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BIOGAS PRODUCTION FROM COW DUNG AND FRUIT WASTE

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ABSTRACT

The study aimed to experiment the potential of biogas production from cow dung and fruit waste and their combinations. The biogas produced by different substrate combinations was measured daily for 30 days together with temperature and pH of the slurry. Biogas production by the different substrates started on different days and was earliest in 100% cow dung (day 4) and latest in 100% fruit waste (day 8). On day 30, 25% cow dung and 75% fruit waste produced the highest volume of biogas (8.25±0.35 psi) equivalent to 4734m, at a mean temperature of 35.25±0.35˚C and pH of 7.75±0.07 and lowest volume of biogas was produced by 100% fruit waste (1.65±0.21 psi). Flame test showed that the biogas from different substrates was flammable, except for the 100% fruit waste. Biogas production by 100% cow dung and 100% fruit waste had negative correlation with the temperature while biogas produced by 75% cow dung+25% fruit waste and 50% cow dung+ 50% fruit waste had positive correlation with the temperature. The biogas production potential by 50% cow dung and 50% fruit waste, 75% cow dung and 25% fruit waste, and 25% cow dung and 75% fruit waste showed that co- digestion of organic waste is an efficient way to enhance biogas production. It is therefore recommended that implementing effective temperature management and maintaining optimal pH levels for specific substrate compositions can contribute to more efficient and reliable biogas production.

Keywords: Biodigester, Biogas, Cow Dung, Flame, Fruit Waste, pH, Temperature

INTRODUCTION

In response to the escalating concerns regarding climate change and the depletion of fossil fuel resources, biogas production has emerged as a significant player in sustainable energy solutions. Biogas, a mixture of methane (CH_4) and carbon dioxide (CO_2), is generated through the anaerobic digestion of organic materials, making it a renewable and environmentally friendly energy source (Appels *et al.*, 2011). Biogas technology not only addresses the energy crisis but also contributes significantly to reducing greenhouse gas emissions by capturing methane emissions from decomposing organic waste, a crucial step in combating climate change and promoting a circular economy (Calvin *et al.*, 2021).

The conversion of organic materials into biogas not only tackles waste management challenges but also offers compelling environmental benefits. Biogas has a significant role to play in the global energy transition because of the need to transform the global electricity systems from fossil fuel-based generation to low-carbon and renewable energy-based power generation (Kabeyi & Olanrewaju, 2022). With huge biomass-to-biogas conversion potential and many feasible biogases-to-electricity conversion technologies, biogas will play an extremely important role in energy transition as a renewable energy fuel resource and feedstock for industrial production of chemical fuels and renewable products (Pedro *et al*., 2021). Furthermore, biogas production curtails reliance on traditional energy sources, thereby reducing the overall carbon footprint (EIA, 2016). Economically, biogas production presents a spectrum of opportunities. The energy harnessed from organic wastes can be used for electricity generation, heating, and cooking, leading to substantial energy cost savings (IEA, 2020). Additionally, surplus biogas can be fed into the grid, creating an income stream for farmers and waste management facilities (IEA, 2020). Some of the benefits of biogas production from organic wastes are enumerated in Onuaguluchi & Njoku (2022).

With increasing energy demands and the urgent necessity to transition to greener energy sources, there is a compelling case to improve the efficiency of biogas generation (IEA, 2020). Research on co-digestion of organic waste can help develop more effective digestion processes, thereby enhancing biogas yield and making it a more economically viable source of energy (Filer *et al.,* 2019). These organic materials can be diverted from landfills, mitigating the environmental impacts associated with waste disposal by enhancing biogas production from cow dung and fruit waste (Mignogna *et al.,* 2023). A majority of the population in many developing countries lives in rural settlements and engages in agriculture which generates biomass that can be used for biogas production and organic fertilizers (Chen *et al*., 2017). With the right infrastructure, farmers can meet their own biogas energy needs and sell excess electricity or biogas as well as organic fertilizers from biogas production leading to sustainable agriculture and energy. Additionally, the efficient utilization of these feedstocks can alleviate energy scarcity concerns, particularly in regions with limited access to traditional energy sources (Okafor *et al*., 2022).

The aim of this research was to assess the potential of cow dung and fruit waste and their combinations in biogas production. It is hoped that this can help in mitigating climate change due greenhouse effect, reduce dependence on fossil fuels, assist in waste management and contribute to SDGs 2, 3, 5, 6, 7, 9 and 11.

MATERIALS AND METHODS

Source of Materials

Fresh cow dung was collected in clean polythene bags from an abattoir in Cele-Itire market, Lagos State, Nigeria. Different fruit waste samples watermelon, orange, apple and pineapple peels were collected from Ikosi fruit market in Ketu Metropolis, Lagos Nigeria, while the plastic containers used in the construction of the anaerobic digester were obtained from Lagos Waste Management Authority (LAWMA) dumpsite in Olusosun area of Ikeja, Lagos state Nigeria.

Anaerobic Digester Set up

Ten 18.9 litre already constructed water dispenser bottles was used as a local anaerobic digester following the description of Onuaguluchi & Njoku (2022). Each digester consisted of an inlet pipe used in feeding the digesters, an outlet tap, and a gas outlet pipe which served as a pathway for collecting the biogas produced (Makádi *et al.,* 2012). The digesters were labeled A (100% cow dung), B (100% fruit waste), C (75% cow dung+25% fruit waste), D (50% cow dung+50% fruit waste) and E (25% cow dung+75% fruit waste) and each digester was replicated twice. They were painted black such that the digesters are opaque to all forms of light, including sunlight as it was not known if the bacteria contained in the substrates were sensitive to light (Onwukeme *et al*., 2016; Zainudeen *et al*., 2021). The digesters had pressure gauge at the top of their set up which was used to determine the amount of biogas produced daily and a brass air valve was used to control the flow of gas in and out of the digester during flame test (IRENA, 2016).

Preparation of Slurry and Loading of Digesters

The preparation of substrate used for biogas production in this study was carried out according to Chilakpu (2020). Before loading the bio-digesters, the inlet and outlet valves were opened to prevent negative pressure build up in the digester and foreign matters like stones were carefully removed from the waste.

The experimental design used in this study included the arrangement of the digesters according to the proportions of the different wastes (fruit waste and cow dung). Each digester was filled with 6 kg of water and proportions of fruit waste and cow dung totally 6 kg. The proportion included 6 kg cow dung, 6 kg fruit waste, 4.5 kg cow dung + 1.5 kg fruit waste, 3 kg cow dung + 3 kg fruit waste, and 1.5 kg cow dung and 4.5 kg fruit waste (Onuaguluchi and Njoku, 2022). After loading the digesters, they were properly sealed using araldite adhesive to cover leakage, and the outlet tap was closed to avoid spillage of the slurry.

Measurement of Parameters of the Digester

The measurement of parameters of the digesters was according to Oladoye *et al*. (2017). The substrate in each digester was manually agitated once daily for about five minutes to prevent long periods of solid settlement before measuring pH and temperature.

Twenty millilitres (20ml) of the feedstock was collected into a clean rubber container through the tap to check for pH and temperature values. The digital pH meter was inserted into the slurry taken from the digester and the readings were taken for the substrate pH while the slurry temperature was also read by inserting the mercury bulb thermometer into the slurry (Zainudeen *et al*., 2021). Biogas production was recorded from the pressure gauge attached to the top of the digester (Onuaguluchi & Njoku 2022). The volume of biogas produced was measured in psi and 1 psi = 573.8268 meters of air

Flame Test

Flame test was carried out for the biogas produced in each of the bio-digesters after thirty (30) days of retention time. The hose was removed from the gas connector and ignited to check for flame colour and flammability.

Data Analysis

Replicate readings obtained from the parameters (biogas production, temperature, and pH) of the digesters were inputted into the Microsoft Excel tables. The mean and standard deviation of each replicate for the volume of biogas production, temperature, and pH were calculated. Also, the data collected were subjected to inferential statistics (correlation) and Analysis of Variance (ANOVA) using the Statistical Analysis Systems software (SAS) 2008.

RESULTS and DISCUSSION

Biogas Production from Different Substrates

Biogas productions from different substrates are shown in Table 1. For 100% cow dung, biogas production started on day 4, reaching its maximum on day 21 (7.30±1.69 psi). The range of biogas production for this substrate during the observation period was 0 to 7.30±1.69 psi. In the case of 100% fruit waste, biogas production began on day 8, peaking on days 22 and 23 (3.00±0.42 and 3.00±0.71 psi) respectively. The overall range for biogas production in this substrate was 0 to 3.00±0.71 psi. The substrate with a mix of 75% cow dung and 25% fruit waste initiated biogas production on day 6, achieving a maximum on day 27 (6.85±0.49 psi). The biogas production increased from day 5 until day 10 reduced and subsequently. The volume of biogas produced varied in different day of the study. For the 50% cow dung and 50% fruit waste, biogas production also began on day 5, reaching its peak on days 29 and 30 (5.75±0.35 psi). The overall range for this substrate was 0 to 5.75±0.35 psi. Lastly, the substrate with 25% cow dung and 75% fruit waste started biogas production on day 5, achieving the highest value on day 22 at 8.25±0.35 psi at a mean temperature of 35.25±0.35˚C and pH of 7.75±0.07 which was the highest mean temperature and pH reached during the study. This result conforms to the works of Chae *et al*. (2008) which show that optimum biogas production occurs at mesophilic stage. The strong positive relationships between biogas production from different substrate, such as 100% cow dung and 100% fruit waste (r=0.92), 50% cow dung + 50% fruit waste (r=0.88), 75% cow dung + 25% fruit waste (r=0.95), and 25% cow dung + 75% fruit waste (r=0.98), suggest a shared dependency on similar substrate compositions. These findings align with the idea that certain microbial communities involved in anaerobic digestion thrive on specific substrate combinations, leading to consistent and synchronized biogas production patterns (Akintokun *et al.,* 2017).

Table 1: Biogas Production (psi) from Different Substrates (1psi=573.8268 meters of air)

Day	100% cow dung	100% fruit waste	75% cow dung and 25% fruit waste	50% cow dung & 50% fruit waste	25% cow dung & 75% fruit waste
1.	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2.	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
3.	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
4.	0.25±0.35	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
5.	1.45±0.35	0.00±0.00	0.00±0.00	0.25±0.35	1.40±0.14
6.	1.70±0.28	0.00±0.00	0.70±0.99	2.75±0.35	1.65±0.21
7.	2.25±0.35	0.00±0.00	1.90±0.42	3.00±0.71	1.70±0.28
8.	2.65±1.06	0.20±0.28	2.15±0.49	4.00±0.71	2.00±0.71
9.	3.20±0.98	0.70±0.28	2.30±0.71	4.00±0.71	2.95±0.07
10.	3.55±1.06	2.25±0.35	1.95±0.35	4.25±0.35	3.40±0.14
11.	4.20±0.98	2.40±0.56	3.35±0.21	4.20±0.85	4.20±0.42
12.	4.75±1.06	2.00±0.71	4.25±0.35	4.70±1.13	4.50±0.71
13.	4.65±0.49	1.90±0.14	4.45±0.63	4.40±0.85	5.35±0.78
14.	4.40±0.14	1.65±0.21	4.75±0.35	4.45±0.64	4.85±0.07
15.	4.90±0.56	1.65±0.21	4.55±0.07	4.00±0.71	4.70±0.28
16.	5.05±1.34	1.75±0.35	4.75±0.35	4.00±1.41	5.75±1.06
17.	6.40±0.14	2.90±0.14	5.25±0.35	5.15±2.33	6.25±1.06
18.	6.00±0.07	2.95±0.07	6.70±0.28	3.95±0.07	7.05±0.64
19.	6.15±0.07	2.35±0.21	6.45±0.63	4.25±0.35	7.85±0.49
20.	5.95±0.63	2.90±1.27	6.50±0.71	4.75±0.35	7.90±0.14
21.	7.30±1.69	2.50±0.42	6.50±1.41	4.75±0.35	7.40±0.14
22.	6.70±3.11	3.00±0.42	6.45±0.64	4.95±0.07	8.25±0.35
23.	6.40±1.55	3.00±0.71	6.50±0.71	5.00±0.71	7.50±0.71
24.	6.10±1.27	2.50±0.71	6.25±0.35	4.25±1.06	7.55±0.49
25.	6.00±1.41	2.50±0.71	6.45±0.78	4.75±1.77	7.50±0.42
26.	5.65±1.20	2.25±0.35	6.60±0.57	4.70±1.13	6.90±1.55
27.	5.45±0.78	1.75±0.35	6.85±0.49	5.00±0.71	6.45±0.64
28.	5.25±0.35	1.65±0.21	6.70±0.28	5.50±0.71	6.00±0.71
29.	4.75±0.35	1.40±0.14	6.40±0.57	5.75±0.35	6.50±0.71
30.	4.90±0.14	1.65±0.21	6.20±0.42	5.75±0.35	5.90±0.14

Temperature of Different Substrates

The temperature variations in different substrates are shown in Table 2. 100% cow dung temperature was 32.75±1.06°C on day 1. The mean temperature ranged from 27.75±0.35°C on day 25 to 35.00±2.82°C on day 7. For the 100% fruit waste, the temperature reading was 34.00±1.41°C on day 1, which had the highest mean temperature on that day compared to the other substrate, fluctuated with a decreasing trend towards the end of the study. It was observed 100% fruit waste recorded the highest mean temperature from day 1 to day 4 of the study. The mean temperature reached a maximum of 34.50±3.53°C on day 7 and a minimum of 25.00±1.41°C on day 29. The substrate with a combination of 75% cow dung and 25% fruit waste temperature was 28.50±2.12°C on day 1, having the lowest mean temperature measured on that day compared to the other substrate. 75% cow dung and 25% fruit waste temperature recorded the lowest mean temperature from day 1 to day 6 of the study. 75% cow dung and 25% fruit waste highest temperature occurred at 35.15±0.21°C on day 14, lowest temperature occurred at 26.50±0.00°C on day 5. For the 50% cow dung and 50% fruit waste substrate, the temperature reading was 30.50±0.71°C on day 1, reached a maximum of 34.45±3.61°C on day 20, a minimum of 27.45±0.21°C on day 22, and fluctuated between 27.45±0.21°C and 34.45±3.61°C. The substrate with 25% cow dung and 75% fruit waste temperature began at 30.75±1.77°C on day 1, reached a maximum of 35.25±0.35°C on day 22, minimum of 27.50±0.71°C on day 11. 25% cow dung and 75% fruit waste substrate produced the highest mean temperature of 35.25±0.35 while 100% fruit waste substrate recorded the lowest mean temperature of 25.00±1.41°C on day 29. The 50% cow dung and 50% fruit waste, for example, exhibited a range from 27.45±0.21°C to 34.45±3.61°C. Such variations may be linked to the continuous degradation of substrates and the associated microbial activity, causing fluctuations in heat production. These findings align with studies by Otun *et al.*, (2015), highlighting the importance of monitoring and controlling temperature for optimizing anaerobic digestion processes. Temperature in 100% cow dung exhibits negative correlations with biogas production from both 100% cow dung (r=-0.49) and 100% fruit waste (r=-0.72). Similarly, temperature in 100% fruit waste shows negative correlations with biogas production from both 100% cow dung (r=-0.66) and 100% fruit waste (r=-0.60).

The negative correlations between temperature and biogas production can be a potential temperature sensitivity of these substrates. As temperature increases, biogas production from these substrates tends to decrease. This negative correlation may be attributed to the thermal limits of specific microbial communities involved in the digestion process. The initiation of biogas production in some digesters corresponds with temperature increases, emphasizing the role of temperature as a crucial factor in initiating and sustaining microbial activity. The peak temperatures also align with the periods of maximum biogas production, indicating a potential correlation between higher temperatures and increased microbial efficiency (Anika *et al.*, 2019). This concurs with findings by Anika *et al*., (2019), who reported temperature-dependent variations in anaerobic digestion performance.

Table 2: Temperature of Slurry from Different Substrates (1psi= 573.8268 meters of air)

Day	100% cow dung.	100% fruit waste.	75% cow dung and 25% fruit waste.	50% cow dung and 50% fruit waste.	25% cow dung and 75% fruit waste.
1	32.75±1.06	34.00±1.41	28.50±2.12	30.50±0.71	30.75±1.77
2	31.50±0.71	33.00±2.82	27.75±1.78	29.50±2.12	30.25±1.77
3	30.50±0.71	32.50±0.71	27.00±0.00	28.00±1.41	29.75±1.06
4	32.25±1.06	32.75±1.77	27.00±1.41	28.75±1.06	30.25±1.06
5	33.25±2.47	32.25±1.06	26.50±0.00	30.50±0.71	31.00±0.00
6	34.00±2.82	33.00±4.24	28.00±4.24	31.00±0.71	31.50±0.71
7	35.00±2.82	34.50±3.53	29.00±1.41	28.25±0.35	28.25±0.35
8	33.50±2.12	33.50±0.71	26.75±2.47	31.00±0.71	30.00±2.83
9	32.75±1.06	33.00±2.83	27.50±0.71	31.25±0.35	30.25±4.60
10	30.25±3.18	33.85±4.03	27.25±3.18	28.50±2.12	32.00±0.71
11	28.25±0.35	27.42±2.28	29.45±1.48	31.20±2.40	27.50±0.71
12	28.80±0.85	28.60±3.39	28.75±1.06	33.60±0.85	28.25±1.06
13	30.75±3.18	30.00±0.28	34.20±2.83	29.75±1.77	29.00±1.41
14	32.55±2.19	28.65±1.62	35.15±0.21	31.25±0.35	30.50±0.71
15	33.10±1.56	28.90±1.41	31.10±1.27	32.15±3.04	31.75±2.47
16	32.25±1.06	28.70±0.42	32.55±2.19	33.50±2.12	28.95±2.90
17	28.15±1.63	30.00±0.28	29.40±1.55	31.70±3.82	30.25±3.18
18	31.60±1.98	30.90±1.27	31.35±3.04	31.35±5.44	32.25±2.47
19	31.35±3.04	28.40±2.26	32.50±0.71	32.00±1.41	34.20±1.70
20	29.75±2.47	29.95±1.20	28.85±0.50	34.45±3.61	34.35±0.21
21	29.80±3.11	26.20±0.28	30.00±4.24	31.25±2.47	33.00±1.41
22	29.40±0.56	29.80±5.37	27.65±0.21	27.45±0.21	35.25±0.35
23	28.50±2.12	28.85±0.92	27.75±0.35	29.60±1.13	32.00±2.83
24	30.75±3.18	28.60±1.69	31.15±5.16	31.50±2.12	32.25±1.77
25	27.75±0.35	26.50±2.12	33.05±5.13	32.00±4.24	31.45±0.77
26	32.65±2.33	26.55±0.64	31.95±2.76	32.00±1.41	30.50±4.95
27	29.50±2.83	25.10±0.99	31.95±0.07	31.20±4.52	29.50±2.12
28	28.90±1.56	26.55±2.19	31.60±0.85	31.40±5.37	29.00±0.71
29	33.95±0.07	25.00±1.41	29.70±2.55	34.00±2.83	28.75±2.47
30	31.75±0.35	25.75±0.35	32.70±1.13	33.75±1.77	28.00±1.41

pH of Different Substrates

The pH in different substrates is shown in Table 3. pH of 100% cow dung substrate was 7.50±0.28 on day 1, reached its lowest at 4.80±0.28 on day 30 and highest at 7.50±0.28 on day 1. For the 100% fruit waste substrate, pH reading was 5.60±1.41 on day 1, the highest mean pH was recorded on day 30 (6.6±0.42) and lowest recorded on day 2 (4.75±0.07), and ranged from 4.75±0.071 to 6.60±0.42. In the substrate with a combination of 75% cow dung and 25% fruit waste, pH was 6.75±0.35 on day 1, highest on day 14 (7.20±0.42) lowest on day 30 (6.25±0.35), fluctuated between 6.25±0.35 and 7.20±0.42. For the 50% cow dung and 50% fruit waste substrate, the pH was 6.40±0.85 on day 1, reached its highest at 7.25±0.35 on day 20, lowest at 5.95±0.07 on day 14, fluctuated between 6.15±0.50 and 7.25±0.35. In the substrate with 25% cow dung and 75% fruit waste, the pH was 7.65±0.21 on day 1, mean pH highest at 7.75±0.07 on day 22 and lowest at 5.10±0.14 on day 16, fluctuated between 5.10±0.14 and 7.75±0.07. It was observed that 25% cow dung and 75% fruit waste substrate produced the highest mean pH of 7.75±0.07 on day 22 while 100% cow dung substrate recorded the lowest mean pH of 4.80±0.28 on day 30.

The pH in the different digesters was one of the major factors that influenced the rate of biogas generated in this study. The result of pH with different substrates on biogas yield shows that 25% cow dung and 75% fruit waste which is alkaline (7.75±0.07) has better yield than other substrates (acidic and neutral). Previous studies by Ukpai & Nnabuchi (2012) revealed that neutral pH of 7 has better biogas compared to acidic and alkaline in both cow and cassava peels. pH of co-digestion substrates were within the alkaline range and this may have influenced the quantity of gas produced as the co-digestion produced the highest gas production (75% cow dung + 25% fruit waste, 50% cow dung + 50% fruit waste, and 25% cow dung and 75% fruit waste). The Cow dung substrate was mostly alkaline and this could be as a result of ammonia accumulation from the low Carbon Nitrogen ratio of the cow dung (Cabrita & Santos, 2023), while the 100% fruit waste substrate was mostly acidic as agreed with the report of Eze & Eze (2018).

pH in 100% cow dung is negatively correlated with biogas production from 100% cow dung (r=-0.58) but positively correlated with pH in 100% fruit waste (r=0.47). Similarly, pH in 100% fruit waste is positively correlated with biogas production from 100% fruit waste (r=0.67) and negatively correlated with pH in 100% cow dung (r=-0.52). The negative correlation between pH in 100% cow dung and biogas production from 100% cow dung (r=-0.58) suggests that as acidity increases, biogas production decreases. This aligns with the understanding that excessively low pH levels can inhibit methanogenic bacteria. Conversely, the positive correlation between pH in 100% fruit waste and biogas production from 100% fruit waste (r=0.67) indicates that higher pH levels may aid biogas production from fruit waste. These relationships underscore the significance of maintaining optimal pH levels for the specific substrate composition in each digester (Deressa *et al.*, 2015). The correlations also suggest that biogas production by fruit waste is alkaline dependent while that of cow dung is acid dependent.

Table 3: pH of the Different Substrates. (1psi= 573.8268 meters of air)

Day	100% cow dung	100% fruit waste	75% cow dung and 25% fruit waste	50% cow dung and 50% fruit waste	25% cow dung and 75% fruit waste
1	7.50±0.28	5.60±1.41	6.75±0.35	6.40±0.85	7.65±0.21
2	6.65±0.64	4.75±0.071	6.50±0.42	6.40±0.85	7.50±0.21
3	6.50±0.28	4.95±0.07	6.60±0.14	6.50±0.71	6.75±0.78
4	6.05±0.07	5.00±0.283	6.45±0.21	6.25±1.20	6.45±0.64
5	6.10±0.42	5.30±0.41	6.30±0.07	6.20±1.27	6.00±0.99
6	6.30±0.14	5.10±0.283	6.40±0.28	6.15±1.20	6.20±0.99
7	6.40±0.14	5.15±0.35	6.70±0.71	6.23±1.24	6.35±0.78
8	6.50±0.07	4.85±0.071	6.75±0.92	6.20±1.20	6.13±1.17
9	6.45±0.07	4.85±0.071	6.90±0.99	6.28±1.24	6.58±0.53
10	6.50±0.14	4.85±0.071	6.93±0.95	6.25±1.34	6.45±0.64
11	5.65±0.92	5.30±0.42	6.90±0.85	6.85±0.49	5.65±0.50
12	5.55±0.78	5.50±0.42	6.85±0.92	6.55±0.78	5.85±0.50
13	5.85±0.07	6.10±0.14	7.00±0.71	6.20±0.85	5.85±0.50
14	5.80±0.07	6.25±0.78	7.20±0.42	5.95±0.07	5.75±0.35
15	6.45±0.78	6.45±0.78	6.95±1.20	6.20±0.07	5.65±0.07
16	5.95±0.07	6.15±1.63	7.05±1.20	6.15±0.50	5.10±0.14
17	6.55±1.34	6.35±1.91	6.58±0.32	6.95±0.35	6.10±1.27
18	6.45±1.06	6.35±0.49	7.05±0.64	7.08±0.18	6.40±1.41
19	6.40±1.13	5.55±0.78	7.05±0.78	6.90±0.57	7.05±0.78
20	5.20±0.14	5.35±0.64	6.90±0.85	7.25±0.35	6.90±0.14
21	6.20±1.56	5.05±0.35	7.03±1.10	7.05±0.64	6.45±0.78
22	5.05±0.21	5.40±0.71	6.65±0.64	7.11±0.55	7.75±0.07
23	5.05±0.35	5.75±0.35	6.65±0.78	6.90±1.41	6.25±0.92
24	5.10±0.14	5.35±0.21	6.65±0.49	6.65±1.63	5.50±0.42
25	5.15±0.07	5.3±0.283	6.40±0.57	7.10±0.57	5.55±0.35
26	5.05±0.07	5.55±0.78	6.55±0.50	7.00±0.14	5.40±0.57
27	5.40±0.85	6.10±0.71	6.40±0.14	6.95±0.21	5.40±0.28
28	5.35±0.92	6.40±0.56	6.30±0.14	6.05±0.64	5.95±0.07
29	4.95±0.35	6.45±0.35	6.30±0.28	6.70±0.28	6.30±0.28
30	4.80±0.28	6.60±0.42	6.25±0.35	6.30±0.28	5.70±0.85

Flame Production by Biogas from the Different Substrates

The gases from the different substrates produced different colours and different flame lengths. The biogas in each of the digesters placed in dark and well ventilated room produced a pale blue flame, while the digesters in light atmosphere produced a yellow flame colour with a reddish mixture. The biogas in each of the digester produced flame except 100% fruit waste which was non-flammable. Through visual estimation, the flame produced by digester with 50% cow dung and 50% fruit waste had the lowest flame height compared with the other types of substrate, and the highest flame height was given by biogas from substrate with 100% cow dung. The non-flammability of the 100% fruit waste substrate could be attributed to the findings of Hamidi & Nasrul (2014) which reported flame is influenced by fuel quality as carbondioxide in gas acts as an inihibitor. Similarly, this conforms to studies by Ilminnafik *et al*. (2019), which shows that the higher the carbondioxide content the lower the biogas heat value, and vice versa.

Correlation between Biogas Production, Temperature and pH of the Different Digester

Table 4 presents a correlation of temperature, pH, and biogas production across different substrates. Biogas produced by the different substrate combination had positive correlation with each other. Biogas produced by 100% cow dung had negative correlation with the temperature (r= -0.49) and pH (r= -0.58) of the slurry from 100% cow dung. However, biogas produced by 100% fruit waste had a negative correlation with the temperature (r= -0.60) and a positive correlation with the pH (r= -0.38) of the slurry from such waste.

For 75% cow dung+25% fruit waste, the amount of biogas produced had a positive correlation with the temperature and pH (r=0.62 and r =0.10) respectively of slurry of such waste. Biogas produced from 50% cow dung and fruit waste also had positive correlation with temperature (r= 0.49) and pH (r=0.34) of the slurry of such waste. In the case of 25% cow dung + 75% fruit waste, the amount of biogas produced had a positive correlation with temperature (r=0.38) and a negative correlation with the pH (r= -0.27) of the slurry from such waste.

Table 4: Correlation of temperature, pH, and biogas produced from cow dung and fruit waste

	100% cd	100% fw	75%cd+ 25%fw	50% cd+ 50% fw	25%cd+ 75%fw	100% cd Temp	100% fw Temp	75% cd + 25% fw Temp	50% cd+ 50% fw Temp	25% cd+ 75% fw Temp	100% cd pH	100% fw pH	75%cd + 25% fw pH	50% cd+ 50%fw pH	25% cd + 75%fw pH
100% cd	1														
100% fw	0.92	1													
75%cd+25%fw	0.95	0.85	1												
50%cd+50%fw	0.88	0.75	0.87	1											
25%cd+75%fw	0.98	0.91	0.97	0.84	1										
100% cd Temp	-0.49	-0.66	-0.44	-0.36	-0.48	1									
100% fw Temp	-0.72	-0.60	-0.82	-0.69	-0.75	0.42	1								
75%cd+25%fw Temp	0.53	0.43	0.62	0.51	0.55	-0.11	-0.64	1							
50%cd+50%fw Temp	0.43	0.31	0.49	0.49	0.45	-0.02	-0.58	0.43	1						
25%cd+75%fw Temp	0.34	0.39	0.25	0.04	0.38	-0.14	0.09	-0.12	-0.14	1					
100% cd pH	-0.58	-0.52	-0.67	-0.62	-0.65	0.35	0.73	-0.34	-0.35	0.02	1				
100% fw pH	0.47	0.38	0.58	0.51	0.48	-0.06	-0.59	0.66	0.48	-0.22	-0.32	1			
75%cd+25%fw pH	0.24	0.32	0.10	0.13	0.17	-0.01	0.14	0.24	0.03	0.25	0.35	-0.03	1		
50%cd+50%fw pH	0.58	0.67	0.58	0.34	0.64	-0.55	-0.42	0.03	0.16	0.48	-0.35	-0.001	0.02	1	
25%cd+75%fw pH	-0.33	-0.20	-0.33	-0.42	-0.27	0.06	0.50	-0.52	-0.44	0.48	0.41	-0.40	0.05	0.16	1

c d = cow dung, fw = fruit waste, Temp = Temperature

CONCLUSION

The results from this study show the influence of substrate composition on biogas production efficiency, and system stability. Temperature variations showcased the thermal dynamics of anaerobic digestion, with differences in initiation and peak temperatures reflecting diverse microbial activities. The pH variations also demonstrated the acidity or alkalinity levels of the anaerobic digestion process, with unique initiation and extreme pH values among digesters. The correlation analysis revealed strong positive relationships between biogas productions from different digesters sharing similar substrate compositions. These correlations suggest the potential for tailored substrate ratios to enhance biogas production consistently. The study revealed further that cow dung is an efficient substrate for biogas production, especially when it is co digested with other organic waste.

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