Experimental approach of producing biogas from fallen leaves with co-digestion

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Abstract. The present study assessed the feasibility of producing biogas from fallen tree leaves. This study provides valuable insights into utilizing locally available organic waste materials for biogas production and contributes to developing sustainable biogas systems. Four species of tree leaves, namely Jackfruit (Artocarpus heterophyllus), Mango (Mangifera indica), Mahogany (Swietenia macrophylla), and Teak (Tectona grandis) were selected for this experiment. The study employed co-digestion as a strategy, with cow-dung (Bos taurus) at 1% (w/v) added to the leaf mixture. Urea was used to control the pH of the mix, and the experiment was conducted in 2-litre digester bottles. The results revealed that the biogas yield from the tree leaves was highly dependent on the species used. Teak leaves had the highest methane yield at 64.3%, followed by Jackfruit leaves at 62.2%, and the lowest yield was observed from Mango leaves. Adding of cow-dung to the mixture of tree leaves enabled the biogas yield, confirming the significance of co-digestion for biogas production. The study also found that pH control was crucial in optimizing biogas yield, with urea effectively maintaining the pH within the desired range of 5.5 to 7.3.

1 Introduction

Renewable energy is becoming increasingly important as the world faces the challenges of climate change and the need for sustainable energy sources. Biogas, produced through anaerobic digestion, is a clean and renewable source of energy that reduces greenhouse gas emissions and contributes to a more sustainable energy system. In addition, the development of biogas and renewable energy systems can also stimulate local economic growth and create job opportunities in rural areas. It is essential to support the development of biogas and renewable energy systems in Bangladesh to help address the country's energy needs and contribute to a more sustainable future [1].

In Bangladesh, fallen tree leaves are abundant in rural areas, with an energy shortage. These leaves can be used as feedstocks for biogas production, providing a locally available and sustainable energy source for rural communities. Using fallen tree leaves for biogas production can help reduce waste, improve rural livelihoods, and contribute to the overall energy security of the country.

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Anaerobic digestion (AD), which entails decomposing complex organic matter (OM) by various anaerobic microorganisms without oxygen, produces biogas. Methane (CH_4), carbon dioxide (CO_2), and many other trace gases and impurities comprise most of the biogas' chemical makeup. Biogas has a unique gas composition that depends on the type of plant and substrate used and is only partially controllable. However, as the methane concentration rises disproportionately towards the end of the residence time, the AD process gets better with longer exposure times. [2] In the first stage, hydrolysis, complex organic compounds in the leaves are broken down into simple sugars, amino acids, and fatty acids. In the acidogenesis stage, the simple organic compounds are converted into volatile fatty acids (VFAs). In the acetogenesis stage, the VFAs are further converted into acetic acid, CO_2, and hydrogen gas [3]. Finally, in the methanogenesis stage, the acetic acid is converted into methane by methanogenic bacteria.

The selection of leaves for the experiment was based on their availability and the feasibility of collecting fallen leaves during specific seasons. Bangladesh has a high abundance of tree species, and Mahogany, Teak, and Mango were identified as among the most commonly available based on Drake et al[4]. The study by Md Hasanuzzaman et al. showed that Mahogany and Mango Trees produced the highest volume of leaf litter [5]. The proximate analysis of Abiodun Bukunmi Aborisade et al on various plant leaves indicated that Indian Coral Flower, Mango, and Jackfruit had the highest percentage of organic matter [6]. Thus, Mango, Jackfruit, Mahogany, and Teak were selected for this experiment based on the criteria of availability and organic matter content.

Creating a suitable environment for microorganism growth is critical for effective methane generation. Previous research has indicated that pH values below 5.5 or above 7.4 negatively impact methane production [7]. Zhou J et al. suggested that pH 7 is the most optimal value for methane production [8]. The addition of urea has been proven to positively affect methane production from biomass by Liu and Ge [9].

The next challenge in biogas production is finding the appropriate sample preparation ratio. SP Jena et al. found that a 50g sample with a 500mL slurry solution yielded the best results in terms of methane production [10], while MA Rouf et al. determined that a 6% pre-treated leaf sample with 2% cow dung was the optimal ratio for maximum methane production [11].

Co-digestion is a process in which multiple feedstocks are combined and digested together. This method can potentially increase biogas production as the microorganisms involved in the digestion process can utilize the nutrients and energy present in different feedstocks [12], [13]. Co-digestion also has the added benefit of increasing the stability of the digestion process and reducing the risk of process failure due to the presence of inhibitory compounds. In addition, co-digestion can help to reduce the overall cost of biogas production as it uses a broader range of locally available organic waste materials.[14]

Co-digestion has been acknowledged for its various advantages; however, an incompatible feedstock mixing ratio can result in organic overloading, acidification, and system failure, causing antagonistic effects [15]. To overcome these challenges, it is necessary to characterize the heterogeneous organic compounds in digester feedstocks and understand their intrinsic biodegradability patterns. [12]

The current literature on co-digestion primarily focuses on process engineering [16], microbial community structure[17], or individual feedstocks [18], [19]. However, there is a significant knowledge gap regarding the compatibility of co-fed substrates, particularly regarding the feasibility of co-digesting cow-manure with various types of leaves. To address this gap, we conducted a study investigating the compatibility of different co-fed substrates and their impact on the anaerobic digestion process. Our findings offer valuable insight into identifying compatible co-feedstocks for optimal organic waste management and guide future research directions.

2 Materials and methods

2.1 Leaves collection and processing

Leaves that had fallen in the vicinity of the campus were collected, sorted, and four distinct types of leaves, namely Jackfruit (Artocarpus heterophyllus), Mango (Mangifera indica), Mahogany (Swietenia macrophylla), and Teak (Tectona grandis), were selected for the experiment. The leaves were dried for 3 days to eliminate any residual moisture. Subsequently, the dried leaves were pulverized into small particles of 5mm diameter using a blender. The reduced particle size enhanced the surface area of the leaves, thereby facilitating improved bacterial contact and subsequent digestion. Fallen Leaves were collected from around the campus. The leaves were sorted and four types of leaves were separated for the experiment, Jackfruit (Artocarpus heterophyllus), Mango (Mangifera indica), Mahogany (Swietenia macrophylla), and Teak (Tectona grandis). Then the leaves were dried for 3 days, so that any exterior water particles could dry up. The leaves were smashed and ground to small 5mm particles using a blender. The fine size of the particle allowed the bacteria to have a greater contact area thus better digestion. The schematic of the digester setup is shown in Fig. 1. It has two channel bottle cap. Both the channels are connected with two way valve to enable us purging the air out of the bottle and connecting to the analyzer for gas composition.

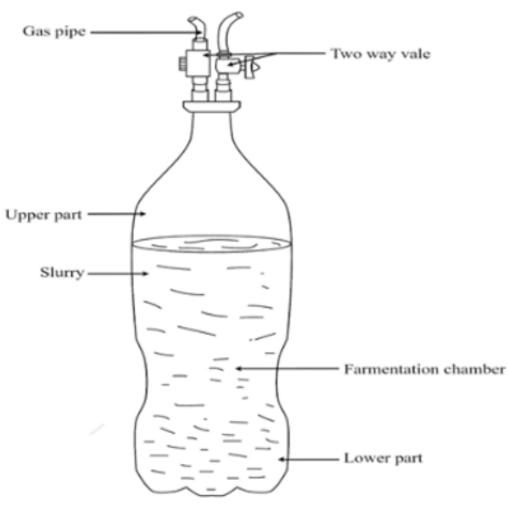

Fig 1. Schematic Diagram of the Digester Setup

2.2 Digester construction

A plastic bottle with a capacity of 2 litres has been analyzed. The bottle exhibits an overall height of 31.5 cm (12.4 inches) and a diameter of 11 cm (4.33 inches). The bottle's interior features two directional control valves, which are fitted with full seals to prevent biogas from escaping into the ambient atmosphere.

2.3 Procedure

2.3.1 Experimental setup

A single bottle setup was established to investigate the presence of methane in a plastic digester. To this end, a mixture of 50g leaf samples and 500 mL of a 2% urea solution was prepared, as this ratio yielded optimal results. The 500 mL solution was then transferred into the plastic digestors. The bottles were tightened to remove air using a vacuum pump and then kept inside the box, covered with a black cloth at 35°C.

2.3.2 Start-up

The leaf water and urea mixture were transferred into the digestor and vacuumed using a pump to initiate the digestion. It was kept for 30 days and the gas percentage was monitored.

2.3.3 Inoculum: cow dung preparation

Cow-dung was collected and stored in a sealed plastic tank for 30 days to facilitate the growth of bacteria. The tank was maintained under atmospheric conditions to promote mesophilic conditions for the bacteria. After 30 days, 5g of the cultured cow-dung was added to the plastic digester, under monitoring. The storage of the cow-dung allowed the bacteria to adapt to mesophilic conditions. At the same time, the addition to the digester aimed to evaluate the impact of the bacteria on the system's functioning [20]. The 30-day storage period was deemed necessary for optimal bacterial growth and adaptation.

2.3.4 Slurry preparation

Different reactors were used to digest other leaves as shown in Table 1. Urea was added to maintain the C/N ratio and the pH level.

Table 1. Slurry preparation for digestors

Digestor	**Sample**	**Amount of Urea**	**Inoculum after 30 days**
Digestor 1	Mango Leaves	1g Urea	5g Cow-dung
Digestor 2	Teak Leaves	1g Urea	5g Cow-dung
Digestor 3	Jackfruit Leaves	1g Urea	5g Cow-dung
Digestor 4	Mahogany Leaves	1g Urea	5g Cow-dung

2.4 Data collection

Gasboard Analyzer-3200 Plus was used to analyze the gas at regular intervals. For monitoring anaerobic digestion projects, Gasboard analyzer-3200 plus is widely used. There are 4 different sensors, which are CH_4, CO2, H2S, O2. The analyzer comes with companion software which allows us to collect and store gas data. The data were recorded and stored using a laptop. The data was taken for 45 days after the addition of cow-dung.

3. Result and discussion

3.1. Biogas without inoculum

All the digestors were kept for 30 days for start-up. The gas was analyzed during that period but no gas formation was observed. The leaves were not showing many signs of digestion either. Methane Generation was observed after the addition of Cow-dung as inoculum.

3.2. Biogas from mango leaves

Co-digestion of Mango Leaves and Cow-dung is shown in Fig.2. The methane production was observed, but the percentage was deficient, at a maximum of 7.48% after 15 days.

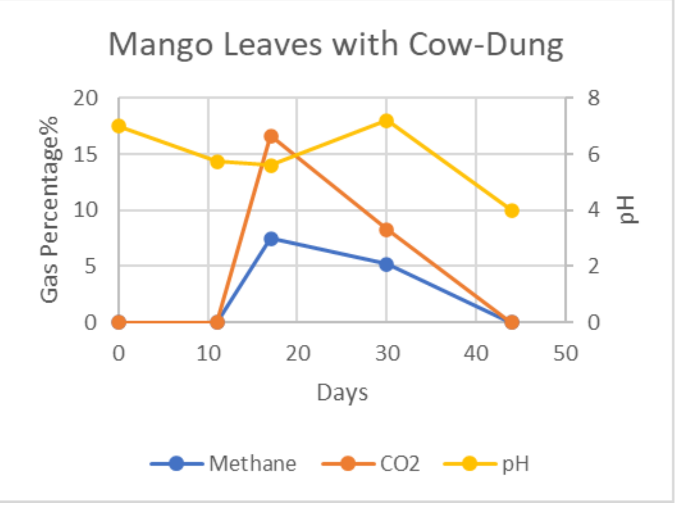

Fig 2. Concentration of CH_4 and CO_2 in Mango leaves Setup

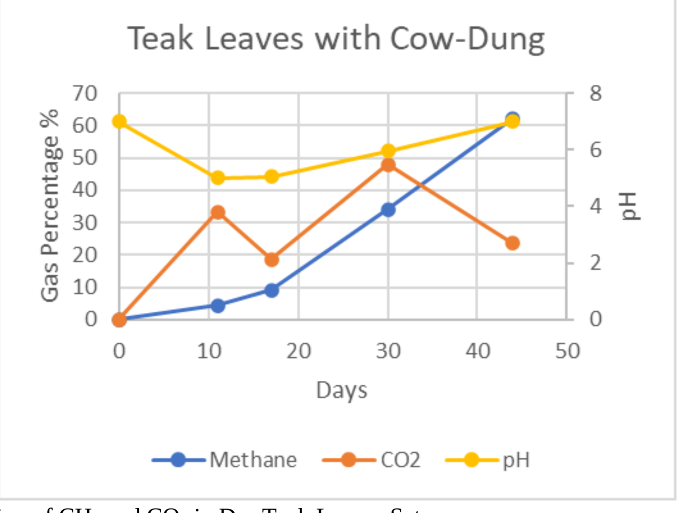

Fig 3. Concentration of CH_4 and CO_2 in Dry Teak Leaves Setup

3.3. Biogas from teak leaves

A co-digestion study was conducted using dry teak leaves and cow dung. As shown in Fig. 3, the resulting mixture was monitored for methane production and the results indicated a

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production level of 64.3% methane, surpassing the minimum requirement of 60% for utilization as fuel. The pH of the mixture was within the optimal range of 5-7 for methane production. The experiment demonstrated the potential for efficient methane generation through the co-digestion of these organic waste materials.

3.4. Biogas from jackfruit leaves

This study investigated the co-digestion of dry jackfruit leaves and cow manure. The results revealed in Fig. 4 that the successful generation of a desirable amount of methane, with a content of 62.2%, surpassing the minimum requirement for utilization as fuel. Additionally, the pH levels were maintained within the ideal range of 5-7 for methane synthesis.

3.5 Biogas from Mahogany leaves

This experiment, which contained Dry Mahogany leaves and cow manure, revealed co-digestion. This arrangement generated methane but not desired amount. The methane level was 20.83% (<60%) as in the Fig. 5 depicted, which is not adequate for burning as fuel. Although, the pH levels were optimal for methane production, ranging from 5-7.

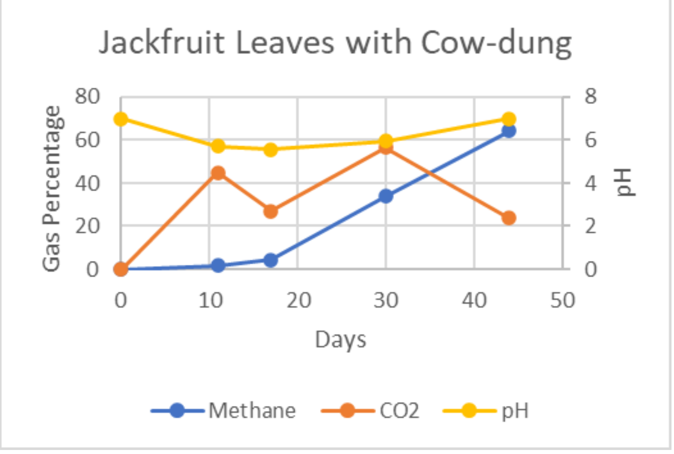

Fig 4. Concentration of CH_4 and CO_2 in Jackfruit leaves Setup

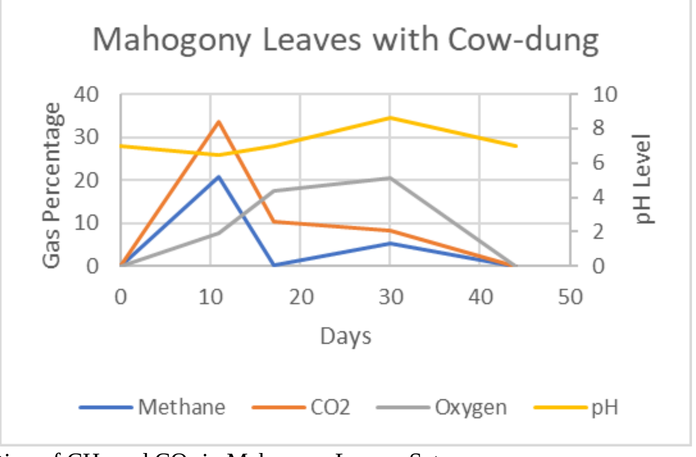

Fig 5. Concentration of CH_4 and CO_2 in Mahogany Leaves Setup

4. Conclusion

By analyzing several parameters, this paper aimed to determine the best method for producing biogas from leaves in Bangladesh. The experiment centred on four distinct types of leaves: Jackfruit, mango, mahogany, and teak. The type of leaves utilized in co-digestion substantially affects biogas production. The methane production levels of teak and jackfruit leaves exceeded 60%, whereas mango and mahogany leaves did not produce desirable results. To determine the optimal conditions for maximum methane production, the study considered various parameters, such as pH, the addition of urea, and the sample preparation ratio. This study demonstrated that using cow-dung inoculum improved the system's functionality. This research contributes to developing sustainable energy systems in Bangladesh by providing crucial insights into leaf biogas production. Hopefully, this study will inspire additional research on renewable energy sources and aid in addressing climate change-related challenges. Researchers and policymakers in developing countries like Bangladesh, where renewable energy sources are crucial for meeting the rising energy demand and mitigating the adverse effects of climate change, can use the findings as a reference.

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