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Original Research

Biogas Production Potentials of Coffee Husk Supplemented with Animal Manure

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Abstract

Coffee is one of the important cash crops globally, consumed with various food products and beverages. Dry coffee processing generates husk as solid waste, often disposed-off untreated in surrounding areas. This experiment is to assess the potential of coffee husk for biogas production when anaerobically co-digested with poultry manure or cow dung. Nine treatment mixtures of coffee husk, poultry manure, and cow dung were evaluated in batch-type anaerobic digesters over 30 days under mesophilic conditions (38°C). Physico-chemical characteristics of the feedstock before and after the digestion were analyzed using standard procedures. Biogas production was monitored for 30 days, revealing significant variations among treatments. The highest cumulative biogas yield was observed in the co-digestion of coffee husk and cow dung in a 1:1 ratio, followed by coffee husk and poultry manure in a 1:1 ratio, with the lowest yield from 100% poultry manure. Additionally, the 1:1 ratio of coffee husk and cow dung exhibited the highest reduction in total solids, volatile solids, and organic carbon. These findings suggest that anaerobic co-digestion of coffee husk and cow dung in equal proportions is optimal for biogas production and warrants further investigation at a pilot scale.

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INTRODUCTION

Energy production and environmental protection are critical global challenges that play a vital role in enhancing social welfare, and driving a country's economic development. The escalating demand for energy, fueled by rapid population growth and industrial advancement, heavily relies on non-renewable sources like fossil fuels. However, the unsustainable utilization of these resources poses environmental risks and jeopardizes energy security. The progression of civilization has largely been propelled by enhancing energy efficiency and harnessing diverse energy forms to expand human capabilities.

The shift from fuel wood to burning of animal dung and crop residues for energy is due to fuel wood scarcity in rural areas that led to land degradation (Abanades et al., 2022). In Africa, a significant number of people depend on biomass fuels such as firewood and charcoal for cooking. However, deforestation rates are accelerating, resulting in dwindling firewood and charcoal resources.

Consequently, many people in Sub-Saharan African nations lack access to basic cooking facilities and may struggle to afford cooking fuels in the future.

The world is approaching a critical juncture where the production yield and overall inventory of fossil fuels, notably petroleum and natural gas, will no longer suffice to meet societal energy needs. Therefore, stakeholders must prioritize the development of alternative renewable energy sources to address the escalating energy consumption and dwindling fossil fuel supplies. Researchers are exploring new technological processes for energy production in response to these challenges, with the selection of technologies being influenced by material properties, as well as social and economic considerations.

Biomass holds significant potential and is widely regarded as the optimal choice for meeting energy demands and ensuring sustainable energy supply in the future (Corro et al., 2013). Biogas, a renewable energy resource derived from biomass waste in agro-industrial processing industries, offers substantial economic advantages over other fuel sources due to its low construction and maintenance costs. Ethiopia boasts considerable potential for renewable energy from wind, solar, and biogas. Among these, biogas stands out as a key renewable resource, primarily composed of methane (CH_4) at 50–75%, followed by carbon dioxide (CO_2) at 25–45%, and other trace gases (7%) resulting from the anaerobic digestion of organic matter (Johari et al., 2020).

Leveraging biogas resources could effectively meet Ethiopia's energy needs with minimal environmental impact. The country generates an immense amount of biomass waste from agricultural and agro-industrial activities that can serve as primary sources for biogas production. Despite the availability of energy sources, access to biogas energy services remains limited within Ethiopian society (Mohammed et al., 2022).

Coffee is a significant agricultural crop that plays a crucial role in the economies of coffee-producing countries worldwide. Ethiopia, known as the birthplace and genetic reservoir of *Coffea arabica*, stands as the major coffee producer in Africa and globally. Over the years, Ethiopia has witnessed a steady increase in annual coffee production, rising from 273,400 metric tons in 2007 to 469,091 metric tons in 2016 (Chala et al., 2018). The volume of coffee by-products generated is directly linked to the country's coffee output.

There are two primary methods of coffee drying: the wet process and the dry process. In the wet drying method includes, pulping of coffee cherries, washing, and polishing before yielding green beans. Conversely, the later method involves hulling the cherries after drying to obtain green beans. The husk is the predominant by-product of the dry method, constituting approximately 50% by weight of the dried cherry (Chala et al., 2018).

Coffee husk is a highly abundant agro-industrial waste that is generated during the pulping process of coffee fruits to extract coffee beans in various coffee-producing regions of Ethiopia. It has been estimated that for every kilogram of coffee beans produced, an equivalent amount of coffee husk is generated as a by-product in dry processing facilities (Pandy et al., 2000). The disposal of coffee wastes typically involves dumping them in large open piles in gorges or near rivers, leading to water and soil pollution. The anaerobic conditions in these storage or composting areas may result in the uncontrolled release of methane (CH_4) and nitrous oxide (N_2O) emissions (Corro et al., 2013). Furthermore, coffee by-products are known to contain high levels of organic pollutants such as proteins, sugars, pectin, tannins, and phenolic compounds that can be harmful to plants, humans, and aquatic life (Chala et al., 2018).

The process of animal manure being broken down anaerobically has been studied extensively. It is a well-known procedure to produce biogas from animal dung. However, compared to other forms of organic waste, including food waste, cow dung digesters yield comparatively little biogas, making their associated costs unpromising. Increasing the biogas production rate of cow dung digesters through co-digesting them with more biodegradable trash is one way to improve the digesters' cost-benefit ratio. By offering a better carbon and nutritional balance, co-digestion of various materials can improve the anaerobic digestion process (Corro et al., 2013; Johari et al., 2020; Sumardiono et al., 2021).

In order to attain a C to N ratio that is anticipated to boost biogas production, two substrates have been mixed and co-digested anaerobically in earlier research (Corro et al., 2013; Chala et al., 2018; Kenasa and Kena, 2019; Johari et al., 2020; Sumardiono et al., 2021). Thus, the purpose of this study was to assess the potential for producing biogas from coffee husk mixed with cow dung or poultry manure using batch anaerobic co-digestion in a laboratory.

MATERIALS AND METHODS

Study Area Description Sample Collection

Coffee husk sample was collected from coffee processing agro-industry available around Gimbi town. The town is found in western Ethiopia situated in the West Wollega Zone of the Oromia Regional State. It is positioned at 9°.10′N 35.50′E with an elevation range between 1845 and 1930 meters above mean sea level. The site was selected purposively due to the abundance of huge amount of coffee husk generated by the industry. Coffee husk samples were collected in plastic bags and transported to Wollega University, Shambu campus. All laboratory experiments were conducted at Microbiology Laboratory.

Feedstock and Inoculum Preparation

Coffee husk, poultry manure, and cow dung were used as substrate for the digestion in various combinations. Wilt fresh coffee husk was collected from private coffee processing agro-industry found around Gimbi town where coffee was regularly hulled. Moist poultry manure was obtained from private poultry farm found in Shambu town with consent after explaining the purpose. Cow dung sample was taken from dairy farm available in Wollega University, Shambu Campus. Rumen fluid which was used as starter culture for an anaerobic breakdown process was also obtained from slaughter house found in the Shambu campus. Coffee husk, poultry manure and cow dung was partially sun-dried and finely ground by blender before using as feedstock (Figure 1 b).

Experimental Design

The amount of feedstock in the digester was fixed to 30g, considering the digester capacity. Anaerobic digestion was conducted using nine treatments (T1-9) (Table 1) with different proportions of coffee husks, cow dung and poultry manure in the laboratory as described by Buivydas et al., (2022). There were three replications of the nine treatments. Ituen et al. (2007) state that distilled water was given to each digester to increase the moisture level in the digesters. Each digester received 5 milliliters of rumen fluid to initiate the anaerobic digestion process (Chynoweth et al., 2001). The techniques of Ituen et al. (2007) were followed to adjust the water content for each treatment.

Table 1

Treatment, composition of the feedstock and volume of each digester

Treatments	Composition	Contents of digesters						
		Mix ratio of CH:PM / CD	Partially dried fixed CH(g)	Partially dried fixed PM(g)	Partially dried fixed CD(g)	Water added in (ml)	Inoculum added in (ml)	Total volume in (ml)
T1	100%CH	1:0	30	0		307.5	5	342.5
T2	70%CH+30PM	7:3	21	9		306.5	5	341.5
T3	50%CH+50PM	1:1	15	15		305.8	5	340.8
T4	30%CH+70PM	3:7	9	21		304.7	5	339.7
T5	100%PM	0:1	0	30		304.1	5	339.1
T6	70%CH+30CD	7:3	21		9	306	5	341
T7	50%CH+50CD	1:1	15		15	305	5	340
T8	30%CH+70CD	3:7	9		21	304	5	339
T9	100%CD	0:1	0		30	302.5	5	337.5

T: Treatment, CH: Coffee husk, CD: Cow dung, PM: Poultry manure

Experimental Set Up

In a batch process, coffee husk co-digested with cow dung or poultry manure was applied to 0.6-liter plastic bottles. To prevent oxygen from leaking out and biogas from being lost, the bottles were tightly sealed with parafilm and adhesive. The bottles were stacked so that the acidified brine solution from the second container was collected in the last bottle, which held the substrate, and the middle bottle, which held the acidified brine solution (Matin et al., 2022). One-centimeter plastic tubing was used to join the three bottles together. The tube that connected the first and second bottles was positioned just above the slurry in the first container and to the top of the second bottle in order to facilitate gas collection into the second bottle (Figure 1 a).

The biogas produced by the fermentation of the slurry was therefore driven from the first bottle to the second bottle, which contains a brine solution, in order to move a volume of the brine solution equal to the amount of biogas generated. In an incubator shaker with irregular, occasional shaking, the digesters were maintained at 38°C to enhance the microbial cells' interaction with the substrate's molecules.

(a)

(b)

Figure 1(a-b). *Experimental set up of the anaerobic digestion process and field samples.*

Determination of the Produced Biogas

Since methane doesn't dissolve in brine solution, the amount of the solution collected in the third bottle (Amount of solution displaced from the second bottle) is equivalent to the amount of biogas produced from the substrate as indicated in Matin et al., (2022). Biogas volumes were measured daily starting from next day of inoculation for about 30 days. The total volume of biogas produced over course of the digestion period was calculated from daily measurements.

Characterization of the Substrates for Physical and Chemical Characteristics

According to the usual procedure for the analysis of water and waste water, parameters such as total solid (TS), volatile solid (VS), fixed solid, pH of the feedstock, and the bio-slurry were determined (Yitayal et al., 2017).

Determination of Moisture Contents, Total Solids, pH and Volatile Solids

Crucibles were cleaned, dried at 105°C for an hour in an oven, cooled in desiccators and weighted. 10g coffee husk, cow dung, and poultry manure were added into the crucibles. The crucibles were allowed to stay in an oven at 105°C for 24 hours. Then, crucibles containing samples were taken out and weighed. Finally, moisture content, total solid and volatile solid of the feedstock and bio-slurry were determined according to Buivydas et al. (2022). pH of the feedstock and bio-slurry were determined using digital pH meter following standard protocol.

Determination of Carbon to Nitrogen Ratio of the Substrates

Using the empirical equation supplied by Ellacuriaga et al. (2021) the carbon content of the samples was determined using volatile solids data. As stated in Yitayal et al. (2017), the amount of nitrogen was determined by titrating the ammonia with a standard solution of 0.1N sodium hydroxide in the presence of methyl red indicator in a 0.1N sulfuric acid solution. The C: N ratio was then ascertained using the data.

Data Analysis

Data were analysed by one-way ANOVA using SAS version 16.0 to test the effect of treatments on amount of biogas production at $p<0.05$.

RESULTS AND DISCUSSION

Physico-chemical Characteristics of the Substrates

The physical and chemical properties of coffee husk samples that were isolated and combined in various ratios both before and after anaerobic digestion displayed in table 2.

Table 2

Comparison of pH, % organic carbon and %MC before and after anaerobic digestion (values are mean ± SE, n=3).

Treatments	Initial pH	Adjusted pH	Final pH	%C initial	%C final	%MC initial	%MC final
T_1	5.2±0.01^{a}	6.8±0.00^{b}	4.41±0.01^{b}	46.05±0.02^{a}	27.85±0.02^{b}	8.63±0.02^{a}	47.15±0.01^{b}
T_2	5.9±0.01^{a}	6.8±0.00 ^{b}	3.91±0.01^{b}	45.11±0.01 ^{a}	26.89±0.02 ^{b}	8.91±0.01^{a}	45.48±0.01^{b}
T_3	6.2±0.02^{a}	6.8±0.00^{b}	4.65±0.01^{b}	44.48±0.02^{a}	26.19±0.02^{b}	9.11±0.02^{a}	44.35±0.02^{b}
T_4	6.3±0.01^{a}	6.8±0.00^{b}	4.7±0.02^{b}	43.82±0.01^{a}	25.63±0.02^{b}	9.3±0.01^{Da}	43.23±0.02^{b}
T_5	6.5±0.02^{a}	6.8±0.00^{b}	5.36±0.01 ^{b}	42.89±0.01^{a}	25.68±0.01^{b}	9.58±0.01^{a}	41.55±0.01^{b}
T6	6.2±0.01^{a}	6.8±0.00^{b}	4.32±0.01^{g}	44.71±0.01^{a}	26.46±0.03^{b}	9.04±0.01^{a}	46.15±0.02^{b}
T7	6.6±0.01^{a}	6.8±0.00 ^{b}	5.05±0.01^{f}	43.81±0.02^{a}	25.5±0.01^{b}	9.32±0.02^{a}	45.47±0.01^{b}
T8	7.2±0.02^{a}	7.2±0.02^{a}	5.39±0.02^{i}	42.91±0.01^{a}	24.68 ±0.02^{b}	9.57±0.01^{a}	44.8±0.01^{b}
T9	8.5±0.01^{a}	6.8±0.00^{b}	5.59±0.01^{h}	41.56±0.01^{a}	23.61±0.02^{b}	9.99±0.01^{a}	44.71±0.01^{b}

Keynote: T1:100%CH, T2:70%CH:30%PM, T3:50%CH:50%, T4:PM30%CH:70%PM, T5:100%PM, T6:70% CH:30%, T7: CD50% CH:50%, T8:CD30% CH:70% T9: CD100%, CH: Coffee husk, CD: Cow dung, PM: poultry manure. Means followed by different letters in the same column are significantly different at P<0.05 (paired samples T-test).

Our findings revealed that the initial pH of the T8 substrate before anaerobic digestion was 7.2, while that of T9 was 8.45 (Table 2). The pH of T8 was not adjusted as it fell within the optimal pH range for biogas production, whereas the pH of T9 was alkaline and above the optimal value for anaerobic digestion, thus it was adjusted to the optimum level (Table 1). This discrepancy in pH values may be attributed to the slightly alkaline nature of cow dung and the slightly acidic nature of poultry manure. To achieve a near-neutral pH between 6.8 and 7.2, which is ideal for the development of an acidophilic system, all substrates were adjusted to pH 6.8 by adding sodium hydroxide and sodium bicarbonate buffer for substrates deviating from the optimal pH before digestion.

The pH of the feedstock was observed to decrease with an increase in coffee husk proportion in the mixture (Table 2), indicating that coffee husk helps maintain the pH within the optimal range necessary for biogas production. This suggests that mixing substrates is an effective strategy for adjusting the pH of the feedstock to optimal values for enhanced biogas production. Significant differences in pH values were observed within treatments before and after anaerobic digestion (P<0.05) (Table 2). The decline in pH values post-digestion may be attributed to reduced methanogenic bacteria activity during the decline phase and acetogenesis, leading to the accumulation of volatile fatty acids that inhibit acetogenic bacteria metabolism.

Moreover, following anaerobic digestion, a substantial decrease in the amount of organic carbon was observed in all treatments (P<0.05) (Table 2). This decrease could be explained by the organic carbon being converted in the digesters into cellular components needed for bacterial growth and reproduction or the creation of biogas. Table 2 illustrates that T7 had the greatest percentage of organic carbon decrease (from 43.8% to 25.5%, or 18.3%), relative to other treatments. According to study on the co-digestion of cow dung and chicken litter by Hidalgo-Sánchez et al. (2023), mixing may enhance the breakdown of organic carbon and the generation of biogas.

Moreover, our results indicated a significant increase in moisture content values after anaerobic digestion (P<0.05) (Table 2). The initial moisture content of partially dried substrates ranged from 8.6% to 10% before anaerobic digestion (Table 2). As these initial moisture content levels were not within the optimal range for biogas production, water was added to adjust them according to Ituen et al. (2007). Subsequently, after the digestion, the mean moisture content values increased, ranging from 41.6% to 47.7% (Table 2).

Table 3

Chemical characteristics of the substrates (coffee husk, cow dung and poultry manure) in various mix ratio before the digestion

Treatments	Organic Carbon of the substrates (%)	Total Nitrogen (%)	C:N Ratio	Ash content
T1	46.05±0.02[a]	1.49±0.01[c]	30.9±0.01[a]	0.51±0.01[d]
T2	45.11±0.01[a]	1.59±0.01[bc]	28.37±0.01[ab]	0.81±0.01[d]
T3	44.48±0.02[ab]	1.66±0.01[bc]	26.79±0.01[C]	1.01±0.02[c]
T4	43.82±0.01[b]	1.72±0.01[ab]	25.48±0.01[cd]	1.2±0.01[c]
T5	42.89±0.01[c]	1.82±0.02[a]	23.57±0.02[d]	1.5±0.01[b]
T6	44.71±0.01[ab]	1.54±0.02[c]	29.03±0.02[a]	0.88±0.02[d]
T7	43.81±0.02[bc]	1.58±0.02[C]	27.73±0.02[b]	1.13±0.03[C]
T8	42.91±0.01[c]	1.61±0.01[b]	26.65±0.01[c]	1.38±0.01[b]
T9	41.56±0.01[d]	1.65±0.01[bc]	25.19±0.01[c]	1.75±0.02[a]

Keynote: T1:100%CH, T2:70%CH:30%PM, T3:50%CH:50%, T4:PM30%CH:70%PM, T5:100%PM, T6:70% CH:30%, T7: CD50% CH:50% , T8:CD30% CH:70% T9: CD100%CD, Mean values with different letters superscript in column indicate significant differences at p<0.05. CH = coffee husks, PM = Poultry manure, CD= Cow dung, %C = percentage of organic carbons, %N = percentage of nitrogen.

The organic carbon content of the substrates ranged from 46.05% to 41.56%, showing significant variations among the treatments (Table 3). Similarly, the total nitrogen content of the substrates ranged from 1.49% to 1.82%, with T1 and T6 recording the lowest and highest values, respectively (Table 3). The C:N ratios of all substrates fell between 23.6 and 30.9 (Table 3), aligning with the optimal range of 20:1 to 30:1 as reported by Prussi et al. (2019). This suggests that coffee husk could be a suitable substrate for biogas production even without the need for mixing it with poultry manure or cow dung. The C:N ratios of all mixture treatments tested in this study remained within the optimal ranges. The C:N ratio of the three substrates and their mixtures tested in this study indicates favorable conditions for bacterial growth, supporting the use of these substrates either in combination or individually for anaerobic digestion to produce biogas.

TS and VS of the Substrates and Bio-slurry

The total solid and volatile solid content were determined for all substrates both before and after the digestion (Figures 2 and 3). The highest initial TS values were found in coffee husk, while the lowest TS was observed in cow dung (Figure 2). This suggests that coffee husk may contain more biodegradable substrates for biogas production compared to poultry manure and cow dung. In this study, the TS content of coffee husk was 91.4%, higher than the 88.3% TS reported by Chala et al., (2018). Conversely, the VS content of coffee husk was 82.9%, lower than the report of Chala et al., (2018) which was 93%. The TS and VS values of poultry manure in this study were 90.4% and 77.2%, respectively, similar to results reported by Triviño-Pineda et al. (2024). Cow dung TS and VS values were 90.1% and 74.8%, respectively, comparable to previous studies (Chala et al., 2018; Kenasa and Kena, 2019).

The findings demonstrated a considerable decrease in the TS and VS values of all substrate categories following the digestion, with mixed substrates showing a larger decline than single substrates (Figures 2 and 3). This may be explained by a balanced process of methanogenesis and acidogenesis taking place in mixed substrates instead of sole substrates (Paes et al., 2023). The drop in VS during digestion shows that the substrate being converted to biogas. The TS and VS content could be adjusted by mixing the substrates; greater TS and VS values were obtained by increasing the fraction of coffee husk (Walker et al., 2009). Despite having the highest volatile solid content for biodegradation among all mixes (Figure 2), coffee husk alone did not produce high biogas, possibly due to its high lignin, cellulose, phenols, and hemicelluloses content which require co-digestion for enhanced digestibility (Chala et al., 2018).

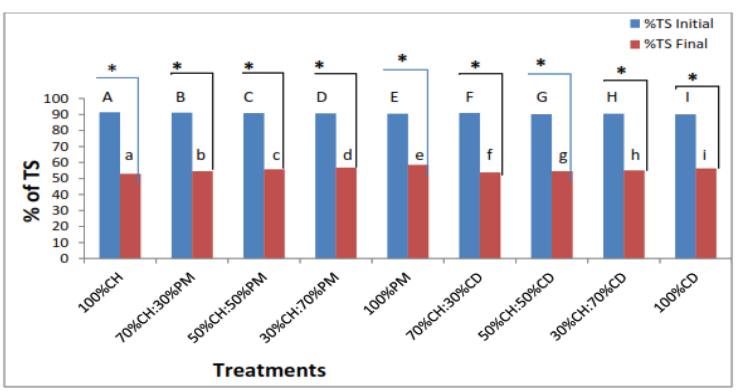

Figure 2. *Total Solid (TS) of substrates before and after anaerobic digestion*

Keynote:Different capital letters represent significant differences at p<0.05, asterisk (*) shows there are significant difference in %TS within treatments before and after the digestion.

Significant differences in TS and VS values were observed within treatments before and after the digestion (Paired samples T-test, $p<0.05$) (Figure 2 and 3). Mixing 50% coffee husk with 50% cow dung resulted in a greater reduction of TS and VS from 90.3% to 50.5% and 78.9% to 45.3%, respectively (Figure 2 and 3). Therefore, the destruction of total solids and volatile solids serves as a valuable parameter for assessing the efficiency of anaerobic digestion and indicating high biogas production potential (Du et al., 2021).

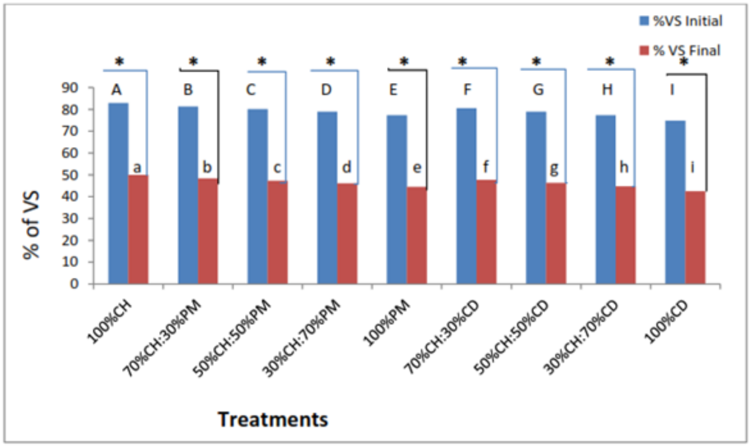

Figure 3. *VS of substrates before and after the digestion. Different capital letters represent Keynote:significant differences at p<0.05, asterisk (*) shows there are significant difference in %VS within treatments before and after the digestion.*

Average Daily and Cumulative Biogas Production Potential of each Treatment

Biogas production was not observed during the initial phase of the experiment, spanning from day one to three. However, on the fourth day, a notable increase in biogas production was recorded, albeit varying among different substrate types; the highest yield was observed for T7, while the lowest was for T1 (Figure 4). The absence of gas production during the first three days could be attributed to the high cellulose content present in coffee husk, which is known to degrade slowly and potentially hinder the hydrolysis stages (Rezaee et al., 2020). Furthermore, the initial lack of gas production may also be linked to the relatively low population of microbes in the rumen fluid used as inoculum, requiring additional time to adapt to the new environment. The quality and quantity of inoculums play a crucial role in the initiation of biogas production, as well as the stability of bio-methanogenesis at the onset of anaerobic digestion (Kenasa and Kena, 2019).

The higher biogas yield measured on the fourth day suggests that the microbes may have reached their log phase, effectively breaking down the readily degradable materials present in the substrates (Hidalgo-Sánchez et al., 2023). Our findings indicate that all substrate types yielded more cumulative biogas compared to PM alone. This could be attributed to the higher availability of biodegradable material in coffee husk and cow dung than in poultry manure, providing a richer source of energy for microbial activity and biogas production. Previous research (Macias-Corral et al., 2008) has highlighted the direct relationship between biogas yield and the organic content and biodegradability of feedstocks.

Following the initial spike in biogas production, there was a fluctuating decline observed after the first measurement, eventually ceasing between days 17 and 27 of the experiment (Figure 4), indicating potential completion or inhibition of the digestion process. The exhaustion of easily decomposable substrates and the accumulation of toxic byproducts due to an increasing microbial population are likely reasons for the cessation of biogas production in the digester (Chala et al., 2018).

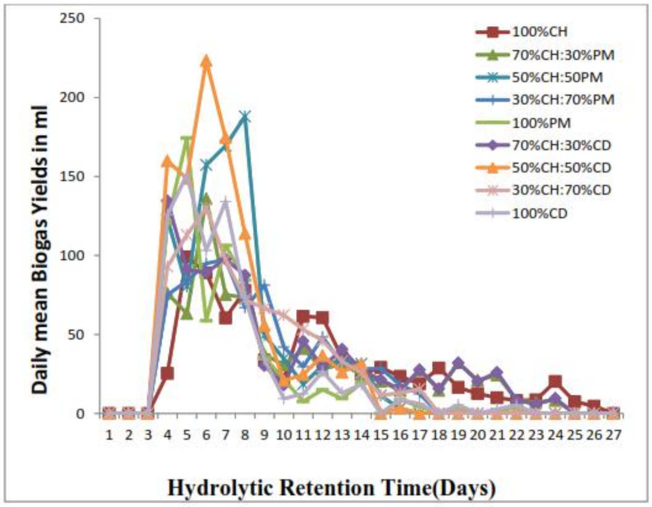

Figure 4. *Daily mean Biogas yield of the different substrate proportion*

Compared to 100% poultry manure (PM), all substrate types lead to higher cumulative biogas yield. This is likely due to the presence of hazardous substances such as grit, sand, feathers, antibiotics, disinfectants, and NH_4^+ in poultry manure, which can reduce biogas production. Although the biogas yield from 100% coffee husk (CH) on a volatile solids (VS) basis was higher than all the mixtures(Figure 3), it did not result in more biogas than five of its mixtures: 70%CH:30% PM, 50%CH:50% PM, 70%CH:30% cow dung(CD), 50%CH:50%CD, and 30% CH:70%CD substrates with a high mix ratio of coffee husk (Figure 5). This could be attributed to the presence of caffeine and tannins in coffee husk, which can make it toxic and slow to degrade in nature, leading to disposal issues and high levels of phenolic compounds from the degradation of lignocellulosic materials (which are slowly degradable) that require other substrates to be mixed in (Neves et al., 2006; Chala et al., 2018).

In substrates containing high amounts of lignin, cellulose, and hemicelluloses, the hydrolysis stage is often the limiting factor and requires careful attention (Triviño-Pineda et al., 2024). Co-digestion of substrates with high cellulose content and pre-treatment to enhance their digestibility is recommended strategies.

The experiment revealed that the highest cumulative biogas production was observed when using a substrate mix consisting of 50% coffee husk (CH) and 50% cow dung (CD) (Figure 5). The results also indicated that as the proportion of coffee husk in the mix increased from 30% to 50% or decreased from 70% to 50%, the cumulative biogas yields also increased. This suggests a more favorable situation with an increasing proportion of coffee husk from 30% to 50% or a decrease from 70% to 50%. This observation highlights the importance of using a selective and appropriate mixture of substrates to enhance the biological and nutritive environment in the digester for microbes, thereby increasing biogas production (Paes et al., 2023).

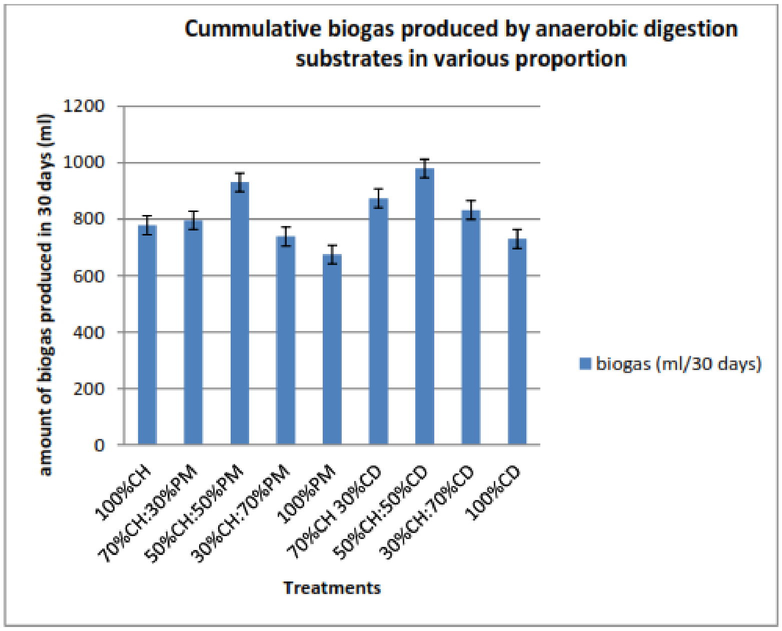

Figure 5. *Total biogas production for each combination of substrate (values are mean ± SE). Keyyynote:Significant differences in cumulative biogas between various treatments mean values are indicated by bars with different letters.*

Previous studies have explored the potential uses of coffee husk and coffee pulp as raw materials for bioprocesses to produce biogas (Neves et al., 2006; Chala et al., 2018). This experiment further confirmed the significant potential of coffee husk for biogas production. The volatile solid content of the coffee husk substrate was found to be 91.37% of total solids, indicating a high degree of biodegradability. This suggests that coffee husk could be a valuable feedstock for biogas production, especially when combined with suitable co-digestion materials such as poultry manure and cow dung. Even in the absence of co-digestion options, coffee husk can still be effectively digested on its own.

CONCLUSIONS

The study revealed that the highest biogas yield was achieved when coffee husk was combined with cow dung in a 1:1 ratio. Additionally, this combination resulted in the greatest reduction in volatile solids (VS), total solids (TS), and carbon content compared to other treatment combinations. Our findings indicated that 91.37% of the volatile solid content in coffee husk was TS, suggesting that a significant portion of coffee husk is biodegradable and can be a valuable feedstock for biogas production. The highest cumulative biogas production was observed with the 1:1 ratio of coffee husk to cow dung, followed by a similar ratio of coffee husk to poultry manure, while the lowest production was noted with 100% poultry manure. Therefore, co-digestion of coffee husk, cow dung, or poultry manure in a 1:1 ratio shows great potential for biogas production and could help alleviate feedstock shortages. In situations where suitable materials for co-digestion are scarce, coffee husk can be digested alone, especially in areas like Gimbi where it is readily available as a raw material for biogas production.

Recommendation

The findings of the current study should be validated through large-scale testing. It is highly recommended to conduct a study on the techno-economic feasibility of implementing this technology in coffee-producing areas to benefit the local community and mitigate environmental pollution caused by coffee husks. The fertilizing potential (micro-nutrient content and other properties) of the bio-slurry from the treatments should be investigated. Additionally, further research is needed to analyze the composition of organic matter (carbohydrates, proteins, lipids) and process indicators (VFA, ammonia levels) in coffee husks. Efforts should also be directed towards assessing the quality of biogas generated from coffee husks using Gas Chromatography.

DECLARATION

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

Data will be made available on request

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