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RESEARCH ARTICLE

Effects of using P.juliflora leaves as additive in anaerobic digestion of poultry wastes

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Abstract

This study explores the influence of P.juliflora leaves as an additive in the anaerobic digestion of poultry droppings from layers and broilers. Six digesters (A, B, C, D, E, and F) were used with a retention time of 31 days. The dry weight content of the digesters include: 100% layer wastes (control), 100% broiler wastes (control), 95% layer wastes + 5% P. juliflora leaves, 90% layer wastes + 10% P. juliflora leaves, 95% broiler wastes + 5% P. juliflora leaves, and 90% broiler wastes + 10% P. juliflora leaves. Layer wastes plus 5% Prosopis Juliflora created 18% more biogas than layer wastes alone, and layer wastes plus 10% Prosopis Juliflora produced 22% more biogas than layer wastes alone, which was the control set-up. In comparison to digester broiler wastes alone, broiler wastes plus 5% and broiler wastes plus 10% both produced 20% and 24% more biogas, respectively. In conclusion, adding 5 and 10 percent of Prosopis Juliflora to poultry manure from layers or broilers has significantly increased the generation of biogas. Broiler wastes plus 10% Prosopis Juliflora yielded the most amount of methane and least amount of hydrogen sulfide, which makes it the most suitable substrate.

Keywords: biogas; renewable energy; digester; additive

Introduction

The recent worldwide rapid population growth, along with the depletion of natural resources, has resulted in a significant increase in fuel prices. This has motivated a number of countries to investigate renewable and alternative sources of energy in order to fulfil their rising energy demands (Ajiboye et al., 2018). Reliance on traditional energy sources such as coal and petroleum has resulted in ecological imbalance, climate change, health risks, and resource depletion (Aragaw & Andargie, 2013). As a result, renewable energy sources such as solar power, biogas, biodiesel, wind power, and tidal power have emerged as the energy revolution's vanguard (Islam, 2012). Due to the continued use of fossil fuels and their associated environmental impact, particularly the influence of greenhouse gases (GHGs) on the environment, research focusing on the creation of alternative fuels from biological sources has expanded. Carbon dioxide (CO2) is the principal cause of growing GHG emissions in the atmosphere. Notably, worldwide energy demand is continually increasing, with fossil fuels still accounting for around 88% of total energy output today (UNEP, 2014). Anaerobic digestion (AD) is a promising, low-energy, and ecologically friendly technique. Recent research has shown that biogas produced using AD has significant advantages over other bioenergy sources (Nishio and Nakashimada, 2007). When opposed to fossil fuels, AD technology can dramatically cut GHG emissions by utilizing readily available resources. Furthermore, digestate, a byproduct of this method, is an ideal alternative to mineral fertilizers in crop cultivation. AD converts organic waste such as manure, food scraps, sludge, and agricultural leftovers into biogas in the absence of oxygen (Iqbal et al., 2014). Due to its minimal ecological impact (Esposito et al., 2012) and great energy recovery potential (Carrère, 2010), the AD process is preferred for transforming trash into fuel. Biogas from AD has significant advantages over other bioenergy production technologies, and it has the potential to replace fossil fuels (Ofoefule et al., 2010).

The anaerobic digestion of organic material produces biogas, which is mostly made of methane. Because the anaerobic degradation process is comparable to the underwater decomposition of organic material in wetlands, biogas is sometimes referred to as "marsh gas" or "swamp gas" (IBA, 2016). Biogas is a colorless, combustible gas made up of 50-70% methane and 20-40% carbon dioxide, with traces of nitrogen, hydrogen, ammonia, hydrogen sulphide, and water vapor (Lasisi and Ojomo, 2017). Biogas, a critical component of the carbon biogeochemical cycle, is naturally produced and can be used as an alternative energy source (Energypedia, 2016).

The current study seeks to assess the biogas yield of increased anaerobic digestion of two distinct breeds of chicken manure using Prosopis Juliflora. The study's objectives include: the design and construction of medium-sized digesters for waste decomposition, the analysis of the physio-chemical and microbiological properties of chicken droppings and Prosopis Juliflora, the evaluation of both the daily and overall cumulative yield of biogas, and the comparison of enhanced Prosopis Juliflora and non-enhanced biogas yield from various digesters.

Literature Review

Despite the economic and environmental benefits of producing biogas from various biological wastes utilising AD technology, the search for more inexpensive, renewable, and sustainable energy sources is pressing due to rising fuel costs (Fantozzi & Buratti, 2011). The poultry sector is a major source of worry, as waste from daily chicken feed is frequently used as organic manure. With the growing number of chickens grown in Nigeria, there is a pressing need to investigate alternate energy sources in order to mitigate the negative effects (Ekka et al., 2016). Several researchers have concentrated on producing biogas from a wide range of widely available agricultural and environmental wastes that are damaging to the environment (Awode et al., 2022). Although anaerobic digestion of biodegradable waste is thought to be a promising source of renewable energy, it has certain drawbacks. These include the slow decomposition of complex organic waste and the presence of carbon dioxide and hydrogen sulphide in the biogas produced (Wang et al., 2023). Before biogas can be utilized as fuel, these components must be eliminated.

However, the introduction of Prosopis juliflora during the anaerobic digestion process could significantly alleviate these restrictions, potentially increasing biogas generation while decreasing carbon dioxide and hydrogen sulphide emissions. Prosopis juliflora (P. juliflora) is a non-traditional feed resource that has been investigated for its potential as an addition in the anaerobic digestion of poultry wastes. Prabhu et al. (2021) evaluated the anaerobic digestion of several biomass wastes, including P. juliflora leaves, and discovered that P. juliflora pods produced the most biogas. Samadi et al. (2022) studied the co-digestion of poultry abattoir and vegetable wastes and discovered that a C/N ratio of 25:1 was ideal for biogas production. However, no particular research on the effects of employing P. juliflora leaves as an addition in anaerobic digestion of chicken wastes were found. Rajagopal et al. (2021) explored the combination of microalgae cultivation and anaerobic digestion of poultry wastes and discovered that the liquid digestate obtained after the digestion process may be used as a substrate for microalgae growth. The study employed various liquid digestate dilutions for microalgae growth and discovered that Chlorella vulgaris CPCC 90 could grow and utilize nutrients from a 10% diluted chicken manure digestate. Awode et al. (2022) evaluated the effect of biochar as a supplement on the anaerobic digestion of layer and grill poultry droppings. The biogas from the digester with the highest biochar content produced the most methane while creating the least hydrogen sulphide. According to the findings of this study, biochar can be utilized as a supplement to improve the efficiency of anaerobic digestion of poultry manure. Hakimi et al. (2021) explored the co-anaerobic digestion of chicken manure with sawdust and local herbs such as serai wangi, peppermint, and orange peel waste as biogas additions. According to the findings of this study, traditional herbs can be utilized as supplements to improve the effectiveness of anaerobic digestion of poultry manure. As a result, the current study makes an important contribution to the body of information on improving biogas production from poultry waste utilizing Prosopis juliflora.

Methodology

Materials

The construction of the digesters was done with: six black plastic kegs of 25 L capacity each (they served as the main digester chambers), six catheter bags of 500 ml (was used to collect the biogas produced), flexible rubber hose (were used to connect the catheter bags to the digesters), 12.5 mm back nuts, stop corks, 12.5 mm pipes, PVC gum (all used for both the inlet and outlet of the digesters), thermometer, pH meter, weighing scale and syringe, (all used for various parameter's measurement), and Prosopis juliflora obtained from school farm are the waste to be used.

Digester Design considerations

In achieving one of the objectives of this research, some parameters were considered in designing and constructing effective and efficient digesters. The parameters include operating volume, digester volume and digester construction. They are briefly explained below.

Operating Volume

When a fixed amount of water is added to a known amount of feedstock, the operational volume of the digester is just the volume of slurry ratio in the digestion (Babatola, 2008, Ajiboye et al., 2018). For optimal digestion operation, it is common practice to use a digester whose total volume is less than the total volume of the slurry. According to Ahmadu et al. (2009), the operating volume of a digester is determined on the basis of a chosen retention time and the daily substrate input quantity of the operating volume is expressed in equation 1.

$$V_o = S_d \times RT\ (m^3/\mathrm{day} \times \text{number of days}) \quad (1)$$

Where:

V_o is the operating volume of digester,

S_d is the daily substrate input and,

RT is the retention time, which is the interval of time the mixed slurry is allowed to decompose in the digester.

Digester Volume

The volume of a digester is equal to the volume of the substrate container, whether the container is prefabricated or ready-made. The number of ready-made 25-l containers is what constitutes the digester volume in this case. The digester capacity, also known as the total volume, must be more than the operational volume to accommodate the expansion of the slurry and the creation of biogas during fermentation. Slurry rise and biogas production require at least 20% of the total volume of the digester, which is why Ahmadu et al. (2009) and Otun et al. (2015) claimed that this volume should not exceed 80% of the total capacity of the digester. The total volume V_T is thus given in equation 2.

$$V_T = V_0 \times 1.25 \quad (2)$$

Digester Construction

Each of the 25-liter containers had a hole drilled into its top and two holes drilled onto its sides. The top holes were roughly 1.5 centimeters in diameter. It was determined that a hose with an external diameter of 1.5 cm would be used to link the digester to the gas collection chamber (Catheter), while a hose with an interior diameter of 0.9 cm would be used for this purpose. Each keg had an additional hole cut in its base with a diameter of 4.1 centimeters; this hole served as the exit from which the slurry used in the pH measurement was drawn. Each digester was outfitted with a thermometer that read daily temperatures. The entire bio-digester system was made airtight by using rubber tubes and glue to seal any perforations.

Sourcing and Collection of Materials

The digester component materials were all procured from Oja-Oba market in Akure, Nigeria. Chicken manures for the two breeds (Layers and Broilers) were collected from the Agricultural research farm of the Federal University of Technology, Akure (FUTA), Nigeria.

Pre-treatment of Waste Specimens

These chicken manures were collected in black sealed polythene bags to preserve their original moisture. Pre-treatment was initiated at the point of collection, and it includes sorting, reduction in particle size and addition of water. Pre–treatment is done to enhance degradation of volatile solids, thus increasing biogas yield.

Sample Preparation and Loading of Digester

The samples were prepared by mixing the manure of each chicken breed in varying component using 50:50 (10 L of water +10 kg of poultry waste) for control sample A and D, 45:5:50 (10 L of water + 10 kg of poultry waste + 1 kg of prosopis Juliflora) for sample B and E, 40:10:50 (10 L of water + 10 kg of poultry waste + 2 kg of prosopis Juliflora) for sample C and F. The composition of the mixtures is shown in Table 1. The mixtures will each be loaded into the Six 25 liters digester fabricated. Thereafter, the set-ups were arranged well for digestion for 30 days**.** To ensure optimal digestion of substrate and to forestall the buildup of scum and layers that could kill off the bacteria and limit biogas generation, the digesters were manually agitated at regular intervals. Each digester had a gas cylinder attached to its outlet, capturing the biogas it produced.

Result And Discussions

Sample Pre-Analysis

The analyses of the poultry waste consisting of the layer waste (LW) and broiler waste (BW) and their mixtures with Prosopis Juliflora in different ratios was carried out in the laboratory to determine their physico-chemical properties. Table 2 shows the moisture content, volatile solid, total solid concentration and the different constituents of the wastes such as ash, fat, crude protein, carbon content, nitrogen content.

Table 1: Detailed Composition of Each Mixture

Mixtures	Digester Label	Type of Enhancement
CM Type 1	A	Non Enhanced
CM Type 1 + P.juliflora	B	Enhanced with P.juliflora leaves (5%)
CM Type 1 + P.juliflora	C	Enhanced with P.juliflora leaves (10%)
CM Type 2	D	Non Enhanced
CM Type 2 + P.juliflora	E	Enhanced with P.juliflora leaves (5%)
CM Type 2 + P.juliflora	F	Enhanced with P.juliflora leaves (10%)

Table 2: Physico-chemical properties of the fresh poultry waste

Parameters	**Digesters**					
	A	B	C	D	E	F
Moisture (%)	69.5	53.4	63.4	68.3	58.2	52.7
Fat (%)	4.3	6.7	4.2	3.9	6.64	6.28
Ash (%)	3.05	2.6	3.7	4.0	2.2	2.1
Fibre (%)	1.03	1.5	1.2	1.37	1.59	1.65
Crude Protein (%)	10.25	12.25	10.42	10.36	12.64	13.42
Nitrogen (%)	1.87	2.68	1.93	2.31	1.84	1.85
Total Solids (%)	32.3	29.2	29.67	28.45	26.4	27.3
Temperature(^{0}C)	30	30	29.5	29	30	29.5
Carbon(%)	14.53	18.62	15.34	18.63	14.26	14.52
Carbohydrate	9.5	8.9	8.69	8.74	9.2	9.05
C/N Ratio	7.77	6.94	7.96	8.06	7.75	7.82
pH	5.6	5.6	6.25	6.3	5.7	5.95
Volatile Solids (mg/%TS)	27.75	28.5	28.24	27.59	25.85	25.7
Phosphorus	1.1	1.5	1.12	1.11	1.45	1.56
Calcium(%)	0.97	2.5	0.94	0.93	1.8	1.94
Potassium(%)	0.78	0.9	0.77	0.75	0.85	0.89
Magnesium(%)	0.35	0.32	0.31	0.32	0.3	0.37
Sodium(%)	0.2	0.25	0.26	0.23	0.23	0.26

Daily, Average and Cumulative Biogas Yield from the Digesters

The daily gas yield was measured and calculated through the difference in daily weight gain of the collecting bags and the increase in the weight gain of the bags. Figure 1 and 2 show the graphs of the daily and cumulative biogas yield of the digesters, respectively.

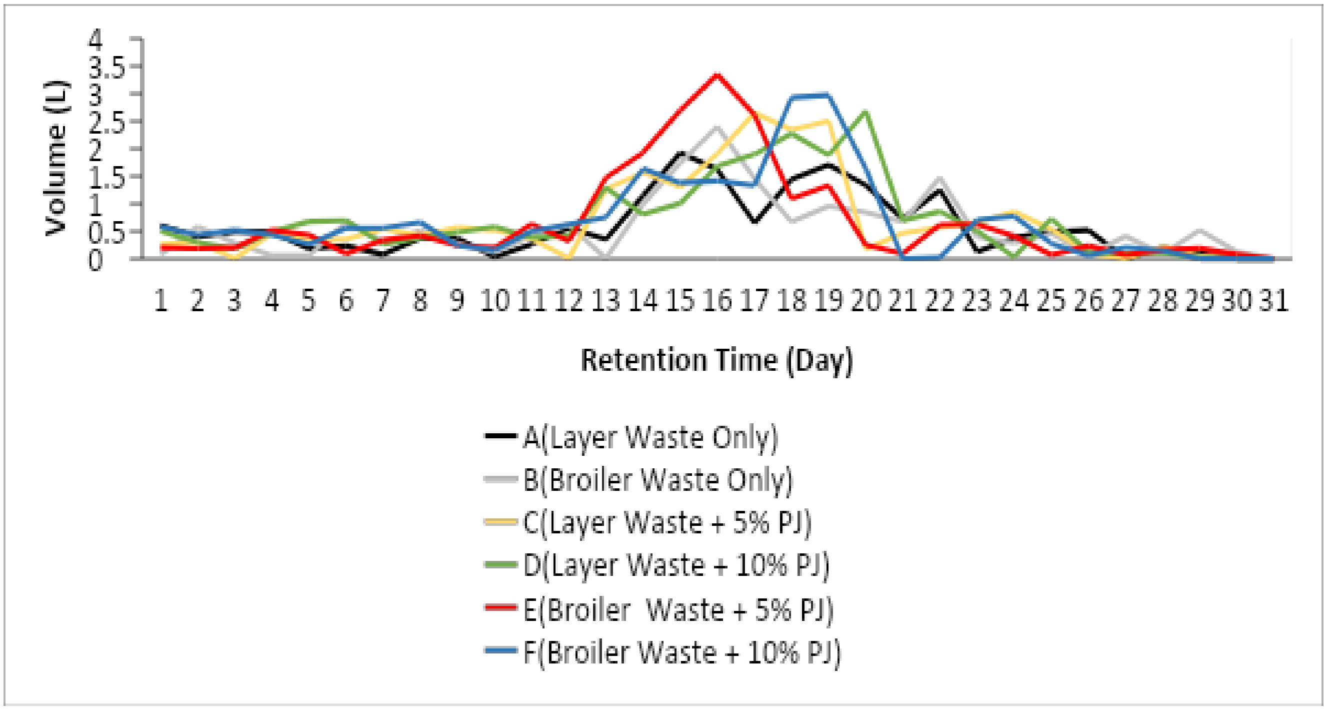

Figure 1: Daily Biogas Yield from digesters

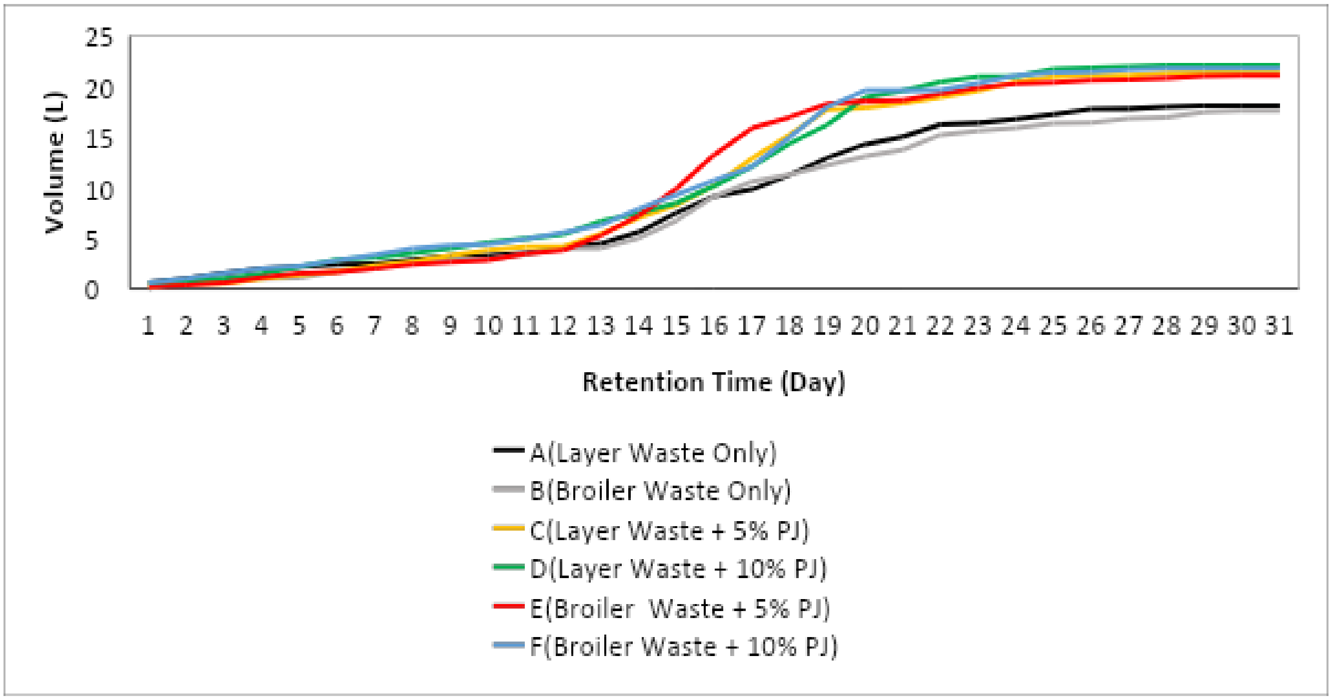

Figure 2: Cumulative Biogas Yield from digesters

The different peaks and troughs located along Figure 1 can be attributed to varying environmental and biological conditions of the different digesters.

As observed in figure 2 the biogas production began on the first day of the retention period in all six digesters due to the extended pre-fermentation period and shows the biogas yield of the digesters over the 30-day retention period which started in small amount on the first day and increased steadily on the subsequent days till the peak yield was reached, and the yield started decreasing drastically until it finally stopped producing biogas, this reduction in daily gas yield is due to the fact that the microorganisms responsible for the production of biogas have consumed a large part of the substrate thereby leading to a drop in biogas production. This same trend was also noticed by Kumar et al. (1987).

From figure 2, for the layer wastes the cumulative yield of digester C showed an 18% increase from the yield of digester A and digester D showed a 22% increase from the yield of digester A while for broiler wastes, digester E showed a 20% increase in cumulative yield from digester B and digester F exhibited a 24% increase in biogas yield.

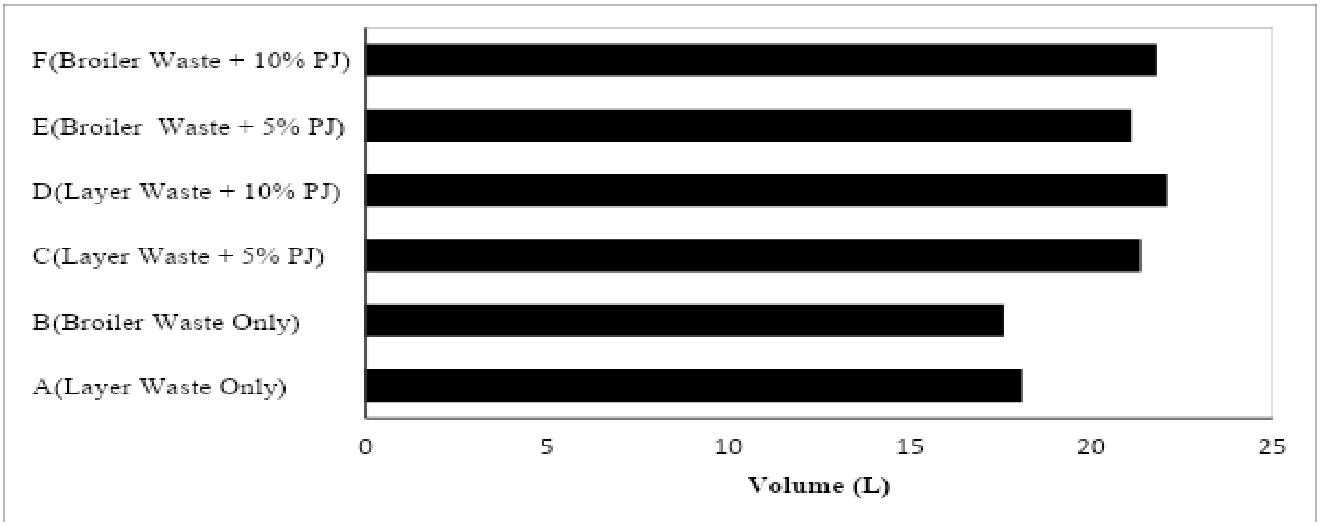

Figure 3: Total Biogas Yield from digesters

It could be seen from figure 3 that the highest biogas yield was from digester F for the broiler wastes and digester D for the layer wastes, but the broiler wastes had a higher yield than the layer wastes which may be due to the higher carbon to nitrogen ratio.

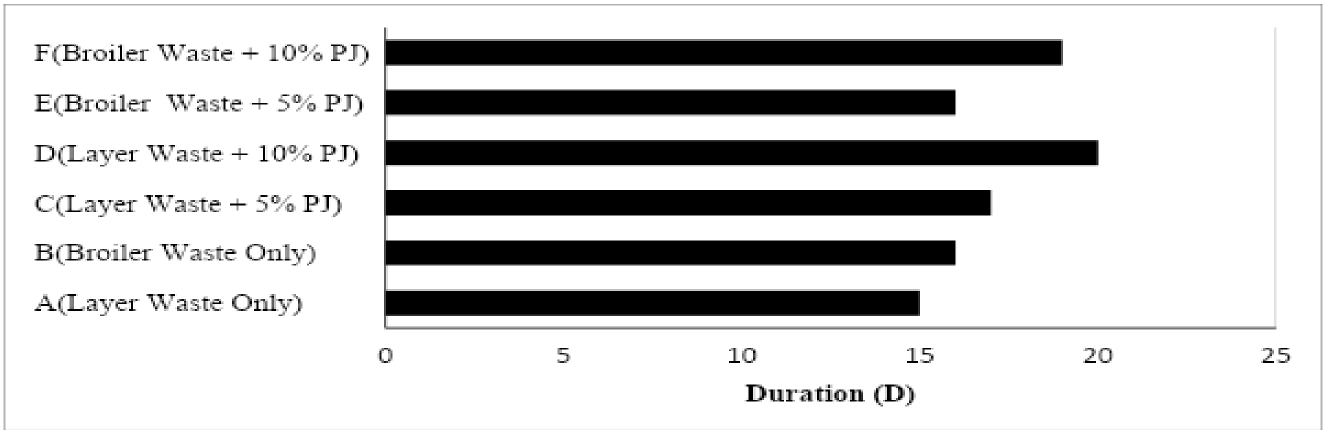

Figure 4: Duration to reach maximum yield

It could be seen from the Figure 4 that when compared to the control set-ups A and B, the set-ups containing Prosopis Juliflora took a longer time to reach their maximum yields as was evident from set-ups D and F which could be due to availability of substrate for the microorganisms to feed on.

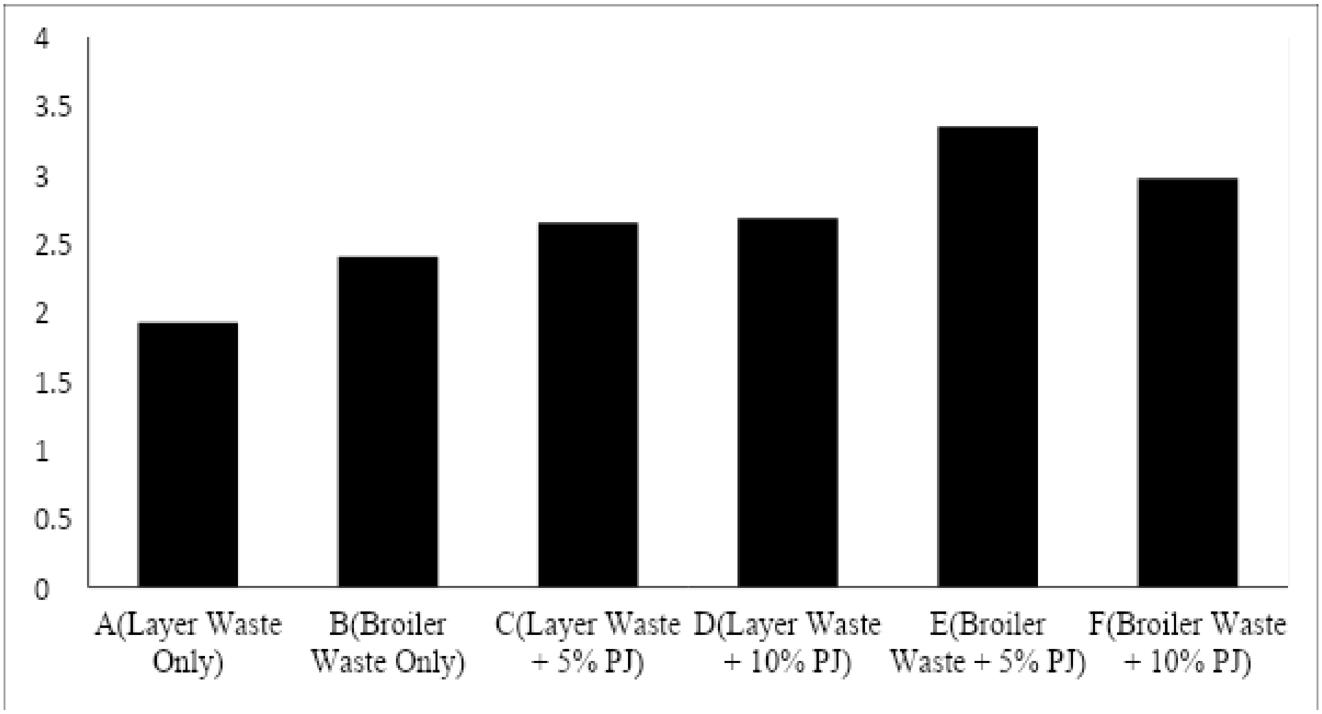

Figure 5: Maximum Biogas Yield from digesters

Digester pH During Retention Period

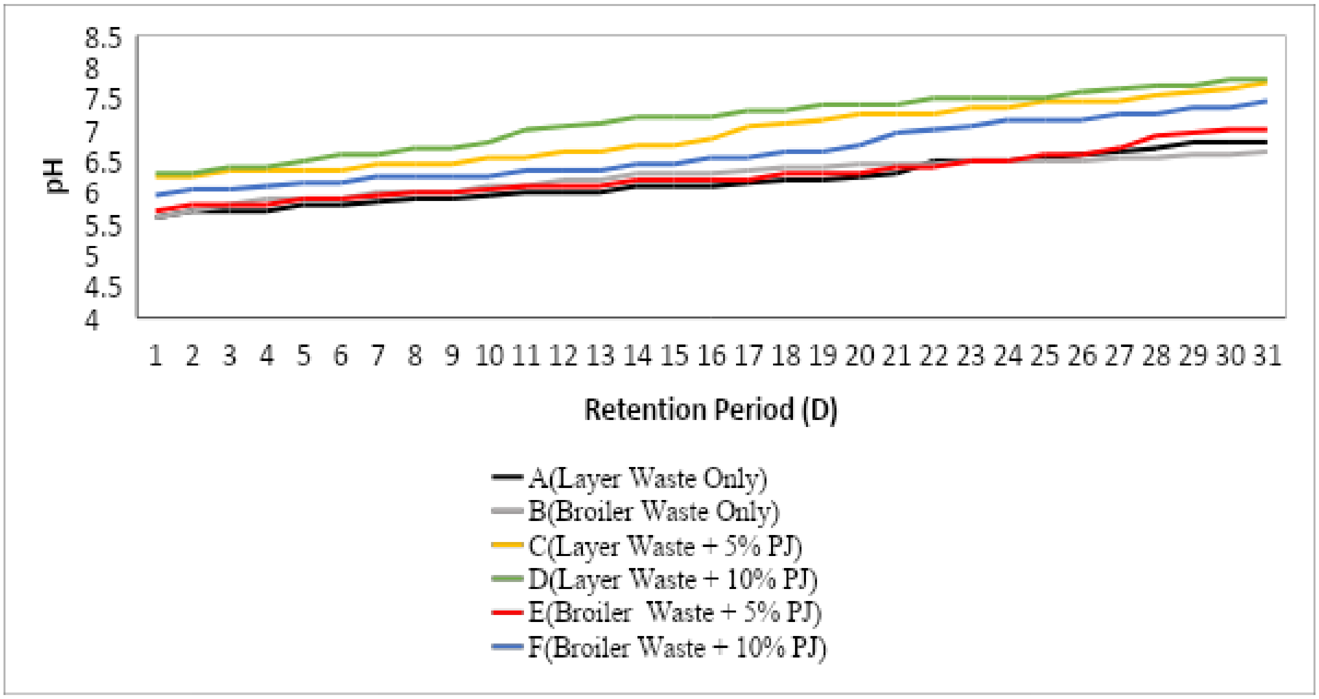

Figure 6: pH of Slurry in Digester

Figure 5 shows that maximum biogas yield was observed to be higher in the digesters containing Prosopis Juliflora when compared to the control set-ups and was even higher in the substrates containing 10% of Prosopis Juliflora when compared to that with 5% Prosopis Juliflora which may be due to the higher carbon to nitrogen ratio.

Daily Monitoring and Comparison of the operating parameters

Digester Temperature During Retention Period

The temperature of the digesters was also recorded daily for the whole period of biogas production. The average ambient temperature observed during the study was 37 ^{0}C while the average digester temperatures for each of the five substrates digested were respectively 29.9 ^{0}C, 29.9 ^{0}C, 30.0 ^{0}C, 30.1 ^{0}C, 29.9 ^{0}C and 29.9 ^{0}C. These values show that there is negligible difference in the average digester temperatures for the six digesters, which provides a common base for comparison of results. The temperatures of the digesters fall in the mesophilic range and the pH falls within a range of 6.2 to 7.6 which is optimal for biogas production as reported by (Aremu & Agarry, 2013).

The pH of the substrates was observed to have increased steadily as shown in Figure 6 as the retention period increased from a slightly acidic to a more alkaline state as the acidogenic bacteria were displaced by the methanogenic bacteria to produce biogas.

Digester pH During Retention Period

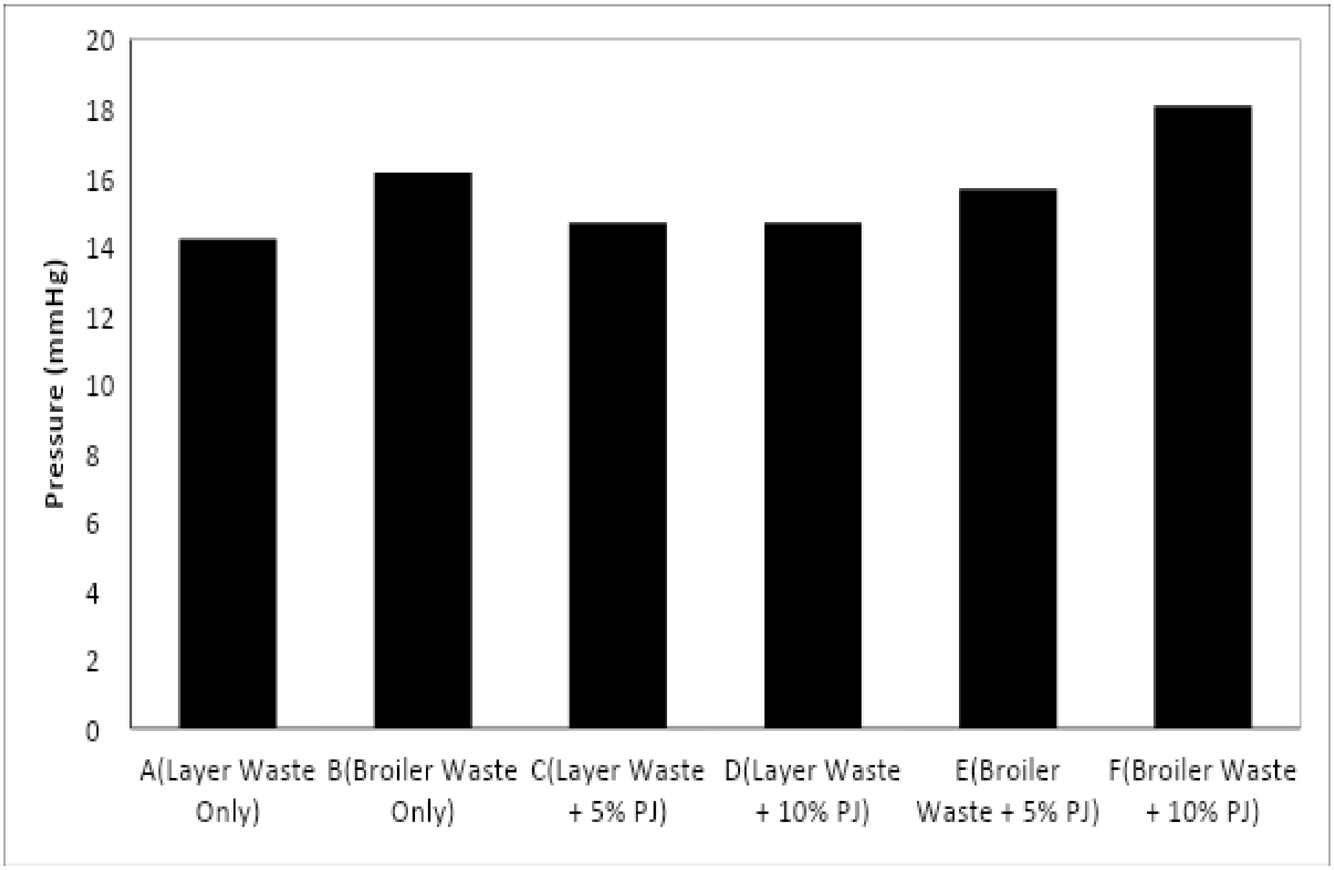

Figure 7: Average Pressure in Digester

The pressure inside the digesters were also observed through the pressure gauge installed in the digester and were recorded daily at the point of collecting the gas collection bags. The average pressures of the six digesters are shown in the figure 7.

Analysis of operating parameters

All analyses were done with Microsoft Excel 2016**.**

Regression Analysis

Table 4: Estimates of multiple regression analysis

Source	SS	df	MS	Number of observation:	186
				F:	532.54
Model	1563	6	1653.17	Prob > F:	0.000
Residual	521.65	179	3.23	R-squared:	0.960
				Adj R-squared:	0.965
Total	2084.65	185	54.62	Root MSE:	1.6402

Cumulative yield	Coefficient	Std. Err.	t	P>t	[95% Conf.	Interval]
Waste type	-1.215	.390	-3.51	0.001	-2.139	-0.599
Duration	0.570	.042	16.21	0.000	0.592	0.756
Percentage addition of Prosopis Juliflora	1.975	0.35	5.740	0.000	-9.311	13.336
Temperature	-0.245	.150	-1.76	0.070	-0.559	0.032
Pressure	0.000	.010	0.04	0.966	-0.019	0.020
pH	4.285	.887	3.87	0.000	1.682	5.181
constant	-15.219	6.669	-2.23	0.014	-28.038	-1.716

Table 5: Constituents of Biogas from GCMS analysis

Digester	**Duration (Day)**	**Gas Composition(%)**			
		CH_4	CO_2	N_2	H_2S
C	10	53.60	41.99	3.11	1.36
	20	57.88	37.53	3.19	1.39
	30	60.40	35.29	3.05	1.26
D	10	56.44	39.29	3.02	1.25
	20	62.54	33.26	3.05	1.16
	30	63.79	32.16	2.96	1.10
F	10	58.85	36.49	3.62	1.04
	20	63.23	33.11	2.72	0.93
	30	66.08	30.59	2.51	0.82

According to Table 4, the cumulative yield decreases by 1.215 units for each change in the categorical variable waste type (e.g., from layer trash to grill waste). The waste type, duration pH, and constant (y-intercept) are the most significant variables in Table 4.3, with p values less than 0.05.

The relationship between the response and predictor variables is described in equation 4.1:

$$\text{Cumulative yield} = 0.57 * \text{duration} + 1.975 * \text{Percantage addition of PJ} - 0.245 * \text{temperature} - 14.877 \quad (3)$$

Biogas Analysis

From the experiment which was carried out, the highest biogas yields were recorded in digesters C, D and F. The gases produced from the 3 set-ups on the 10th, 20th and 30th day of the retention period were collected and taken to the laboratory for analysis of the constituents and the properties of the gas from the two samples. A Shimadzu GC gas chromatograph mass spectroscopy instrument was used.

From the Table 5 it can be seen that the methane composition increases with time, the carbon (IV) oxide decreases with time and the nitrogen and hydrogen sulphide gas also decrease with time. The decrease in the hydrogen sulphide gas is responsible for the reduction in odor of the feedstock with time.

The highest methane content was observed in the digester F i.e., broiler wastes and 10% Prosopis Juliflora on the 30th day but digester D showed the highest percentage increase in methane content; increasing by 13% from the 10th day to the 30th day and it is closely followed by digester F which shows a 12.28% increase. Figures 8, 9, and 10 show the correlations between biogas production in digesters C, D, and F and the relative amounts of methane and hydrogen sulfide in the gas.

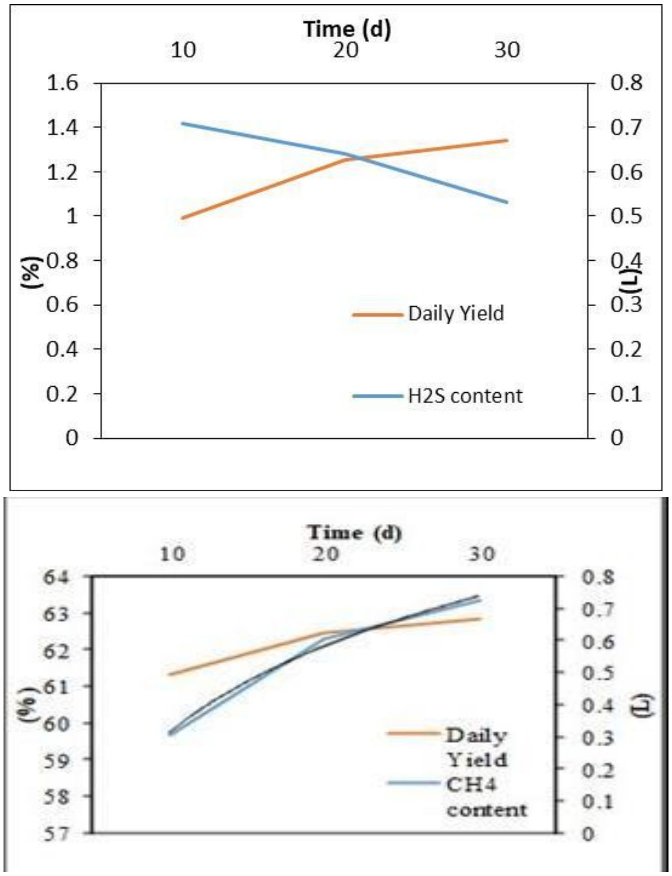

Figure 8: Digester C (a) CH_4 content & Daily Yield (b)H_2S content & Daily yield

From figure 14 it could be noticed that in digester C the relationship between the daily yield and the methane content is positively correlated while the daily yield and hydrogen sulphide content are negatively correlated.

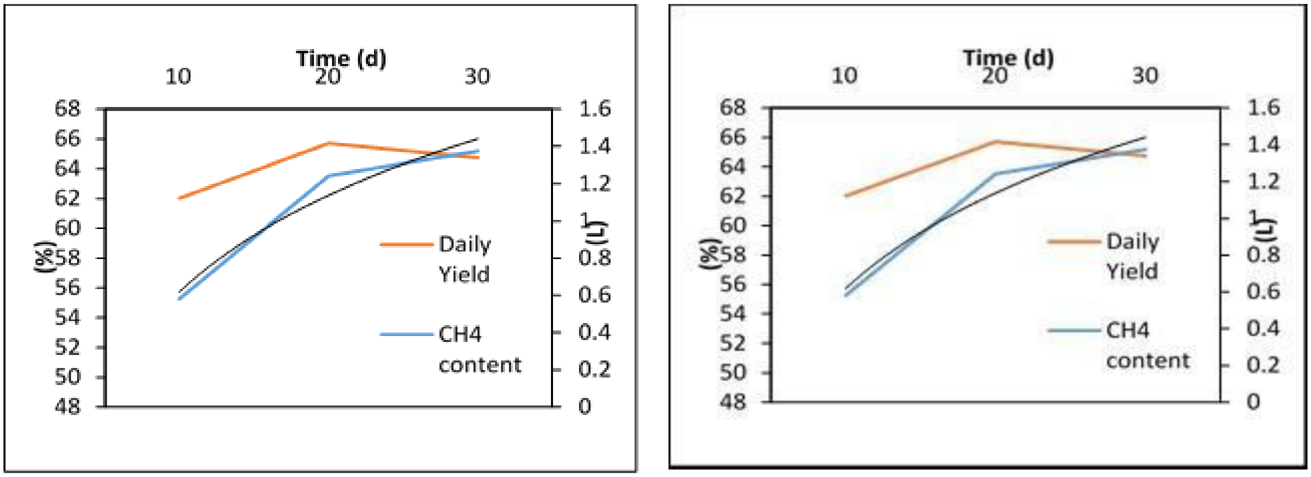

Figure 9: Digester C (a) CH_4 content & Daily Yield (b)H_2S content & Daily yield

From figure 9 it could be noticed that in digester D the relationship between the daily yield and the methane content is positively correlated while the daily yield and hydrogen sulphide content are negatively correlated.

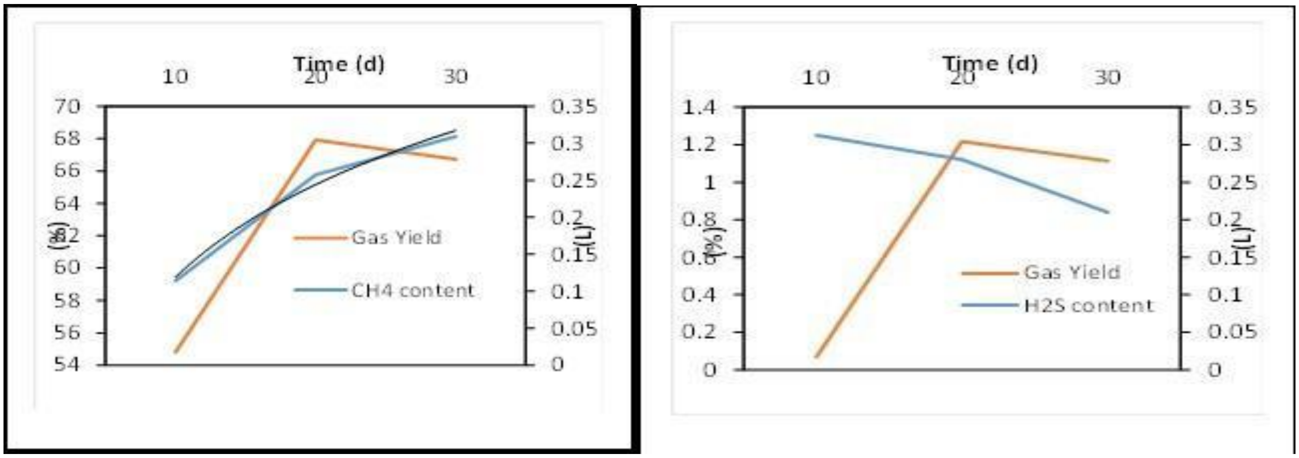

Figure 10: Digester F (a) CH_4 content & Daily Yield (b)H_2S content & Daily yield

From figure 10 it could be noticed that in digester F the relationship between the daily yield and the methane content is positively correlated while the daily yield and hydrogen sulphide content are negatively correlated.

Discussions

The objective of this study was to study the effect of adding prosopis juliflora in controlled proportions to poultry wastes, namely layers and broilers. From the preliminary tests carried out on the wastes, it was observed that broiler wastes had a lesser carbon to nitrogen ratio than the layer wastes and the substrates containing Prosopis Juliflora had a higher carbon to nitrogen ratio than the control set-ups. This shows that there is a relationship between the carbon to nitrogen ratio and the biogas yield, as reported by Deublein and Steinhauser (2011). Biogas yield increased steadily from the time feedstocks were introduced until the third week, when it began to decline (possibly because microorganisms in the digester consumed the biodegradable part of the feedstock, causing the population of microorganisms to decrease, in turn decreasing the biogas yield (Kossman et al., 2001).

The highest biogas yields were recorded in the digesters using Prosopis Juliflora, with the layer wastes plus 10% Prosopis Juliflora digester producing 22% more biogas than the layer wastes only digester and the broiler wastes plus 10% Prosopis Juliflora digester. The biogas yield with the addition of Prosopis Juliflora was 24% higher than with just broiler wastes, corroborating what Thanarasu (2019) found.

After collecting and analyzing samples of gas on days 10, 20, and 30. It was determined that the methane content of the biogas increased with time. Methane was found in lower concentrations in the gas on day 10, but at higher levels on days 20 and 30. Sasse (1988) has also documented this. Digester F achieved the greatest H2S reduction, by a factor of 32.8%.

Conclusion

This project research revealed the amount of the gas that can be produced from the two types of poultry wastes (layer wastes and broiler wastes) can be increased by adding prosopis juliflora at different proportions to poultry wastes (layer and broiler wastes).

According to the research, layer wastes plus 5% Prosopis Juliflora created 18% more biogas than layer wastes alone, and layer wastes plus 10% Prosopis Juliflora produced 22% more biogas than layer wastes alone, which was the control set-up. In comparison to digester broiler wastes alone, broiler wastes plus 5% and broiler wastes plus 10% both produced 20% and 24% more biogas, respectively. In conclusion, adding 5 and 10 percent of Prosopis Juliflora to poultry manure from layers or broilers has significantly increased the generation of biogas. Broiler wastes + 10% Prosopis Juliflora produced the highest amount of methane and least amount of toxic gas i.e. hydrogen sulfide, which makes it the most suitable substrate. This study provided information on the quantity and quality of biogas produced from the anaerobic digestion of chicken manure mixed with Prosopis Juliflora through enhanced scheme and established the importance of Prosopis Juliflora in the co-digestion of solid wastes for high biogas yield.

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Conflict of interest

The authors have no competing interests

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