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Comparative Study of Biogas Production from Jackfruit Waste, Banana Peels, and Pineapple Peels Co-Digested with Cow Dung

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Abstract

Only 42% of Uganda's population has access to electricity. The population continues to use firewood and charcoal as a source of energy, which leads to depletion of forests thus to climate change. The purpose of this study was to assess the potential of biogas production from jackfruit waste, banana peels, and pineapple peels when co-digested with cow dung as an alternative energy source. Substrates for each waste were co-digested with varying proportions (0%, 25%, and 50%) of cow dung using laboratory-scale 250 mL anaerobic digestors. The total biogas generation for jackfruit waste, banana peels, and pineapple peels after 30 days of anaerobic digestion was 82.3, 189, and 262 mL, respectively. When jack fruit waste, pineapple peels and banana peels were co-digested with 25% cow dung, the total amount of biogas produced increased by a factor of two and three, respectively. However, 50% of cow dung only significantly ($p \le 0.05$) improved for jack fruit waste by two folds. Therefore, the results indicated that jackfruit waste, banana and pineapple peels can be used for biogas production to augment energy supply.

Keywords

Biogas, Co-Digestion, Jackfruit Waste, Banana, Pineapple Peels

1. Introduction

Energy is one of the essential factors leading to global prosperity. It is synonymous with citizens' access to health care and education. The correlation between the Human Development Index and energy consumption per capita shows countries with access to energy are more developed [1]. The dependence of the world on fossil fuels as a primary energy source is becoming threatened due to the depreciating sources against the increasing demands from the fast-increasing population. According to United Nations [2], the world's population is projected to raise to 10 billion by the year 2040, creating competition for the available energy resources. Higher energy prices have led to excruciatingly high inflation, pushed households into poverty, forced some firms to reduce output or even close down, and delayed economic growth to the point that some countries are on the verge of a severe recession [3]. More than a billion people worldwide do not have access to electricity, while approximately 2.5 billion rely on conventional biomass fuels to meet their basic cooking energy needs. In 2019, roughly 580 million people in Sub-Saharan Africa lacked access to electricity, with an additional 890 million cooking on traditional fuels [4].

The level of electricity access in Uganda remains low at about 42% nationwide, and lower for the rural areas for all forms of energy [4]. The population's major source of energy remains biomass in the form of firewood and charcoal. Traditional biomass accounts for around 94% of primary energy consumption, primarily for heating and cooking [5]. This has contributed to loss an estimated amount of 60.4% of forest estates in the last 25 years for Uganda [6]. Additionally, dependence on biomass energy expose users especially women to both physical and psychological health challenges [7]. Biomass fuels from agricultural waste are becoming an attractive potential source of renewable energy due to increasing demands for clean energy [8] [9]. Presently, biomass is converted into products with high-quality energy, such as biomass liquid fuels [10], briquettes [11] [12] [13] [14] and biogas [15] [16] [17]. Production of secondary fuel through the utilization of agricultural waste comes with other benefits such as safe waste disposal, which help in protection of the environment [9] [18] [19]. Furthermore, a by-product of anaerobic digestion, bio-slurry, can be used to restore depleted soil fertility for enhanced crop output [20] [21].

Biomass is available in Uganda in the form of agricultural and food processing industry waste [8] [22]. Uganda's banana fruit processing alone is estimated to generate more than 4.3 million MT of banana waste annually [23]. Additionally, one of the top pineapple-producing districts in Uganda, Kayunga produces 15,960 tons of pineapple in a single season, 80% of which is waste [24]. Furthermore, each year, about 0.3 million MT of jackfruit is produced per district in the producing areas, with 65% of the ripe fruit's gross weight being wasted [25] [26]. There are several ways to convert agricultural biomass to energy, and they can differ depending on the type of waste, the conversion method, the infrastructure, and the ultimate uses [18]. With the development of waste-to-energy (WTE) technologies such pyrolysis, anaerobic digestion, incineration, composting, and refuse-derived fuel (RDF), energy may be recovered and products with added value such as electricity, fuels, heat, organic fertilizers, and chemicals can be produced [27].

According to Komakech *et al.*, [28], agricultural organic waste littered in Kampala (Uganda's capital) has an average gross energy content of 17.3 MJ/kg. Nabaterega *et al.* [13] quantified the waste generated by small-scale food processing factories and found that organic waste has biodegradable solids ranging from 60% to 97.3% while the moisture content ranges from 45% to 97.3% wet basis. Such values justify the potential of biomass waste for energy conversion. Substrates with 50% moisture content and above are more suitable for bio-conversion processes rather than thermal conversion processes [29] [30] [31]. The purpose of this study was to explore the utilization of jackfruit waste, banana peels, and pineapple peels for the generation of biogas when co-digested with cow dung.

2. Materials and Methods

2.1. Substrate Collection and Characterization

Jackfruits, banana, and pineapples for the generation of waste were collected from Kangulumira Sub County (0˚34’54"N, 32˚01’35", 1130 masl). Kangulumira was specifically selected since it’s among the leading producers of jackfruit [25] and pineapples in the Uganda [32]. They were thoroughly cleaned with water and cut manually using a knife to separate waste and edible proportions. Jackfruit wastes (seeds not included), banana peels, and pineapple peels were shredded using an organic shredder machine (locally fabricated) to appropriate size (less than 14 mm) [17]. This was done to increase the surface area for microorganism action and decrease cellulose crystallinity to improve the digestibility and the conversion of saccharides during hydrolysis. The resultant samples were divided in to two portions; one poertion was soaked in water and stored for 14 days to allow for partial breakdown of complex sugars, while the second portion was used for carrying out lignocellulosic and elemental analysis.

After 14 days of partial digestion, samples in triplicates were taken to the laboratory for proximate analysis of physicochemical parameters namely: pH; moisture content; MC (wt.%), total solids, TS (wt.%); and volatile solids, VS (wt.%) using standard methods (Equations (1)-(3)) [33]. The empty weight of the crucible, m_1 (g) was recorded first. Then, approx. 10 g of the sample was filled into the crucible and the weight of the filled crucible, m_2 (g) once again obtained. The weighed crucibles were placed into the drying oven cabinet at 105˚C for 24 hours to allow for water evaporation. The weight of the crucible, m_3 (g) with the dried sample was then recorded. Subsequently, the samples were calcined in the muffle furnace at first for six hours at 550˚C. After the calcination, the hot crucibles were cooled down in desiccators and weighed once again, m_4.(g). The total solids, moisture content, and volatile solids were calculated following, respectively.

$$TS(\%) = \left(\left(m_3 - m_1\right)/\left(m_2 - m_1\right)\right) \times 100 \quad (1)$$

$$MC(\%) = 100 - TS \quad (2)$$

$$VS(\%TS) = \left(\left(m_3 - m_4\right)/\left(m_2 - m_1\right)\right) \times 100 \quad (3)$$

The pH values for the substrates were determined using Multiparameter (pH/EC/TDS/SALT) Pocket Meter (PT162). The meter probe was dipped into a well-shaken sample, and the pH value directly read off from the digital screen.

An ULTRA CHS-580 elemental analyzer was used to analyze for the carbon, hydrogen, and Sulphur contents (ASTM D5373) [34]. The samples were homogenized and then weighed by electronic balance and recorded before being fed into the furnace that utilizes 99.5% oxygen purity.

The total nitrogen content of the substrates was determined by the Kjeldahl procedure. About 2 g of dried samples of the substrates were placed in a digestion tube with 15 mL of concentrated Sulphuric acid, followed by about 7 g of potassium sulphate and copper. The digestion tube was then heated at 37˚C from a digestion block. Sodium hydroxide was added to change ammonium ion to ammonia, and the nitrogen was separated by distilling the ammonia and collecting the distillate in 0.1N Sulphuric acid solution. Determination of the amount of nitrogen on the condensate flask was done by titration of the ammonia with a standard solution of 0.1N sodium hydroxide in the presence of methyl red as an indicator and 0.1N Sulphuric acid solutions. Finally, the amount of nitrogen present was calculated using Equation (4)

$$\text{TKN} = \left(\left(V_1 - V_0\right) \times c \times f \times 0.014\right) / \left(m \times 100\right) \tag{4}$$

where TKN: Total Kjeldahl nitrogen content, V_1: Volume of the Sulphuric acid consumed when titrating the sample (mL), V_0: Volume of the Sulphuric acid consumed when titrating the blank reading (mL), c: Normality of the acid (mg/L), f: Factor of the acid, m: Mass of the sample (g).

Lignin, cellulose, and hemicellulose composition in the substrates were conducted using the Van-Soest and Wine methodology [35] and the refluxing apparatus procedures. The methodology uses two analytical methods: neutral-detergent fibre (NDF) and acid detergent fibre (ADF). NDF analyzes the total fibre in the samples, that is, the residue that remains after treatment of the biomass with a neutral detergent solution (sodium lauryl sulphate and EDTA). ADF deals with the lignocellulose determination where the residues that remained after treatment with an acid detergent solution are oxidized with Cetyl trimethylammonium bromide in H_2SO_4 solution.

$$\text{Hemicellulose} = \text{NDF} - \text{ADF}$$

$$\text{Lignin} = \text{ADL}$$

$$\text{Cellulose} = \text{NDF} - \left(\text{Hemicellulose} + \text{Lignin}\right)$$

where: NDF = Neutral Detergent Fibre, ADF = Acid Detergent Fibre, and ADL = Acid Detergent Lignin.

2.2. Biogas Experimentation

The biogas experimentation involved defining the experimental design, digester set up, determining the volumes and the composition of the biogas from jackfruit waste, banana peels and pineapple peels when co-digested with cow dung. This was done following the Biochemical Methane Potential (BMP) assay protocol for anaerobic digestion [36]. The feedstocks were prepared in different proportions as shown in **Table 1**. Each treatment was replicated three times in a

Table 1. Experimental design.

Treatment	Composition by volatile solids (%)
T1	100 Jackfruit waste
T2	75 Jackfruit waste and 25 Cow dung
T3	50 Jackfruit waste and 50 Cow dung
T4	100 Banana peels
T5	75 Banana peels and 25 Cow dung
T6	50 Banana peels and 50 Cow dung
T7	100 Pineapple peels
T8	75 Pineapple peels and 25 Cow dung
T9	50 Pineapple peels and 50 Cow dung

completely randomized design.

Evaluation of the quality attributes for biogas generated from jackfruit waste, banana peels, and pineapple peels was investigated using batch digestion. The digestion system consisted of 500 mL digester flasks submerged in a 20-liter temperature regulating water bath (GRIFFCHEM HH-S6), 250 mL gas storage flask, and a 250 mL measuring cylinder for determining the generated biogas in the displacement method. The water bath maintained the temperatures at 36.5˚C ± 0.5˚C.

Biogas Yield and Composition

The percentage of methane determines the biogas's energy content. A Geotech gas analyzer model GA5000 (Italy) was used to measure the quality (Methane composition) at the end of the experiment. The water displacement method was used to measure the volume of the gas produced in the anaerobic reactors every three days. A flexible tubing connecting to the digester's gas outlet was inserted into an upside-down measuring cylinder that was partially submerged in water in a glass trough to see the gas collection. The volume of gas produced is equal to the volume of water displaced from the measurement cylinder [37].

2.3. Statistical Analysis

Energy content data collected from the biogas experiments were statistically analyzed using R Software. One-Way ANOVA with Tukey's post-hoc analysis to determine statistical significance difference between different combinations for biogas production was used. All significance tests were conducted at a 0.05 significance level.

3. Results and discussion

3.1. Characterization of Substrates for Biogas Production

3.1.1. Proximate Analysis

For all the parameters (moisture content, total solids, and volatile solids), there was a significant difference ($p \le 0.05$) between the substrates (jackfruit waste, banana peels, pineapple peels, and cow dung) as presented in **Table 2**. The moisture content for all the substrates Jackfruit waste, banana peels, and pineapple peels were above 70%. Biomass with moisture content > 70% is suited for anaerobic digestion since direct burning is not economical as a significant amount of energy for evaporation of water will be used [38].

The total solids ranged between 12% to 23% with pineapple peels having the lowest (12.32%) and cow dung the highest (23.83%). Ejiroghene *et al.* [39] recommend a total solids percentage of 10. Total solids amounts help in balancing the water requirements for microbial activity during anaerobic digestion. Jackfruit waste had the highest volatile matter (92.61%) followed by pineapple peels (91.5%), cow dung (82.76%) and banana peels the lowest (81.68%). The results obtained are comparable to the literature. Nabaterega *et al.* [15] reported 80.7%, 88.3%, and 79.4% moisture content and 93.3%, 94.8%, and 97.4% of volatile soilds for banana peels, pineapple peels and jackfruit waste respectively collected from a food processing plant. Gumisiriza *et al.* [16] reported 83.3% and 86.78% of moisture content and volatile solids respectively for banana peels. Zziwa *et al.* [40] reported 90.84% and 81.32% volatile solids for pineapple peels and cow dung. The total solids for cow dung agree with Zziwa *et al.* [40] while for pineapple peels (6.8%) is lower than reported in this study. Both studies did not consider the varieties of pineapples, therefore, difference in volatiles solids could have resulted from the varieties used. Suhartini *et al.* [41] conducted a study about the biomethane potential of five agricultural residues that reported 84.83% moisture content and 92.7% volatile solids for jackfruit waste and noted that for any given wet weight of feedstock, the VS content is usually positively correlated to biogas production.

3.1.2. Ultimate Analysis

The results recorded from the ultimate analysis of jackfruit waste, banana peels, and pineapple peels are presented in **Table 3**. The carbon content for the three substrates was ideal with the banana peels having the highest at 41.55% but not significantly different from that of jackfruit (39.81%). The hydrogen content for all the substrates is averagely the same (approximately 5%) and Sulphur (<0.5%). Nitrogen content was highest in banana peels whereas oxygen is highest in pineapple peels. The ultimate analysis results for jackfruit waste agree with Alves

Table 2. Proximate analysis for the substrates.

Substrate	Moisture content (%)^{wb}	Total solids (%)^{wb}	Volatile solids (%)
Jackfruit waste	81.69^{b}	18.31^{b}	92.61^{b}
Banana peels	79.64^{a,b}	20.36^{b,c}	81.68^{a}
Pineapple peels	87.68^{c}	12.32^{a}	91.50^{b}
Cow dung	76.77^{a}	23.83^{c}	82.76^{a}

wb-wet basis. Means in the same column with different superscripts are significantly different at $p \leq 0.05$.

et al. [42], with higher amounts of carbon and oxygen and negligible amounts of hydrogen, Sulphur, and nitrogen. However, the results are slightly different from ones obtained by Nsubuga *et al.* [43] having values ranging from 43.89% - 48.08% for carbon, 5.43% - 7.13% for Hydrogen, 0.11% - 0.51% for Sulphur, 1.42% - 1.57% for Nitrogen and 41.06% - 45.27% for Oxygen. The difference in the two results might be attributed to a combination of both soft and firm jackfruit varieties for this study. The C/N ratio for jackfruit waste is 31.6, agree with Viswanath *et al.* [44] (33.1). The C/N ratio for banana peels, pineapple peels, and cow dung are 31.02, 34.36, and 15.44 all out of the recommended range, 20 - 30 for optimum biogas production [45] [46]. When the carbon to nitrogen ratio is high, methanogens quickly use the nitrogen to meet their protein needs and stop reacting with the material's remaining carbon content, which reduces gas production. On the other hand, nitro-gen will be released and accumulate in the form of an ammonium ion if the C/N ratio is extremely low (NH_4). The pH of the bio-digestate in the digester will rise as a result of the excess NH_4, and a pH higher than 8.5 will begin to have a deleterious effect on the methanogen population [47] [48].

3.1.3. Lignocellulose Analysis

The result for the lignocellulosic analysis of substrates is presented in **Table 4**. Cellulose formed a bigger percentage for Jackfruit waste (26.43%) and banana

Table 3. Ultimate analysis for the substrates.

Parameter (%)	Substrate			
	Jackfruit waste	Banana peels	Pineapple peels	Cow dung
Carbon, C	39.81^c	41.55^c	27.45^a	31.57^b
Hydrogen, H	5.551^b	5.694^b	4.470^a	5.377^b
Sulphur, S	0.452^c	0.161^a	0.293^b	0.289^b
Nitrogen, N	1.262^b	1.340^b	0.799^a	2.047^c
Oxygen, O*	52.92^a	51.26^a	66.98^c	60.72^b
C/N	31.60	31.02	34.36	15.44

*O = 100-C-H-S-N. Means in the same row with different superscripts are significantly different at $p \leq 0.05$.

Table 4. Lignocellulosic analysis for the substrates.

Parameter (%)	Substrate		
	Jackfruit waste	Banana peels	Pineapple peels
Hemicellulose	6.815^a	26.89^c	16.03^b
Cellulose	26.43^c	20.99^b	7.861^a
Lignin	3.086^b	1.987^a	1.994^a

Means in the same row with different superscripts are significantly different at $p \leq 0.05$.

peels (20.99%) compared to pineapple peels 7.861%. Banana peels had exceptionally high hemicellulose (26.89%) compared to pineapple peels (16.03%) and jackfruit waste (6.815%). The lignin content for banana peels and pineapple was not significantly different ($p \leq 0.05$) and lower than that of jackfruit. The results obtained from this study for banana peels are slightly lower compared to Kabenge *et al.* [49] and higher compared to Pathak, Mandavgane, and Kulkarni [50]. The results for pineapple peels dont agree with Madureira *et al.* [51].

3.2. Characterization of Biogas

3.2.1. Quantity of Biogas

The daily and cumulative biogas production from jackfruit waste, banana peels, and pineapple peels with different combinations of cow dung over the period of 30 days is shown in **Figure 1** and **Figure 2** respectively below. The results show

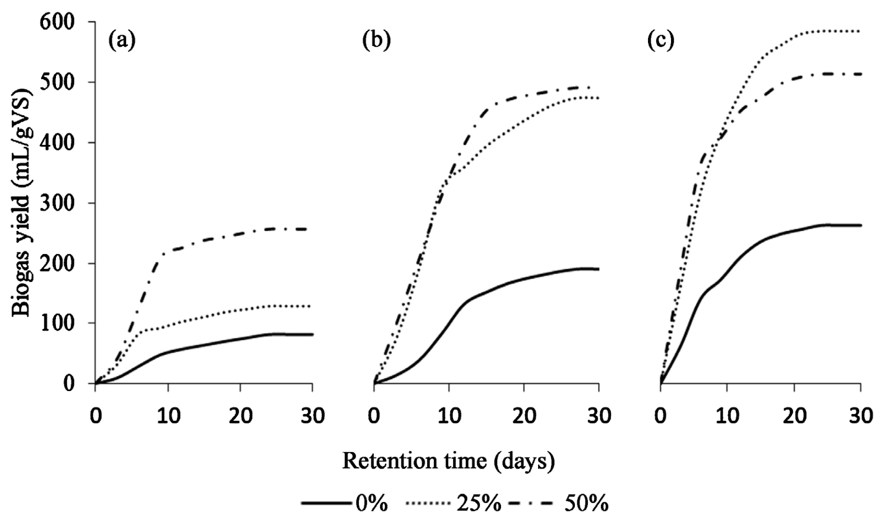

Figure 1. Cumulative biogas production for different co-digestion mixtures of jack fruit waste (a), banana peels (b) and pineapple peels (c) with varying percentages of cow dung.

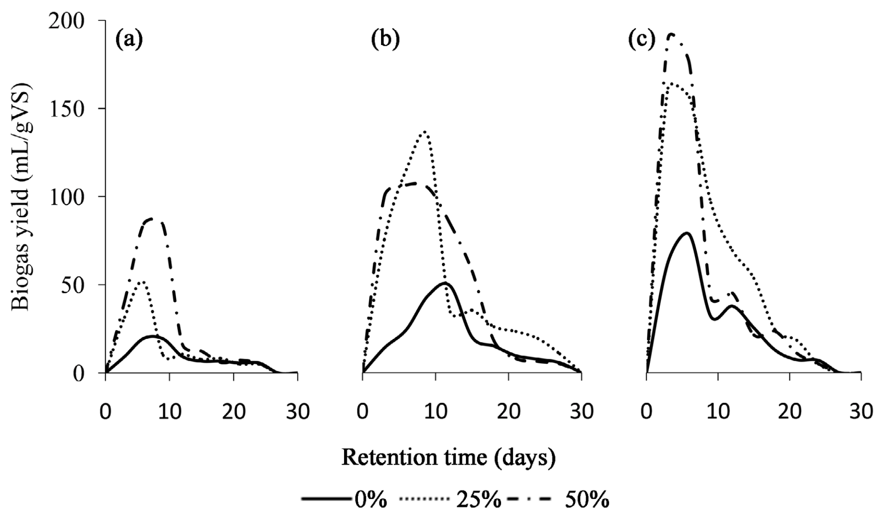

Figure 2. Daily biogas production for different co-digestion mixtures of jack fruit waste (a), banana peels (b) and pineapple peels (c) with varying percentages of cow dung.

that gas production started before the third day and increased rapidly in the first 6, 9, and 6 days for jackfruit waste, banana peels, and pineapple peels digestors respectively, reaching the peak daily biogas production and dropped progressively after. Pineapple peels produced the highest volumes of biogas for all the three levels of combinations; 262 mL with 0% cow dung, 581.7 mL with 25% cow dung, and 510.7 mL with 50% of cow dung (**Table 5** and **Figure 1**).

The results for co-digestion of pineapple peels with cow dung did not significantly improve the total biogas production. Co-digestion of pineapple, orange, apple, banana and jackfruits produce more biogas (975 mL) compared to pineapple alone (900 mL) due to the high concentration of solids and total viable count of microbes than the sole fruit substrate [52] [53]. Jackfruit recorded the lowest production of biogas (495 mL) while banana recorded the second lowest (555 mL)., however, these results are relatively higher compared to the current study. Umeghalu *et al.* [54] observed an increase in gas yield from 343.56 to 610.2 mL when co-digested with cow paunch and from 314.6 to 550.66 mL when co-digested with poultry droppings within the same 30 days observation period. Generally, the hydraulic retention time for all the treatments was 30 days. The 3rd-21st days of the experiment were the most productive period. The short HRT might be attributed to pre-treatments done on the substrates. All the three agricultural substrates were size reduced to approximately 14mm (mechanical pre-treatment) and stored for 14 days to allow for partial degradation of complex sugars. The results obtained agree with Abdelsalam *et al.* [55], who found that co-digestion of lettuce leaves and manure yields 782.6 mL/gVS compared to the 633 mL/gVS mono-digestion of cow dung. Additionally, Meng *et al.* [56] found out in the study with the co-digestion of vinasse straw with cow dung, the cumulative biogas yield was 633.4 mL/gVS which is comparable to the results of the present study. Biogas quality is measured as a percentage of methane. The results agree with the previous results ranging from 50% - 75% [57]. Therefore, the co-digestion contributed to the increase of biogas quality.

3.2.2. Biogas Quality

The quality of biogas produced represents the percentage of methane. The methane content was measured after 30 days of the experiment. **Table 6** shows the methane composition for biogas generated from different co-digestion mixtures of jackfruit waste, banana peels and pineapple peels. Samples with more cow

Table 5. Total Biogas production from different co-digestion mixtures.

Cow dung added (%)	Substrate		
	Jackfruit waste	Banana peels	Pineapple peels
0	82.3^{a}	189.0^{a}	262.0^{a}
25	129.7^{b}	472.0^{b}	581.7^{b}
50	256.3^{c}	488.7^{b}	510.7^{b}

Means in the same row with different superscripts are significantly different at $p \leq 0.05$.

Table 6. Total Biogas production from different co-digestion mixtures.

Cow dung added (%)	Substrate		
	Jackfruit waste	Banana peels	Pineapple peels
0	31.5[a]	45.0[a]	63.2[b]
25	65.6[c]	63.9[b]	55.5[a]
50	54.5[b]	64.1[b]	70.6[c]

Means in the same row with different superscripts are significantly different at $p \leq 0.05$.

dung had more methane content. Co-digestion of 25% of cow dung significantly improved the methane content for jack fruit waste samples from 31.5% to 65.6%; banana peels from 45% to 63.9% but for pineapple peels lowered from 63.2% to 55.5%. Additional 25% of cow dung significantly increased methane content for pineapple peels samples reaching a maximum of 70.6% but for banana peels, the improvement was not significant and for the jackfruit waste, the quality was significantly lowered to 54.5%.

4. Conclusion

In this study, the potential for generation of biogas from jackfruit waste, banana and pineapple peels was evaluated. The substrates had high moisture content (76% - 87%) and volatile solids (81% - 92%), which is suitable for anaerobic digestion. Jackfruit waste produces 82.3 mL of biogas overall, followed by banana peels with 189 mL and pineapple peels with 262 mL, respectively. The total biogas production from jackfruit waste, banana peels and pineapple peels are 82.3, 189, 262 mL peels respectively. Co-digestion with 25% of cow dung significantly ($p \leq 0.05$) improves the total biogas production by two folds for jack fruit waste and three folds for both pineapple peels and banana peels. However, addition of cow dung to 50% only significantly improves the total biogas production by two folds for jack fruit waste only. According to the study, jackfruit waste, pineapple peels, and banana peels can be used depending on the season and combined with cow manure to produce biogas for energy production. It is highly recommended to do a techno-economic analysis and life cycle assessment of the energy generation from organic waste. This should involve a thorough investigation to reach a realistic evaluation of the agricultural waste resources that are available as well as the venture's economic and environmental viability.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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