Simple Experiment: Identifying Fruit and Vegetable Waste with the Fastest Biogas Production Rate Under Anaerobic Conditions

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Publication Date: 2025/08/07

Abstract: This study aims to identify the types of fruit and vegetable waste that produce biogas most quickly under anaerobic conditions. The method used is anaerobic fermentation on various combinations of organic waste with and without added sugar, for 12 days. A total of 11 groups tested waste combinations such as papaya, apple, jackfruit, dragon fruit, pear, cucumber, and spinach, with four types of POC code treatments: A1 (fruit without sugar), A2 (fruit + sugar), B1 (vegetables without sugar), and B2 (vegetables + sugar). The results showed that treatment with code A2 (fruit waste + sugar) provided the fastest biogas production rate and resulted in an explosion in the reactor, indicating high methane gas pressure. The most reactive types of fruit waste in producing biogas were jackfruit and dragon fruit, while from the vegetable category, spinach in treatments B1 and B2 also showed a significant response. This study concluded that the combination of fruit waste + sugar (A2) and vegetable waste + sugar (B2) can accelerate methane gas formation and is very potential for household-scale biogas production.

Keywords: *Biogas, Fruit Waste, Vegetable Waste, Anaerobic Fermentation, Sugar.*

How to Cite: Haryatie Sarie; Daryono; Roby; Yuanita; Riama Rita Manulang (2025) Simple Experiment: Identifying Fruit and Vegetable Waste with the Fastest Biogas Production Rate Under Anaerobic Conditions. *International Journal of Innovative Science and Research Technology*, 10(7), 3206-3211.
https://doi.org/10.38124/ijisrt/25jul1530

I. INTRODUCTION

Biogas production from organic waste is an alternative solution to address the energy crisis and waste accumulation problems. Fruits and vegetables are types of waste that are easily degraded anaerobically and produce methane gas (CH_4). The addition of sugar is known to accelerate the fermentation process because it provides a quick carbon source for methanogenic microorganisms. This study aims to examine the effect of waste type and sugar addition treatment on the rate and potential of biogas formation. Converting organic waste to biogas presents a viable solution to the growing problem of waste accumulation. Biogas production not only alleviates waste disposal challenges but also contributes to renewable energy generation. This process involves anaerobic digestion, where microorganisms break down organic matter, producing methane-rich biogas.

The benefits of Biogas Production are: a. Waste Reduction, Biogas systems can significantly reduce the volume of organic waste, divert it from landfills and reduce greenhouse gas emissions associated with waste decomposition (Robinson, 2023). b. The presence of a renewable energy source, namely Methane produced can be used for heating, electricity generation, or as vehicle fuel, promoting energy independence and sustainability (Robinson, 2023)]. c. The presence of a nutrient-rich by-product, namely Digestat, which remains after biogas production is a nutrient-rich fertilizer, improving soil health and supporting agricultural productivity (Robinson, 2023). d. Contribution to the Carbon Cycle, namely the anaerobic digestion process can help balance carbon fluxes by converting organic carbon into biogas, thus playing a role in the global carbon cycle (Zondervan et al., 2023). e. Reduction of CO2 emissions by capturing methane, a potent greenhouse gas, biogas production can help mitigate the impacts of climate change associated with the decomposition of organic waste (Robinson, 2023).

While biogas production offers numerous benefits, careful management is required to ensure that the process does not cause undesirable environmental consequences, such as methane leakage or nutrient runoff from digestate applications. Biogas offers numerous benefits, making it a valuable renewable energy source. Its production from organic waste not only meets energy needs but also contributes to environmental sustainability and economic development. The following section outlines the key advantages of biogas adoption, namely: 1. Reduction of greenhouse gas emissions: Biogas production can significantly reduce CO2 emissions, with households

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jul1530

potentially reducing emissions by approximately 6.75 tons per year through biogas adoption (Kimutai et al., 2024). 2. Waste Management: Biogas systems convert organic waste into energy, reducing landfill use and pollution from decomposing waste (Jameel et al., 2024). 3. Improved Air Quality: Biogas reduces dependence on traditional fuels, leading to better air quality and lower exposure to harmful pollutants (Kimutai et al., 2024).

The Economic Benefits of Biogas are: 1. Cost Savings: Households can save approximately US $25 per month by replacing wood fuel with biogas (Kimutai et al., 2024). 2. Job Creation: Construction and maintenance of biogas systems generate employment opportunities (Kimutai et al., 2024). 3. Increased Agricultural Productivity: Digestate produced from biogas systems serves as a high-quality fertilizer, increasing soil fertility and crop yields (Jameel et al., 2024). As for the social impacts, namely Improved Health by Reducing smoke exposure from biogas use benefits vulnerable populations, especially women and children, by reducing respiratory problems (Kimutai et al., 2024). And its impact on Energy Security, namely Biogas contributes to energy independence, reducing energy poverty in rural areas (Kimutai et al., 2024). While biogas presents many benefits, challenges such as technological limitations and financial constraints can hinder its widespread adoption (Ani, 2024)]. Overcoming these barriers is critical to maximizing the potential of biogas as a sustainable energy solution.

Utilization of fruit and vegetable waste (FVW) for biogas production through anaerobic digestion presents a sustainable solution for waste management and renewable energy generation. Various studies have highlighted the effectiveness of different digestion methods, including mono-digestion and co-digestion, in increasing biogas yield and improving the quality of the resulting biofertilizer. For Biogas Production techniques, they include: 1. Mono-digestion: Anaerobic mono-digestion of FVW has shown significant biogas yields, with specific production rates reaching up to 720 L/kg of volatile solids when combined with dairy cow wastewater (Hinterholz et al., 2024). 2. Co-digestion: Co-digestion with other organic materials, such as cow dung, can further increase biogas production. For example, long bean waste produced 1853.76 mL of biogas/g COD in a mesophilic batch process (Chusna et al., 2024).

Microbial Community Dynamics Microbial communities play a crucial role in biogas production. Research has identified key bacterial groups, such as Firmicutes and Methanothrix, which are essential for effective anaerobic digestion (Chatterjee & Mazumder, 2024). The addition of mineral fertilizers has been shown to stimulate microbial growth, increasing methane production by up to 40% (Borowski et al., 2023). The environmental and economic benefits of biogas are: 1. Utilizing FVW for biogas not only reduces waste but also contributes to environmental sustainability by lowering the carbon footprint and improving soil quality through the application of biofertilizers (Hinterholz et al., 2024). 2. The transition to a circular economy is facilitated by recycling organic waste into energy and nutrients for agricultural purposes.

While the benefits of using FVW for biogas production are substantial, challenges such as the need for pretreatment of specific plant wastes and optimization of microbial communities remain areas for further research. Identifying fruit and vegetable waste for biogas production offers numerous benefits, contributing to sustainable energy solutions and environmental health. Anaerobic digestion of this organic material not only produces renewable energy but also reduces waste and promotes nutrient recycling. The following sections outline the key advantages of this process:

Benefits to the Environment are: 1. Waste Reduction: Utilizing fruit and vegetable waste minimizes landfill use, reducing methane emissions from decaying organic matter (Tura & Lemma, 2019). 2. Carbon Footprint: Biogas production from waste contributes to a lower carbon footprint, supporting climate change mitigation efforts (Hinterholz et al., 2024). Energy Production Renewable Energy Sources Biogas serves as a sustainable alternative to fossil fuels, providing energy for cooking and heating (Banarase & Phirke, 2024)]. And High Yield examples such as Digestion together with other organic materials, such as dairy wastewater, can significantly increase biogas yields, reaching up to 720 L of biogas per kg of volatile solids (Hinterholz et al., 2024).

Biofertilizer Production is a byproduct of biogas production is a nutrient-rich slurry, which can be used as a biofertilizer, improving soil quality and increasing agricultural sustainability (Tura & Lemma, 2019; Chaurasia et al., 2021). While the benefits of biogas production from fruit and vegetable waste are substantial, challenges such as the need for efficient waste collection and processing infrastructure remain. Addressing these issues is crucial to maximize the potential of biogas as a renewable energy source. According to Aybek, 2017) that Identifying fruit and vegetable waste for biogas production offers economic and environmental benefits, including renewable energy generation, reduced waste disposal, and minimized soil, water, and air pollution, while also providing organic fertilizer for agricultural purposes.

II. RESEARCH METHODS

This research is experimental with a design of 4 main treatments based on the type of waste and the addition of sugar, namely:

- A1 = Fruit waste without sugar
- A2 = Fruit waste + sugar
- B1 = Vegetable waste without sugar
- B2 = Vegetable waste + sugar

Each group used a different combination of fruits or vegetables. The fermentation process took place anaerobically in a sealed bottle for 12 days. Success was indicated by an explosion or a significant increase in

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jul1530

pressure in the reactor bottle, indicating the formation of biogas. Biogas formation can indeed cause explosions, especially when certain conditions are met. Biogas, primarily composed of methane (CH4) and carbon dioxide (CO2), is flammable and can create an explosive atmosphere when mixed with air.

III. TOOLS AND MATERIALS

➢ *Tools:*

- Used 1.5 liter plastic mineral water bottles with tight caps
- Digital scales
- Scissors and chopper/cutting tool Funnel Measuring cup
- Duct tape or plastic seal for tightening the bottle caps

➢ *Ingredients:*

- Fresh fruit waste (apples, bananas, papaya, jackfruit, dragon fruit, etc.)
- Fresh vegetable waste (mustard greens, spinach, cabbage, kale, etc.)
- Granulated sugar (as an additional carbon source)
- Clean water

➢ *Ways of Working*

- Waste Preparation: Wash fruit and vegetable waste thoroughly and cut it into small pieces for easy fermentation. Weigh out 300 grams of each ingredient per bottle (adjust according to the bottle capacity and remaining air space). For treatments A2 and B2, add 3 tablespoons of granulated sugar to the waste mixture.
- Mixing and Fermentation: Add waste and water in a 1:1 ratio (by volume) into the bottle using a funnel. Close the bottle tightly, ensuring no air can enter (anaerobic fermentation). Store the bottle at room temperature for 12 days. Observe and record any changes that occur daily (e.g., swelling of the bottle). The bottle exploding or significant swelling in the bottle is the main indicator of biogas formation.
- Safety: Keep the bottle away from sources of fire or heat due to the potential for the formation of flammable methane gas (CH_4). Place the bottle in a closed container (e.g., a plastic box) to avoid the risk of a sudden explosion.

➢ *Data Analysis*

The data were analyzed using simple qualitative descriptive methods based on visual indicators of gas formation during the fermentation process. The main parameters observed included: Time of bottle swelling or explosion Intensity of swelling as an indication of gas pressure Comparison between treatments based on waste type (fruit or vegetable) and sugar addition The results of the 12-day observation were observed daily and compiled in a table to show the differences in response between treatments. The data were then presented in the form of bar or line graphs to facilitate visualization of comparisons between treatments on the potential for biogas formation.

IV. RESULTS AND DISCUSSION

A. *Results*

Biogas is a renewable energy source that has great potential to replace fossil fuels as the main energy source. One way to produce biogas is by using fruit and vegetable waste as the main raw material. A biogas production explosion can be achieved by applying a specific treatment code to the waste. In the context of this research, the results of the biogas production explosion based on the fruit and vegetable waste treatment code will be discussed. The treatment code includes the fermentation process, temperature, humidity, and pH settings, as well as the ratio of fruit and vegetable waste mixtures. Through the application of the appropriate treatment code, it is hoped that waste that quickly produces biogas significantly can be identified. The following table shows the results of the observations.

Table 1 Biogas Production Explosion Results Based on Treatment Code

No	Types of Waste	Exploding Code	Information
1	Papaya, Apple	A2	A2: Fruit waste + sugar
2	Jackfruit	A2	A2: Fruit waste + Sugar
3	Dragon fruit, pears, apples, papaya, bananas, jackfruit	A1, A2	A1: Sugar-free fruit waste A2: Fruit waste + Sugar
4	Apple, Pear, Cucumber	A2	A2: Fruit waste + Sugar
5	Dragon fruit	A1, A2	A1: Sugar -free Fruit waste A2: Fruit waste+ Sugar
6	jackfruit	A2, B2	A2: Fruit waste + Sugar B2: Vegetable waste + Sugar
7	jackfruit, Pear, Apple	A2	A2: Fruit Waste + Sugar
8	Dragon fruit, Apple	A1, A2	A1: Sugar -free fruit A2: Fruit waste + Sugar
9	Dragon fruit	A1, A2	A1: Sugar Free Fruit waste A2: Fruit waste + Sugar
10	Jackfruit	A1, A2	A1: Sugar Free Fruit waste A2: Fruit waste + Sugar
11	Pear, spinach	B1, A2	A2: Fruit waste + Sugar

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jul1530

			B1: Sugar Free vegetable waste
		Total bottle explosion	A1 = 5 A2 = 11*(fastest) B1 = 1 B2 = 1

B. Discussion

Code A2 (fruit waste + sugar) showed dominance in the explosion results, representing 10 of the 11 groups that produced large amounts of gas. This indicates that the addition of sugar is very significant in accelerating the fermentation of fruit waste. Code A1 (fruit waste without sugar) also showed good results, especially for dragon fruit and jackfruit, indicating that these two types of fruit have a high natural sugar content. Codes B1 and B2 appeared in the group using spinach, indicating that vegetables can also produce biogas, although at a lower intensity. .

Table 1 presents the biogas production results from various types of fruit and vegetable waste, with different treatments represented by "POC Code = liquid organic fertilizer." These treatments include the addition of sugar or no sugar, as well as combinations of fruit and vegetable waste.

- *Papaya, Apple*

Recommended Code: A2 = Description: Fruit waste + sugar, Analysis: For the combination of Papaya and Apple waste, the best treatment for biogas production is by adding sugar (A2). This shows that the addition of sugar significantly increases biogas production from this fruit mixture. Sugar provides a carbon source that is easily accessible to microorganisms, thus speeding up the fermentation process and producing a larger volume of gas.

- *Jackfruit*

Recommended Code: A2 = Description: Fruit waste + sugar, Analysis: Jackfruit single waste also showed optimal performance with the addition of sugar (A2). This indicates that Jackfruit, as a fruit waste, responds positively to the addition of sugar substrate to increase microbial activity and biogas production.

- *Dragon Fruit, Pear, Apple, Papaya, Banana Jackfruit*

Recommended Codes: A1, A2 = Description: A1: Fruit waste without sugar; A2: Fruit waste + sugar, Analysis: This very diverse mixed waste group (Dragon fruit, Pear, Apple, Papaya, Banana Jackfruit) shows potential for biogas production both with and without sugar. The presence of A1 (without sugar) and A2 (with sugar) as recommended codes indicates flexibility in the treatment of this waste mixture. Although the addition of sugar can increase production, it is likely that this fruit mixture is inherently rich in natural sugars, so fermentation without added sugar can also occur effectively.

- *Apple, Pear, Cucumber*

Recommended Code: A1, A2 = Description: A1: Fruit waste without sugar; A2: Fruit waste + sugar, Analysis: Similar to the previous mixture group, the combination of Apple, Pear, and Cucumber also showed good results with treatments A1 (without sugar) and A2 (with sugar). The presence of Cucumber (vegetable) in this mixture may affect the nutrient composition, but overall, both with and without sugar, this mixture is effective for biogas production.

- *Dragon Fruit*

Recommended Code: A1, A2 = Description: A1: Fruit waste without sugar; A2: Fruit waste + sugar, Analysis: Dragon fruit as a single waste shows that biogas production can be achieved either with or without the addition of sugar. This indicates that Dragon fruit has sufficient nutritional content to support the fermentation process, even without additional substrate. However, the addition of sugar (A2) will likely accelerate and increase the production quantity.

- *Jackfruit*

Recommended Codes: A2, B2 = Description: A2: Fruit waste + sugar; B2: Vegetable waste without sugar, Analysis: This data for Jackfruit shows two recommended codes: A2 (fruit waste + sugar) and B2 (vegetable waste without sugar). The presence of B2 is interesting because Jackfruit is botanically a fruit, not a vegetable. However, if “Vegetable waste without sugar” refers to a specific treatment applied to fruit waste such as Jackfruit, this may indicate that some treatments without sugar, even if categorized as “vegetable,” can produce significant biogas.

- *Jackfruit, Pear, Apple*

Recommended Code: A2 = Description: Fruit waste + sugar, Analysis: For the Jackfruit, Pear, and Apple mixture, the optimal treatment is with the addition of sugar (A2). This is consistent with the finding that many fruit wastes benefit from the addition of sugar for efficient biogas production.

- *Dragon Fruit, Apple*

Recommended Code: A1, A2 = Description: A1: Fruit waste without sugar; A2: Fruit waste + sugar, Analysis: The mixture of Dragon fruit and Apple also showed good results with or without the addition of sugar. This again confirms that some fruit combinations have inherent potential for good biogas fermentation.

- *Dragon Fruit*

Recommended Code: A1, A2 = Description: A1: Fruit waste without sugar; A2: Fruit waste + sugar, Analysis: Further confirmation that Dragon fruit as a single waste can be used for biogas production either with treatment without sugar or with the addition of sugar.

- *Jackfruit*

Recommended POC Codes: A1, A2 = Description: A1: Fruit waste without sugar; A2: Fruit waste + sugar, Analysis: Consistent with previous observations, Jackfruit demonstrated the ability to produce biogas effectively with

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jul1530

and without the addition of sugar, although the addition of sugar would likely optimize the process.

➢ *Pear, Spinach*

Recommended Codes: B1, A2 = Description: A2: Fruit waste + sugar; B1: Vegetable waste without sugar, Analysis: The combination of Pear (fruit) and Spinach (vegetable) showed interesting results. Code B1 (vegetable waste without sugar) shows that Spinach, as a vegetable waste, contributes significantly to biogas production even without added sugar. On the other hand, A2 (fruit waste + sugar) shows that the presence of Pear benefits from the addition of sugar. This highlights the difference in nutrient requirements between fruit and vegetable waste; vegetable waste may have sufficient components for fermentation without added sugar, while fruit waste may require sugar to achieve optimal production.

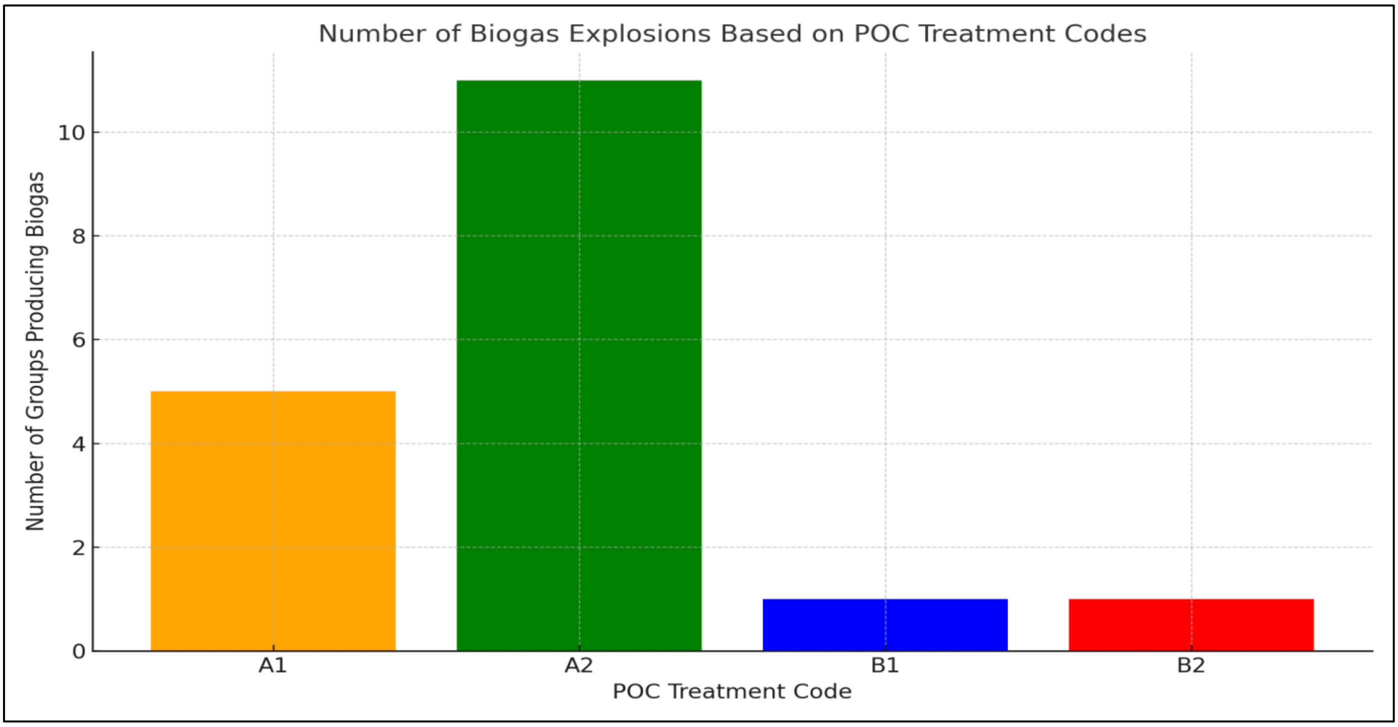

Fig 1 Comparison Chart of Fruit and Vegetable Waste that Produces Biogas

Overall, the data show that sugar addition (Code A2) was the dominant treatment for most fruit wastes, indicating that sugar is an important substrate to accelerate and enhance biogas production from these materials. However, some waste types, especially when mixed or in the case of Dragon Fruit and Jackfruit, also showed the ability to produce effective biogas even without the addition of sugar (Code A1). Treatment with vegetable waste (Code B1 and B2) showed that vegetable waste has different characteristics in terms of substrate requirements, with the potential to produce biogas without added sugar. These results provide important insights for optimizing biogas production processes from various types of agro-industrial waste.

Research on biogas production from organic wastes, particularly fruits and vegetables, highlights its potential as a renewable energy source. Various studies demonstrate that anaerobic digestion of mixed organic materials, including vegetable and fruit wastes, can yield significant amounts of biogas. For instance, a study found that cooking leftover vegetable waste produced the highest methane content when combined with cow dung, yielding 950 grams of biogas(Ramadhan et al., 2023). Another investigation into mixed fruit and vegetable wastes indicated a cumulative biogas production of 105.5 mL per 1000g of food waste, emphasizing the efficiency of using diverse substrates(Tura & Lemma, 2019). Additionally, co-digestion strategies, such as incorporating cow dung and nutrient supplements like urea, have been shown to enhance biogas yields significantly, with optimal conditions yielding up to 44 mL of biogas(Banarase & Phirke, 2024). Overall, these findings underscore the effectiveness of utilizing organic waste for biogas production, contributing to sustainable waste management and energy solutions(Dani et al., 2024) (Manthia et al., 2018).

V. SCIENTIFIC IMPLICATIONS

The addition of sugar as a simple carbohydrate source has been shown to enhance the performance of fermentative microbes in producing methane gas. This aligns with the basic principle of anaerobic fermentation, where easily decomposed substrates (such as sugar) accelerate acidogenesis and methanogenesis.

VI. CONCLUSION

This simple experimental study shows that: Fruit waste with added sugar (code A2) is the most effective treatment in accelerating and increasing biogas production. Dragon fruit and jackfruit are the most reactive waste types, even

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jul1530

without added sugar. Spinach, with or without sugar, also has the potential to produce biogas, albeit at a lower intensity.

RECOMMENDATION

The development of a household-scale biogas reactor could prioritize the use of fruit waste, particularly jackfruit and dragon fruit, with the addition of sugar as a fermentation accelerator. Further research is recommended using quantitative analysis of methane volume and gas composition testing.

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