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BIOGAS PRODUCTION AND CHARACTERIZATION FROM CO-DIGESTION OF CATTLE DUNG WITH MAIZE COB

A. A. Kuleve, S. Ande, N. Surma, N. Ichoron and J. I. Onah

Department of Chemistry, Joseph Sarwuan Tarka University Makurdi, PMB 2373 Makurdi
Corresponding Author: Email: asaamogaaugustine@gmail.com +2347064675866

ABSTRACT

Biogas technology is taking root in Nigeria in line with the global quest for a transition to sustainable renewable energies. This study investigates the co-digestion of cattle dung and maize cob waste for enhanced biogas production in laboratory-scale digesters. Three digesters were set up under varying experimental conditions. The results demonstrated that cattle dung and maize cob co-digestion significantly enhanced biogas production (410.20 mL) in the digester with the most optimal organic loading rate. The study showed that optimal inoculum-to-substrate ratio and organic loading rate promote the early onset of biogas production due to enhanced microbial activity. The analysis of variance (ANOVA) revealed that retention time (RT) and I/S ratio were key factors influencing biogas yield. Methane content ranged from 53.00 % in the control to 60.80 % in D2, and hydrogen sulphide concentrations were reduced in D2 compared to the control. These findings show that the co-digestion of cattle dung and maize cob waste optimizes biogas yield, and methane content, and reduces harmful gas emissions. The study demonstrates the importance of substrate selection, organic loading rate, and retention time for efficient biogas.

INTRODUCTION

The unsustainable nature of energies derived from fossil fuels and the problems that resulted from their use during the past century necessitated the search for more sustainable and environmentally friendly sources of energy. Biogas is one such alternative that has taken centre stage in this search. Its major components are methane and carbon (IV) Oxide derived from the decomposition of biological substances by microbes in environments devoid of oxygen; which process is called anaerobic digestion (AD). It converts waste that would ordinarily constitute an environmental hazard and require monetary cost to remediate to useful energy. The biogas produced has huge energy potential – it can be used directly as cooking gas, in gas lamps to provide illumination, as fuel for heating, powering electric generators, and in fuel cells to power electric cars [1] The development and deployment of large-scale AD technologies seem to be in its infancy in Nigeria. Currently, most biogas production plants available in Nigeria use feedstock derived from the excreta of livestock including cattle dung, piggery manure, fowl feces, and sewage sludge. These substrates contain biodegrading microbes that convert organic substances into biogas.[2] Animal manures however have low content of organic matter (7 % for cattle manure, 5 % for swine, and 6 % for poultry dung), and thus produce low yield of biogas. [3] The poor yield of biogas from feedstock made of livestock excrement is partly

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because livestock excreta such as cattle dung has a low Carbon:Nitrogen ratio and hence metabolizes at slower rates than crop residue with high Carbon (C) to Nitrogen (N) (C: N) ratio during the anaerobic digestion. It is thought that co-digesting agricultural residues that contain high carbon contents with livestock manure can buffer the mixture due to the higher C:N ratio of co-digested substrates and result in higher biogas yield.[4], [5] The practice of co-digesting crop residue with livestock manure is gaining traction globally. In Nigeria, maize cobs are available in large quantities as agricultural waste. They can be used for co-digestion with livestock substrates to produce biogas but not many studies have been conducted in this area. Studies on the co-digestion of maize residue with animal manures have focused more on the stalks and leaves.[6][7] Okewale et al [8] investigated biogas from the co-digestion of maize cobs with swine and poultry manures but their study involved the pre-treatment of the maize cobs with an alkali before mechanization, which increases the cost of production. This study investigated the production of biogas from the co-digestion of cattle dung (CD) with maize cob waste (MCW) without pre-treatment with alkali.

MATERIALS AND METHODS

Sample Collection and Preparation

Cattle dung (CD) was collected in February 2024 from the livestock pen at the Livestock Teaching and Research Farm of Joseph Sarwuan Tarka University, Makurdi (JOSTUM), and sundried for 5 days to a constant weight. The dried CD was pounded in a porcelain mortar with a pestle to powder and sealed in plastic containers to be used for co-digestion experiments.

Maize cobbs were collected from the Department of Crop Production, JOSTUM in December, 2023; sundried for 7 days and pulverised into fine particles (≤ 10 mm) using a burr mill.

Determination of Total Solid (TS) and Volatile Solids (VS) of substrates

Cow dung and maize cob waste (10 g each) in three replicates were placed in crucibles of known weight (M_1); the weight of the sample plus crucible was also recorded (M_2). The samples were oven-dried for 5 hr at 103 ℃ to a constant weight (M_3). The mass M_3 was calcinated in a furnace initially for 30 min at 220 ℃ and then for 2 hours at 550 ℃. The final weight (M_4) was recorded after cooling in a desiccator. The TS and VS for both CD and MCW were computed from Equations 1 and 2 as described by Zhou et al.[9]

$$TS_{\%} = \frac{M_3 - M_1}{M_2 - M_1} \times 100\ \% \qquad (1)$$

$$VS_{\%} = \frac{M_3 - M_4}{M_2 - M_1} \times 100\ \% \qquad (2)$$

Determination of Carbon – Nitrogen (C:N) ratio of substrates and digestates

The C:N ratio was determined by dry combustion method earlier described by Musa [10].

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Determination of organic loading rate (OLR)

In this study, three OLRs were investigated – 3.5, 4.5 and 5.5 (g VS/L). The mass of MCW substrates was estimated using equation 3

$$Q_{MCW} = \frac{OLR \times V_r}{S} \qquad (3)$$

Q_{MCW} = amount of maize cob waste (MCW) substrate added in batch digester (g)

OLR = Organic loading rate; 3.4, 4.5, 5.5 (g VSL^{-1})

S_s = concentration of organic matter in MCW; (0.93%TS × 0.86%VS) experimentally determined

V_R = reactor/digester working volume 0.25 (L).

Determination of substrate mass for co-digestion

Informed by literature ≤ 10 g of cattle dung was used for co-digestion. The estimated substrate masses of MCW from equation 3 were used to calculate the VS mass ratio for co-digestion.

$$M_s = \frac{M_i \times C_i}{M_s \times C_s} \qquad (4)$$

Where; M_s – VS mass ratio, M_i– inoculum mass 10 g (constant) assumed for the batch digestion,

C_i – concentration of organic matter in cattle dung -CD (inoculum), (0.82%TS × 0.65%VS) experimentally determined.

Biogas production

The experimental setup comprised three digesters with different experimental conditions in duplicate and a control. In the first digester (D1), 6 g of powdery CD was co-digested with 1.1 g of pulverized MCW (≤ 10 mm) at the OLR of 7.1 g VS/L and inoculum to substrate (I/S) ratio of 5:5. The second digester (D2) was made up of 4.8 g CD and 1.4 g MCW at 6.2 g VS/L OLR and I/S ratio of 3:5 while the third digester (D3) contained 5.6 g CD and 1.7 g MCW at 7.3 g VS/L OLR and I/S ratio of 3:5. Each digester and contents were mixed with 250 mL of distilled water and swirled rigorously to achieve a homogenous mixture A control batch with 5 g of CD mixed with 250 mL of water at 10 g VS/L OLR was also prepared. The pH of all the digesters was taken at the beginning and end of the experimental periods. The amount of biogas produced was measured volumetrically based on the liquid displacement method as previously reported by Sarker and Moller.[11] The Analysis of Variance (ANOVA) was used to examine the effects of Inoculum-to-Substrate ratio (I/S), organic loading rates (OLR), and retention time on cumulative biogas yield.

In the ANOVA test, the goodness of fit was determined by coefficient variation, R^2-squared change while the statistical significance of the regression model was checked by the Fisher statistical test (F-test). The discrimination of mean was based on the Duncan New Multiple Range (DNMRT). Other inferential statistics such as the t-test and Chi square test for

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significant variation in cumulative biogas yield and composition of biogas in the different digesters was achieved using the software Statgraphic Centurion (Ver 19, Statgraphic Technologies Inc., Virginia, USA, 2022).

RESULTS AND DISCUSSION

The results are presented in Tables 1 and 2 and 3 below

Table 1: Composition of Substrates used in the Production of Biogas

Substrate	**TS (%)**	**VS (%)**	**N (%)**	**C (%)**	**VS (%TS)**	**C: N**
Cattle Dung (CD)						
	82.42	64.84	2.82	37.61	78.67	13.34
	82.44	64.88	3.53	37.63	78.70	10.66
	82.44	64.87	3.18	37.62	78.69	11.83
Mean	**82.43**	**64.86**	**3.18**	**37.62**	**79.69**	**11.94**
Maize Cob Waste (MCW)						
	92.88	85.76	1.07	49.74	92.33	46.49
	92.86	85.72	1.12	49.72	92.31	44.39
	92.87	85.75	1.08	49.74	92.33	46.06
Mean	**92.87**	**85.74**	**1.09**	**49.42**	**92.33**	**45.63**

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Table 2: Summary of Daily Biogas Yield (mL) of the Different Digesters

Time (Days)	D2	D1	D3	Control
9	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00
18	13.20	0.00	0.00	0.00
19	0.20	0.00	0.00	0.00
20	0.50	9.90	18.21	0.00
21	14.20	8.30	1.99	0.00
22	1.00	8.20	5.30	8.80
23	5.00	2.90	14.60	3.90
24	23.50	3.50	4.60	6.10
25	1.60	6.00	6.20	9.30
26	2.90	0.10	9.20	4.70
27	18.10	5.40	6.20	7.90
28	54.40	26.10	7.90	21.40
29	25.60	19.80	37.00	4.70
30	38.90	42.30	39.60	48.40
31	11.40	36.40	60.10	23.20
32	60.80	43.10	38.20	41.80
33	68.80	38.30	19.20	22.60
34	52.40	13.00	10.80	29.90
35	17.70	6.90	1.40	0.40
36	0.10	1.90	0.00	0.00
37	0.00	0.00	0.00	1.00
38	0.00	0.00	0.00	0.00
39	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00

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Table 3: Composition of Biogas in Digesters Measured with Multiple Gas Meter

Digesters ID	CH_4 (%)	CO_2 (%)	H_2S (ppm)
D1	58.90	41.40	2141.00
D1	57.20	41.10	2090.00
Mean	**58.05**	**41.25**	**2115.50**
D2	60.50	37.30	989.00
D2	61.10	38.10	1012.00
Mean	**60.80**	**37.70**	**1000.50**
D3	54.10	41.40	2139.00
D3	57.30	42.60	2531.00
Mean	**55.70**	**42.00**	**2335.00**
Control	52.90	44.30	3211.00
Control	53.10	41.90	3443.00
Mean	**53.00**	**43.10**	**3327.00**

DISCUSSION

The results of this study provide insights into the characteristics of the substrates used in biogas production and the influence of co-digestion on biogas yield. The mean total solids (TS) content of 82.43% for cattle dung (CD) (Table 1) is within the range reported in previous studies, indicating consistency in the composition of CD across various studies.[12], [13], [14] The variation in volatile solids (VS), which is largely influenced by the nature of cattle feed and water intake, underscores the need for a standardized approach to substrate selection in anaerobic digestion.

The nitrogen (N) content of 3.18 % in CD observed in this study (Table 1) is higher than the values reported by[8]. This supports the assertion by Fischer et al. [15] that nitrogen levels in CD fluctuate over time due to volatilization and leaching. Since nitrogen plays a critical role in microbial growth and biogas yield, maintaining an optimal nitrogen balance is essential to prevent ammonia accumulation, which can inhibit the digestion process. The carbon (C) content of 37.62% and the carbon-to-nitrogen (C:N) ratio of 11.94, though consistent with literature values, indicate a deviation from the optimal C:N ratio of 20–34. This suggests that CD alone may not be ideal for maximizing biogas yield due to its low C: N ratio.

The maize cob waste (MCW) used in this study exhibited a TS content of 92.87 %, consistent with literature values, affirming its high organic content and suitability as a substrate for anaerobic digestion. The VS and VS (%TS) values of 85.74% and 92.33%, respectively, align with findings from previous studies, highlighting MCW's high biodegradability. The nitrogen

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content of 1.09 % in MCW, while higher than values reported in some studies, may be attributed to variations in fertilizer use, climatic conditions, and harvest periods. The high carbon content (49.42%) and C:N ratio (45.62) of MCW make it an ideal candidate for co-digestion with CD to achieve an optimal C: N ratio for biogas production.

The co-digestion of CD and MCW significantly enhanced biogas production, as indicated by the cumulative yields in the experimental treatments. Digester D2, which contained an optimal organic loading rate (OLR) of 4.5 gVS/L, exhibited the highest cumulative biogas yield of 410.20 mL, in agreement with the findings of previous studies [8], [16], [17]. The early onset of biogas production in D2 (day 18) compared to the other digesters suggests that an appropriate substrate-to-inoculum ratio enhances microbial activity and accelerates digestion. Conversely, the lower biogas yield in D3, attributed to a lower substrate concentration, highlights the importance of optimizing OLR for efficient biogas production.

The biogas yield in the various digesters (Table 2) indicates that retention time (RT) and inoculum-to-substrate (I/S) ratio significantly influenced cumulative biogas yield. This is in agreement with previous studies that highlight the relationship between RT and biogas yield [18], [11], and underscores the importance of sufficient incubation time for microbial activity and biogas accumulation.

The composition analysis of biogas showed that methane content ranged from 53.00 % (Control) to 60.80 % (D2), aligning with literature values.[1] While the CH_4 content in D2 was slightly lower than the 66.60% reported by Okewale et al. [8], it falls within the expected range of 50–70 % for biogas. Similarly, carbon dioxide (CO_2) content varied from 37.70 % (D2) to 43.10 % (Control), consistent with previous studies, while hydrogen sulfide concentrations remained within the reported range for biogas production.[19] The lower H_2S content in D2 (1000.50 ppm) compared to the Control (3327.00 ppm) suggests that an optimal substrate composition can minimize undesirable gas emissions.

CONCLUSION

Overall, this study demonstrates that co-digestion of CD and MCW enhances biogas yield, optimizes CH_4 content, and minimizes inhibitory compounds such as H_2S. The findings demonstrate the need for careful substrate selection, optimal OLR, and appropriate RT to maximize biogas production efficiency.

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