00^f\pm0.00$	$12.41^g\pm0.01$	$123.20^c\pm0.00$	$161.41^a\pm0.01$	$122.80^a\pm0.00$	$101.80^b\pm0.00$
Wm	$0.00^a\pm0.00$	$0.00^b\pm0.00$	$12.00^c\pm0.00$	$49.01^a\pm0.01$	$82.80^c\pm0.00$	$254.41^b\pm0.01$	$265.40^a\pm0.00$	$157.40^b\pm0.00$	$96.60^b\pm0.00$	$103.22^a\pm0.01$
Control	$0.00^a\pm0.00$	$15.00^a\pm0.01$	$11.81^d\pm0.01$	$26.21^b\pm0.01$	$85.00^b\pm0.00$	$196.00^c\pm0.00$	$79.20^f\pm0.00$	$89.01^e\pm0.02$	$35.20^e\pm0.00$	$12.01^g\pm0.01$

Values are means of triplicates ± standard deviation (SD). Values bearing the same superscripts along the columns were similar and no significant statistical difference ($p<0.05$) was observed for them, while those with different superscripts differed significantly. Key: W = Watermelon waste, M = Mango waste, P = Pawpaw waste, WM = Watermelon waste + Mango waste, PW = Pawpaw waste + Watermelon waste, MP= Mango waste + Pawpaw waste, MWP = Mango waste + Watermelon waste+ Pawpaw waste BD = before digestion

Also the result agrees with the temperature ranges reported by Aremu and Agarry [25]. According to Adelekan and Bamgboye [26], the digestion temperatures within this range are favourable to the mesophilic bacteria populations.

The results of the total viable anaerobic microbial counts in the different substrate treatments before and after anaerobic digestion showed a steady variation in the counts as anaerobic digestion progressed (Table 3). The counts varied significantly ($p < 0.05$) between the substrate treatments and the digestion intervals. The counts decreased and increased at different rates throughout the anaerobic digestion process. This observation corroborates with the report by Asikong *et al.* (2013) on similar studies. The highest total viable anaerobic counts were recorded in the digester fed with combination of mango waste, water melon waste and pawpaw waste (M+W+P) while the lowest was obtained from the digester fed with pawpaw waste alone. According to Nagamiani and Rasmasamy [27], the nature of the substrate fed in an anaerobic digester determines the type and extent of microorganisms present in the digester and the subsequent biogas yield.

Watermelon waste displayed excellent biogas generation potential and mango waste to a lesser extent also displayed biogas generation ability, while pawpaw waste performed poorly. The highest individual production rate was recorded for watermelon slurry with the average biogas production of 2971 cm^3, followed by control (cow dung slurry) with a mean total biogas yield of 2741 cm^3, next was the mango slurry followed by pawpaw slurry (Figure 2). High volumes of biogas generation were observed from 20th to 45th days of digestion and peaked at the 25th day, indicating that longer retention times have positive effect on biogas production (Table 4). Furthermore, of the three, watermelon exhibited the highest potential (64%) compared to the other two fruit wastes investigated. Additionally, mango waste to a lesser extent also displayed biogas generation ability (34%) while pawpaw waste performed poorly (2%). See Figures 3. In combination with mango waste, watermelon waste showed an increased biogas production potential (67%). See Figures 4.

In an earlier study, where biogas production potentials of fruits and vegetables wastes was examined, it was observed that the control (cow dung) had the highest biogas production of 1554 cm^3 while the test samples which were wastes of pineapple, orange, pumpkin, and spinach gave 965, 612, 373 and 269 cm^3, respectively. They concluded that the differences in yields were substrate dependent [28]. Compared with our findings, the highest biogas yield of 2971cm^3 was recorded for watermelon treatment followed by a yield of 2741 cm^3 from the control (cow dung) while the other two test samples mango and pawpaw gave yields of 1577cm^3 and 85cm^3, respectively. This showed that the different substrate types employed in this study greatly influenced the resulting biogas yield.

In another study where they used vegetable wastes, mango, pineapple, tomato, jackfruits, banana and orange fruit wastes to produce biogas, it was shown that the rate of production was dependent on time as they obtained 74.5% yield of biogas within 12hours while it went down to 59.03% within 24 hours [13]. Compared to our findings, only an average of 100cm^3 biogas was produced within the first 15 days (Table 5), however production peaked within 20 to 35 days before dropping within the last 10 days of the digestion. This shows that the rate of production was influenced by time. In a recent study, wastes generated from avocado, papaya, mango, tomato, banana peel, and cow manure were used in biogas production. They obtained a pH ranged of 6.7-7.4 [8]. When compared with our findings, we recorded a pH range of 5.0-8.1 before and during the digestion process, this could explain why the biogas production fluctuated from the onset of production. Budiyono *et al* [29] compared biogas production when cow dung is added or not added with various substrates. In their study, they showed that substrate that had cow dung added to them gave better biogas production. Compared to our findings, pawpaw waste treatment did not perform well despite being seeded with inoculum prepared from cow dung slurry from an old but active cow dung digester. This could be attributed to the high acidity recorded for the pawpaw waste. This proves that a high acid level does not support biogas generation. Maile *et al.* [30] reported initial low pH values due to acidic nature of fruits and these were later buffered to 6.5-7.5 during their anaerobic digestion of fruits and vegetables. In our study, during the early days of digestion, there was no biogas formed in all the fruit waste treatments except for watermelon treatment as a result of the high acid content. However, significant quantities of biogas were produced as the systems' acidity progressively balanced out. This showed that watermelon waste has an optimum pH level required for adequate biogas generation.
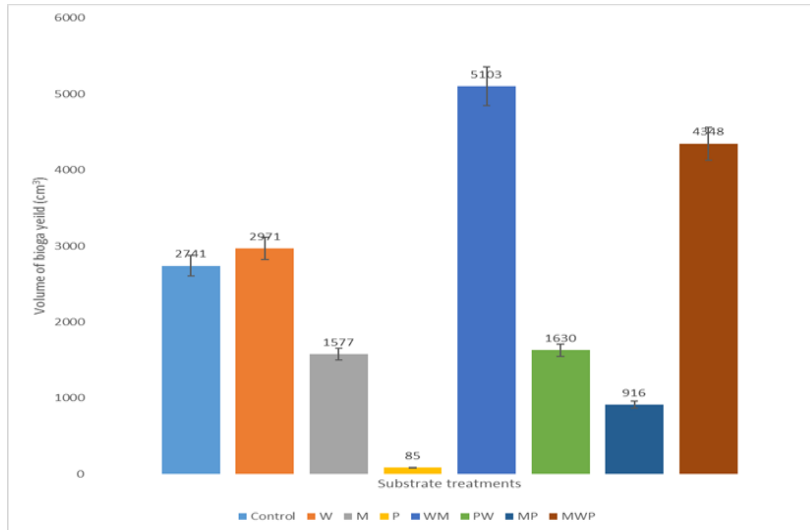
Figure 2 The total biogas yield during anaerobic digestion of substrates over a retention time of 45 days

Key: W = Watermelon waste, M = Mango waste, P = Pawpaw waste, WM = Watermelon waste + Mango waste, PW = Pawpaw waste + Watermelon waste, MP= Mango waste + Pawpaw waste, MWP = Mango waste + Watermelon waste+ Pawpaw waste
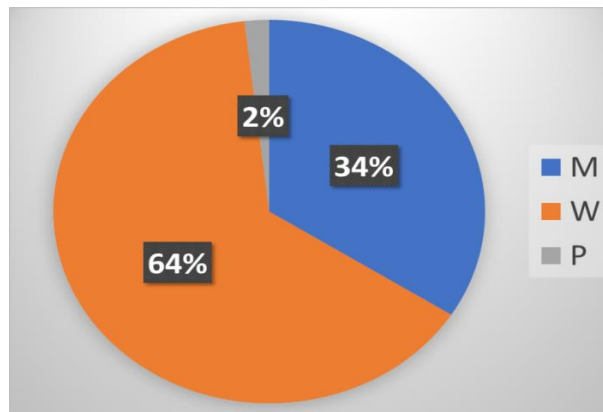

Figure 3 Percentage biogas yield from the three single substrate treatments; Mango waste (M), Watermelon waste (W), Pawpaw waste (P)
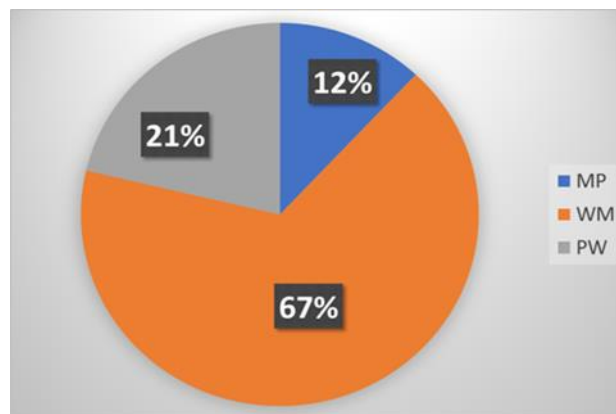

Figure 4 Percentage biogas yield from the double substrate treatments; Mango + Pawpaw waste (MP), Watermelon + Mango waste (WM), Pawpaw + Watermelon waste (PW).

Figure 5 Flammability of the biogas generated

Figure 6 Anaerobic jar containing culture plates and anaerobic GasPak for incubation

4. Conclusion

The power of organic wastes and their inert capabilities to generate biogas in conjunction with microorganisms is of great economic value if fully harnessed and is of practical relevance especially in waste management. The results of this study has gone a long way in ascertaining the energy production capabilities of fruit wastes as well as reveal the complex consortia of microorganisms involved in anaerobic degradation of organic wastes in the anaerobic digesters. Therefore the excellent biodegradability potential displayed by watermelon waste and to a lesser extent mango waste is of great importance in waste management and the energy transition vision of Nigeria.

Compliance with ethical standards

Disclosure of conflict of interest

There were no conflict of interest/ competing interests.

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