



## Research article

## Optimization of biogas yield from anaerobic co-digestion of corn-chaff and cow dung digestate: RSM and python approach

Sunday Chukwuka Iweka<sup>a,\*</sup>, K.C. Owuama<sup>b</sup>, J.L. Chukwuneke<sup>c</sup>, O.A. Falowo<sup>d</sup><sup>a</sup> Department of Mechanical Engineering, Delta State University of Science and Technology, Ozoro, Nigeria<sup>b</sup> Department of Mechanical Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Nigeria<sup>c</sup> Department of Mechanical Engineering, Nnamdi Azikiwe University, Awka, Nigeria<sup>d</sup> Department of Chemical Engineering, Landmark University, Omu-Aran, Nigeria

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## ABSTRACT

The utilization of various feedstocks of unique characteristics in producing biogas could potentially enhance the application of clean fuel from biomass wastes. Two modelling tools were used to explore biogas production from plant and animal wastes. In this study, corn chaff was inoculated with cow dung digestate using different mixing ratios of substrate/inoculum (S/I) of 1:1, 1:1.55, and 1:3.5 for hydraulic retention time (HRT) of 25, 31, and 37 days as modelled using Central Composite Design (Face Centered Design) to optimize the process and predict the optimal response. The result shows that the mixture ratio of 1:1.55 for 37 days gave a cumulative highest biogas yield of 6.19 L under mesophilic conditions. The model p-value is <0.0001, an indication that the model term is significant. The python coding of the input factors gave the optimal value of 4.71 L, which is similar to the result obtained via CCD. Thus, both CCD (Face Centered Design) and python coding are reliable in the optimization of biogas production as they both predicted the same optimal values and approximately the same highest cumulative biogas yield. The GC-MS characterization of produced biogas revealed that it contains 68% methane and 22.76% CO<sub>2</sub>. Other constituents present are confirmed by FTIR analysis results. The methane in produced biogas has a flashpoint of -182 °C, which is extremely flammable. This data shows that both CCD and python coding can model biogas production with high accuracy and biogas produced can be used for heating purposes.

## 1. Introduction

Anaerobic digestion of organic biomass and wastes is an alternative process to ensure continuity of energy supply, and this has attracted enormous attention due to its ability to reduce greenhouse gas emissions. The biogas produced from this process is a good energy source that could replace fossil fuels in the generation of heat and power (Weiland, 2010). Biogas is a biofuel produced from the decomposition or fermentation of organic materials from plant and animal waste in an anaerobic digester (Iweka et al., 2019). There are two main functions of the biogas production system; these are the digestion of organic matter into biogas and subsequent use of biofuel produced for energy generation (Bacchetti et al., 2013). In the wastewater treatment plant, utilizing the energy produced from the anaerobic digestion process could offset a large part of the energy required for its operation (Papadias et al., 2012). Besides the use of biogas for thermal generation, it could be upgraded into biomethane (Bacchetti et al., 2013).

Energy input from single and multiple feedstocks used for biogas production has been evaluated, while the characteristics of the feedstock used highly influence the energy produced (Pöschl et al., 2010). In the operation of a digester to produce biogas, different feedstocks applicable in different countries or regions are used. Many of these feedstocks cannot produce the required biogas due to their characteristics. Digestion of a single feedstock such as animal manure can be difficult due to its particular physical properties or chemical content. As a result, different forms of feedstock are co-digested to produce biogas. For example, some biogas plants are installed to co-digest agricultural residues with industrial waste and municipal solid waste (Pöschl et al., 2010). Co-digestion of different feedstocks has the following benefits: organic matter stabilization, energy generation, and methane emission reduction during storage (Bacchetti et al., 2013).

Anaerobic degradation involves microorganisms acting through a series of fermentation processes to hydrolyse solid residues to produce simpler organic acids which are subsequently digested to yield acetic acid

\* Corresponding author.

E-mail address: [chukaiweka@yahoo.com](mailto:chukaiweka@yahoo.com) (S.C. Iweka).

as well as H<sub>2</sub> and CO<sub>2</sub>. Methanogenic bacteria are involved in the last stage of the fermentation by splitting acetic acid to form methane and CO<sub>2</sub> (Pöschl et al., 2010).

Generally, animal manure has been the most commonly used substrate for biogas production from anaerobic processes. However, it is not economically viable since the biogas yield from the process is low (Jingura and Matengaifa, 2009). The cow dung digestate discharged from a digester contains about 1–12% solids and consists of refractory organics, new cells formed during digestion, and ash (Mukhuba et al., 2018; Okolie et al., 2018). The slurry can be used in its liquid or solid fractions, dried, or as total slurry.

Agricultural wastes are non-product materials from the processing of agricultural products which are economically considered to have little or no value. The generation of agricultural waste in Nigeria is worrisome and there is no adequate data to capture the lifecycle assessment of these wastes. Many of these wastes are environmental irritants, and some of them have recently been used in biofuel production, either in catalyst development (Falowo et al., 2020) or biogas generation (Dahunsi et al., 2019a). The biogas potential of the organic wastes in Nigeria was estimated and could contribute substantially to substantial energy and bio-fertilizer for domestic purposes (Ngumah et al., 2013). Agricultural waste could be used alone in anaerobic digestion or co-digestion with other animal manure. Biogas has been produced from a mixture of plantain, cassava, and pineapple peels (Ilaboya et al., 2010). Most agricultural wastes are lignocellulosic materials, and their structure and composition make them unsuitable as feedstock for anaerobic digestion (Dahunsi, 2019). The structure and composition of lignocellulosic materials could limit the effectiveness of the digestion, hence the need to pretreat them before they can be fed into the digester for hydrolysis. The organic waste from animals is biodegradable. The co-digestion of different feedstocks in a single digester is advantageous due to the easiness of adjusting the C/N ratio, thereby increasing the methane production yield (Yong et al., 2015).

Some of the factors affecting the biogas amount have been investigated (Dahunsi et al., 2016). Generally, factors such as digester temperature, retention time, fermentation pH value, digester pressure, volatile fatty acid, and sublayer composition have been identified to affect the digestion of feedstock in the anaerobic process (Dobre et al., 2014). Other factors, such as agitation rate, additives, toxicity, loading rate, and dilution ratio (Mahanta et al., 2005). Therefore, it is essential to regulate all influencing factors suitably for the process to operate optimally. Artificial neural networks (ANN) coupled with genetic algorithms (GA) were previously used to model and optimize biogas production from poultry droppings (Oloko-Oba et al., 2018), mixed substrate (Kana et al., 2012), organic waste (Qdais et al., 2010), and slurry (Dach et al., 2016). In addition, biogas production has been modelled and optimized using response surface methodology (RSM). The optimization of biogas yield from banana pseudo-stem fibre (Pei et al., 2014), mixed canola residues with cattle manure (Safari et al., 2018), poultry manure (Yilmaz and Şahan, 2020) were carried out using RSM. Dahunsi et al. (2016) modelled and optimized biogas production using both ANN and CCRD of RSM. Python is an interactive programming language with simple and elegant syntax, yet powerful. It contains an extension module for the parallel manipulation of numerical data (Sanner, 1999). Besides, python as an algorithm tool can predict a precise numeric value for biogas yield. For example, it has been applied to model production data from Chinese biogas plants to enhance their performance (De Clercq et al., 2019).

The focus of this study is to optimize biogas production from biomass wastes through anaerobic digestion using CCD of RSM, and python coding, a predictive model tool. Hence, the feasibility of using corn chaff inoculated with cow dung digestate under mesophilic conditions was investigated via CCD and python package to model the mixing ratio and HRT of the anaerobic process. This study will help facility operators of biogas facilities to facilitate their decision-making process if the predictive model obtained can be integrated into their operation.

## 2. Materials and methods

### 2.1. Collection of inoculums

The inoculum used in this study was collected from the digestate of a running biogas digester at Obafemi Awolowo University (OAU) Ile-Ife using cow dung as feedstock. After collection, it was immediately transported to the biochemical engineering laboratory at OAU, where the VS and TS analysis were carried out.

### 2.2. Preparation of biomass

To establish the relationship between the chemical composition of different corn chaffs and their biogas yield potential, two commonly available corn chaffs were selected; the Native corn chaff and the Agric corn chaff. The local pap producer from Delta State, Nigeria, collected all of the corn chaffs. The collected corn chaffs were washed, dried, and reduced to a mesh size of 200. Thereafter, the corn chaffs were refrigerated for one day at refrigeration temperature to remove background methane. Then total solid TS and volatile solid VS were calculated using standard methods. APHA, 2005.

### 2.3. Method for calculating TS and VS

The total solid and volatile solid amounts of the selected feedstocks were analysed using standard methods (APHA 2005). The substrate TS was determined by measuring the weight difference of a sample placed in an oven at 105 °C for 24 h. The weight before and after the sample was oven-drying was measured. The sample was kept in a desiccator after withdrawal to prevent the absorption of moisture while the crucibles cooled. The VS of the samples was determined in a muffle furnace at 550 °C for hours. The TS and VS experiments were determined in triplicate. The substrate slurry was prepared according to the mixing ratio generated by CCD modeling.

#### 2.3.1. Volatile solids, and total solids for the experiment

Please refer Table 1 under section 2.3.1.

### 2.4. The digester and experimental procedure

The digestion experiment for this study was carried out in an air-tight glass digester of a volume of 256 mL with butyl rubber stoppers. The reactors were airtight with loading openings, sample withdrawal on the butyl rubber outlet, and an automated agitation mechanism. The digestion process was operated and maintained between the temperatures of 25–33 °C, and the biogas yield was measured in pressure (mbar) and subsequently converted to volume (litres). The cumulative volume of biogas generated in the glass reactor was measured in regular intervals using a gas pressure build-up detector device.

The corn chaff (substrate) and digestate (inoculum) were loaded into the digester in various ratios to occupy 55% of the total digester volume, leaving enough space for the biogas to build up. The batch digester was operated under mesophilic conditions, and the biogas volume produced from the digestion process was measured every 24-hour interval by a gas pressure build-up detector device.

### 2.5. Characterization of biogas produced

Chromatography analysis of the biogas produced was done using a Varian 3800/4000 gas chromatograph/mass spectrometer (Agilent Technologies, USA), with nitrogen as the gas carrier at a constant pressure of 100 kpa and a flow rate of 20 mL/min, equipped with an Agilent column, an HP-5MS capillary column (30 m 0.25 mm 0.25 m ID) and a thermal conductivity detector (TCD). The temperature of the injector, column oven, and detector were 120 °C, 120 °C, and 160 °C respectively, at a rate of 10 °C/min increase. The injection port temperature was at

**Table 1.** Volatile solids, and Total solids for the experiment.

Crucible Name	Crucible (g) (P)	C + S (wet) (g) (Q)	C + S (dried) 105 °C (R)	C + Ash (g) (550 °C) (S)	TS g/kg wet (T)	Ash g/kg wet (U)	VS g/kg Wet (T- U)
1	Cow dung digestate Inoculum						
4C	36.3014	86.8697	42.1664	38.1878	115.98	37.30	78.68
4B	34.4249	81.0610	38.9154	36.2087	96.29	38.25	58.04
1B	34.7634	80.6443	39.1077	36.4548	94.69	36.87	57.82
<b>A<sub>v</sub></b>					<b>102.32</b>	<b>37.47</b>	<b>64.85</b>
2	Corn chaff (Native)						
15	79.3406	129.3656	95.2369	79.7934	317.77	9.05	308.72
11	89.1688	141.9350	106.3921	89.5663	326.41	7.53	318.87
3	92.0314	146.1857	109.8607	92.7760	329.46	13.75	315.46
<b>D<sub>v</sub></b>					<b>324.46</b>	<b>10.11</b>	<b>314.35</b>
4	Agric (Foreign) corn chaff ( <b>not recommended</b> )						
1	34.7813	79.6412	49.5285	37.6103	328.74	63.06	265.68
7A	33.9493	71.6852	46.3328	36.1750	328.16	58.98	269.18
1C	37.0766	69.6269	47.7724	38.8340	328.59	53.99	274.60
<b>q<sub>v</sub></b>					<b>328.50</b>	<b>58.68</b>	<b>269.82</b>

**Table 2.** Physicochemical constituents of prepared slurry.

Parameters	TS (g/kg)	VS (g/kg)	C/N	pH	Temperature (°C)	Ash weight (g/kg)	Moisture content (%)
Slurry	S/I 1:1						
Value	293.64	268.5	23:1	7.95	33	47.7	89.4
Slurry	S/I 1:1.55						
Value	273.34	239.7	21.5	7.97	31	48.43	90.4
Slurry	S/I 1:3.5						
Value	225	208	20.7	8.1	30	43	90.6

250 °C. Calibration was done using standard methane concentrations of 100, 300, and 10 000 ppm respectively, and 500 ppm carbon dioxide gas. The samples dissolved in chloroform were run fully at a range of 60–550 amu and the results were compared by using the NIST 10<sup>7</sup> Spectral library search program.

After the instrument was warmed up for 30 min, the sample button was pressed to determine the composition of methane. Before the gas was charged to the GC-MS, water was removed in a cold trap because the presence of water disturbed the measurement and affected its accuracy.

The Fourier-transform infrared spectroscopy (FTIR) of produced biogas was analysed using a spectrophotometer (Shimadzu IR affinity-1). The flashpoint test of the produced biogas sample was carried out as described by Odejobi et al. (2016). The biogas sample was ignited to determine the temperature it generates flame. The time taken in relation to the calorific value of the biogas was recorded (Alfa et al., 2014; Dahunsi et al., 2019b).

### 3. Results and discussion

#### 3.1. Physical and chemical constituents of inoculum, substrate, and slurry

The pre-digestion analysis of the inoculum showed the physico-chemical constituent to have total solids (TS) of 102.32 g/kg, ash weight of 37.47 g/kg, moisture content of 91.42%, and volatile solids (VS) of 64.85 g/kg. The pH of the inoculum used was 7.82.

The physicochemical analysis of the two corn chaffs used in this study revealed that native corn chaff has total solids of 324.46 g/kg, an ash weight of 10.11 g/kg, and volatile solids of 314.35 g/kg, while Agric corn chaff has total solids of 328.50 g/kg, an ash weight of 58.68 g/kg, and volatile solids of 269.82 g/kg. Considering this result, there is not much difference in the value of the total solids of both corn chaffs. However, the volatile solids in the native corn chaff are

significantly higher than that of the cultivated corn chaff. Hence, the native corn chaff was adopted and used for further study, as shown in Table 1.

The physicochemical characteristics of the prepared slurry were presented in Table 2. Before the co-digestion of corn chaff inoculated with cow dung digestate, the TS, VS, carbon/Nitrogen (C/N) ratio, pH, slurry temperature, ash weight, and moisture content were determined.

#### 3.2. Anaerobic co-digestion of corn chaff and cow dung digestate modeling results

In this study, a face-centered design of CCD was employed to model and optimize the anaerobic digestion of corn chaff aided with cow dung

**Table 3.** Corn chaff with Cow Dung Digestate Inoculum.

Run	A: Mixing ratio	B: HRT (days)	Cumulative biogas yield (L)
1	1	31	2.3776
2	0.3	31	4.0124
3	0.65	31	4.7455
4	0.65	31	4.8888
5	0.3	25	3.7122
6	0.65	31	4.6913
7	0.3	37	5.0884
8	0.65	31	4.5865
9	1	25	0.6542
10	0.65	31	4.7565
11	0.65	25	3.5523
12	1	37	4.5342
13	0.65	37	6.1883

**Table 4.** ANOVA Results of Corn chaff digestate Digestion.

Source	Sum of Square	Df	Mean Square	F-value	p-value
Model	22.79	5	4.56	414.82	<0.0001
A-Mixing ratio	4.59	1	4.59	417.77	<0.0001
B- HRT	10.38	1	10.38	944.82	<0.0001
AB	1.57	1	1.57	142.64	<0.0001
A <sup>2</sup>	5.88	1	5.88	535.09	<0.0001
B <sup>2</sup>	0.1298	1	0.1298	11.81	0.0109
Residual	0.0769	7	0.0110	-	-
Lack of Fit	0.0287	3	0.0096	0.7951	0.5571
Pure Error	0.0482	4	0.0120		
Cor Total	22.87	12			

**Table 5.** Model fitness parameters.

Parameters	value
Std. deviation.	0.1048
Mean	4.14
C.V%	2.53
R <sup>2</sup>	0.9966
Adjusted R <sup>2</sup>	0.9942
Predicted R <sup>2</sup>	0.9869
Adequate Precision	78.5032

digestate. Two factors investigated are the mixing ratio of substrate to inoculum (S/I) and hydraulic retention time (HRT). Thirteen (13) experimental runs were generated at different operating conditions of S/I and HRT but maintained at a mesophilic temperature range of 25–33 °C. The cumulative biogas yields produced for each operating condition are presented in Table 3.

From the results, the mixing ratio of substrate to ratio (1:1.55) and HRT of 37 days gave the highest cumulative biogas yield while the lowest cumulative biogas yield was generated at the substrate to inoculum ratio (1:1) and 25 days HRT. Having a considerable amount of inoculum to substrate at a longer HRT could be responsible for the large biogas produced in this study. The Analysis of Variance (ANOVA) of anaerobic digestion of corn chaff inoculated with cow dung digestate was presented in Table 4.

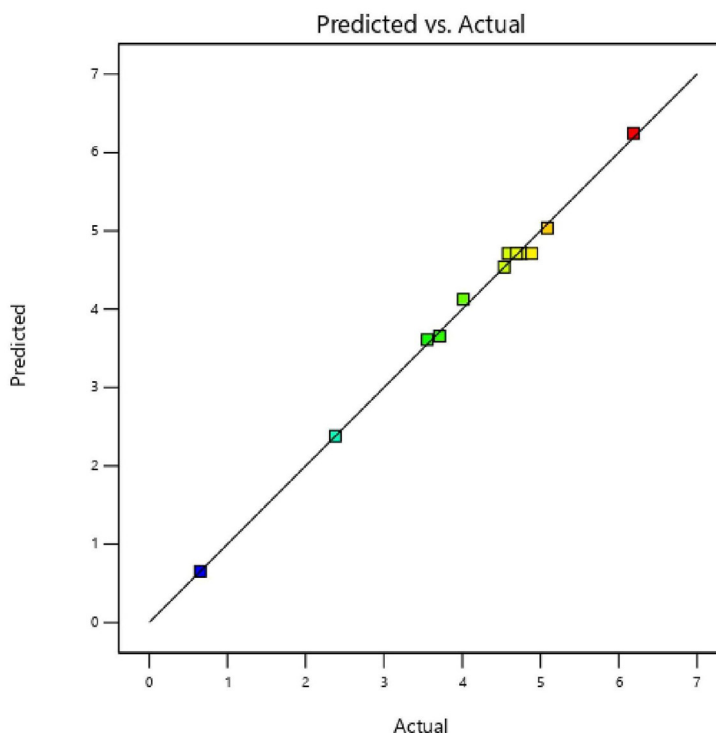
The model employed for this process is significant with a p-value < 0.0001. From Table 4, generally, p-values less than 0.0500 mean that the represented terms are significant, while the p-value of a model term greater than 0.05 indicates insignificance. In this case, A, B, AB, A<sup>2</sup>, B<sup>2</sup> are significant model terms. The F-value of 0.80 implies the lack of fit is not significant relative to the pure error. There is a 55.71% chance that a lack of Fit F-value this large could occur due to noise. A non-significant lack of fit is good because it indicates the model's fitness in describing this process (Falowo et al., 2019).

The estimated statistical parameters that determine the fitness of the model are shown in Table 4. The R<sup>2</sup>, Adjusted R<sup>2</sup>, and Predicted R<sup>2</sup> are close to 1, an indication that the experimental results obtained are reliable and consistent. The coefficient of determination (R<sup>2</sup>) of 0.9966 indicates that the obtained model can explain 99.66% of the variability observed in the model response, which further affirmed the reliability of the results. The predicted R<sup>2</sup> of 0.9869 is in reasonable agreement with the adjusted R<sup>2</sup> of 0.9942, with the difference between these parameters being less than 0.2. Moreover, an adequate precision of 78.50 implies that the model has enough signals to navigate design space since the value obtained in this study is greater than 4 as shown in Table 5.

The regression equation in terms of coded factors is developed to establish a mathematical relationship between the response of anaerobic digestion (biogas amount) and two independent process variables as represented in Eq. (1).

**Cumulative Biogas Yield**

Color points by value of Cumulative Biogas Yield:  
0.6542  6.1883



**Figure 1.** Plot of predicted response against actual biogas yields.

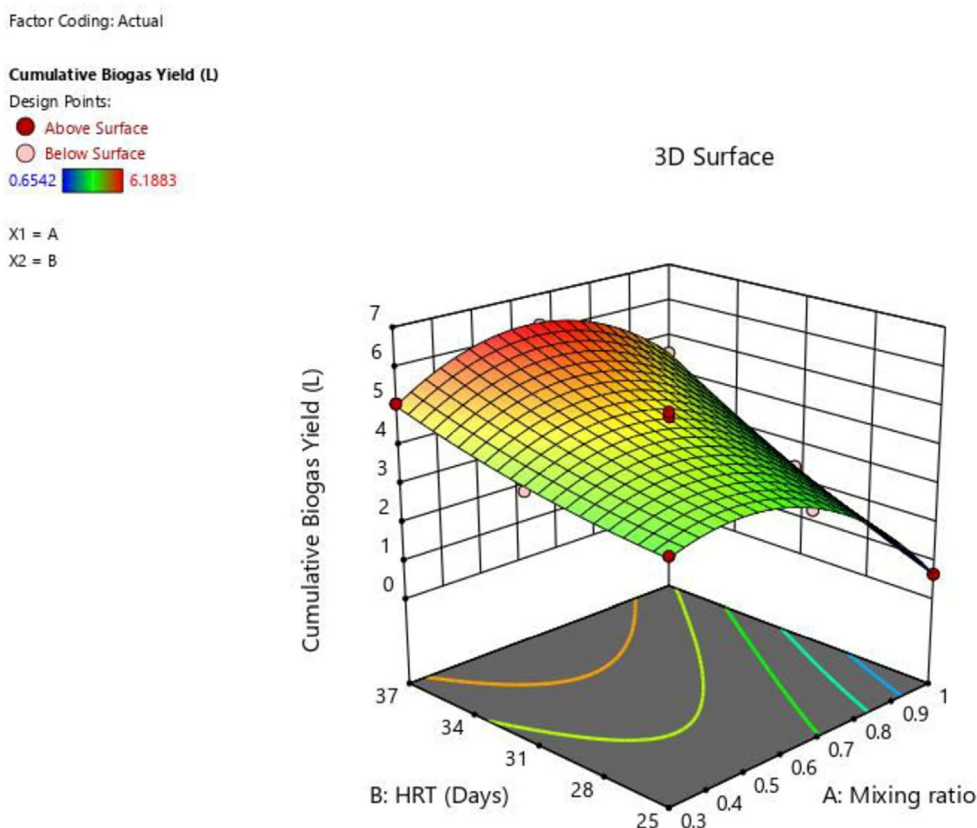


Figure 2. Three-dimensional plot of cumulative biogas yield against mixing ratio, and HRT.

$$CBY(L) = + 4.71 - 0.8747A + 1.32B + 0.6260AB - 1.46A^2 + 0.2168B^2 \quad (1)$$

where CBY is the cumulative biogas yield, A is the mixing ratio of substrate to inoculum, and B is the hydraulic retention time. This equation can be used to make predictions about the response to a given level of each factor.

The plot of predicted against the actual value of biogas yield is depicted in Figure 1. All the data points are either on or close to the line of fitness. This further supports the high R<sup>2</sup> obtained for this model. The three-dimensional plot of cumulative biogas volume against the mixing

ratio and HRT is depicted in Figure 2. The mixing ratio significantly affects the overall biogas yield, as revealed by ANOVA results.

An increase in the mixing ratio was observed to increase the biogas yield. However, a further increase in the mixing ratio to S/I (1:3.5) leads to a sharp reduction in the cumulative biogas yield. Similarly, the cumulative biogas volume increases with an increase in HRT. Though the increase is marginal, the highest biogas yield was obtained at the highest HRT as shown in Figure 2. Increasing both the mixing ratio and HRT enhances biogas production until the cumulative biogas yield declines. It can be observed from the result that S/I (1:3.5) negatively affect biogas production. This effect might be the determinant factor when both factors are at the highest level. The contour plot showing the mixing ratio and HRT with corresponding cumulative biogas yield is shown in

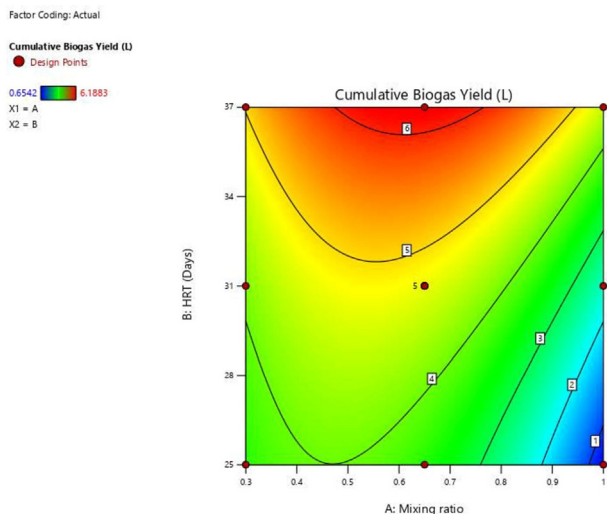


Figure 3. Contour plot of cumulative biogas yield against mixing ratio and HRT.

Table 6. Process variables and biogas yield from python coding.

Process variables		Cumulative biogas yield (liters)
HRT	Mixture ratio	
31	1	2.3769
31	0.3	4.1263
31	0.65	4.7106
31	0.65	4.7106
25	0.3	3.6537
31	0.65	4.7106
37	0.3	5.0324
31	0.65	4.7106
25	1	0.6525
31	0.65	4.7106
25	0.65	3.6121
37	1	4.5349
37	0.65	6.2427

**Table 7.** Composition of GC-MS analysed biogas.

S/I (mixing ratio)	HRT (days)	Methane CH <sub>4</sub> (%)	Carbon dioxide CO <sub>2</sub> (%)	Nitrogen N <sub>2</sub> (%)	Hydrogen sulphide H <sub>2</sub> S (%)
0.65	31	63.22	29.35	3.05	0.87
0.65	31	65.93	24.22	3.02	0.84
1	31	64.20	25.09	2.99	0.82
0.3	25	52.42	39.04	2.69	0.63
0.65	31	58.31	32.31	2.91	0.43
1	25	51.86	38.90	2.96	0.68
0.65	31	65.30	25.12	3.42	0.94
0.3	31	65.43	27.43	2.96	0.77
1	37	63.72	27.26	2.94	0.79
0.65	25	49.81	40.72	2.94	0.68
0.3	37	68.15	22.76	2.98	0.75
0.65	31	54.64	39.04	2.64	0.45
0.65	37	66.01	24.11	3.11	0.90

Figure 3. It can be observed that cumulative biogas volume is at its highest at the moderate mixing ratio (S/I 1:1.55) and highest HRT.

3.3. Python coding predictive results

Results obtained from the python coding algorithm in the appendix are presented in Table 6. The biogas outputs as predicted are similar to the experimental results and predicted values from CCD of RSM. It is not the focus of this study to compare which modelling tool is more accurate. The objective is to establish that these two analytic tools can use the dataset to predict accurately the dynamics of biological processes such as anaerobic digestion. The python coding used in this study is provided in the supplementary information (Appendix) and can be reproduced according to the practical needs of the user.

3.4. Optimization and validation of experimental data

The optimum condition of the independent factors chosen for the biogas production from co-digestion of corn chaff and cow dung digestate

**Table 8.** Functional group and wavelength of produced biogas.

Functional Group	Wavelength (cm <sup>-1</sup> )		Vibrational Motion
	Range	Actual	
Alcohol and Hydroxy	3400–3200	3194.217	O–H Stretch
Aliphatic alkene/alkyl	3000–2800	2993.961	C–H Stretch
Methylene	2935–2915	2925.212	C–H Stretch
Carboxylic acids	3400–2400	2752.864	O–H Stretch
Methylene	2845–2610	2623.375	C–H Stretch
Isothiocyanate	2150–1990	2088.583	-NCS Stretch
Anhydride	1870–1820	1860.602	C=O Stretch
Methyl	1380–1370	1378.097	C–H bend
Aliphatic alkyl	1300–700	1285.946	C–C Vibrations

was obtained from a regression model equation using Design Expert (v. 12 State Ease U.S.A). For the optimization, the desirability of 100% was selected to maximize biogas production from all experimental conditions. The highest condition for biogas production was statistically predicted; HRT was 37 days and the mixing ratio was 0.65 with a corresponding yield of 6.19 L. The optimization was performed thrice using the stated conditions and an average cumulative biogas volume of 4.1376 L was obtained experimentally. This value is in agreement with the average cumulative value (4.1373 L) predicted by python coding for the same conditions.

3.5. Characterization of biogas produced

The composition of the produced biogas from corn chaffs inoculated with cow-dung digestate is presented in Table 7, and the chromatogram is shown in Figure 4. A biogas gas sample from each experimental data point was characterized using a gas chromatograph-mass spectrometer (GC-MS). As observed from all samples, methane is the major constituent of the biogas characterized (49.81–68.15% by volume) followed by CO<sub>2</sub> (22.76–40.72% by volume). Biogas with high methane content is desirable since it is suitable for diesel engines with a high compression ratio (Duc and Wattanavichien, 2007). It can be observed from the result that the sample with high HRT possessed a higher methane content than the

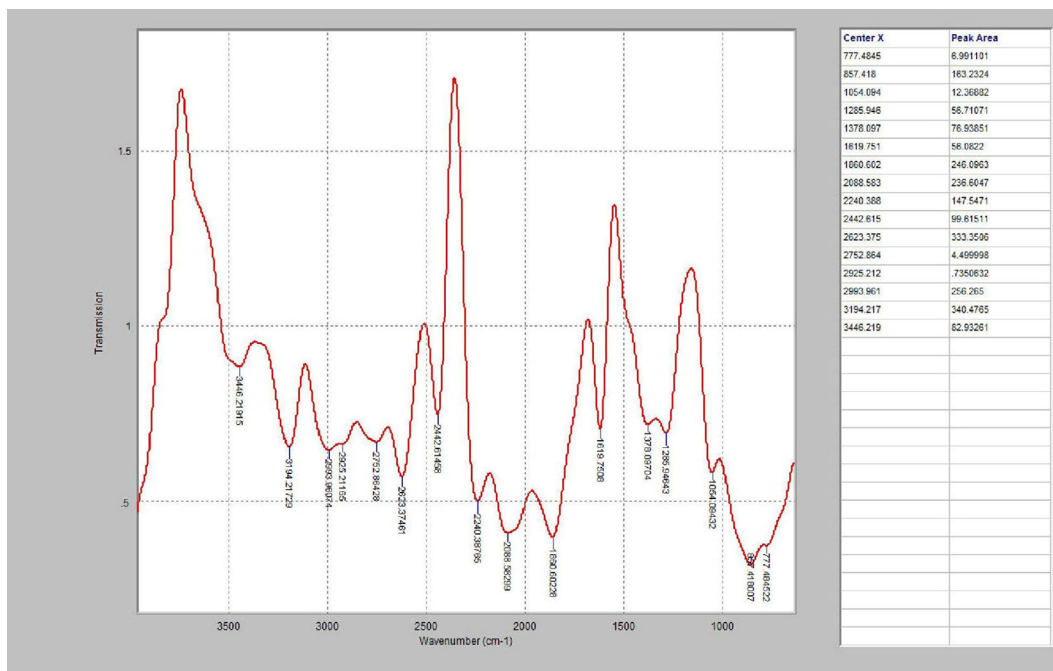


Figure 4. FTIR spectrum of produced biogas with 66.01%.

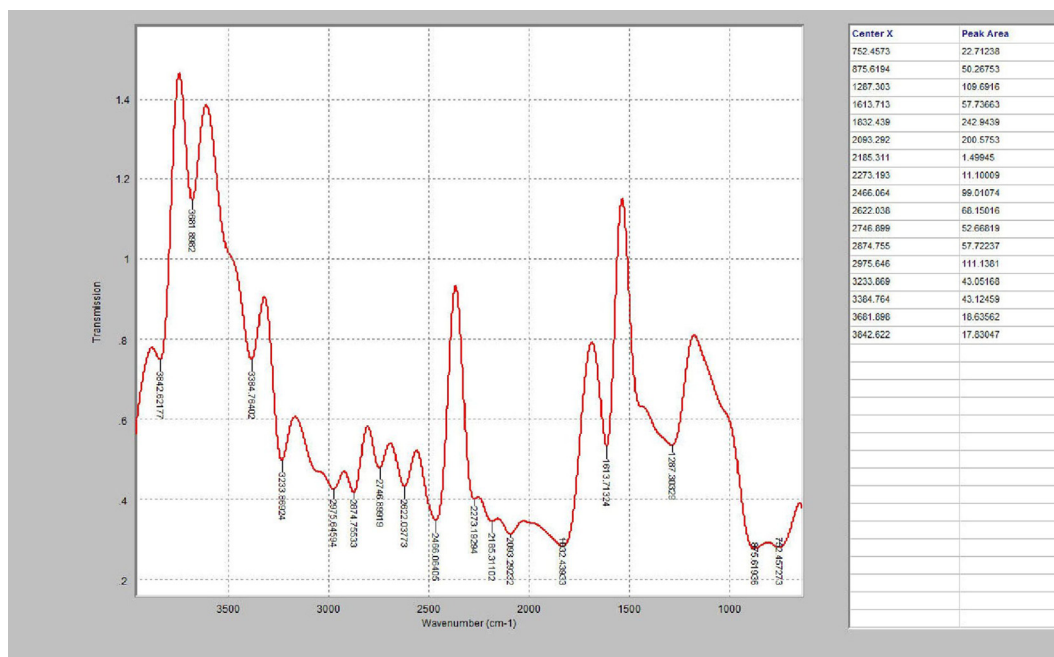


Figure 5. FTIR spectrum of produced biogas of 68.15%.

Table 9. Bio-methane potential results of the inoculum, and inoculated substrate.

No.	Sample	BMP (L CH <sub>4</sub> /g VS)	Hydraulic retention time (days)	Temperature (°C)
1	Cow Dung Digestate (Inoculum)	0.01	61	25–33
2	CDD + Feed	0.17	61	25–33

sample with low HRT. The effect of the mixing ratio on biogas composition is less profound since all samples irrespective of their mixing ratio contain a high amount of methane (CH<sub>4</sub>) by volume at high HRT. Also, from the experiment, the reactor with a 0.3 mixing ratio for 37 days gave a 5.03 L volume but 68% methane, while the reactor with a 0.65 mixing ratio for 37 days gave a 6.19 L volume but 66% methane. Thus, the reactor with the highest accumulated volume does not have better biogas quality as shown in Tables 6 and 7. This experiment proves that quantity does not guarantee quality. The flashpoint of the sample having 68.15% by volume of methane is determined by the digital cleavage closed cup method. The Digital cleavage closed cup has a node for detecting temperature and a chamber for inserting the biogas sample as well as the temperature scale and time. A flashpoint of -182 °C was obtained for the sample analysed.

The FTIR spectrum revealed the major constituent of the produced biogas yield. Functional groups, wavelength range, and the molecular motion found in a typical biogas sample are presented in Table 8. In the identification of the biogas constituent produced, the actual wavenumber of the analysed biogas sample is also shown in Table 8 while the biogas spectrum is depicted in Figure 5. The existence of a broad absorption band between 4000 and 3200 cm<sup>-1</sup> could be due to the O–H stretching of the hydroxyl group from carboxylic group bonding or water. However, a wavenumber between 3760 and 3520 cm<sup>-1</sup> has been selected for CO<sub>2</sub> (Chlipaa et al., 2019) identified in biogas. Moreover, a wavenumber in the region of 3250–2650 cm<sup>-1</sup> has been assigned to methane (CH<sub>4</sub>). It can be seen that the functional groups in this region are dominated by aliphatic alkyl and methylene with C–H vibrational stretching. In the absorption band of wavelength 2143 cm<sup>-1</sup>, CO has been reported (Chlipaa et al., 2019). Similarly, the region having a wavenumber

2150–1865 contains a functional group with a C=O stretching vibration. This region can be adjudged to indicate the presence of CO and other components present in biogas. The observed peak at 1613.713 cm<sup>-1</sup> shows the presence of C–N stretching vibration in the sample.

### 3.6. Biomethane potential results

The bio-methane potential of the inoculum and substrate is presented in Table 9 under mesophilic temperature.

## 4. Conclusion

The possibility of co-digestion of various feedstocks in producing biogas via anaerobic digestion could further promote the usage of cleaner fuel. This would eliminate environmental pollution resulting from this biomass due to meat production and agricultural activities. Using cow dung digestate as inoculum to corn chaff digestion has been demonstrated to be a veritable means of producing biogas through an anaerobic process. A considerable quantity of comparable biogas was generated in the process. Among the factors affecting the cumulative volume of biogas yield are the mixing ratio and hydraulic retention time as they significantly impact this process as shown by the ANOVA result. The contribution of HRT to the variation observed in the responses of this process doubles that of the mixing ratio, as indicated by its large F-value. Meanwhile, a mixing ratio of S/I of 0.65 is sufficient to enable the anaerobic fermentation to be operated maximally in this study. The further increase affects cumulative biogas yield, which suggests that the microbial activities within the digester are imbalanced. The R<sup>2</sup> of 0.9966 and other statistical parameters suggest that the anaerobic digestion of cow dung digestate and corn chaff in producing biogas could be described adequately by the model.

The predicted accumulated highest biogas yield was 6.24 L, a similar value to the experimentally obtained accumulated highest biogas yield of 6.19 L at the highest conditions of 0.65 mixing ratio and 37 days of retention time. However, the highest value of biogas yield obtained from the experiment value was marginally lower than the cumulative biogas yield from python coding. Also, the experiment discovered that the

reactor with a 0.3 mixing ratio for 37 days gave a 5.03 L volume but 68% methane, while the reactor with a 0.65 mixing ratio for 37 days gave a 6.19 L volume but 66% methane. Thus, the reactor with the highest accumulated volume does not have better biogas quality as shown in Tables 6 and 7. The produced biogas contains 68% methane and 21% CO<sub>2</sub> by volume, and the methane flashpoint was determined to be -182 °C, which indicates its flammability. Hence, the feedstocks employed in this study could enable biogas plants to be operated and produced in an efficient and sustainable manner on a large scale.

## Declarations

### Author contribution statement

Sunday Chukwuka Iweka: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Owuama K. C.: Contributed reagents, materials, analysis tools or data.

Chukwunke J. L.: Analyzed and interpreted the data.

Falowo O. A.: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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### Data availability statement

Data will be made available on request.

### Declaration of interests statement

The authors declare no conflict of interest.

### Additional information

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