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Research Article

Anaerobic Co-Digestion of Human Feces with Rice Straw for Biogas Production: A Case Study in Sunyani

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The choice of feedstock for biogas production should not only be limited to organic waste like agricultural products, food, and animal waste. Human feces could also be considered a source of biogas production. The ever-increasing cost of fossil fuels and environmental pollution threats are forcing the search for alternative energy sources. Several types of research have to unlock the mysteries behind the difficulties of producing biogas from human feces, especially the production of more HN_3, which is a greenhouse gas because of its low C:N ratio. This research experimentally investigated how to reduce their amount using rice straw with a high C:N ratio. Several combinations were made between the human waste and the rice straw at different ratios during the experiment. The result shows that the optimal outcome for methane production fell on the 50% HF and 50% RS combination due to the actions of both aerobic and anaerobic processes.

1. Introduction

The rise in the demand for clean and affordable energy and the requirement for mitigating the release of harmful elements into the environment has led to the continuous search for sustainable and renewable energy generation options. Using fossil fuel products like oil and its derivatives, natural gas and coals are no longer a good choice since they are depleting with time and will ultimately phase out in the future. The use of fossil energy leads to the production of pollutants like the emissions of greenhouse gases (GHG), whose principal gas is carbon dioxide leading to a rise in temperatures in the environment, [1, 2].

Even though several researchers have focused on using animal manure, food waste, and municipal wastes for biogas production to help reduce the energy security situation, human excreta is rarely considered [3]. Also, experimental studies reporting data on human excreta as biogas raw material under ambient conditions are limited [3].

To alleviate these problems, there is a need to find suitable techniques for treating human excreta to improve existing practices. That will help minimize the risks of environmental pollution and increase energy generation. This study will use methanization, which is the anaerobic digestion of organic waste. It will allow the production of methane gas, alternative energy to fossil fuels, indirectly contributing to the cleaning of the environment [4]. Sewage/waste can be considered a suitable remedy as it can generate biogas (CH_4–55%, CO_2–35%, and small traces of other gases) to meet household energy demands, such as heating, cooling, electricity, and vehicle fuel [5]. Human wastes, specifically feces, can produce about 0.35–0.5 m^3/kg of biogas. In Ghana and Africa, most human feces management systems are done through on-site sanitation methods [6]. Fecal matter in septic tanks requires severe treatment before it is released into the environment [7]. With this pressing environmental challenge, the country does not have enough sewage treatment plants, which causes the waste (fecal sludge) to pollute water bodies and land [8]. This danger leads to contamination of humans with pathogens through contaminated drinking water [9]. From field studies, it is mentioned that poor fecal sludge treatment interventions in Ghana have led to 41 million cases of diarrhea and 7,300 related deaths in 2017 [10].

To improve living standards through environmental sanitation, improved hygiene conditions, and renewable energy production in Ghana, using human excreta for biogas production must become one of the focal points for anaerobic digestion. Studies have shown the difficulties associated with using human feces for biogas production; an example is a research organized in Indonesia [11]. They found that the system produces more ammonia (NH_3) than methane (CH_4). This problem could be explained by the C:N ratio of the substrate, which is between 6 and 10 instead of 25 $<$C:N$<$30 for optimal biogas production [11]. Thus, to contribute to this problem, this research aimed to optimize biogas production from human excreta by determining the amount of rice straw to be added to the human feces to act as a carbon-rich substrate (C:N ratio between 44.0 and 74.2) to compensate for the carbon deficit in human excreta [12].

2. Materials and Methods

2.1. Feedstock Physicochemical Characterization. Samples of human feces were collected from some toilet rooms within the Sunyani municipal (around the University of Energy and Natural Resources) and rice straw from the rice farms around. The determination of moisture, total solids (TS), and volatile solids (VS) in the human feces and the rice straws were carried out according to U.S. Environment Protection Agency procedure [13]; the carbon and the nitrogen were determined according to the Hach method and the ASTM D3172-89 method [11, 14].

2.2. Pretreatment of Raw Materials for the Anaerobic Digestion Process. Numerous studies have shown that the pretreatment of the raw material during an anaerobic digestion process is an essential step particularly for plant materials [15], because it modifies the structure of the cellulose to facilitate the conversion into simple sugars of high molecular weight, like carbohydrates by enzymes [16]. Especially, in the case of rice straw, biomass with high lignin content must be pretreated before being used in the production of methane as a substrate to amplify its degradation by microorganisms and accelerate the anaerobic digestion process [17].

The human fecal samples after collection are put in a paste form by mixing it with water and stirring for some time to make the substrate homogeneous before the anaerobic digestion. The straws from the rice are broken into smaller particles using a blender to make the cell wall accessible to the substrate for the decomposition by the microbes. Research has confirmed increasing the surface area and the deterioration of its polymer structure increases the rate of hydrolysis during digestion [16, 18, 19]. Thus, the fibers' degradation and methane yield are improved when the particle size is reduced [20].

2.3. The Total Solid Content in the Mixture. The total solid is one of the factors affecting the performance of anaerobic digestion [21]. Previous works on the influence of total solid concentration on biogas production reported that for optimal production of the biogas process, the total solid should be between 7.2% and 9% [22, 23]. Another study found that the perfect total solid combination/ratio between cow manure and water is 1 : 3 [24].

In this work, after the different combinations of fecal matter with rice straw as presented in Table 1, the total solid of the combined raw materials was mixed with water in a ratio of 1 : 3 (three units of water to one unit of the mixture into each digester i.e., 3 mL of water for 1 g of mixture).

2.4. Determination of Anaerobic Effect of the Rice Straw/Human Mixture Feces Mixture. Human feces (HF) and rice straw (RS) were mixed according to the ratios presented in Table 1. The anaerobic digesters were made in the laboratory using glass bottles. The type of culture is the batch mode. For 30 days, the digesters were conditioned under the temperature of 39° C ±1 in the oven (Lab-line Imperial II Incubator) to guarantee the best possible conditions for fermentation and degradation of the material by microbes [25].

These experiments were repeated three times under the same condition. The volumes of methane gas and other gases were measured daily during the digestion process (i.e., MEI NENG analyzer). The data were analyzed using descriptive statistics (t-test) in SPSS to compare the biogas yield potential of different combinations of HF and RS.

3. Results and Discussion

3.1. Physicochemical Characteristics of Human Feces. After physicochemical analysis of the different samples, the results are shown in Table 2. The study revealed that human fecal matter in Sunyani-Ghana is not different from elsewhere. In Indonesia, human feces have approximately a C:N ratio between 6 and 10 [11]; in Sunyani-Ghana, the carbon-nitrogen ratio is equal to 6.62. This result is due to a high percentage of nitrogen and a low percentage of carbon in the collected fecal matter.

Studies conducted in the United Kingdom revealed that the percentage composition of moisture in feces is between 63 and 86% [26]. Samples collected in Sunyani-Ghana have a moisture content percentage of 79.5%, which may be due

Table 1: Combination of mixtures.

Digester number	Combination ratio of raw materials (%)		Initial weight of TS in raw material (gm)		Initial weight of raw material used (gm) for digestion		Initial weight of TS in combined raw materials (gm)
	HF	RS	HF	RS	HF	RS	HF+RS
D1	100%	0%	16.0	0.0	78.4	0.0	16
D2	90%	10%	14.4	1.6	70.6	1.8	16
D3	80%	20%	12.8	3.2	62.7	3.6	16
D4	70%	30%	11.2	4.8	54.9	5.5	16
D5	60%	40%	9.6	6.4	47.0	7.3	16
D6	50%	50%	8.0	8.0	39.2	9.1	16
D7	40%	60%	6.4	9.6	31.4	10.9	16
D8	30%	70%	4.8	11.2	23.5	12.8	16
D9	20%	80%	3.2	12.8	15.7	14.6	16
D10	10%	90%	1.6	14.4	7.8	16.4	16
D11	0%	100%	0.0	16.0	0.0	18.2	16

Table 2: Physiochemical analysis of samples.

Parameter	Unit	Human feces	Dry rice straw
Moisture content	%	79.5	12.22
TS	%	20.5	87.69
VS	%	68.12	65.30
C	%	39.50	32.2
N	%	5.97	0.98
C:N	—	6.62	32.65

to the age of the people from whom the feces were collected. Excreta collected from adults contains more moisture than younger people; older adults consume enough water to reduce the risk of constipation compared to the younger ones, who generally do not have digestion problems [27].

3.2. Physicochemical Characteristics of Rice Straw. The following parameters were obtained from the rice straw: moisture content (12.22%), total and volatile solids (87.69 and 65.30%), and carbon and nitrogen content (32.2 and 0.98%) collected within Sunyani. This values are not different from other varieties of rice straw [21], an example is 12.31% moisture, 87.33% total solids, 65.50% volatile solids, 32.19% carbon, and 0.98% nitrogen [28] .

3.3. Presentation and Discussion of the Trend of the Biogas Yield of the Different Combinations of HF and RS. For the determination of the optimal combination ratio between human feces (HF) and rice straw (RS) likely to produce the most significant amount of gas, the amount of biogas generated was recorded at the end of each day using a biogas analyzer during the 30 days of anaerobic digestion experiment.

The thirty days of anaerobic digestion were divided into six sections consisting of five days each (i.e., 1-5, 6-10, 11-15, 16-20, 21-25, and 26-30, all in days) as presented in Figure 1.

Section 1 (1-5 days *of digestion)*: In the first section of the experiment, a significant amount of gas is produced from each combination. The most significant production was extracted from the mixture of 100% HF and 0% RS (2296 ml), while the least was obtained from HF/RS 20/80 and HF/RS 10 : 90. HF/RS 0/100 combination generated a volume less than 500 ml.

The other combinations also gave volumes that are less than 2296 ml. Unfortunately, the trend is not linear, but randomly distributed, as it does not follow the percentage of combinations of HF and RS (90 : 10, 80 : 20, 70 : 30, 60 : 40, 50 : 50, 40 : 60, and 30 : 70). At the onset of the anaerobic digestion, the combinations HF/RS 20/80, HF/RS 10 : 90, and HF/RS 0/100 did not have considerable amount of microorganisms to begin the decomposition of the rice straw immediately. Microorganisms need sufficient time to multiply to have a significant decomposition effect on the rice straw [29]. On the other hand, this step is accelerated in 100% HF and 0% RS because each gram of feces contains about 10 million viruses, one million bacteria, and 1000 parasites [26]. The rapid increase in volume can also be attributed to the fact that CO_2 was formed at the initial level due to aerobic bacteria using O_2 to survive.

Section 2 (6-10 days *of digestion)*: From 6 to 10 days, the same trend in results was observed in terms of the volume of gas obtained. One notable observation was the decrease in biogas production from 2296 ml to 1749 ml for 100% HF and 0% RS combination and an increase for the rest of the combinations. This is because of the depletion in the oxygen level to support the lives of the microorganisms. This situation caused the death of aerobic bacteria leading to a reduction in their activities inside the digester to make place for anaerobic microorganisms [30]. The observed increase for the rest of the digesters is due to their latency phase. At this stage, growth rate is substantially low because the bacteria

Figure 1: Overview of daily biogas yield from different combinations of HF and RS.

adapt better to their mid-life level [31]. Hence, an increase in volume as compared to the 100% HF and 0% RS combination.

Section 3 (11-15 days *of digestion)*: From the eleventh to the fifteenth days, there was drop in biogas production for all the combinations except for 50% HF with 50% RS, which had a volume of 2478 ml. The combinations having more than 50% HF have approximately an average biogas production of 1120.8 ml each, compared to the combinations having more than 50% of RS, with an average production of 891.6 ml. Because of these results, it can be concluded that the growth of microorganisms in an anaerobic medium is inversely proportional to the duration of fermentation (10 days) due to the rapid decrease in nutrients contained in the fecal matter over time [16]. In addition, the high production of biogas observed in the digesters containing 50% or less RS can be explained by a significant decomposition and conversion into organic acids of the volatile solids contained in the rice straw, which will be transformed into methane by methanogens [21].

Section 4 (16-20 days *of digestion*): From the fifteenth to the twentieth day of digestion, the production of biogas in each digester increases as a function of the day except for the 100% HF and 0% RS combination, which had a decrease in biogas production; this growth for the combinations could be due to the decomposition of the majority of the rice straw contained in each digester and the conversion of the volatile solids into organic acids which will serve indirectly as food for the methanogens to produce methane. The continuous decrease at the 100% HF and 0% RS levels can be explained by the decrease in nutrients in the digester and, therefore, the death of bacteria [11].

Section 5 and section 6 (21-30 days *of digestion)*: From the twenty-first to the thirtieth day of digestion, a slight similarity in the daily biogas production at the level of each combination was observed; it is the stationary phase of the anaerobic microorganisms. Bacteria that multiply compensate for those that die. Because of this, microorganisms have difficulty degrading these rice straws compared to the degradation of human fecal matter. Biochemical degradation of lignin explains the general limitation role of bacteria in the degradation of lignin macromolecules since bacteria are only responsible for the decomposition of side chains and monomers [32]. Likewise, the results presented by [18, 33] both worked on lignin degradation and shown that bacteria can detach the aliphatic side chains from the molecule but that the phenol-ether bonds remained non-localized by the bacteria. Consequently, limiting their competence to degrade lignin.

3.4. Comparison of Potential Biogas Yield from Each Combination of HF and RS. After 30 days of the co-digestion experiment, the data collected were used to compare different combinations of HF and RS. From the paired samples, t-test analysis of the data based on the mean comparison gave Figure 2 which is the rank in descending order of gas production.

Based on the comparison of the average amount of biogas produced, the different combination can be classified into biogas production potential of 100-200 ml, 200-300 ml, and 300-400 ml.

The 80 : 20, 70 : 30, 20 : 80, 0 : 100, and 10 : 90 combinations of HF and RS have their gas production potentials between 100 and 200 ml with each standard deviation (80 : 20, 70 : 30,

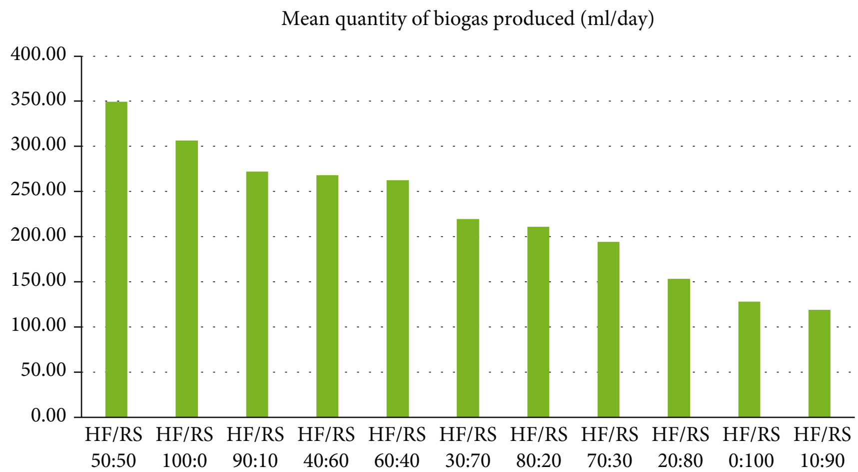

FIGURE 2: Decreasing order of gas production.

TABLE 3: Difference in the potential of biogas yield from different combinations of HF and RS.

Different combination	Mean difference (ml/day)	Std. deviation	T-value	95% confidence interval of the difference Lower	Upper
HF/RS 100 : 0	306.40	113.422	14.796	264.05	348.75
HF/RS 90 : 10	272.03	104.191	14.301	233.13	310.94
HF/RS 80 : 20	210.80	57.064	20.233	189.49	232.11
HF/RS 70 : 30	194.50	77.121	13.814	165.70	223.30
HF/RS 60 : 40	262.40	80.691	17.811	232.27	292.53
HF/RS 50 : 50	349.23	93.212	20.521	314.43	384.04
HF/RS 40 : 60	268.00	94.120	15.596	232.86	303.14
HF/RS 30 : 70	219.63	71.200	16.896	193.05	246.22
HF/RS 20 : 80	153.13	55.152	15.208	132.54	173.73
HF/RS 10 : 90	119.20	126.997	5.141	71.78	166.62
HF/RS 0 : 100	128.27	72.288	9.719	101.27	155.26

20 : 80, 0 : 100, and 10 : 90) and values (57.064, 77.121, 55.152, 72.288, and 126.997) when the amount of HF is reduced compared to the RS contained in the reactor (Table 3).

In the range of biogas production between 200 and 300 ml, the combinations 90 : 10, 40 : 60, 60 : 40, and 30 : 70 have a similar production potential because they have very close standard deviation values (Table 3).

The last group of average gas production between 300 and 400 ml is made up of only two combinations which are that of 50 : 50 and 100 : 0 HF/RS, with very close standard deviations (Table 3).

In a general, all the combinations have a potential for the daily production of biogas directly linked to the percentage of the quantity of different raw materials that compose them. Thus, the value of each mixture's carbon-nitrogen ratio can explain the potential for the average daily production of diversified biogas (Table 4). Referring to Table 3, it was noticed that any combination having a carbon nitrogen ratio less than 25 (HF/RS 100 : 0; HF/RS 90 : 10; HF/RS 80 : 20; HF/RS 70 : 30, and HF/RS 60 : 4) were poor in production compared to those with their carbon nitrogen ratio between 25 : 0 about 30 : 0 (HF/RS 50 : 50; HF/RS 40 : 60; HF/RS 30 : 70; HF/RS 20 : 80; HF/RS 10 : 90; and HF/RS 0 : 100). These results confirm the recommendations made by [34–38] when they mentioned that for high biogas production, the carbon-nitrogen ratio should be between 25 and 30.

3.5. Potential Methane Yield from Each Combination of Human Feces with Rice Straw. Based on the observations, it can be stated that with an amount of fecal matter between 60 and 100% of the total mixture; the production of biogas is higher compared to the mixtures comprising 60% and 100% of the straw in the total mixture, but the production of biogas remains more remarkable at the level of 50% HF and 50% RS.

From 30 days of digestion, the gases were analyzed to determine the percentage of methane produced; mixtures with more than 60% of straw produced more methane and less of the other greenhouse gases compared to combinations containing more than 60% HF. But the production of methane is still more remarkable in volume (6390.70 ml for 30 days) and percentage (61% for the 50% HF and 50%

Table 4: C:N ratio for the combinations.

Digesters (combination)	HF/RS 100 : 0	HF/RS 90 : 10	HF/RS 80 : 20	HF/RS 70 : 30	HF/RS 60 : 40	HF/RS 50 : 50	HF/RS 40 : 60	HF/RS 30 : 70	HF/RS 20 : 80	HF/RS 10 : 90	HF/RS 0 : 100
C:N ratio of different combination	6.6	16.1	20.5	23.1	24.8	26.0	26.9	27.5	28.1	28.5	32.7

RS). This confirms the results published by [38] on the optimal combination ratio of cow dung and rice straw, where the combination ratio of 50% of each substrate is the best producer of biogas.

These results obtained for the combination with more than 60% of the rice straw in the total mixture are due to the higher carbon content resulting in a more significant formation of carbon dioxide and a lower pH value. However, a large amount of carbon dioxide produced in the digester adversely affects the activity of methanogenic bacteria, significantly reducing methane production [39, 40].

The results obtained at the level of mixtures with more than 60% HF in combinations confirm the presence of higher nitrogen content leading to an increased production of ammonia, which can increase the pH which also prevents the activity of microorganisms in the digester and therefore stops the production of methane [39]. In all, the acidification or basicity of the medium harms the activity of methanogens since they work in an almost buffer medium (pH approximately equal to 7). [41].

4. Conclusion

The results obtained showed that the addition of rice straw to human feces under anaerobic conditions had a significant effect on the biogas yield. The best ratio was HF: RS 50 : 50 since methane production was at its best with a volume of 6390.70 ml for 30 days and a percentage (61%) consistent with other review works [3].

Furthermore, to confirm these results, it would be well to repeat this experiment several times under other parameters that affect the anaerobic digestion process during biogas production to make imminent and impeccable recommendations.

Data Availability

Data will be made available upon request from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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