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Research Article
Comparative Study of Biogas Production from Plantain Peels Mixed with Poultry Droppings and Poultry Droppings Only

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Abstract

Background and Objective: Biogas production from raw material is a renewable and clean source of energy. This research work investigate the biogas production from poultry droppings mixed with plantain peels and poultry droppings without plantain peels. **Materials and Methods:** Chemical and proximate compositions of digestate were carried out with the aids to determine the potential use for agricultural purposes. Statistical analysis was performed using Microsoft Excel and 4 factor Response Surface Methodology (RSM). **Results:** Result obtained from poultry droppings mixed with plantain peels and poultry droppings without mixing with plantain peels indicates the maximum biogas yield. The predicted values were validated and the average optimum biogas volumes obtained. Analysis of variance of regression equation shows the coefficient of determination (R^2) of 99.67 and 99.98%, respectively. The measured temperatures (ambient, slurry, gas layer, interface between slurry and gas layer) during the fermentation process were found to be within the mesophilic temperature range. The chemical and proximate compositions of the digestates show that it could be used as replacement for biological fertilizers. **Conclusion:** Therefore, it can be concluded that mixing plantain peels with poultry droppings increased the biogas volume.

Key words: Plantain peels, poultry droppings, biogas, optimization, fossil fuel, proximate composition

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The fossil fuel used as energy source[1] causes environmental degradation like global warming and poses several health risks to man. For a heavily populated nation like Nigeria, taking into consideration its heavy reliance on the non-renewable energy sources, the negative effects associated with these fossil fuels becomes predominant with increased daily consumption[1]. However, the use of renewable and clean energy as a replacement for fossil fuel and its derivatives are faced with high cost of refining fossil fuel, petroleum and its allied products, due to unstable oil prices and policies of oil producing nations. These reasons begs for the case of fossil fuels as major energy sources to be addressed urgently to avoid having an economy with no reliable energy source for its socio-economic growth. The Nigerian economy is heavily dependent on its oil sector which accounts for 85% of government revenues generated yearly[1]. Alternative sources of energy have been discovered and are currently implemented in most parts of the world to reduce the dependency on non-renewables. These alternative fuels have been found to have better characteristics than the fossil fuels owing to it, combustion with no smokes cheaper to generate or acquire with no adverse effects on the environment and pose no health risk to man[2]. Biogas, a bio-fuel is a renewable source of energy. It's a gas produced by the biological breakdown of organic matter in the absence of oxygen by a process called anaerobic digestion. During anaerobic digestion, four biochemical processes are involved, viz-a-viz hydrolysis (complex carbohydrates, fats and proteins are first hydrolyzed to their monomers by exoenzymes and bacterial cellulose), acidogenesis (monomers are further decomposed into short chain acids such as: acetic acid, propionic acid, butyric acid, valeric acid and caprionic acid), acetogenesis (these short-chain acids are converted into acetate, hydrogen and carbon dioxide) and methanogenesis[3] (methanogens convert the intermediates produced into methane and carbon dioxide). Furthermore, large amount of agricultural, industrial and domestic wastes containing nitrogen, phosphorus as well as potassium are generated daily all over the world and these wastes possess disposal problem. Plantain peels is a domestic waste with high potassium and phosphorus content, present as mineral compositions having high calorific and nutritive values. These wastes are disposed in landfill or discarded in most cases and causes public health hazards and diseases, it leads to surface and groundwater pollution through leachate and promotes breeding of flies, mosquitoes, rats and other disease bearing vector which emits unpleasant odor and methane which is a major greenhouse gas contributing to global warming[4]. Poultry droppings are a mixture of animal excreta and bedding materials such as sawdust etc., in which the nutrient content differs within the same conditional management[5]. Poultry droppings contain a higher content of biodegradable organic matter than the waste of any other livestock, which can be maximally handled by anaerobic digestion[2]. Therefore, main objective of this study was to combine and compare plantain peels mixed with poultry droppings and poultry droppings for generation of biogas.

MATERIALS AND METHODS

Study area: This research work was carried out in the Department of Agricultural and Biosystems Engineering, University of Ilorin. The experimental study duration was from April-August, 2019.

Materials: Fresh plantain peels was obtained from a restaurant (Item 7), University of Ilorin, Kwara state. It was washed with distilled water to eliminate the adherent dirt, dried to constant weight and milled to reduce the size and to increase surface area for microbial actions[6].

Poultry droppings were obtained from Hadebs farm, Kilanko, Offa garage, Ilorin, Kwara state, Nigeria. All chemical and reagents used were of analytical grades with no further purification and includes, distilled water, activated carbon pellets, ferric chloride, sodium hydroxide, H_2SO_4 and N_aSO_4 were obtained from Finlab Nig. Ltd.

Methods

Biogas reactor design with gas collection system: The digester was constructed and run by the methods used by researchers[6,7] with little alterations. A 205 L methane reactor with shape implemented for proper mixing was made from galvanized steel because of its strength and durability in acid and basic environments. Different holes were bored on the lid of the digester for the slurry inlet, the insertion of temperature sensors and the gas outlet. The digester was painted black, air tight, raised above ground level and exposed to sunlight for easy absorption. A stirrer was attached at the top of the digester while the slurry outlet was at the lowest end of the digester. A vulcanizer's tube was used to collect and store the biogas. Rubber hose was used to attach the digester to the gas collection system through the water displacement method. The volume of biogas was measured through the height displaced by the gas through the liquid column. The base area of gas collector and biogas volume was computed[2] using Eq. 1 and 2:

$$\text{Base area of gas collector} = \frac{\pi D^2}{4} \qquad (1)$$

where, D is diameter of gas holder.

$$\text{Biogas volume} = \text{Base area of gas collector} \times \text{Measurable height of gas collector} \qquad (2)$$

Slurry preparation: The substrates of poultry droppings mixed with plantain peels and poultry droppings only were mixed with distilled water using the ratio 1 kg of feedstock: 2 kg of water: 1 kg of plantain peels (1:2:1) in a reactor, since thermal pretreatment removes pathogen also improves dewatering performance and reduces viscosity of the digestate with sub-sequent enhancement of digestate handling, the slurry was thermally pretreated at temperature of 50°C. The pH of the slurry was checked in order to know the degree of acidity of the slurry. $NaOH_{(aq)}$ was added to the slurry of poultry droppings mixed with plantain peels to reduce its acidity from 5.4-7.21 and H_2SO_4 was added to the slurry of poultry droppings to increase the pH to 7.21 for neutral medium, to help organism adaptation during anaerobic digestion.

Experimental procedure: Before feeding the digester, the rubber hose connecting the gas outlet from the digester to the gas holder was disconnected, such that the gas outlet was left open. This was done to prevent negative pressure build up in the digester. The slurry was fed into the digester through the inlet and was sealed to prevent air from getting into the digester and gas from escaping[7]. The slurry was allowed to occupy two-third of the digester space leaving height of 29.1 cm as space for gas production. The slurry inflow was directed downward to cause the solids to accumulate at the bottom of the tank for easy removal after digestion. The contents of the digester were manually stirred daily through a stirrer attached to the digester for uniformity of the microbial activities in the digester daily at 9 am, 1 pm and 5 pm, respectively. The gas was collected through water displacement method and the fermentation process was monitored for 50 days. During this period, daily ambient, slurry, interface between slurry and gas and gas layer temperatures were monitored, the pH of the digestate and the height of the biogas holder were measured daily.

Desulphurification: The desulphurification tank contains activated carbon pellets and ferric chloride to selectively adsorb carbon dioxide and hydrogen sulfide from the biogas. Due to the percentage composition of CO_2 in biogas, it lowers the calorific value of biogas produced[8]. Biogas with reduced CO_2 content burn with a bright luminous flame[9]. Hence, the raw biogas collected was allowed to pass through a desulphurification tank so as to remove CO_2 and H_2S.

Correlation of temperature with biogas volume by RSM: Central Composite Optimal Design (CCOD) was employed to correlate the relationship among the temperatures and biogas volume. Five-level-four-factors (ambient, slurry, gas layer and interface temperatures) design was applied, the central point was increased by 2 step-lengths and the central point per groups was increased by a step length while the run per HTC axial group was also increased by 2 step length. Chosen alpha spherical 2 with K>5 = 1.41421 with face centered 1, 50 experimental runs were generated. This included 16 factorial points, 14 axial points and 20 central points to provide information regarding the interior of the experimental region, making it possible to evaluate the curvature effect. Selected factors for biogas volume relationship were ambient temperature, X_1 (T_{amb}), slurry temperature, X_2 (T_{slurry}), interface temperature, X_3 (T_{int}) and gas layer temperature, X_4 (T_{gL}). The quality of the fit of the model was evaluated using test of significance and analysis of variance (ANOVA). The fitted quadratic response model[2] is described by Eq. 3:

$$Y = b_0 + \sum_{i=1}^{k} b_i X_i + \sum_{i=1}^{k} b_{ii} X_i^2 + \sum_{i<j}^{k} b_{ij} X_i X_j + e \qquad (3)$$

where, Y is response factor (biogas volume), b_0 is the intercept value, b_i (i = 1, 2, k) is the first order model coefficient, b_{ij} is the interaction effect and b_{ii} represents the quadratic coefficients of X_i and e is the random error.

Chemical and proximate analyses of the digestates: Chemical and proximate compositional analysis of the substrate and digestate such as; ash content, carbon content, nitrogen content, calcium, pH, phosphorus, potassium and C/N ratio were carried out using method already adopted by Adepoju *et al.*[2] as described below:

- **Ash content (%):** An empty crucible was fire polished in a muffled furnace and allowed to cool in a desiccator containing calcium chloride for 20 min and then weighed. About 2.0 g of dried sample of digestate was weighed out into the crucible and transferred into a muffle furnace at 650°C for 3 h. The crucible was removed from the furnace, placed in desiccator and then allowed to cool and then re-weighed to get the final weight. The percentage of ash content of the sample was calculated using Eq. 4:

$$\text{Ash (\%)} = \frac{X-Y}{W}\times 100 \quad (4)$$

Where:

X = Weight of crucible+ash
Y = Weight of crucible
W = Weight of sample to be determined in grams before ashing

- **Phosphorus content:** About 5 mL aliquot of the soil extract was pipette into a 25 mL volumetric flask and distilled water of 10 mL was added. About 4 mL of reagent of phosphorus standard solution was added and made up to volume with distilled water. The blue colour was allowed to develop for 15 min and remain stable for 24 h. Phosphorus content in solution was then determined using Jenway Spectrophotometer at 660 µm
- **Kjeldahl nitrogen:** A representative sample was prepared and 1 g was weighed to an accuracy of 0.1 mg into a digestion tube. Two kjeltabs were added (5 g Na_2SO_4 and 1 g $CuSO_4.5H_2O$ and selenium). About 12 mL of concentrated H_2SO_4 was carefully added and shook to wet the acid with the sample. The exhaust system was attached to the digestion tubes in the rack and the water aspirator was set to full effect. The rack was loaded with exhaust into a preheated digestion block (420°C) and contained within the exhaust head. After 5 min, the water aspirator was turned down until the acid fumed. Digestion was continued until all samples were clear with a blue/green solution (normally after 30-60 min). The rack of tubes was removed with exhaust still in place and put in the stand to cool for 15 min. About 80 mL of de-ionized water was carefully added to the tubes. The steam valve on the kjeltec 1002 was opened and distilled for approximately 4 min. At the end of the distillation cycle the steam valve was closed and the distillate was titrated with standardized HCl until the blue/grey end point was achieved and the volume of acid consumed in the titration was recorded. Kjeldahl nitrogen was estimated using Eq. 5:

$$\text{Kjeldahl nitrogen (KN)} = \frac{(T-B)\times N\times 14,007\times 100}{\text{Weight of sample (mg)}} \quad (5)$$

Where:

T = Titration volume for sample (mL)
B = Titration volume for blank (mL)
N = Normality of acid to 4 places of decimal, M.W of Nitrogen. 14.007

- **Total alkalinity:** About 1 mL of the sample (digestate) was diluted with 9 mL of distilled water and then inserted into the tube-hole of the apparatus and covered. Blank test of distilled water was then run and total alkalinity was determined. This procedure was also used to determine ammonia nitrogen, total phosphate, total solids, aluminium, potassium, copper, iron, magnesium, calcium, zinc and Chemical Oxygen Demand (COD).

Statistical analysis

Statistical analysis by microsoft excel with linear regression and correlation: Microsoft Excel Version 2013 was used to plot the graphs of biogas volume against the period of digestion (50 days). Linear regression model and correlation was used to evaluate the regression parameters β0 (intercept) and β1 (slope), respectively and ANOVA table was prepared as earlier used by Adepoju *et al.*[2].

RESULTS AND DISCUSSION

Volume of biogas: Biogas production occurred in a constructed biogas plants called anaerobic digestion[10] and was measured for 50 days. In order to get a higher biogas yield, the substrate contained high quality and biodegradable organic matters from which methane concentration produced was in higher percentage[11]. The height of digester and biogas volume were measured daily in the afternoon. From Table 1, it was observed that the volume of biogas was slow at the beginning, increased on the 17th day and decreased on the 20th day and maintained a steady increase till the 35th day before maintaining a constant yield to the end of the digestion process in a batch anaerobic digestion. Biogas production rate in batch condition is directly proportional to specific growth rate of methanogenic bacteria in the bio-digester[12]. Observations show that, when plantain peels was mixed poultry droppings, the rate of biogas production was increased which agrees with previous studies[13-15].

Temperature variations and pH: The temperature variations for the morning, afternoon and evening of the fermentation process of poultry droppings mixed with plantain peels and poultry droppings without mixing with plantain peels. The

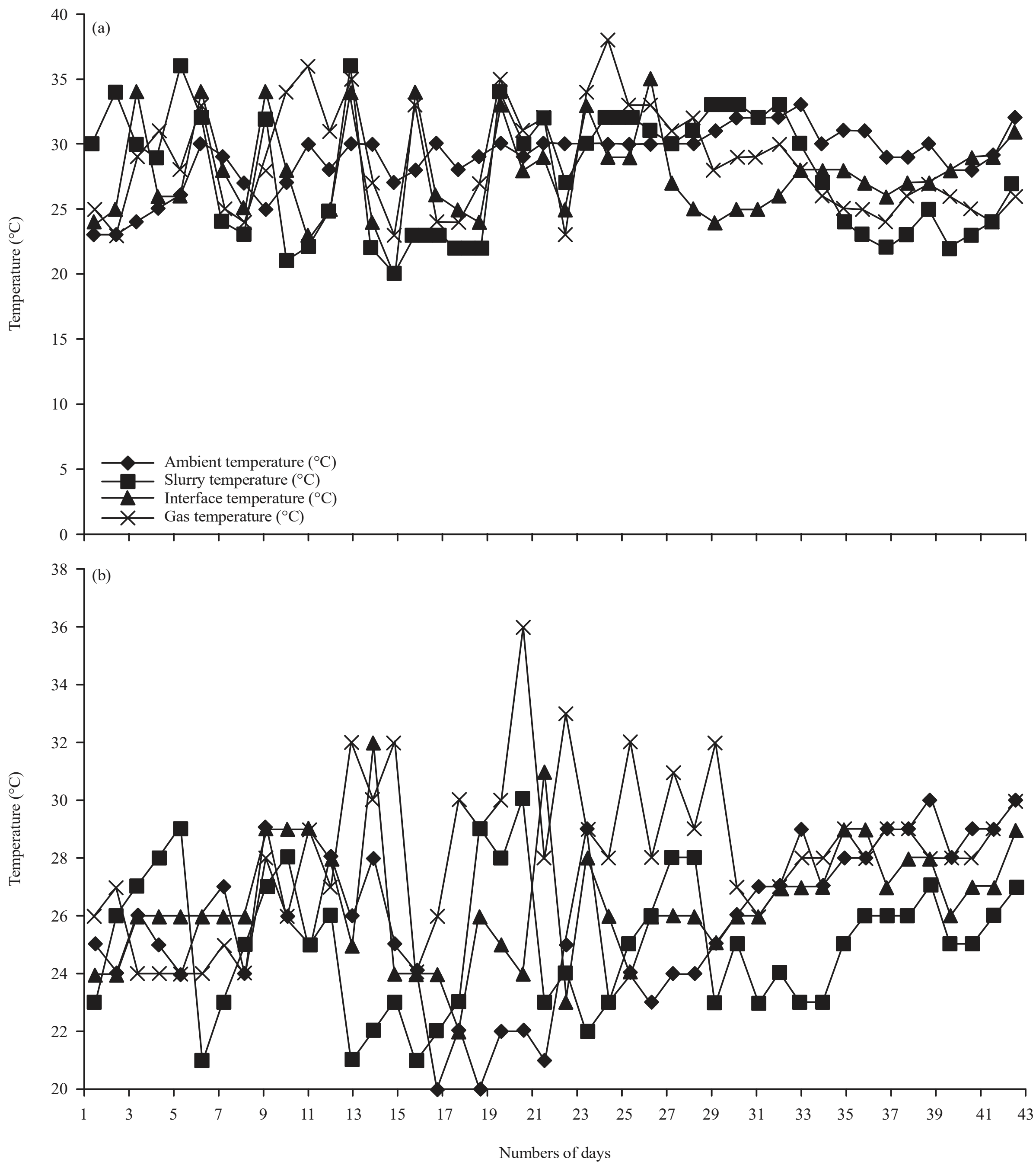

Fig. 1(a-b): Graph of temperature variations poultry droppings (a) Without plantain peels and (b) With plantain peels

plots of temperature versus days are shown in Fig. 1a, b. It was observed that throughout the duration of the digestion process, the temperature was found to be within the mesophilic range (30-40°C) and could be attributed to the weather conditions of the experiment area which encouraged digestion[13]. During the exponential growth phase period, the temperature of the ambient, slurry, interface and gas layer was found to be between 20-30, 18-29, 19-31 and 19-34°C, respectively. The plot of pH against the weeks of digestion process is shown in Fig. 2. The weekly pH recorded was found to vary erratically between the acidic to basic range[16], which was attributed to the nature of feed in the digester. pH of the digestion changes progressively from acidic to alkaline during the process of biogas production[13]. To maintain the C/N level of the digester, substrates of poultry droppings were mixed with plantain peels[17].

Table 1: Daily readings of biogas volume and height of digester

	Poultry droppings mixed with plantain peels		Poultry droppings	
Days	Height (m^2)	Biogas volume (m^2)×10^{-2}	Height (m^2)	Biogas volume (m^2)×10^{-2}
1	1.94	2.07	1.33	1.42
2	2.01	2.15	1.42	1.51
3	2.03	2.17	1.42	1.52
4	2.11	2.25	1.50	1.60
5	2.14	2.28	1.54	1.64
6	2.17	2.31	1.56	1.66
7	2.02	2.16	1.42	1.52
8	1.97	2.10	1.45	1.55
9	2.02	2.16	1.41	1.50
10	1.99	2.13	1.39	1.48
11	2.17	2.31	1.57	1.67
12	2.15	2.28	1.54	1.64
13	2.21	2.36	1.61	1.72
14	2.14	2.28	1.53	1.63
15	2.16	2.30	1.56	1.66
16	2.08	2.22	1.48	1.58
17	2.86	3.05	2.27	2.42
18	2.87	3.06	2.27	2.42
19	2.86	3.05	2.26	2.41
20	2.87	3.06	2.26	2.41
21	2.05	2.19	1.42	1.52
22	2.05	2.19	1.42	1.52
23	2.04	2.18	1.43	1.53
24	2.05	2.19	1.44	1.54
25	2.17	2.31	1.56	1.66
26	2.17	2.31	1.56	1.66
27	2.16	2.30	1.57	1.67
28	2.17	2.31	1.57	1.67
29	1.95	2.08	1.35	1.44
30	1.95	2.08	1.33	1.42
31	2.13	2.27	1.53	1.63
32	2.17	2.31	1.55	1.65
33	2.08	2.22	1.48	1.57
34	2.21	2.36	1.61	1.72
35	2.87	3.06	2.26	2.41
36	2.81	3.00	2.26	2.41
37	2.87	3.06	2.27	2.42
38	2.77	2.96	2.25	2.40
39	2.87	3.06	2.27	2.42
40	2.80	2.99	2.26	2.41
41	2.87	3.06	2.26	2.41
42	2.87	3.06	2.25	2.40
43	2.81	3.00	2.27	2.42
44	2.87	3.06	2.26	2.41
45	2.91	3.10	2.26	2.41
46	2.87	3.06	2.27	2.42
47	2.87	3.06	2.27	2.42
48	2.92	3.11	2.26	2.41
49	2.87	3.06	2.27	2.42
50	2.87	3.06	2.26	2.41

Table 2: ANOVA for linear regression model and correlation for poultry droppings mixed with plantain peels and poultry droppings

	df		Sum of square(10^{-4})		Mean square(10^{-4})		F-value		Prob>F
Source	PDPP	PD	PDPP	PD	PDPP	PD	PDPP	PD	PDPP and PD
Model	1	1	4.19	4.34	4.19	4.34	46.56	48	<0.0001
Error	48	48s	4.14	4.14	0.09	0.09			
Total	49	49	8.34	8.48					

ANOVA: Analysis of variance, df: Degree of freedom, PD: Poultry droppings, PDPP: Poultry droppings and plantain peels

Table 3: Test of significance for every regression coefficient

Source	Term df	Error df	F-value	p-value	
Whole-plot	2	4.94	1999.85	<0.0001	Significant
X_1	1	4.21	43.26	0.0023	
X_1^2	1	5.92	3962.87	<0.0001	
Subplot	12	24.20	458.65	<0.0001	Significant
X_2	1	27.15	0.4456	0.5101	
X_3	1	27.15	0.9296	0.3435	
X_4	1	27.15	32.61	<0.0001	
$X_1 X_2$	1	27.15	10.11	0.0037	
$X_1 X_3$	1	27.15	7.93	0.0090	
$X_1 X_4$	1	27.15	0.4043	0.5302	
$X_2 X_3$	1	27.15	0.6683	0.4207	
$X_2 X_4$	1	27.15	6.94	0.0138	
$X_3 X_4$	1	27.15	74.47	<0.0001	
X_2^2	1	24.84	2501.46	<0.0001	
X_3^2	1	24.84	1538.76	<0.0001	
X_4^2	1	24.84	1538.76	<0.0001	
Std. Dev.	0.0284		R^2	0.9967	
Mean	2.56		Adjusted R^2	0.9951	
CV (%)	1.11				

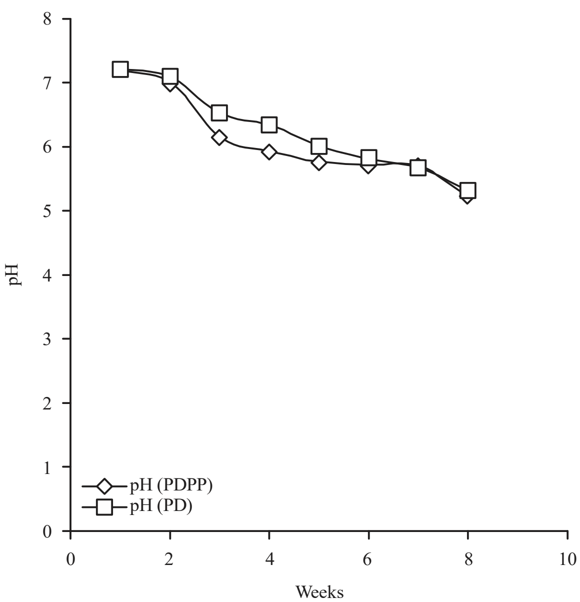

Fig. 2: Weekly pH of poultry droppings mixed plantain peels (PDPP) and poultry droppings (PD) against number of weeks of the digestion period

Statistical analysis

Statistical analysis of biogas produced using microsoft excel 2013: The statistical analysis results of linear regression model and correlation was carried out. The input model variable was the number of days while the output variable was the volume of biogas produced. Table 2 shows the Total Sum of the Square (SST) which is a measure of the total variability of the biogas volume of poultry droppings mixed with plantain peels and poultry droppings only, was obtained as 8.34 and 11.26×10^{-4}, the SSR called the regression sum of square, which measures the total variability of the fitted values was obtained as 4.19 and 4.33×10^{-4}. The Sum of Square Error (SSE) which is the measure of the unexplained variability was obtained as 4.14and 4.14×10^{-4}, respectively. To obtain the degree of freedom for the ANOVA, the parameters are the number of digesters while the number of experiments is the number of days for the digestion process. The probability values obtained are less than 0.05 which explains that the regression and correlation model terms are significant.

Statistical analysis by response surface methodology (RSM)

Statistical analysis of poultry droppings mixed with plantain peels: Design expert 12.0.3.1 software was employed to evaluate the coefficients of the full regression model equation and their statistical significance. Table 3 shows the test of significance for every regression coefficient. The results showed that the p-values of the model terms were significant, i.e., $p<0.05$. In this case, the two linear terms (X_1, X_4), the 4 cross-products (X_1X_2, X_1X_3, X_2X_4, X_3X_4) and the 4 quadratic terms (X_{12}, X_{22}, X_{32} and X_{42}) were all remarkably significant model terms at 95% confidence level except X_2, X_3, X_2X_3 and X_1X_4. However, all other model terms were more significant than X_2X_4. In order to minimize error, all the coefficients were considered in the design. The model F-value (subplot) of 458.65 with error df of 24.20 implied the model was significant. The data obtained fitted best to a quadratic model. It exhibited low standard deviation of 2.28×10^{-5} and high "R-squared" values. The coefficient of determination (R^2) was 99.67%, R-Sq. (adj.) was found to be 99.51% and all p-value coefficients were less than 0.1, which implied that the

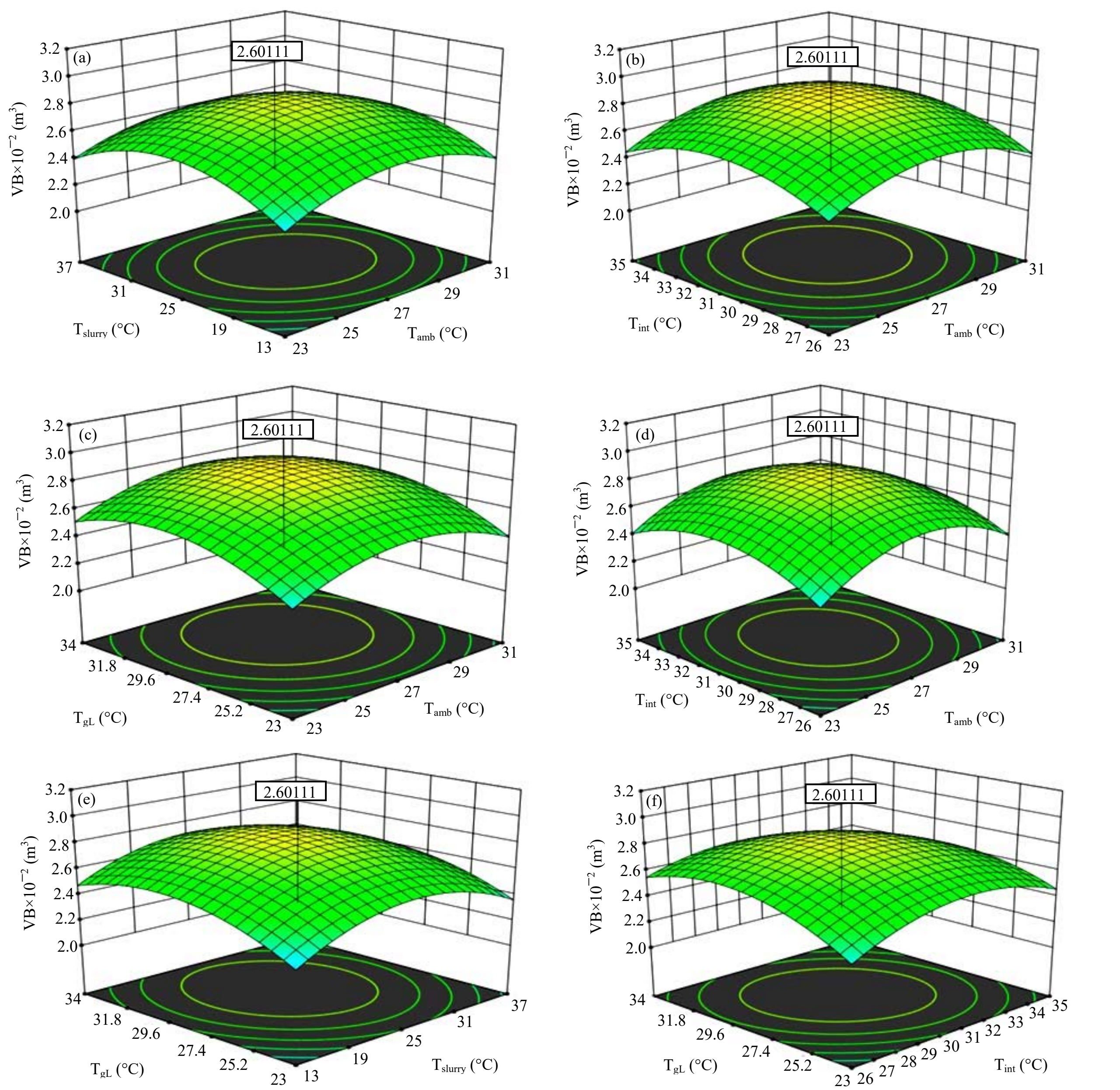

Fig. 3(a-f): (a-f)3-D's plots of the interaction between temperatures on volume of biogas produced of poultry droppings mixed with plantain peels

model proved suitable for the adequate representation of the actual relationship among the selected factors (Table 3). These values revealed that this regression was statistically significant, only 0.033% of total variations were not explained by this regression model. Meanwhile, the R^2 indicated a high consistency between the experimental values and the predicted values. The final equation was done in terms of actual factors for the central composite optimal design response surface quadratic model is expressed in Eq. 6:

$$Y \times 10^{-2}\ (m^3) = \begin{bmatrix} -23.08531 + 0.658030X_1 + 0.107524X_2 + \\ 0.618295X_3 + 0.440287X_4 \\ -0.000456X_1X_2 + 0.001076X_1X_3 + \\ 0.000199X_1X_4 - 0.000104X_2X_3 \\ -0.000275X_2X_4 - 0.002399X_3X_4 - \\ 0.012542X_1^2 - 0.001691X_2^2 \\ -0.009429X_3^2 - 0.006312X_2^2 \end{bmatrix} \quad (6)$$

Graph can provide a kind of visual method to observe responsive value and to test parameter level relation. Figure 3 shows the contour and the 3-dimensional response surface

Table 4: Test of significance for every regression coefficient

Source	Term df	Error df	F-value	p-value	
Whole-plot	2	8.03	23648.14	<0.0001	Significant
X_1	1	7.30	553.22	<0.0001	
X_1^2	1	8.90	46760.63	<0.0001	
Subplot	12	27.71	5160.50	<0.0001	Significant
X_2	1	30.20	1.27	0.2677	
X_3	1	30.20	38.57	<0.0001	
X_4	1	30.20	674.43	<0.0001	
$X_1 X_2$	1	30.20	231.40	<0.0001	
$X_1 X_3$	1	30.20	80.80	<0.0001	
$X_1 X_4$	1	30.20	0.4781	0.4946	
$X_2 X_3$	1	30.20	5.893E-29	1.0000	
$X_2 X_4$	1	30.20	68.85	<0.0001	
$X_3 X_4$	1	30.20	883.99	<0.0001	
X_2^2	1	25.03	32938.41	<0.0001	
X_3^2	1	25.03	20340.21	<0.0001	
X_4^2	1	25.03	20077.09	<0.0001	
Std. Dev.	0.0078		R^2	0.9998	
Mean	1.92		Adjusted R^2	0.9997	
CV (%)	0.4048				

plots representing the effect of ambient temperature (T_{amb}), slurry temperature (T_{slurry}), interface temperature (T_{int}) and gas layer temperature (T_{gL}) on volume of biogas produced. The results showed that there were perfect interactions between the selected variables and the volume of biogas obtained. However, the mutual effects noticed between the slurry temperature with ambient temperature (Fig. 3a) and interface temperature with slurry temperature (Fig. 3d) indicated the superiority effects over other factors considered for biogas production. The low interactions observed between gas layer temperature with interface temperature (Fig. 3f) and interface temperature with ambient temperature (Fig. 3b) are far better than that noticed between gas layer temperature with slurry temperature (Fig. 3e) and gas layer temperature and ambient temperature (Fig. 3c). It was also observed that the highest biogas volume obtained was 3.11×10^{-2} m^3/day at ambient temperature of 27°C, slurry temperature of 25°C, interface temperature of 30.5°C and gas layer temperature of 28.5°C, respectively. However, statistical analysis by response surface methodology predicted a biogas volume of 3.05×10^{-2} m^3/day at the same temperatures. The predicted value was validated and the average optimum biogas volume was 2.60×10^{-2} m^3/day at ambient temperature of 24.18°C, slurry temperature of 17.57°C, interface temperature of 27.25°C and gas layer temperature of 25.02°C, respectively, which was well within the range predicted.

Statistical analysis of poultry droppings: Design Expert 12.0.3.1 software was employed to evaluate and determine the coefficients of the full regression model equation and their statistical significance. Table 4 shows the test of significance for every regression coefficient. The results showed that the p-values of the model terms were significant, with p<0.05. In this case, the three linear terms (X_1, X_3, X_4), the 4 cross-products (X_1X_2, X_1X_3, X_2X_4, X_3X_4) and the four quadratic terms (X_{12}, X_{22}, X_{32} and X_{42}) were all remarkably significant model terms at 95% confidence level except for X_2, X_2X_3 and X_1X_4 that were non significant with very low F-value. However, X_1^2 with the highest F-model = 46760.30 is the most significant model term but all other model terms were more significant than X_3 with F-model value = 38.57. In order to minimize error, all the coefficients were considered in the design. The model F-value (subplot) of 5160.50 with error df of 27.71 implied the model was significant. The data obtained fitted best to a quadratic model. It exhibited low standard deviation of 0.0078 and high "R-Squared" values. The coefficient of determination (R^2) was 99.98% while the R-Sq. (adj.) was found to be 99.97% and all p-value coefficients were less than 0.1, which implied that the model proved suitable for the adequate representation of the actual relationship among the selected factors. These values revealed that this regression was statistically significant, only 0.02% of total variations were not explained by this regression model. Meanwhile, the R^2 indicated a high consistency between the experimental values and the predicted values. The final equation in terms of actual factors for the central composite optimal design response surface quadratic model is expressed in Eq. 7:

$$Y\times10^{-2}\ (m^3)=\begin{bmatrix} -25.24207+0.901922X_1+0.361055X_2+ \\ 0.398216X_3+0.299190X_4 \\ -0.001209X_1X_2+0.000844X_1X_3+ \\ 0.000051X_1X_4-1.52896E-16X_2X_3 \\ -0.000330X_2X_4-0.001396X_3X_4- \\ 0.016655X_1^2-0.005801X_2^2 \\ -0.006367X_3^2-0.003905X_2^2 \end{bmatrix} \quad (7)$$

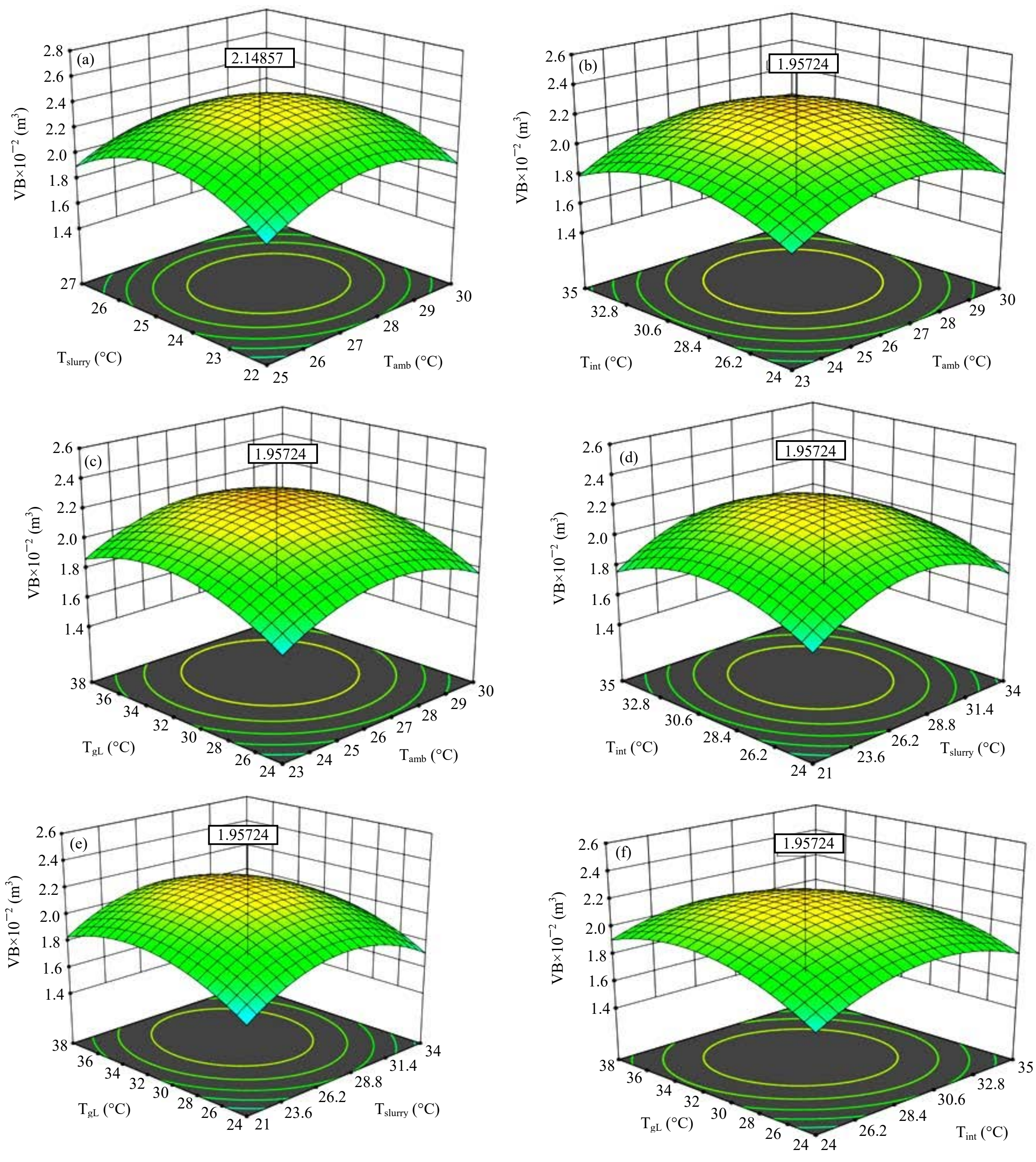

Fig. 4(a-f): (a-f)3-D's plots of the interaction between temperatures and volume of biogas produced from poultry droppings

Table 5: Chemical and proximate analysis of the digestate

Digestates	pH	C (mg/LC)	N (mg/LN)	C/N	P (mg/LP)	K (mg/LK)	Ca (mg/LCa)	Ash (%)
PDPP	7.92	72.01	6.23	4.8:1	32.41	4.51	34.02	24
PD	7.85	70.11	6.01	4.8:1	29.57	4.31	32.23	22

PDPP: Poultry droppings mixed with plantain peels, PD: Poultry droppings, K: Potassium, N: Nitrogen, C: Carbon, C/N: Carbon: Nitrogen, Ca: Calcium, N: Nitrogen, P: Phosphorous

A graph can provide a kind of visual method to observe responsive value and to test parameter level relation. Figure 4 shows the contour and the 3-dimensional response surface plots representing the effect of interaction of the ambient temperature (T_{amb}), slurry temperature (T_{slurry}), interface temperature (T_{int}) and gas layer temperature (T_{gL}) on volume of biogas produced. The results showed that there were perfect interactions between the selected variables and the volume of biogas obtained. However, the mutual effects noticed between the slurry temperature with gas layer temperature (Fig. 4e), interface temperature with ambient temperature (Fig. 4b) and slurry temperature with ambient temperature (Fig. 4a) proved the superiority effects over other interactive factors considered for biogas production. The slight interactive effects observed between ambient temperature with gas layer temperature (Fig. 4c), interface temperature with slurry temperature (Fig. 4d) and gas layer temperature with interface temperature (Fig. 4f) showed the lesser interaction when compare with the corresponding counterpart. It was also observed that the highest biogas volume obtained was 2.42×10^{-2} m^3/day at ambient temperature of 26.5°C, slurry temperature of 27.5°C, interface temperature of 29.5°C and gas layer temperature of 31°C, respectively. However, statistical analysis by response surface methodology predicted a biogas volume of 2.41×10^{-2} m^3/day at the same temperatures. The predicted value was validated and the average optimum biogas volume was obtained as 1.96×10^{-2} m^3/day at ambient temperature of 24.10°C, slurry temperature 23.46°C, interface temperature of 25.51°C and gas layer temperature of 26.57°C, respectively, which was well within the range predicted.

Chemical and proximate analysis of the digestate for PDPP and PD: Table 5 shows the chemical and proximate analysis of the digestates after the anaerobic digestion shows the percentage variation. Chemical and proximate analyses were determined using a digital photometer. An effective way of finding the availability of the amount of nutrients accessible for bacterial action during digestion is through the determination of the total solids of the wastes. Poultry droppings have a higher potential for organic manure compared with plantain peels because of its higher ash content. However the high values of nitrogen, phosphorus and potassium in the digestate indicates that the end product is useful for fertilizer application. The weight sample of 0.165 g of the digestate for each of the digester was used in the determination of the proximate analysis results. From the results, it was observed that the digestate of poultry droppings mixed with plantain peels has the highest value of pH, C, N, C/N, P, K and ash content compared with when it was not mixed with plantain peels. The values of NPK from the digestate of poultry droppings mixed with plantain peels and poultry droppings without mixing with plantain peels 6.23, 32.41, 4.51 mg L^{-1} and 6.01, 29.57, 4.31 mg L^{-1}, respectively which makes it applicable for fertilizer applications and agrees with previous study[15]. Reduction of size of the plantain peels helps the digestion rate to be faster[18] and was within the mesophilic temperature range that required for biogas generation[2].

CONCLUSION

Biogas production from poultry droppings mixed with plantain peels and poultry droppings only and their statistical analysis were carried out. The highest experimental daily biogas volume was obtained on the eighteenth day (18th day) of the digestion process.

The temperatures of the slurry, ambient, interface and gas layer measured during the fermentation period were within the mesophilic temperature ranges (30-40°C). Chemical and proximate analysis of the digestate shows that poultry droppings mixed with plantain peels and poultry droppings only improved organic manure for agricultural production. Chicken droppings should be acquired in a place free of dirt to avoid delay in purification.

SIGNIFICANCE STATEMENT

This study discovered the effectiveness of animal waste in biogas generation that can be beneficial for renewable energy production. This study will help the researchers to uncover the critical areas of making use of chicken droppings as aids for methane generation that many researchers were not able to explore. Thus a new theory on efficiency of response surface methodology for the statistical analysis of poultry droppings mixed with plantain peels for the optimum biogas production was arrived at.

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