

## ENHANCEMENT STRATEGY OF BIOGAS PRODUCTION FROM DIFFERENT KITCHEN WASTE BY CO-DIGESTION

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**Abstract**– This study investigates the enhancement of biogas production through the co-digestion of cow manure and food scraps using various additive and pre-treatment strategies. Among the tested additives, urea demonstrated the highest efficacy, contributing nitrogen essential for microbial growth and maintaining an optimal carbon-to-nitrogen (C/N) ratio. Metal ions facilitated enzyme activation and microbial functioning, while yeast and iron oxide nanoparticles enhanced microbial metabolism and overall system stability. Furthermore, NaOH pre-treatment effectively increased substrate solubilisation, promoting hydrolysis efficiency. The results confirmed a maximum biogas yield of 56 ml with urea supplementation—nearly three times higher than the control. These findings underscore the potential of targeted additive use and pre-treatment approaches in significantly improving anaerobic digestion efficiency for sustainable waste-to-energy conversion.

### INTRODUCTION

The continuous escalation of anthropogenic activities in recent decades has significantly accelerated the emission of greenhouse gases, particularly carbon dioxide (CO<sub>2</sub>), which is widely recognized as a primary driver of global warming and climate change. These environmental disturbances have placed immense pressure on biodiversity and ecosystems worldwide, necessitating the exploration of sustainable alternatives to fossil fuel-based energy sources. With the global energy demand steadily rising, there is an urgent need to transition towards renewable energy systems that are environmentally friendly, sustainable, and efficient.

Among the various renewable energy options—such as hydropower, wind, solar, and geothermal energy—biofuels like biogas, bioethanol, and biodiesel stand out due to their capacity for waste valorization and lower environmental impact (Mostafa *et al.*, 2019). Biogas, in particular, offers dual advantages: it not only provides a renewable energy source but also addresses the critical issue of

organic waste management. Generated through anaerobic digestion of organic matter, biogas is primarily composed of methane (CH<sub>4</sub>) and carbon dioxide (CO<sub>2</sub>), along with minor quantities of hydrogen, nitrogen, hydrogen sulfide, and other trace gases (Banerjee *et al.*, 2022; Patil *et al.*, 2019).

Anaerobic digestion is a complex, multistage biochemical process facilitated by consortia of microorganisms that break down biodegradable material in the absence of oxygen. The key phases include hydrolysis, acidogenesis, acetogenesis, and methanogenesis, with methanogenesis being the most sensitive and rate-limiting stage due to the slow growth rate of methanogens and their susceptibility to environmental parameters such as pH, temperature, and ammonia levels (Tshemese *et al.*, 2023; Mostafa *et al.*, 2019).

In India, the rapid urbanization and shift in consumption patterns have led to the generation of substantial quantities of kitchen and food waste. According to the Food Waste Index Report (2021), Indian households discard nearly 50 kg of food per person annually. This organic fraction of municipal solid waste presents a promising substrate for biogas

production through co-digestion, a technique that involves combining multiple types of organic waste to improve nutrient balance, enhance microbial activity, and boost methane yield (Apte *et al.*, 2013; Patel and Pamnani, 2017).

Recent studies have demonstrated that pre-treatment strategies—such as the use of metal ions, nanoparticles, yeast, urea, and alkaline agents like NaOH—can significantly enhance the efficiency of anaerobic digestion and biogas output by improving substrate availability and microbial performance (Yekta, 2014; Abdelwahab *et al.*, 2020; Gao *et al.*, 2020). In addition, the selection of appropriate reactor configurations, such as two-phase continuous systems and membrane-based bioreactors, can further optimize the process by managing high organic loading rates and ensuring stable methane production (Bouallagui *et al.*, 2005; Youngsukkasem *et al.*, 2013).

The present study focuses on the enhancement strategies for biogas production from different types of kitchen waste through co-digestion techniques. The goal is to identify optimal pretreatment methods and reactor conditions that maximize methane yield while ensuring process stability. This research contributes to the growing body of knowledge in waste-to-energy technologies and offers practical insights into sustainable urban waste management and renewable energy generation.

## MATERIALS AND METHODS

### Collection and Preparation of Kitchen Waste

Different categories of kitchen waste were collected from residential households, local markets, and temples around Tapovan, Amravati. The waste consisted primarily of vegetable waste (e.g., brinjal, spinach, onion, radish, fenugreek, and other leafy vegetables) and fruit waste (mainly banana peels). Any non-biodegradable materials such as stones or plastic were manually removed. The organic waste was chopped and blended with water to prepare a homogeneous thick slurry.

### Inoculum Preparation

Fresh **cow dung** was sourced from a nearby cattle farm (Tapovan, Amravati) and mixed with water to form a slurry. This acted as the inoculum and co-substrate to enhance microbial activity and biogas yield. The kitchen waste slurry and cow dung were mixed in a 1:2 ratio (w/w) for all experiments.

### Characterization of Kitchen Waste

The kitchen waste was characterized before and after digestion to determine Total Solids (TS%), Volatile Solids (VS%), Moisture Content (MC%), pH.

#### Total Solids (TS %)

Total solids calculation Total solids in the feedstock include both organic and inorganic materials, according Khaleel *et al.*, (2024). The calculation of TS was based on APHA, 1998. A porcelain dish weighing W1 was filled with 20 g of fresh waste, or slurry, weighing W2. This was dried overnight at 105 °C (W3) in a hot air oven. The formula was used to calculate the TS%.

$$\%TS = \frac{W3 - W1}{W2} \times 100$$

Where: W1: Weight of empty porcelain dish, W2: Weight of fresh sample + dish, W3: Weight after drying at 105°C overnight

#### Volatile Solids (VS %)

Ash, excluding inorganic salts, is the product of volatile solids, which is the fuel for organic matter. Additionally, it was determined in line with APHA, 1998. For at least one hour, the dried sample from the oven (W3) was heated to a temperature of 550 °C to obtain a weight. Using the formula below, W4. Volatile% was calculated.

$$\%VS = \frac{W4 - W1}{W3 - W1} \times 100$$

#### Moisture Content (MC %)

A good indicator of the amount of moisture in biogas is its relative humidity. In the (W1) china dish the 20 g of fresh waste (W2) is dried in a roaster overnight at a temperature of 120pC to get the weight of the dried sample in a china dish (W3). Also, humidity content was calculated by using the given formula (Bradley *et al.*, 2010).

$$\%MC = \frac{W2 - W3}{W2 - W1} \times 100$$

#### pH Measurement

Litmus paper pH paper was used to measure the pH both before and after the waste was digested. Both before and after the experiment was finished, a manual pH reading was taken (Amano *et al.*, 2017).

### Synthesis and Characterization of Iron Oxide Nanoparticles

#### Synthesis

Iron oxide nanoparticles were synthesized using a

co-precipitation method involving 2 M FeSO<sub>4</sub>, 1 M FeCl<sub>3</sub>, Titration with 1 M NHOH under magnetic stirring to precipitate iron oxide (Hussain *et al.*, 2023).

### Characterization Techniques

**Visual Observation** done by observing Colour change from brown to black indicated nanoparticle formation. UV-Visible Spectroscopy Confirmed absorption peak between 295–301 nm characteristic of iron oxide NPs. Nano drop Spectrophotometry used to determine SPR and concentration. **Nanoparticle Tracking Analysis (NTA)** used to measure particle size, zeta potential, and distribution in liquid suspension (Muthukumar *et al.*, 2024)



**Photo 1.** Serum bottles filled with waste slurry and cow dung

### Biogas Production Experiments

#### Batch Reactor Setup

Medium-sized serum bottles (fermenters) were used. Each bottle was filled with prepared kitchen waste-cow dung slurry (1:2 ratio), leaving 20–25% headspace. Anaerobic conditions were maintained using balloons/plastic coverings and valve adjustments. All fermenters were incubated at 37°C for 7 days (Hydraulic Retention Time, HRT). (Mohamed Khaleel, 2024).

#### Experimental Treatments

No additives were added in control, only kitchen waste and cow dung slurry in ratio of 1:2. In experimental set up metal Ions like trace elements (Fe, Zn, Mg, Ni, and Cu) were added. 1 mg/mL urea solution added to enhance nitrogen availability. 0.1 g of synthesized iron oxide Nanoparticles added. Activated yeast i.e. *Saccharomyces cerevisiae* added after rehydration. NaOH Pre-treatment done by kitchen waste pre-treated with 2–8% NaOH for 24

hours, neutralized to pH 7.0, dried at 105°C for 5 hours, and then used in digestion (Mohamed Khaleel, 2024).

### Biogas Measurement and Data Analysis

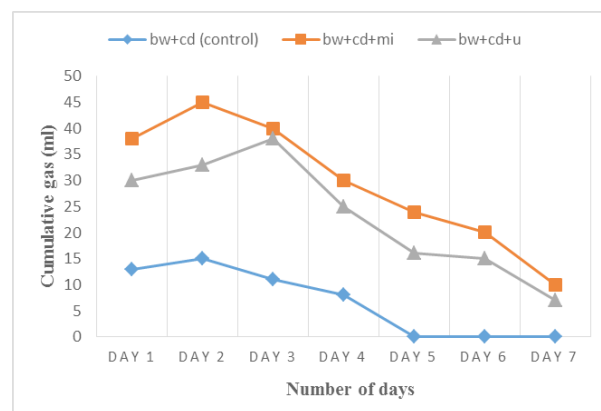
Daily biogas production was recorded using a graduated glass syringe. Data were collected for each experimental setup for 7 consecutive days, followed by Comparative analysis of gas volume across treatments and characterization of post-digestion slurry to evaluate substrate degradation efficiency.

## RESULTS AND DISCUSSION

The present study aimed to perform enhancement strategies of biogas production from different kitchen waste by co-digestion. Characterization of waste. The following table shows values of parameters like total solids, volatile solids, moisture content, and variation in pH before and after the digestion process. It was observed that the total solid for banana peel there was the most (Achinas *et al.*, 2019) and for spinach the ach it was the lowest, while the case of volatile solid brinjal has shown a low % of organic waste whereas garden pea has shown most. The next parameter is moisture content it is found to be high in spinach and low in mixed waste (seoprijanto *et al.*, 2021). The banana peels again showed a low pH value and it was seen as slightly alkaline in the case of mixed waste.

### Characterization of Kitchen Waste

Characterization parameters such as Total Solids (TS %), Volatile Solids (VS %), Moisture Content (MC %), and pH were recorded before and after the digestion process. The results demonstrated



**Fig. 1.** Biogas produced from brinjal waste by adding metal ions and Urea

variability across different types of kitchen waste. Banana peels showed the highest initial TS and acidic pH, indicating potential for biogas production due to high lignocellulose content (Achinas *et al.*, 2019). Spinach had the highest moisture content, while brinjal had the lowest volatile solids, reflecting lower biodegradability. Garden pea presented the highest volatile solids, thus greater potential for biogas conversion (Seoprijanto *et al.*, 2021). Mixed waste showed balanced characteristics and a slightly alkaline pH.

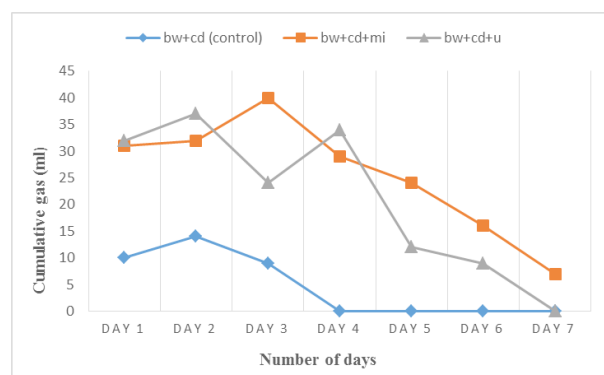


Fig. 2. Biogas produced from banana peels waste by adding metal ions and urea

### Biogas Production with Metal Ions and Urea

Each type of kitchen waste was co-digested with cow dung and enhanced using **metal ions** and **urea**:

- **Brinjal waste:** Metal ions showed a peak production on day 2 (45 ml), while urea peaked on day 3 (38 ml). This suggests that balanced trace elements enhance microbial activity (Yekta, 2014).
- **Banana peels:** Metal ions were more effective (peak: 40 mL on day 3), while urea showed slightly less yield (37 ml), possibly due to

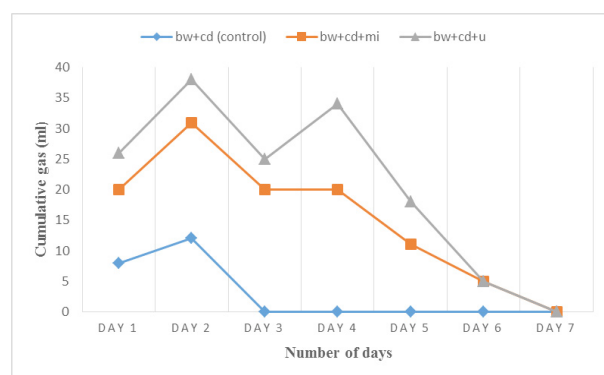


Fig. 3. Biogas produced from spinach waste by adding metal ions and Urea

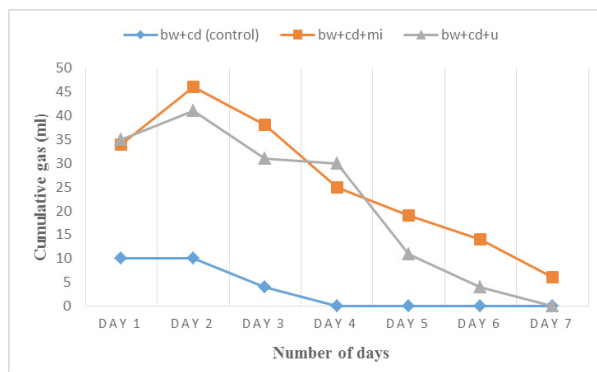


Fig. 4. Biogas produced from garden pea waste by adding metal ions and Urea

ammonia accumulation inhibiting digestion (Yu *et al.*, 2023).

- **Spinach:** Urea resulted in higher production (38 mL) than metal ions (30 mL), indicating that that spinach is a good raw material to produce biogas, and our results were quite similar to their findings. Nitrogen supplementation favoured degradation.

**Garden pea:** Urea again outperformed metal ions with a peak of 46 mL vs. 41 mL (Herrmann *et al.*, 2016).

**Mixed waste:** Urea showed the highest gas production (56 ml on day 2), followed by metal ions (52 ml on day 3). The results emphasize the synergistic effect of diverse substrates and nutrient supplementation (Mostafa *et al.*, 2019).

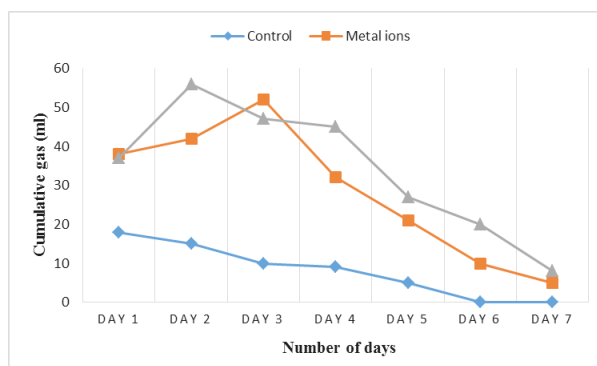


Fig. 5. Biogas produced from mixed waste by adding metal ions and urea

### Biogas Production with Yeast, NaOH, and Nanoparticles (Mixed Waste Only)

#### Yeast Treatment

Yeast-treated mixed waste yielded a maximum of 53 mL on day 3. Yeast enhanced the microbial ecosystem by increasing volatile fatty acid (VFA)

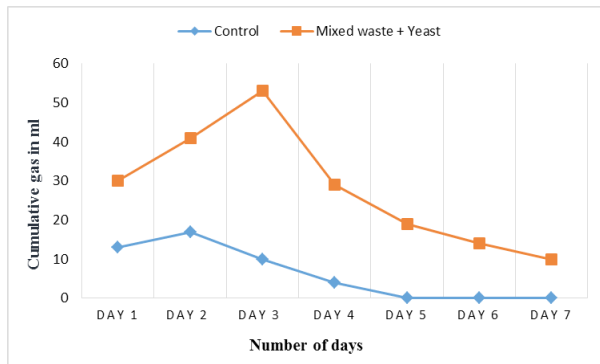


Fig. 6. Biogas production when mixed waste treated with yeast



consumption and promoting methanogenesis (Gao *et al.*, 2020; Ekpeni *et al.*, 2014).

### NaOH Treatment

Pre-treatment with 6% NaOH followed by neutralization improved biogas yield to **47 ml**, confirming that alkali hydrolysis facilitated the breakdown of complex polymers (Singh *et al.*, 2019).

### Nanoparticle Treatment

Iron oxide nanoparticles increased gas production

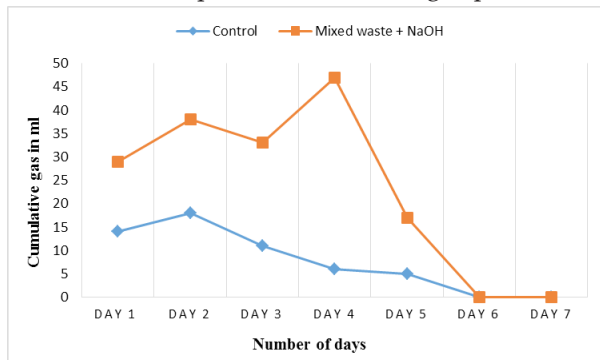


Fig. 7. Biogas production when Mixed waste treated with NaOH

up to 48 mL, attributed to improved microbial metabolism and electron transfer processes (Ambuchi *et al.*, 2016). Characterization confirmed iron oxide morphology with zeta potential at  $-16.2$  mV, aligning with standard values (Verma *et al.*, 2024).



Photo 1. Synthesized iron oxide nanoparticles

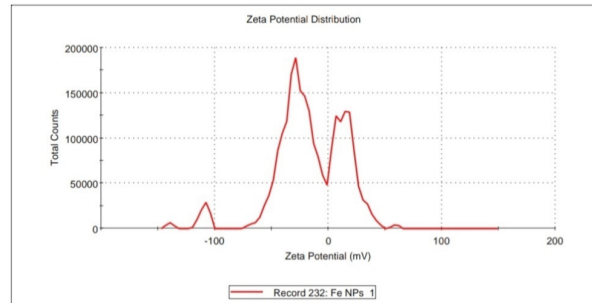


Fig. 8. Zeta potential distribution of iron oxide nanoparticle

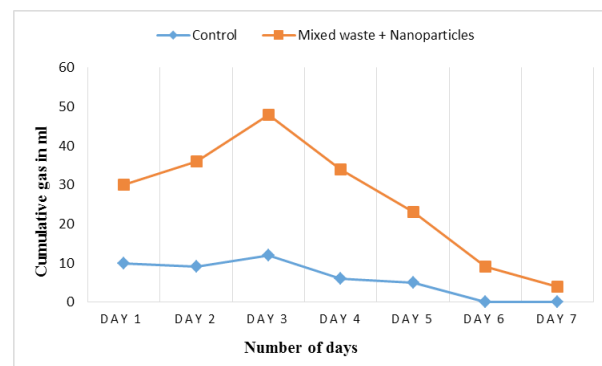
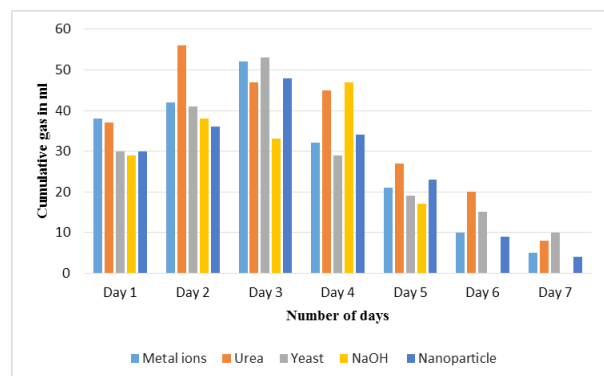


Fig. 9. Biogas production when mixed waste treated with nanoparticles

### Comparative Evaluation

A comparison of all enhancement strategies applied to mixed kitchen waste revealed the following peak biogas yields:

Urea emerged as the most effective additive, followed by yeast and metal ions. The improved yields highlight the importance of C/N balance,



**Fig. 10.** Comparative study of biogas production from mixed waste using different techniques

micronutrient supply, and pretreatment strategies in enhancing anaerobic digestion.

### CONCLUSION

This study demonstrates that co-digestion of kitchen waste with cow dung, supplemented with various enhancement strategies, significantly improves biogas production. Among the tested additives urea proved to be the most effective, providing nitrogen for optimal microbial growth and maintaining the ideal C/N ratio. Metal ions supported enzyme activation and microbial function. Yeast and iron oxide nanoparticles boosted microbial metabolism and stability. NaOH pre-treatment enhanced substrate solubilisation, aiding hydrolysis.

The highest biogas yield from mixed waste reached 56 mL with urea addition—almost threefold greater than the control. These findings suggest that pre-treatment and additive strategies can play a crucial role in optimizing anaerobic digestion for waste-to-energy applications.

In the future, these strategies can be scaled for eco-friendly biogas generation systems, contributing to decentralized energy solutions and sustainable waste management in urban and semi-urban settings. The application of such biotechnological advancements holds significant potential in reducing fossil fuel dependency and enhancing environmental sustainability.

**Conflict of Interest** -None

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