Potential Enhancement of Biogas Production from Co-Digestion of *Ricinus communis* and *Datura stramonium* Leaves with Vegetable Waste

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Abstract :- Production of biogas through anaerobic digestion of organic waste materials provides an alternative environmentally eco-friendly renewable energy. In this study, biogas production from co-digestion of vegetable waste (VW), Datura stramonium leaves (DSL) and Ricinus Communis Leaves (RCL) in three mix ratios(60%DSRCL: 40%VW, 50%DSRCL: 50%VW and 40%DSRCL: 60%VW were evaluated under mesophilic condition at 38ºC using a batch mode digester over 30days fermentation. In all the treatments, physico-chemical parameter ssuchas pH, total solid, volatile solid, organic carbon, nitrogen and carbon to nitrogen ratio were measured before and after anaerobic digestion. The results indicated that pH and total nitrogen significantly increased after AD, whereas VS and organic carbon decreased significantly after AD. Biogas yield was found to be higher when the two substrates were co-digested than when digested alone. Of all mix ratios, 60% DSRC leaves co-digested with 40% VW resulted in the highest biogas. Over all the results of this study indicate that the increase in biogas yield and reduction in volatile solids and total solids can be significantly enhanced when vegetable waste is co-digested with Ricinus communis and Datura stramonium leaves (RCDSL)in 60%:40% mix ratio.

Keywords*: Anaerobic digestion, Biogas, Co-digestion, Vegetable Waste, Datura stramonium and Ricinus communis.*

1. Introduction

One of the most significant challenges to global prosperity is energy. The global energy crisis remains a pressing issue, with estimates indicating that around 1.5 billion people still lack access to electricity and approximately 2 billion people do not have access to modern energy services (World Bank, 2006). In the coming fifty years, the world is expected to face severe energy shortages. According to Courtney and Dorman (2003), natural gas reserves could be depleted in 50 years, while crude oil may run out in 40 to 70 years.

Anaerobic digestion is a promising technology for treating agricultural waste, livestock manure, and other biodegradable materials such as biomass, municipal solid waste, and industrial biodegradable waste (J. Ye et al., 2013). Key factors influencing biogas production include the C ratio, alkalinity, and biodegradability index (I. Koniuszewska et al., 2020; A.H. Bhatt and L. Tao, 2020). Nitrogen is essential for microbial cell structure development, while carbon provides energy for microbes (S.K. Tripathi et al., 2021). A substrate with a low C ratio requires co-digestion with a high C ratio feedstock, as microbes prefer a C ratio of 20–30:1 for optimal digestion (J.-M. Zhou, 2017). The composition of lignocellulose, which varies based on species, growth conditions, and maturity, has been reviewed in several studies (R. Ravindran and A.K. Jaiswal, 2016; C.

Sawatdeenarunat et al., 2015). Lignocellulosic materials primarily consist of lignin, hemicellulose, and cellulose (S. Mirmohamadsadeghi et al., 2021), resulting in a high C ratio and lower biogas production.

Co-digesting feedstocks with varying C ratios can enhance biogas production through synergistic effects. This combination provides better nutrient balance, accelerating the anaerobic digestion process by supporting microbial growth (A. Mshandete et al., 2006). For instance, biogas production increased from 230–450 L/kgVS when fruit waste, dung, and vegetable waste were co-digested at 35°C in a continuous digester (F. Callaghan et al., 2002), while molasses and cow manure boosted production from 60–230 L/kgVS in batch digesters (S. Misi and C. Forster, 2004). Several factors affect biogas yield, including temperature (V. Toutian, 2020), C ratio (L. Naik et al., 2020), pH (B. Budiyono et al., 2013), organic loading rate (OLR), hydraulic retention time (HRT) (B. Rincon et al., 2009), substrate particle size, total solids (Y. Nalinga and I. Legonda, 2023), and digester configuration (D. Liu et al., 2006). Utilizing waste materials for biogas production not only reduces greenhouse gas emissions but also minimizes odors from decomposing organic waste and generates energy.

Although there has been limited research on the energy potential of banana and Irish potato peels, more investigation is needed to handle large volumes of organic waste for biogas production. In this study, Datura stramonium and Ricinus communis leaves were co-digested with vegetable waste in varying proportions to examine the factors affecting biogas yield. To date, no published literature has focused on the co-digestion of vegetable waste with mixed Datura stramonium and Ricinus communis leaves, making this research novel. This study evaluates the effects of temperature, pH, and substrate mixing ratios on biogas production from mixed Ricinus communis and Datura stramonium leaves combined with vegetable waste. It contributes to renewable energy generation, the reduction of environmental pollution, and addressing climate change—issues that are currently at the forefront of the global agenda. The key advantage of this approach is that it generates environmentally-friendly biogas as a renewable energy source, helping to meet rising energy demands and reduce greenhouse gas emissions (V.B. Barua and A.S. Kalamdhad, 2019). This research was designed to investigate biogas production from the co-digestion of Datura stramonium and Ricinus communis leaves with vegetable waste.

2. Materials and methods

2.1 Substrates

The Ricinus communis leaves, Datura stramonium leaves, and in vegetable waste were procured from the region surrounding Tiruvannamalai in Tamil Nadu. To prevent microbial action from causing the combined substrates to degrade, the assembled substrates were maintained at a temperature lower than 4°C

2.2 Analytical methods

The rate of biogas production and pH were frequently checked, and samples from the influent and effluent were taken and tested as per standard method for pH, total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), and COD (APHA 2015). With measured COD effluent and biogas, HRT was able to reach a stable state condition. The experimental data obtained from the steady state was taken into consideration in order to assess the process performance of the Batch reactor systems. To measure the total biogas evolved with biogas generation and the composition determined by gas chromatography, the water displacement method was used

3. Experiment

Each borosilicate glass container, with a capacity of 1 liter, was used as a batch reactor in the study, as shown in Figure 1. To maintain anaerobic conditions, the bottle opening was tightly sealed with a rubber stopper. Two ports were provided for biogas collection and sampling. A water displacement unit was connected to the reactor to measure the biogas produced. A gas collection chamber was created above the filled sludge and mixed substrates by adding 100 ml of fermented seed sludge and 600 ml of mixed *ricinus communis* and *datura stramonium* leaves to the reactor.

Nitrogen was used to purge the batch reactor bottles to create an anaerobic atmosphere. The experiment was optimized at 35°C for the mixing ratios and tested at constant pH in the basic range for varied HRT. Daily monitoring was done for the parameters pH, organic carbon, organic nitrogen and biogas.

Figure .1 Anaerobic batch reactors setup for various mixing proportions and pH

A gas collection chamber was created above the filled sludge and mixed substrates by adding 100 ml of fermented seed sludge and 600 ml of mixed *ricinus communis* and *datura stramonium* leaves to the reactor. Nitrogen was used to purge the batch reactor bottles to create an anaerobic atmosphere. The experiment was optimized at 35°C for the mixing ratios and tested at constant pH in the basic range for varied HRT. Daily monitoring was done for the parameters pH, organic carbon, organic nitrogen and biogas.

4. Results and Discussion

4.1 Characteristics of feedstock

Datura stramonium and *Ricinus communis* leaves (DSRCL) along with vegetable waste (VW) were used as feedstocks for the anaerobic digestion (AD) process to produce biogas. Both DSRCL and VW were collected from the main campus of Govt Polytechnic College, Tiruvannamalai. To ensure consistency in the mixture, the substrates were dried and ground using a high-speed, multi-purpose crushing machine. The total solids (TS) content was measured prior to AD using equal portions (10g each) of the dried substrates. The two substrates were then mixed in varying ratios based on their TS content to create five treatments: 60% DSRCL : 40% VW, 50% DSRCL : 50% VW, and 40% DSRCL : 60% VW.

To initiate the AD process, the mixed substrates were combined with the appropriate amount of distilled water and 100 mL of fermented sludge (Sutaryo et al., 2012). The fermented sludge was sourced from the municipal wastewater treatment facility in Tiruvannamalai, filtered through a cloth with a 0.5 mm sieve, and carefully transferred into a plastic bottle. The substrates were subjected to anaerobic digestion in a 0.5 L digester for 30 days at 35°C. The pH of the slurry was maintained within the optimal range for biogas production (approximately neutral) by adding sodium hydroxide or hydrochloric acid, following the guidelines of Yadvika et al. (2004).

Table1 Characteristics of mixed *Ricinus communis*, *Datura stramonium* leaves and vegetable waste in different mixing ratios

Parameters	60DSRC:40VW	50DSRC:50VW	40DSRC:60VW
pH	6.2	6.8	6.5
COD	16800	16500	16700
TS	12390	13450	12976
TSS	85632	86540	82430
TDS	6400	6700	7000
MLSS	6800	6200	6500
MLVSS	5200	4700	4200

4.2 Effect of pH and Temperature

The data presented in Figure 2 shows pH variations over 30 days for three different substrate mixtures. pH is a critical factor in anaerobic digestion, influencing microbial activity during hydrolysis, acidogenesis, and methanogenesis

- **Initial Phase (Days 1–5):** Lower pH values in the 50% DSRCL : 50% VW and 40% DSRCL : 60% VW mixtures indicate a higher rate of acidogenesis. This suggests more intense degradation of organic matter into volatile fatty acids (VFAs), which could inhibit biogas production if the pH drops below 6.5.

- **Stabilization Phase (Days 6–15):** pH levels stabilize between 6.8 and 7.2 across all mixtures. This phase marks the transition from acidogenesis to methanogenesis, signifying balanced microbial activity and likely leading to increased biogas production.

- **Methanogenesis Phase (Days 16–30):** The pH remains between 7.0 and 7.5, which is ideal for methanogenic bacteria. This indicates that biogas production, particularly methane, would have been at its highest during this period, especially in the 50% DSRCL : 50% VW and 40% DSRCL : 60% VW mixtures.

The optimal pH range for anaerobic digestion is typically between 6.8 and 7.4, as methanogenic bacteria are sensitive to acidic conditions. Angelidaki et al. (2003) found that biogas production significantly decreases when pH falls below 6.5 due to inhibited methanogenesis. In this study, the 40% DSRCL : 60% VW mixture initially exhibited a lower pH, consistent with findings by Liu et al. (2018), which suggest that acid accumulation in high organic load substrates can delay early methane production. However, once the pH stabilizes around 7.0, as observed in all three mixtures by Day 20, biogas production is expected to increase, in line with Rajeshwari et al. (2000).

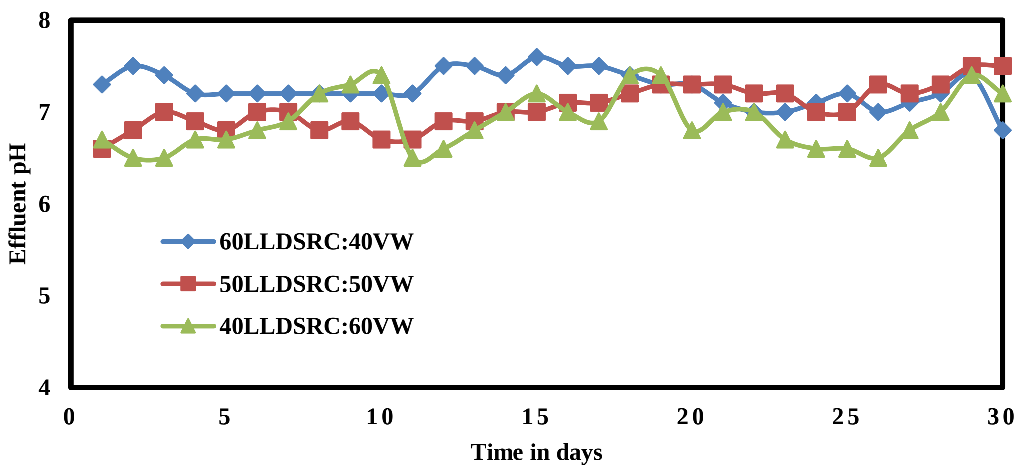

Figure.2 Effluent pH for 60%DSRC: 40%VW, 50%DSRC: 50%VW and 40%DSRC: 60%VW

4.3 Carbon and Nitrogen content before and after anaerobic digestion process, C: N ratio

Before the anaerobic digestion process, the carbon-to-nitrogen (C) ratio showed different trends across the various substrate mixtures. Initially, mixtures with higher proportions of *Datura stramonium* and *Ricinus communis* (DSRC) had a higher C ratio compared to those with more vegetable waste (VW). For instance, the 60% DSRC : 40% VW mixture started with a C ratio of 23.08, as shown in Figures 4.3 and 4.4, which gradually increased, peaking at 28.00 by Day 15. This increase indicates a buildup of available nitrogen as the organic material decomposed. On the other hand, mixtures with a higher proportion of VW, such as the 40% DSRC : 60% VW mix, had lower initial C ratios, beginning at 20.54. This reflects the higher nitrogen content in vegetable waste, leading to a more balanced C ratio at the start of the process. Over time, the data reveals a slight rise in the C ratio, followed by stabilization and a decline towards the end of the 30-day period. This pattern suggests an initial increase in nitrogen availability due to microbial decomposition, with the subsequent decrease attributed to the consumption of easily degradable carbon compounds.

After the anaerobic digestion (AD) process, the C ratio in all substrate mixtures dropped significantly. This decrease is due to the microbial breakdown of carbon-rich compounds during digestion. In the 60% DSRC : 40% VW mixture, the C ratio declined from 22.00 on Day 1 to 15.00 on Day 30, highlighting the effective conversion of carbon into biogas and leaving behind a nitrogen-enriched digestate. Similarly, the 40% DSRC : 60% VW mixture, which had a lower initial C ratio of 20.00, decreased to 13.84 by Day 30, reflecting the faster degradation of organic matter in vegetable waste-rich mixtures, as shown in Figures 4.3 and 4.4. The overall trend across all mixtures indicates that anaerobic digestion leads to a substantial reduction in the C ratio, making the resulting digestate more suitable for agricultural use, where a lower C ratio enhances soil fertility. The higher proportion of vegetable waste in the substrate contributed to a quicker reduction in the C ratio, underscoring its effectiveness in boosting microbial activity during the AD process.

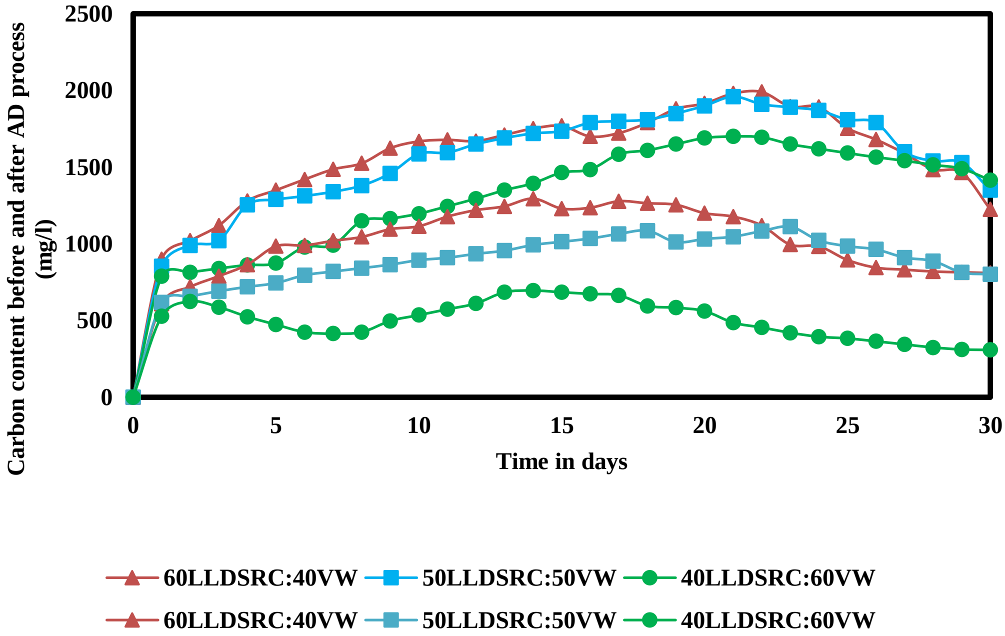

Figure.3 Organic carbon to Nitrogen ratio before and after digestion process

4.3 Determination of Daily Average and Cumulative Biogas Production in each Digester

Biogas production was monitored over a 30-day period for three different substrate mixtures: 60% DSRC : 40% VW, 50% DSRC : 50% VW, and 40% DSRC : 60% VW. The volume of biogas generated varied significantly based on the substrate composition, demonstrating the influence of different proportions of *Datura stramonium* and *Ricinus communis* (DSRC) and vegetable waste (VW) on anaerobic digestion. The 60% DSRC : 40% VW mixture produced the highest cumulative biogas yield, totaling 2587 mL over 30 days, as shown in Figure 4.1. Biogas production started on Day 1 with 12 mL and increased consistently throughout the period, peaking at 162 mL on Day 22. The higher DSRC content in this mixture likely contributed to sustained biogas production due to its lignocellulosic material, which decomposes slowly, providing a steady supply of organic matter for microbial activity.

The 50% DSRC : 50% VW mixture generated a total of 2068 mL of biogas, which was lower than the 60% DSRC : 40% VW mixture but still significant. Biogas production began at 18 mL on Day 1, with the highest production recorded on Day 21 at 125 mL. The balanced ratio of DSRC and VW in this mixture likely resulted in a moderate rate of biogas generation, striking a balance between the slow-degrading DSRC and the fast-degrading vegetable waste. The 40% DSRC : 60% VW mixture, with the highest proportion of vegetable waste, produced the least biogas, totaling 1620 mL over 30 days. Production began at 12 mL on Day 1, peaking at 103 mL on Day 18. The lower biogas yield from this mixture suggests that while vegetable waste provides easily digestible organic material, it may not sustain biogas production as effectively over time compared to mixtures with higher DSRC content.

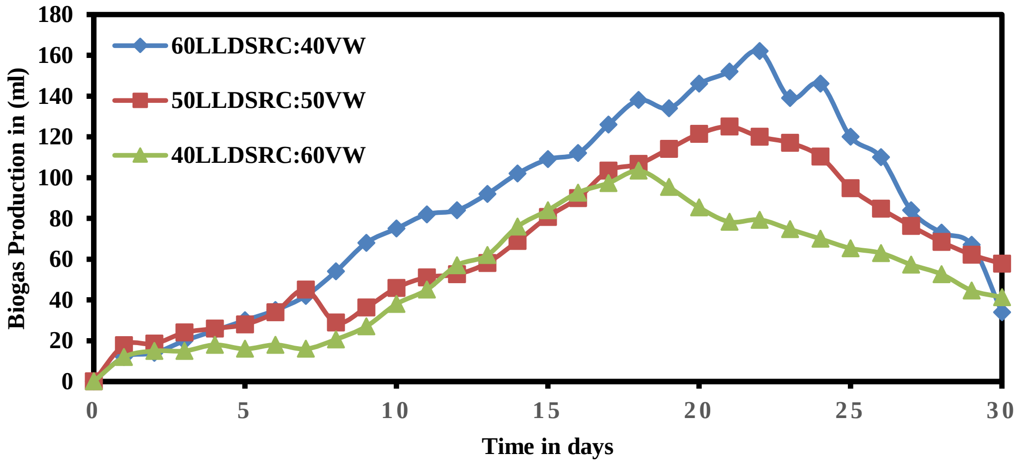

Figure .4 Biogas production in ml for 60%DSRC: 40%VW, 50%DSRC: 50%VW and 40%DSRC: 60%VW

5. Conclusions

This research paper explores the potential of producing biogas through the co-digestion of *Ricinus communis* and *Datura stramonium* leaves with vegetable waste, focusing on optimizing the parameters that influence biogas production. Co-digestion of DSRC leaves with vegetable waste enhances biogas production compared to using vegetable waste alone. Specifically, a mixture of 60% DSRC and 40% VW proved to be an effective feedstock, resulting in higher biogas yield due to greater organic carbon reduction. The results indicated a significant decrease in organic carbon and volatile solids (VS) after anaerobic digestion (AD), while pH and total nitrogen levels increased. Among all the digesters, the 60% DSRC : 40% VW mixture produced the highest biogas yield.

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