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OPTIMIZATION INVESTIGATION OF BIOGAS POTENTIAL OF TITHONIA DIVERSIFOLIA AS AN ALTERNATIVE ENERGY SOURCE

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ABSTRACT

This research work dwells on the anaerobic digestions of rumen with Tithonia diversifolia *(T.* diversifolia) *for biogas production. The anaerobic digestions of rumen with T. diversifolia was carried out for 30 days within the mesophilic temperature range (30.0 °C - 40.0 °C) using a digester with dimensions 50 cm x 25 cm. Results obtained indicated that the maximum biogas volume obtained was 7.05 x 10^{-3} m^3 on 29th day. The temperature of the digestate remained constant throughout the fermentation period. The pH of the medium changes progressively from acidic to slightly alkaline (6.41 to 7.2). In order to estimate the statistical analysis, linear regression and correlation model were used, Analysis of Variance (ANOVA) was constructed. The coefficient of determination R^2 with Prob>F=0.0001 was 0.7339, the regression parameters* β_0 (intercept) and β_1 (slope) *were obtained as 6.05 x 10^{-6} and 1.942 x 10^{-3}, respectively. The Root Mean Square Error (RSME) was 7.84 x 10 $^{-5}$, the Sum of the Square Error (SSE) was 1.72 x 10^{-5}, the total sum of the square error (SST) was 6.46 x 10^{-5} and regression of the square (SSR) was 4.74 x 10^{-6}. The estimated regression function equation of biogas volume was expressed as* y = *0.00000605239x + 0 .001941651. The physicochemical properties of the digester feedstock before and after the anaerobic digestion showed that the COD, ash content, organic carbon, total kjedahl nitrogen, pH increased after the anaerobic digestion while the total solids, volatile solids, aluminum, copper, iron, calcium and ammonia nitrogen decreased. The C/N ratio of the feedstock was approximately 4:1. The study showed that T. diversifolia with rumen can produce sufficient carbon that accelerated effective gas generation.*

Keywords: *Tithonia diversifolia*, rumen, Digester, Microsoft excel version, Physicochemical properties, Statistical analysis.

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Contribution/ Originality

This study contributes in the existing literature the use of T. diversifolia co-digested with rumen for biogas production. This study uses new estimation methodology such as least square to optimize the process of production. This study originates the formula like linear regression parameters.

1. INTRODUCTION

In recent times, where the demand for energy is growing by the day, the need for exploring and exploiting new sources of energy which are renewable as well as environmental friendly cannot be over emphasized [1-3]. Meanwhile, wastes have been considered a source of renewable energy in our world and are now seen as means of transforming our economy, protect our security and save our planet from the ravages of climate change. Biogas technology offers an attractive platform to utilize and convert these wastes for meeting rural energy needs if it is properly harnessed. In rural areas especially in Nigeria, various cellulosic biomasses (agricultural waste) are available which can be utilized in the production of biogas. Biogas technology can be defined as the use of biological process in the absence of oxygen for the breakdown of organic matter into biogas and high quality fertilizer (digestate); the gas produced can be used to generate utilities such as electricity and heat or hot water, the digestate can be used as fertilizer, bedding, mulch and potting soil which is often used on farms in order to prevent waste pollution. Furthermore, for higher biogas yields the substrate must contain high-quality and degradable organic matters, from which a higher percentage of the methane concentration is produced [4].

Meanwhile, in India, it has been estimated that biogas has a potential of generating 6.38 x 10^{10} m^3 of energy from 980 million tons of cattle dung annually produced with heat value of this gas amounts to 1.3 x 10^{12} MJ [5]. Besides this, 350 million tons of manure could also produce if this quantity of dung is used for biogas production; hereby replace 76% of natural gas demand of the country. In addition to this, there will be no need of laying pipeline supply network connecting cities, as bio-waste is available plenty in each city and village of the Country. Bacteria degradation of biological and organic matter in the absence of oxygen known as anaerobic digestion generates biogas. The anaerobic digestion is an effective proven technology for handling and treating biological wastes and effluents for generation of district heating and electricity supplies, as well as clean environment. Though, many types of biomass can be used for biogas production. If anaerobic digestion is managed properly, biogas can be captured and used in place of fossil fuels thereby providing a CO_2 free energy source. For instance in the U.S and Canada, there are over 121 million cattle (USDA) which provides cattle manure useful for biogas production.

However, biogas has been produced with the use of agricultural waste, manures from domestic animals or combination of the two. In view of these, Zhang, et al. [6] worked on biogas production from brown grease using a pilot-scale high-rate anaerobic digester, Jiang, et al. [7] work on biogas production potential of aquatic plants. Fertilizer and sanitary quality of digestate biofertilizer from the co-digestion of food waste and human extract was reported by Owamah, et al. [8]. In another work, optimization of biogas from chicken droppings with *Cymbopogon citratus* was also reported by Owamah, et al. [9]. The work of Rasi, et al. [10] was based on determination of organic silicon compounds in biogas from wastewater treatments plants, landfills, and co-digestion plants. Meanwhile, Ayhan, et al. [11] worked on biogas production from maize silage and dairy cattle manure. In the same vein, Markowski, et al. [12] worked on optimization low temperature biogas production from biomass by anaerobic digestion. Shanmugan and Horan [13] also work on optimizing the biogas production from leather fleshing waste by co-digestion with MSW.

In this work, the plant material used as the biomass to generate biogas was *T. diversifolia* popularly known as Mexican Wild Sunflower. The *T. diversifolia* is a woody herb or succulent shrub, stoloniferous, annual and perennial, which can reach 2 to 3 cm high. It is planted and cultivated in many countries for its tall yellow flowers. The flower heads are solitary on a peduncle 6-13 cm long. Each mature stem may bear several flowers at the top of the top of the branches. *T. diversifolia* has been used for a wide variety of purposes around the world, including compost, land demarcation, soil erosion control, building materials and shelter for poultry. Further usage includes fodder for ruminants and rabbits that can eat leaves, soft branches and even the flowers and its potential have been tested in pigs and poultry. Therefore, this research work utilized *T. diversifolia* in the presence of rumen for biogas production. For statistical analysis, linear regression and correlation was used. In addition, the quality of the biogas produced was evaluated by carrying out the physicochemical properties.

2. MATERIALS AND METHODS

2.1. Materials

Since *T. diversifolia* is like a weed to Landmark Community, freshly harvested *T. diversifolia* was collected from Landmark University. The collected *T. diversifolia* was washed to remove the unwanted impurities and then grinded into semi-fine particles in order to increase its surface area for microbial actions. The grinded *T. diversifolia* was collected in a cleaned bucket for further processing.

Freshly rumen content used as inoculums which carries the microbial load was collected from the Landmark University Cafeteria (LUC) immediately after butchering the cow and was kept in a plastic collector. All chemical and reagents used were of analytical grades made by GFS Chemicals, Inc., 867 McKinley Ave., Columbus OH 43223 (99.7-100%) and BDH Analar Ltd., Poole England (99%) and supplied by FINLAB Nig. Ltd.

2.2. Methods

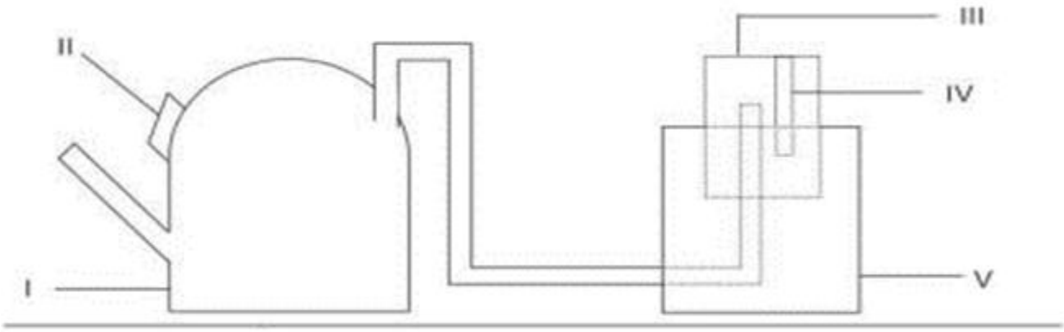
2.2.1. Design of Digester and Gas Collection System

The digester and water displacement system were design and operated according to the methods described by Karki [14]; Fountoulakis, et al. [15]. A 25 L capacity anaerobic digester was fabricated at the metal fabricating workshop in Omu-Aran, Kwara State, Nigeria. It was made of galvanized plate shaped in cylindrical shape for stability and better mixing of substrate. The digester was painted with black paint in order for it to absorb heat energy from the sun during the day and provide supplementary heat during the night. It has a handle with a stirrer fixed on top of the digester. The digester had three openings on top of it which serves as feed inlet, thermometer inlet and the third, for gas outlet. The digester had a tap fixed to bottom side for the collection of samples and slurry outlet. Rubber hose was used to connect the digester to the gas collection system. The gas produced in the digester cylinder was collected in the gas collection cylinder with water jacket having dimensions 25 cm high and 27 cm diameter working on the principle of water displacement for easy measurement of the volume of gas produced per day. The displacement is dependent on the pressure and volume of gas produced. The circular base area (CBA) of the cylinder was computed using Eqn. (1) whereas the biogas volume (BV) was obtained as the height of gas collection cylinder above the water level multiply by the CBA Eqn. (2). The gas collected in the water jacket set-up is passed through the gas cylinder for storage daily. Fig. 1 shows the schematic view of the experimental set-up of the biogas production process.

$$Circular\ Base\ Area = \frac{\pi r^2}{2} = \frac{\pi D^2}{4} = \frac{3.142(0.25)^2}{4} = 0.04910714\ \mathrm{m}^2 \qquad (1)$$

$$\text{Biogas volume} = \text{CBA}\ (Height) = 0.04910714\,H \qquad (2)$$

Where, H is the height of gas collection cylinder above the water level.



Keys: I = Digester, II = Hygrometer, III = Gas holder, IV = Regulator, V = Water Jacket

Fig-1. A schematic view of experimental set-up

Source: Dahunsi and Oranusi [16]

2.2.2. Pretreatment Procedure

The collected freshly grinded *T. diversifolia* was made into slurry in the ratio 1:1 (feed/water). Because, thermal pretreatment has been said to lead to pathogen removal and also improves dewatering performance and reduces viscosity of the digestate with subsequent enhancement of digestate handling, the slurry was thermally pretreated between 70 and 80 °C and then allowed to cool to 45 °C. The pH of the slurry was checked weekly in order to know the degree of acidity of the substrate and also to be able to apply the right chemical pretreatment to the substrate since *T. diversifolia* is a lignin agricultural material.

2.2.3. Inoculum Preparation

Freshly rumen content collected was used as inoculums. The inoculum was then kept in the oven at 32 °C for four days to give room for multiplication of the organisms as well as for

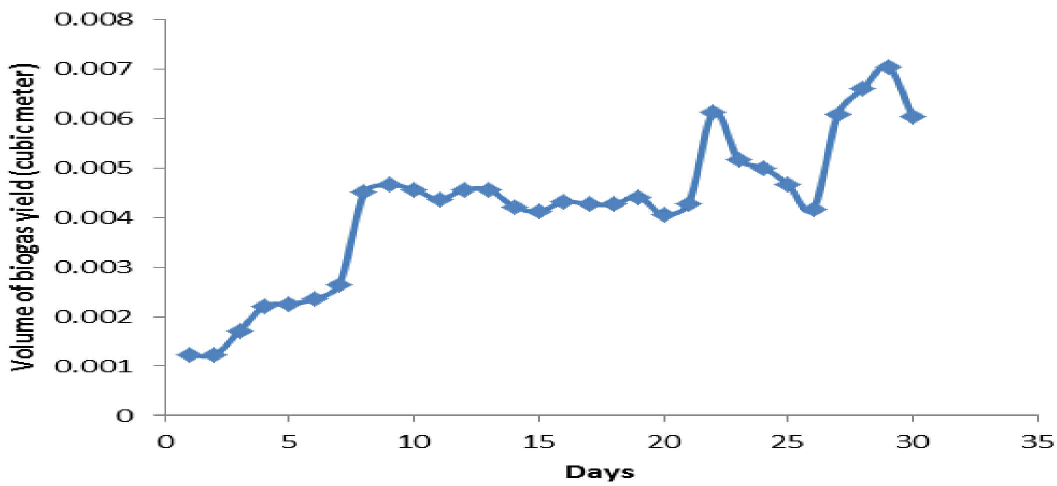


Fig-2. Plot of daily biogas production

Source: Microsoft Excel

Partial decomposition to aids faster growth before loading of digester. The analysis for microbial load was carried out by sterile dilution method.

2.2.4. Experimental Procedure

The designed digester having a capacity of 25 L was loaded with 18.0 L of the pretreated slurry (substrate), 2.17 L of the inoculum was added and then mixed together thoroughly. The pH of the mixture was then taking using an HANNA instrument HI 2210 pH meter and then recorded. The total solid content was carried out by collection of sample from the feed outlet of the digester and analyzed by oven drying at 150 °C for 24 h. The mercury in glass thermometer was used to monitor and measure the temperature of the content of the digester and daily readings of the biogas production were recorded (Table 1). The experiment was maintained until the volume of biogas produced decreases. The total retention duration was 30 days, after which the digestate sample was collected for analysis.

2.2.5. Statistical Analysis

To optimize the process condition, Microsoft Excel Version 2013 was used to plot the graph of biogas produced per day. The linear regression and correlation was used to evaluate the regression parameters β_o (intercept) and β_1 (slope) Eqn. (3) and Eqn. (4), respectively. The coefficient of determination (R^2) was obtained using Eqn. (5) while the square root of mean square error (RMSE) was also obtained using Eqn. (6) and Eqn. (7), respectively. ANOVA table was also prepared.

Table-1. Daily readings of the biogas production

Days	Volume of biogas yield (m^3)	Days	Volume of biogas yield (m^3)
1	0.0012275	16	0.0043208
2	0.0012275	17	0.0042717
3	0.0017185	18	0.0042717
4	0.0022095	19	0.004419
5	0.0022586	20	0.00405075
6	0.0023568	21	0.0042717
7	0.0026514	22	0.0061375
8	0.0045172	23	0.00518005
9	0.0046645	24	0.0050082
10	0.0045663	25	0.0046645
11	0.0043699	26	0.0041735
12	0.0045663	27	0.0060884
13	0.0045663	28	0.00660395
14	0.0042226	29	0.00704585
15	0.0041244	30	0.0060393

Source: Experimental results

$$\grave{\beta}_1 = \frac{S_{xy}}{S_{xx}} \quad (3)$$

Where:

$$S_{xy} = \sum (x_i - \bar{x})(y_i - \bar{y})$$

$$\grave{\beta}_0 = \bar{y} - \grave{\beta}_1 \bar{x} \quad (4)$$

$$R^2 = \sum \frac{(\grave{y}_i - \bar{y})}{(y_i - \grave{y}_i)^2} \quad (5)$$

Where y = the average mean of biogas yield and x = the average mean of retention time

Where:

$$\acute{y}_i = \grave{\beta}_0 + \grave{\beta}_1 \bar{x}$$

$$RSME = \sqrt{\frac{\sum (y_i - \grave{y}_i)^2}{(n-2)}} \quad (6)$$

2.2.6. Physicochemical Properties

The physicochemical properties such as total alkalinity, ammonia nitrogen, total phosphate, total solids, aluminum, potassium, copper, iron, magnesium, calcium, zinc, COD (Chemical Oxygen Demand) were analysed using the ELE International Photometer while the analysis on organic carbon, total kjedahl nitrogen, ash content, conductivity test were carried out using Walkley-black titration method, Kjeltex auto-distillation apparatus model, Muffle furnace, Electrochemical analyser (Consort C6020), respectively. Meanwhile, volatile solids content was calculated from the ash content value.

3. RESULTS AND DISCUSSION

3.1. Biogas Production

Fig. 2 shows the plot of daily biogas production which was taking 15 h every day. It was noted on the first and second days of fermentation that the volume of biogas yield was 1.228 x 10^{-3} m^3. It was also noted that there was 72.8% increase in volume of biogas produced between second and the eight day. The graph reflected a downward decreased of 9.78% from ninth (9^{th}) day to twenty one (21^{st}) day, further decreased of 32% was noticed from twenty second day to twenty six day. Meanwhile, there was an upward biogas production from twenty six (26^{th}) days to twenty ninth (29^{th}) day with an increase of 39.37% and then drop gradually after thirty (30^{th}) day. It reached its peak on the twenty ninth (29^{th}) day with 7 x 10^{-3} m^3 before it finally fell on the thirtieth day and was recorded for the rest of the study period.

Showed in Fig. 3 is the graph of daily temperature recorded during the digestion. From the graph, the temperature of the digestate remained constant at mesophilic range (30.0 - 40.0 °C) throughout the fermentation period. Earlier reports shows that temperature has been observed

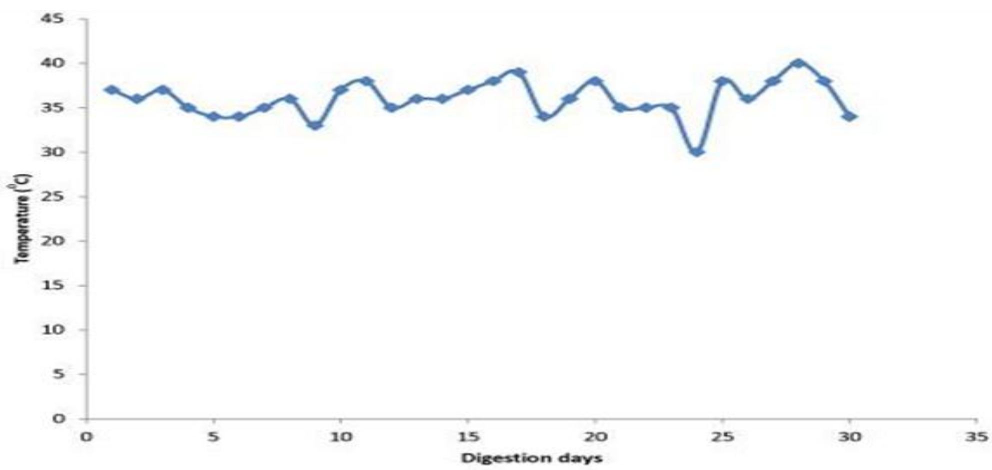


Fig-3. Daily temperature changes for digestion period

Source: Microsoft Excel

to be quite critical for anaerobic digestion, since methane producing bacteria operate most efficiently at temperatures 30.0-40.0 °C or 50.0 - 60.0 °C [4, 17]. It was therefore noted that temperature does not seem to have any significant effect on the amount of gas produced daily as revealed in this study. Also, daily gas generation tends not to follow a specific pattern and this is relative based on the fact that other parameters apart from temperature could have been responsible for the amount of biogas produced per day. This is similar to the report of Dahunsi and Oranusi [16] that the recovery time for biogas production as well as the quality and quantity of biogas produced from agricultural materials are a vital function of the nature, and composition of the digester feedstock. The nature and the type of material used *(T. diversifolia)* usually contain high lignin content coupled with its cellulosic nature which cannot be easily biodegraded, could have contributed to the slow development of methanogens and consequently low methane production.

Also, Fig. 4 shows that the pH of the medium changes progressively from acidic (6.41) to slightly alkaline (10.70) within the 14th day and 21th day. After 21th day, there was a gradual decreased in pH until the pH reached 7.2 and was maintained (Fig. 4). Observation on the pH fluctuation could be attributed to the nature of the feed within the digester [2, 18-20].

3.2. Statistical Analysis

Table 2 shows the results of linear regression and correlation called ANOVA table. The regression parameters also known as regression coefficients β_0 *and* β_1 were obtained to be 6.05 x 10^{-6} and 1.942 x 10^{-3}, respectively. The coefficient of determination R^2 which plays an important role during model checking and also explained the proportion of variability that explained by the

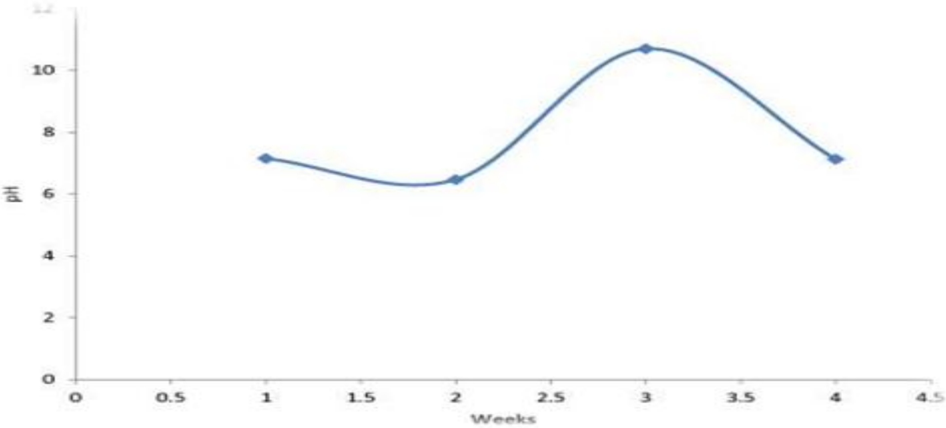


Fig-4. Weekly pH changes digestion period

Source: Microsoft Excel

Model was obtained as 0.7339 (73.39%). The value of R^2 close to one implies that most of the variability is explained by regression model. Meanwhile, the total sum of the square (SST) which is a measure of the total variability of the biogas yield was obtained as 6.46 x 10^{-5}, the SSR called the regression sum of the square, which measure the total variability of the fitted values was obtained as 4.74 x 10^{-5}. The RMSE and the SSE which are the measure of the unexplained variability were also obtained as 7.84 x 10^{-5} and 1.72 x 10^{-5}, respectively. The least square which is also called the estimated regression function of biogas produced per day is expressed in Eqn. 7.

$$Y = 0.00000605239x + 0.001941651 \quad (7)$$

Table-2. ANOVA Table

Source	DF	Sum of square	Mean square	F value	Prob>F
Model	1	SSR	MSR=SSR/1		
Error	n-2	SSE	MSE=SSE/n-2	MSR/MSE	<0.0001
Total	n-1	SST			
	Root MSE		**R^2**		

ANOVA Table

Source	DF	Sum of square	Mean square	F value	Prob>F
Model	1	4.74 E-05	4.74 E-05		
Error	28	1.72 E-05	6.14 E-07	77.17087	<0.0001
Total	29	6.46 E-05			
RMSE = 7.837 x 10^{-4},		R^2 = 0.7339			

Source: Statistical analysis result

3.3. Physicochemical Properties of Substrate and Digestate

The physicochemical properties of the digester feedstock before and after the anaerobic digestion are shown in (Table 3). The values obtained for Chemical Oxygen Demand (COD), ash content, organic carbon, total kjedahl nitrogen, pH showed an increased after the anaerobic digestion while other parameters such as total solids, volatile solids, aluminum, copper, iron, calcium and ammonia nitrogen decreased in values after the digestion process. This observation is in line with what was earlier reported by Owamah, et al. [8]. However, the values of nitrogen, phosphorus and potassium in the digestate indicate that it will be good for fertilizer application for agricultural products. The Carbon/Nitrogen ratio of the feedstock was approximately 4:1. The value obtained for C/N ratio was far less than the optimum between 20:1 and 30:1 for biogas generation from biomass. Insufficient carbon may have contributed to retarded effective gas generation at some point during the digestion.

Table-3. Physicochemical properties of substrate and digestate

Test	Substrate	Digestate
Total alkalinity (mg/L $CaCO_3$)	220	410
Ammonia nitrogen (mg/L N)	0.31	0.22
Total phosphate (mg/L P)	2.37	2.37
pH	7.15	7.4
Total solid content %	8.5	6.54
Aluminum (mg/L Al)	0.25	0.24
Potassium (mg/L K)	3.3	3.6
Copper (mg/L Cu)	1.9	1.7
Iron (mg/L Fe)	3.1	2.85
Magnesium (mg/L Mg)	28	31
Calcium (mg/L Ca)	165	145
Nitrate nitrogen (mg/L N)	0.115	0.274
Zinc (mg/L Zn)	2.47	3.03
COD (mg/L O_2)	410	950
Total kjedahl nitrogen %N	3.859	4.329
Organic carbon %C	12.56	13.8
Ash %	21.36	22
Phosphorus (ppm)	5	8
DO (dissolved oxygen mg/L O2)	Nil	1.08
VS %	78.64	78
Conductivity(mS/cm)	11.21	6.25

Source: Physicochemical analysis results

4. CONCLUSIONS

The following conclusions were drawn from the present study investigating the optimization of biogas potential of *Tithonia diversifolia* as an energy source.

i. Maximum yield of biogas was obtained as 7.05 x 10^{-3} m^3 on 29th day, followed by 6.6 x 10^{-3} m^3 on 28th day and 6.14 x 10^{-3} m^3 on 22nd days, respectively.

ii. The temperature of the digestate remained constant at mesophilic range (30.0 - 40.0 °C) throughout the fermentation period. Hence, temperature does not have any significant effect on the amount of gas produced daily as revealed in this study.

iii. The pH of the medium changes progressively from acidic to slightly alkaline. This could be attributed to the nature of the feed within the digester.

iv. The coefficient of determination R^2 which plays an important role during model checking and also explained the proportion of variability that explained by the model was 0.7339, implies that most of the variability is explained by regression model equation.

v. Based on physicochemical properties of the digester feedstock before and after the anaerobic digestion, the Chemical Oxygen Demand (COD), ash content, organic carbon, total kjedahl nitrogen, pH increased after the anaerobic digestion while the total solids, volatile solids, aluminum, copper, iron, calcium and ammonia nitrogen decreased in values after the digestion process.

vi. The Carbon/Nitrogen ratio of the feedstock was approximately 4:1. The value obtained was far better than the optimum for biogas generation from biomass (30:1). This may be due to sufficient carbon that accelerated effective gas generation at some point during the digestion.

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Competing Interests: The authors declare that they have no competing interests.

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