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Modification of plastic tank for bio-digestion of food wastes for biogas generation for cooking foods

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The anaerobic states of the modified bio-digester and potentials of the generated biogas in cooking foods were evaluated. The study adopted experimental design. Data generated were analyzed using one - way analysis of variance and independent t-test. Carbon, free fatty acid, chemical and biochemical oxygen demand decreased significantly ($p<0.05$) while moisture and protein contents of the wastes increased significantly ($p<0.05$) after digestion. The 50% cow dung and 50% yam peel, and 50% cow dung and 50% vegetable had significantly ($p<0.05$) higher total (12.48%) and volatile (8.10%) solid contents respectively before digestion, but decreased significantly ($p<0.05$) after digestion. The pH of fermenting slurry was changing in line with the condition within the digester. Bacillus spp., *Escherichia* coli, klebsiella, Salmonella, Staphylococcus and Streptococcus were predominant microorganisms in all stages of biogas production from different wastes. Biogas generated from the wastes cooked significantly ($p<0.05$) faster than kerosene but not faster than liquefied petroleum gas. Cooking with biogas did not have any significant ($p>0.05$) effect on the proximate and sensory characteristics of foods when compared with the foods cooked with liquefied natural gas and kerosene.

Key words: Bio-degradation, food waste, cowdung, microorganisms, yam peel.

INTRODUCTION

Biogas innovation offers an attractive platform for the creation of alternative source of energy if they are appropriately harnessed (Opeh and Okezie, 2011). Biogas is generated in the absence of oxygen by microorganisms in a process known as anaerobic digestion (Fang et al., 2010; Arsova, 2010). The conversion of organic matter into biogas is mainly by the action of different groups of microorganisms such as bacteria, fungi and protozoan. These microorganisms are classified into four groups such as hydrolytic, acidogenic (fermenting), acetogenic and methanogenic bacteria. They act on the different stages of the waste digestion to bring about effective biogas production (Asikong et al., 2016). During hydrolysis, bacteria transform the organic substrate into monomers and polymers, such as proteins, carbohydrates and fatty acids. Acidogenesis involves further breakdown of the remaining components by acidogenic bacteria into short chain volatile fatty acids, ketones, alcohols, hydrogen and carbohydrate. The rest of the acidogenesis products are transformed by acetogenic bacteria into hydrogen, carbohydrate and acetic acid. Methanogenic microorganisms utilize intermediate products of these proceeding stages and convert them into methane, carbohydrate and water. The

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*Corresponding author. E-mail: toteupstar@yahoo.com major types of domestic anaerobic degradation system are the Chinese dome, Indian floating drum, Plug flow and the Puxin digesters (Jegede et al., 2019). They have no mechanical blenders and are unheated systems which make them cost effective and well appropriate for farmers and people living in rural areas. In sub-Sahara Africa especially Nigeria, domestic anaerobic degradation systems have had little success compared to Asia and Latin American countries due to inadequate technical application and social acknowledgment (Kalia, 2007). The realistic implementation of biogas innovation is in progress and has not acquired justifiable awareness (Opeh and Okezie, 2011). Furthermore, household digester fabricated from plastic for biogas generation from food wastes for cooking foods has not been adequately studied (Eze and Uzodinma, 2009; Nwankwo et al., 2017). Household digesters for biogas production from food wastes could be cost effective and eco-friendly energy substitute for cooking foods compared to other cooking fuel (Nwankwo et al., 2020).. However, this research focused on evaluating the anaerobic states of the modified bio-digester and potentials of the generated biogas in cooking foods compared to other cooking fuel.

MATERIALS AND METHODS

Procurement of wastes

Kitchen wastes (yam peels and vegetable wastes) and cow dung were used for biogas production. The yam peels were collected in dried form from local yam fryers in Nsukka town, while vegetable waste was collected from restaurant located on the campus of the University of Nigeria, Nsukka. The cow dung was collected from the slaughter house at Nsukka Central abattoir.

Procedure for modification of plastic tank

The construction of the whole digester assembly involved different stages of work which include;

(i) Digester cover
(ii) Agitator
(iii) Fermentation chamber

The digester cover was designed with hard foam material. The form material was tapered and rimmed with Lathe machine (Model C6241, make; Shanghai Changji, China) in such a way to cover the digester without biogas linkage. The digester cover was about 0.152 m in height, 0.023 m upper and 0.021 m lower diameters with a wood handle (0.04 m diameter and 0.111 m in height). The material used in designing the digester cover could withstand harsh environmental condition and could cover the digester in order to maintain anaerobic condition. The agitator (mass = 7.84 kg) was made of circle arms (0.24 m diameter each) joined with iron steel rode of 0.61 m in length to enable the agitator to move to and fro freely. The iron steel joining the two circle arms was welded to a vertical iron rode of 1.22 m in length with two iron rods cross at the top (0.52 in length each). The two iron rods cross at the top of the vertical rode was to enable the agitation of the waste at the upper side of the digester. The center of vertical iron rode was welded to horizontal iron rode (0.73 m in length) which was welded to another 45° bend iron rode (1.34 m in length) with a handle (0.24 m in length). The design of the agitator was such that a torque (τ) applied from the outside of the digester would be simply transmitted into the digester to agitate the system (Olaniyan et al., 2014). Owing to the toxic and corrosive nature of the waste inside the digester, it is necessary that the fermentation tank has good resistance to corrosion. As a result of the non-availability of right materials as well as the very expensive nature of the few available ones, PVC tank was used since it is cheap, durable and is able to resist corrosion. The slurry digester influent chamber was designed in such a way that it could be able to accommodate the agitator and the kitchen waste was able to go into the digester without blockage. The digester influent chamber was designed with 4” (0.11 m) PVC back nut, 4” (0.11 m) PVC male adepter, 4” (0.11 m) PVC 45° elbow bend and 4” (0.11 m) PVC pipe. The agitator handle was allowed to pass through the influent chamber. The effluent chamber was designed with 4” (0.11 m) PVC back nut, 4” (0.11 m) PVC male adapter and 4” (0.11 m) plastic ball valve such that all the slurry could be easily discharged after digestion (Figure 1). The materials and cost for the modification of plastic tank as the bio-degradation system is shown in Table 1.

Waste digestion and analysis

Three batches of experimental anaerobic bio-digestion were conducted for 28 days involving 50% cow dung and 50% yam peel and vegetable waste (WB_1), 50% cow dung and 50% yam peel waste (WB_2), and 50% cow dung and 50% vegetable waste (WB_3). Each waste was weighed and diluted with water (1:3) and anaerobically digested in three different 3.6 m^3 capacity plastic digester. The chemical characteristics and microbial analysis of the wastes were determined (AOAC, 2010). The pressure of the biogas produced was recorded daily with pressure gauge (model No.500 CE, make: Nagoya Aichi, Japan). Generated biogas from each waste was used to cook foods (yam and rice) thrice daily. Cooking time, proximate composition and sensory evaluation scores of foods cooked with generated biogas were compared to that of liquefied petroleum gas and kerosene (Iwe, 2002; Itodo et al., 2007).

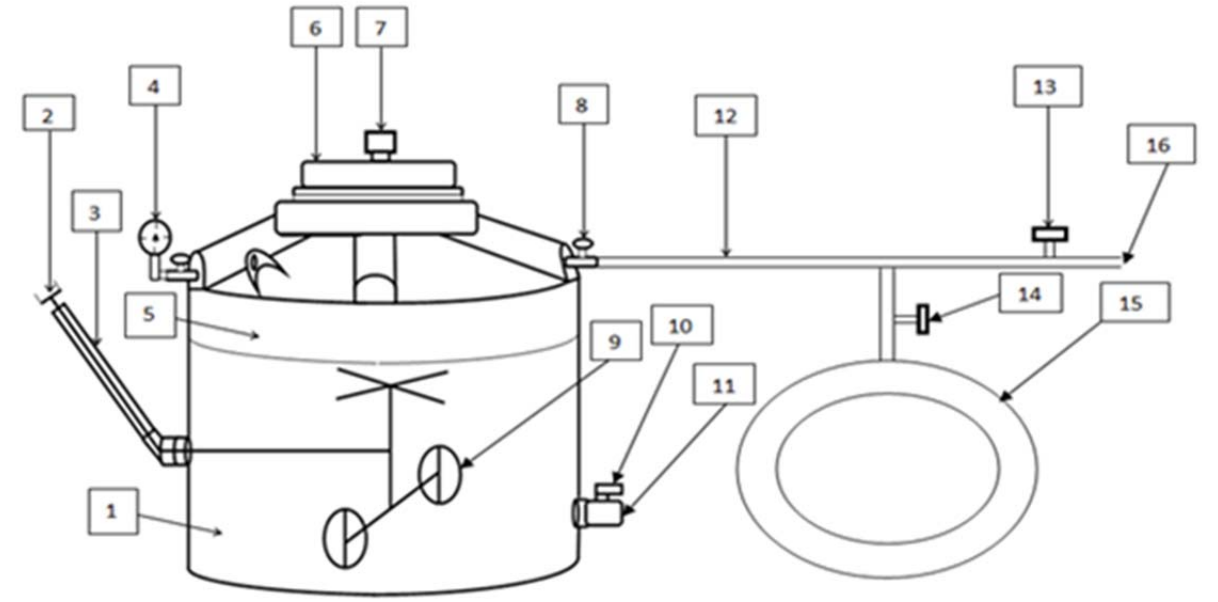
Statistical analysis

The study adopted experimental design. Data generated were analyzed using one - way analysis of variance and independent t-test ($p<0.05$).

RESULTS AND DISCUSSION

Chemical properties of wastes before and after digestion

The result in Table 2 shown the chemical properties of wastes before and after digestion. The total solid, volatile solid, carbon, free fatty acid, chemical and biochemical oxygen demand decreased significantly ($p<0.05$) while moisture and protein contents of the wastes increased significantly ($p<0.05$) after digestion. Comparable result was reported by Okunola et al. (2018) and Nwankwo et al. (2020) which was attributed to activities of microorganisms for biogas production. The wastes moisture content ranged from 75.07 to 80.88% before digestion but increased up to 84.76% after digestion. Yadav et al. (2014) reported that high moisture content



Whole digester assemble

1 = fermentation chamber, 2 = agitator handle, 3 = slurry inlet, 4 = pressure gauge, 5 = gas storage chamber, 6 = foam cork, 7 = cork handle, 8 = nido pressure nossle, 9 = agitator, 10 = ball gauge control, 11 = slurry outlet, 12 = gas hose, 13 = nido valve, 14 = nido valve, 15 =tyre tube for pressure control, 16 = gas outlet.

Figure 1. Schematic diagram of digester

Table 1. Materials and cost for the modification of plastic bio digester.

S/N	Quantity	Materials	Cost of each	Total
1	1	3600 L Geepee Tank	75000.00	75000.00
2	2	1” Back nut	1000.00	2000.00
3	2	4” Back nut	6500.00	13000.00
4	1	4” Ball gauge	2000.00	2000.00
5	2	4” Adapter	600.00	1200.00
6	1	4” × 45^{o} bend	1500.00	1500.00
7	1	5 feet 4” pipe	1500.00	1500.00
8	20	Thread tape	300.00	6000.00
9	2	Smallest Abro gum	1200.00	2400.00
10	2	1 × ¾” bushing	500.00	1000.00
11	2	20 L gallon / Bowel	2100.00	4200.00
12	2	Rubber cork	1000.00	2000.00
13	2	Nido value	1500.00	3000.00
14	1	Tapered foam cork	3800.00	3800 .00
15	2	Nido pressure nossle	1500.00	3000.00
16	1	Pressure gauge	1500.00	1500.00
17	1	T- Joint	800.00	800.00
18	8	Yards of Quality gas hose	500.00	4000.00
		Tyre tube	4500	4500.00
19		Construction of stirrer and other iron work	6000.00	6000.00
20		Transport	2000.00	2000.00
21		Plumbing workmanship	4000.00	4000.00
			Grand total	₦144,400.00

Table 2. Chemical properties of undigested and digested wastes.

Parameter	Treatments	Waste blend		
		WB_1 (%)	**WB_2 (%)**	**WB_3 (%)**
Moisture	Undigested	$78.08^{b}\pm0.01$	$75.07^{c}\pm1.20$	$80.88^{a}\pm0.50$
	Digested	$80.64^{b}\pm0.20$	$80.04^{b}\pm0.27$	$84.76^{a}\pm0.70$
Ash	Undigested	$4.76^{a}\pm0.27$	$4.46^{a}\pm0.34$	$4.86^{a}\pm0.11$
	Digested	$3.45^{a}\pm0.40$	$3.29^{a}\pm0.24$	$3.20^{a}\pm0.70$
Fibre	Undigested	$4.25^{a}\pm0.30$	$4.47^{a}\pm0.40$	$4.82^{a}\pm0.70$
	Digested	$2.16^{a}\pm0.20$	$2.12^{a}\pm0.27$	$2.82^{a}\pm1.60$
Fat	Undigested	$1.11^{a}\pm0.40$	$1.03^{a}\pm0.30$	$1.01^{a}\pm0.11$
	Digested	$0.56^{b}\pm0.27$	$0.40^{c}\pm0.33$	$0.30^{c}\pm0.12$
Protein	Undigested	$0.92^{c}\pm0.30$	$1.24^{b}\pm0.54$	$0.81^{d}\pm1.14$
	Digested	$1.62^{b}\pm0.14$	$1.74^{a}\pm0.42$	$1.24^{b}\pm1.60$
Carbohydrate	Undigested	$12.22^{b}\pm0.02$	$14.93^{a}\pm0.52$	$9.28^{c}\pm1.14$
	Digested	$10.26^{a}\pm0.16$	$11.24^{a}\pm0.44$	$6.02^{b}\pm0.19$
Total solid	Undigested	$9.48^{b}\pm0.41$	$10.28^{b}\pm0.22$	$12.48^{a}\pm0.42$
	Digested	$7.36^{b}\pm0.21$	$7.48^{b}\pm0.51$	$7.46^{b}\pm0.48$
Volatile solid	Undigested	$7.98^{b}\pm0.21$	$8.10^{b}\pm0.71$	$6.52^{b}\pm0.20$
	Digested	$6.10^{b}\pm0.31$	$6.17^{b}\pm0.31$	$4.26^{c}\pm0.64$
Carbon content	Undigested	$5.58^{a}\pm0.21$	$3.12^{a}\pm0.41$	$3.14^{a}\pm0.24$
	Digested	$1.16^{b}\pm0.40$	$1.24^{b}\pm0.06$	$0.08^{c}\pm0.52$
Free fatty acid	Undigested	$0.08^{a}\pm0.20$	$0.10^{a}\pm0.041$	$0.06^{a}\pm0.22$
	Digested	$0.02^{c}\pm0.62$	$0.04^{b}\pm0.04$	$0.02^{c}\pm0.40$
Biochemical oxygen demand	Undigested	$50.58^{c}\pm0.02$	$47.54^{b}\pm0.41$	$45.41^{c}\pm0.06$
	Digested	$16.48^{c}\pm0.41$	$15.20^{b}\pm0.11$	$15.42^{bc}\pm0.31$
Chemical oxygen demand	Undigested	$140.80^{b}\pm0.71$	$130.42^{c}\pm0.22$	$133.12^{d}\pm0.72$
	Digested	$65.70^{c}\pm0.11$	$82.40^{a}\pm0.34$	$60.78^{d}\pm0.54$

Values are means ± standard deviation of three determinations. Values on the same row with alphabets with different superscripts are significantly ($p<0.05$) different. WB_1 = 50% cow dung and 50% yam peel and vegetable, WB_2 = 50% cow dung and 50% yam peel, WB_3 = 50% cow dung and 50% vegetable.

in the waste will encourage movement and contact between microorganism and organic molecules. The moisture also increased after digestion due to decrease in the amount of volatile and total solid (Eze and Agbo, 2010a; Yadav et al., 2014). Decrease in carbohydrate, total solid and volatile solid was more significant ($p<0.05$) in WB_3 than others after digestion. This could be due to the production of organic acids (Yadav et al., 2014). The free fatty acids of wastes ranged from 0.06 to 0.10% and decreased significantly ($p<0.05$) after digestion. There was more significant ($p<0.05$) reduction in biochemical and chemical oxygen demand in WB_1 than others after digestion may due to more conversion of organic matter in WB_1 by microorganisms for biogas production (Utami et al., 2016).

Physical properties and volume of biogas production during waste digestion

The result in Table 3 showed that the ambient temperature ranged from 29 to 36°C and slurry temperature ranged from 31 °C to 37 °C during waste

Table 3. Physical properties and volume of biogas production during waste digestion.

Retention time (days)	Waste blends												
	WB_1					WB_2				WB_3			
	Ambient temp (°C)	**Slurry temp (°C)**	**pH**	**Pressure (mmHg)**	**Biogas production (Litre/day)**	**Slurry temp (°C)**	**pH**	**Pressure (mmHg)**	**Biogas production (Litre/day)**	**Slurry temp (°C)**	**pH**	**Pressure (mmHg)**	**Biogas production (Litre/day)**
Charging day				0	0			0	0			0	0
1	32	33	6.70	0	0	31	6.24	0	0	33	6.76	0	0
2	29	32	6.70	11	399	32	6.28	0	0	33	6.70	10	396
3	30	31	6.70	12	456	36	6.26	12	454	34	6.72	12	464
4	31	31	6.71	15	466	35	6.42	13	462	34	6.60	13	468
5	32	30	6.71	25	474	32	6.76	27	540	32	6.71	20	464
6	30	31	6.70	33	534	33	6.72	31	634	34	6.70	25	538
7	29	32	6.70	34	574	35	6.76	33	663	35	6.76	29	554
8	32	33	6.71	36	710	31	6.78	36	723	32	6.70	34	604
9	30	35	6.71	34	675	29	6.78	36	727	33	6.86	32	644
10	32	32	6.72	34	652	29	6.78	34	689	34	6.84	32	640
11	30	33	6.72	34	648	33	6.74	32	682	35	6.84	32	652
12	35	32	6.72	33	682	31	6.75	33	687	34	6.81	33	668
13	33	32	6.72	36	668	29	6.75	33	674	33	6.81	32	654
14	35	31	6.71	32	701	32	6.75	33	677	32	6.81	34	572
15	32	32	6.71	34	587	30	6.77	32	634	31	6.81	31	666
16	31	31	6.71	34	590	32	6.74	31	596	31	6.81	31	576
17	30	32	6.70	31	572	32	6.74	31	612	32	6.81	31	652
18	30	33	6.72	32	672	32	6.72	30	577	36	6.70	33	668
19	32	33	6.70	31	684	29	6.72	30	598	35	6.80	33	551
20	30	32	6.70	30	712	31	6.73	30	599	34	6.80	34	574
21	30	31	6.71	32	668	31	6.74	30	577	35	6.80	31	534
22	30	29	6.71	32	572	30	6.76	31	604	35	6.80	30	554
23	32	32	6.71	33	584	29	6.74	31	602	32	6.78	30	598
24	31	31	6.71	30	668	29	6.72	31	594	31	6.78	32	585
25	32	30	6.71	30	572	29	6.77	30	591	34	6.77	30	538
26	32	33	6.71	31	560	30	6.78	30	583	36	6.78	29	518
27	34	32	6.72	29	524	30	6.79	30	577	34	6.76	25	534
28	32	31	6.72	31	558	33	6.75	29	554	36	6.78	27	542
mean	**31.28**	**31.78**			**577.21**	**31.7**			**568.21**	**33.57**			**550.28**

WB_1 = 50% cow dung and 50% yam peel and vegetable, WB_2 = 50% cow dung and 50% yam peel, WB_3 = 50% cow dung and 50% vegetable.

digestion. Slurry temperatures supported optimal biogas production because there was high biogas production as slurry temperature ranged from 31 ^{o}C to 37 ^{o}C. The pH of the three experimental wastes was fluctuating between 6.70 and 6.81 Similar result was reported by Nwankwo et al. (2020).. Fluctuation in pH may be due to higher acidogenesis and lower methanogenic activities, and vice vise (Beevi et al., 2013). Steady pH values were observed in waste WB_3 (6.81) from 12th to 17th day and WB_2 (6.75) from 12th to 14th day respectively. Steady pH values may be due to simultaneous acid production and also quick consumption of the acid by microorganisms for biogas production (Aragaw et al., 2013), Biogas production of WB_1 increased gradually until it got to the 8th day (710 L); after which its biogas production began to fluctuate with highest biogas (712 L) production on the 20th day (Table 3). This might be attributed to a positive synergetic effect on the digestion of cow dung and food waste which provided more balanced nutrients (Aragaw et al., 2013). Just as in the volume of the biogas, the biogas pressure between 12th and 20th day was higher compared to other days, which was above 30 mmHg upto 36 mmHg in WB_1. High pressure over 29-37 mmHg might affect the activities of methanogenic bacteria and biogas production (Dobre et al., 2014). Similar results were reported by Ebunilo et al. (2016) and Olorunmaiye et al. (2016) where the pressure fluctuation between 5 and 52 mmHg was recorded. The biogas production from WB_2 and WB_3 increased each day to the maximum on the 9th day (727 L) and on the 12 day (668 L) respectively, afterward biogas production began to fluctuate with corresponding biogas pressure between 10 and 36 mmHg. Similar result was reported by Aragaw et al. (2013) and Nwankwo et al. (2017). An increase in pressure may be as a result of increase in volume of biogas and temperature in the digester (Ebunilo et al., 2016; Olorunmaiye et al., 2016).

Microbial isolates and total viable count at different stages of waste digestion

The result in Table 4 showed that immediately after charging, total viable count of the three experimental wastes ranged from 2.42×10^{8} to 3.82×10^{7} cfu/ml and a total of eight morphologically and physiologically different bacteria species (A*spergillus nigar*, *Bacillus spp.*, *Escherichia coli*, *Klebsiella*, *Salmonella*, *lactobacillus*, *Pseudomonas*, *Staphylococcus* and *Streptococcus*) and two fungi species (*Aspergillus* spp and *Sacchromyces*) were also isolated.

This might be attributed to the nature of the substrate (Ali Shah et al., 2014; Idire et al., 2016). Immediately biogas production started, the total viable count increased significantly ($p<0.05$) while the isolated microorganisms reduced to six bacteria species. This may be due to the condition in the bio-degradation system was thermo-dynamically unfavorable to the microorganisms initial presence immediately after charging (Ali Shah et al., 2014) while significant ($p<0.05$) increase immediately biogas production started mighty be due to high microbial populations involved in the hydrolytic and fermentative phases of biogas production. Comparable results were reported by Eze and Agbo (2010b) and Asikong et al. (2016). At the peak of biogas production, the total viable count was significantly ($p<0.05$) higher than the initial stage of biogas production with WB_1 (5.81×10^{8} cfu/ml) recording higher than others. This may be due to varying amount of different wastes.

The microbial loads and isolated microorganisms also decreased significantly ($p<0.05$) at the point of discharge. Similar result was reported by Asikong et al. (2016). This may be due to deposition of microbial metabolites and gradual exhaustion of nutrient from the wastes (Ziemiński and Frąc, 2012; Li et al., 2015; Asikong et al., 2016).

Effect of cooking with different heat sources on proximate composition and sensory characteristics of yam and rice

The result in Table 5 showed that the biogas generated from different wastes cooked significantly ($p<0.05$) faster than kerosene but not faster than liquefied petroleum gas. Carbon dioxide and other gas (apart from methane) in biogas could reduce its cooking efficiency as reported by Eze (2012) and Nwankwo et al. (2020).

Abdulkareem (2005) concluded that refining biogas before using could improve its efficiency. In terms of proximate composition, significantly ($p<0.05$) higher moisture content was recorded for yam and rice cooked with kerosene compared to other sources of heat may be due to longer cooking time which allowed the foods to absorbed more water. The crude protein, fat, fibre, ash and carbohydrate contents were reduced insignificantly ($p>0.05$) in both yam and rice after cooking. Reduction in ash content could be that some soluble minerals dissolved in water during boiling (Assa et al., 2014). Significant ($p>0.05$) difference was not observed in sensory characteristics of yam and rice cooked with biogas, liquefied petroleum gas and kerosene (Table 6). Cooking with biogas did not affect the sensory characteristics of yam and rice differently when compared to liquefied petroleum gas and kerosene. It is quite difficult to pinpoint any of the heating sources as the best in terms of their effect on proximate and sensory characteristics of foods (Eze, 2012).

Conclusion

The significant ($p<0.05$) decrease in chemical properties such ash, fibre, fat, carbohydrate, total solid, volatile solid, carbon, free fatty acid, chemical and biochemical oxygen demand after digestion and ability of bio-digester to generate average flammable biogas (0.574 m^3per

Table 4. Microbial isolates and total viable count at different stages of waste digestion

	Waste blends					
	WB_1		**WB_2**		**WB_3**	
Stages of identification	**Isolates**	**Total viable count** (cfu/ml)	**Isolates**	**Total viable count** (cfu/ml)	**Isolates**	**Total viable count** (cfu/ml)
Immediately after charging	**Bacteria species** *Bacillus spp* *E. coli.* *Klebsiella* *Salmonella* *Staphylococcus* *Streptococcus* *Pseudomonas* **Fungi species** *Saccharomyces* *Aspergillus spp.*	3.33×10^7	**Bacteria species** *Bacillus spp* *E. coli* *Lactobacillus* *Klebsiella* *Salmonella* *Staphylococcus* *Pseudomonas* **Fungi species** *Aspergillus spp*	2.84×10^7	**Bacteria species** *Bacillus spp* *E. coli* *Klebsiella* *Salmonella* *Staphylococcus* *Streptococcus*	2.42×10^7
Immediately gas production starts	**Bacteria species** *Bacillus spp* *E. coli* *Klebsiella* *Salmonella* *Staphylococcus* *Streptococcus*	4.70×10^8	**Bacteria species** *Bacillus spp* *E. coli* *Klebsiella* *Salmonella* *Staphylococcus*	4.58×10^8	**Bacteria species** *Bacillus spp* *E. coli* *Klebsiella* *Salmonella* *Staphylococcus* *Streptococcus*	5.92×10^7
At the peak of gas production	**Bacteria species** *Baccilus spp* *E. coli* *Klebsiella* *Staphylococcus* *Streptococcus*	5.81×10^8	**Bacteria species** *Bacillus spp* *E. coli* *Klebsiella* *Salmonella* *Staphylococcus*	4.87×10^8	**Bacteria species** *Bacillus spp* *E. coli* *Salmonella* *taphylococcus* *Streptococcus*	4.78×10^8
At the point of discharge	**Bacteria species** *Baccilus spp* *E. coli* *klebsiella* *Streptococcus*	4.62×10^8	**Bacteria species** *Bacillus spp* *E. coli* *Klebsiella* *Staphylococcus*	4.88×10^8	**Bacteria species** *Bacillus spp* *E. coli* *Salmonella* *taphylococcus*	3.52×10^8

WB_1 = 50% cow dung and 50% yam peel and vegetable, WB_2 = 50% cow dung and 50% yam peel, WB_3 = 50% cow dung and 50% vegetable.

day) sufficient to cook three meals per day for 3 to 4 persons were an indication of high efficiency performance of the bio-digester. The

Table 5. Cooking time and proximate composition of rice cooked with different sources of heat.

Heat source	Cooking time (minutes)		Proximate composition											
			Moisture (%)		Crude protein (%)		Crude fat (%)		Crude fibre (%)		Ash (%)		Carbohydrate (%)	
	Yam	Rice	Yam	Rice	Yam	Rice	Yam	Rice	Yam	Rice	Yam	Rice	Yam	Rice
Raw rice			56.70^{f}	9.62^{d}	3.34^{a}	4.51	0.94^{a}	1.96^{a}	1.56^{a}	1.74^{a}	3.40^{a}	1.86^{a}	34.02^{a}	80.31^{a}
WB_1	13.40^{b}	37.37^{b}	67.50^{bd}	65.44^{b}	2.80^{a}	3.62^{a}	0.88^{a}	1.62^{a}	1.44^{a}	1.51^{a}	2.84^{a}	1.73^{a}	24.54^{bd}	26.08^{c}
WB_2	13.42^{b}	37.44^{b}	68.30^{b}	65.42^{b}	2.88^{a}	3.74^{a}	0.84^{a}	1.74^{a}	1.46^{a}	1.52^{a}	2.62^{a}	1.75^{a}	23.90^{b}	25.83^{d}
WB_3	13.34^{b}	37.74^{b}	67.10^{cde}	65.41^{b}	2.80^{a}	3.34^{a}	0.80^{a}	1.78^{a}	1.49^{a}	1.41^{a}	2.86^{a}	1.78^{a}	24.95^{b}	26.28^{cd}
LPG	11.20^{c}	32.14^{c}	67.80^{bce}	62.42^{c}	2.72^{a}	3.14^{a}	0.78^{a}	1.34^{a}	1.44^{a}	1.44^{a}	2.58^{a}	1.83^{a}	24.68^{bc}	29.83^{b}
Kerosene	18.56^{a}	44.17^{a}	72.90^{a}	68.38^{a}	2.78^{a}	4.12^{a}	0.85^{a}	1.74^{a}	1.46^{a}	1.54^{a}	2.68^{a}	1.76^{a}	19.33^{e}	22.46^{e}

Values are means ± standard deviation of three determinations. Values on the same column with different superscripts are significantly different ($p<0.05$). WB_1 = 50% cow dung and 50% yam peel and vegetable, WB_2 = 50% cow dung and 50% yam peel, WB_3 = 50% cow dung and 50% vegetable. LPG = Liquefied petroleum gas.

Table 6. Sensory evaluation of yam and rice cooked with different sources of heat.

Heat source	Sensory characteristics									
	Colour		Appearance		Aroma		Taste		Overall acceptability	
	Yam	Rice	Yam	Rice	Yam	Rice	Yam	Rice	Yam	Rice
WB_1	7.60^{a}	7.55^{a}	7.21^{a}	6.43^{a}	7.08^{a}	5.77^{a}	7.61^{a}	6.42^{a}	7.46^{a}	6.48^{a}
WB_2	7.16^{a}	7.23^{a}	6.76^{a}	6.54^{a}	6.86^{a}	5.45^{a}	7.31^{a}	6.34^{a}	7.46^{a}	6.58^{a}
WB_3	7.73^{a}	7.44^{a}	6.86^{a}	6.47^{a}	7.21^{a}	5.42^{a}	7.46^{a}	6.41^{a}	7.16^{a}	6.38^{a}
Liquefied petroleum gas	7.20^{a}	7.84^{a}	7.26^{a}	6.64^{a}	6.86^{a}	5.24^{a}	7.51^{a}	6.41^{a}	7.41^{a}	6.42^{a}
Kerosene	7.01^{a}	7.90^{a}	7.48^{a}	6.72^{a}	7.11^{a}	5.32^{a}	7.26^{a}	6.44^{a}	7.32^{a}	6.16^{a}

Values are means of twenty determinations. Values on the same column with different superscripts are significantly different ($p < 0.05$). WB_1 = 50% cow dung and 50% yam peel and vegetable, WB_2 = 50% cow dung and 50% yam peel, WB_3 = 50% cow dung and 50% vegetable.

microbial load increased significantly during biogas production and continued to increase significantly ($p<0.05$) at the peak of gas production and then reduced significantly ($p<0.05$) at the point of discharge. *Bacillus* spp., *E. coli*, *klebsiella* spp., *Salmonella* spp., *Staphylococcus* spp. and *Streptococcus* spp were predominant microorganisms in all stages of biogas production from different wastes. However, considering the fact that liquefied petroleum gas cooks significantly ($p<0.05$) faster than biogas, it is quite expensive for the average household in developing countries, especially Nigeria. Biogas can be an alternative cooking fuel in developing countries because it is cheaper and an environmental friendly. Moreover the cost and materials for fabricating the plastic bio-digester is cheap and durable. Finally, cooking with biogas as observed in this study did not have any significant ($p>0.05$) effect on the proximate composition and sensory characteristic of food when compared with the food cooked with liquefied petroleum gas and kerosene.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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