

The Effect of Substrate Mixture Ratio on Biogas Volume in Co-digestion of Water Hyacinth (*Eichhornia crassipes*) and Cow Manure through Anaerobic Digestion

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ABSTRACT

Biogas is a renewable energy source that can be produced from organic waste, such as water hyacinth and cow dung. Utilizing these two materials through co-digestion has the potential to increase biogas production due to a better nutrient balance. This study aims to analyze the effect of the substrate ratio on the volume of biogas produced through anaerobic digestion. The method used is a Systematic Literature Review (SLR) by reviewing five relevant scientific articles based on certain inclusion and exclusion criteria. The parameters analyzed include the substrate ratio, biogas volume, and hydraulic retention time (HRT) or fermentation duration. The results of the study indicate that the substrate ratio has a significant influence on biogas production. Ratios that are close to balance, such as 50:50 and 47:53, tend to produce more optimal and stable biogas volume. Conversely, unbalanced ratios, such as 33:67, show varying results depending on operational conditions. Differences in biogas volume between studies are also influenced by other factors, such as retention time, raw material characteristics, and process conditions such as pH and temperature. The lignocellulose content of water hyacinth can inhibit the degradation process if not balanced with an adequate nitrogen source from cow dung. In conclusion, a balanced substrate ratio plays a crucial role in increasing biogas production, but it needs to be supported by controlling other operational parameters to achieve optimal and sustainable results.

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Introduction

The ever-increasing global energy demand coupled with population growth and industrial development is driving the search for alternative, sustainable, and environmentally friendly energy sources (Bote et al., 2020; Hudakorn & Sritrakul, 2020; Srinivas Kasulla et al., 2023). Dependence on fossil fuels not only leads to resource limitations but also increases greenhouse gas emissions, which trigger climate change. Therefore, developing renewable energy is a strategic solution to address these issues. One potential form of renewable energy is biogas, produced through anaerobic digestion, the decomposition of organic matter by microorganisms in the absence of oxygen, producing

methane as the main component (Asante et al., 2024; Bote et al., 2020; Carlini et al., 2018).

Biogas utilization has several advantages, including reducing organic waste, reducing environmental pollution, and producing energy that can be used directly as fuel (Oduor et al., 2022). In the context of waste management, the use of abundant, underutilized raw materials is crucial (Cahyati et al., 2023). One such waste with significant potential is water hyacinth (*Eichhornia crassipes*), an invasive aquatic plant with a very fast growth rate (Agustine et al., 2023; Kurniawan & Samani, 2022; Nawir et al., 2018). The presence of water hyacinth often causes environmental problems, such as covering water surfaces, obstructing water flow, and reducing dissolved oxygen levels, which impact the lives of aquatic organisms (Wembe et al., 2023). On the other hand, cow dung is an abundant livestock waste product with a high organic content. Cow dung also contains anaerobic microorganisms that play a crucial role in the biogas production process. However, the use of each material alone has limitations. Water hyacinth has a high lignocellulose content, particularly lignin, making it relatively difficult to degrade biologically (Darnengsih et al., 2016; Fattah et al., 2022; Siswanto & Susanto, 2018). Meanwhile, cow dung tends to have a low carbon-to-nitrogen (C/N) ratio, so its sole use can hinder the biogas production process.

To overcome these limitations, one approach is co-digestion, which combines two or more substrates in a single anaerobic digestion system. Co-digestion of water hyacinth and cow dung is expected to increase biogas production efficiency by improving the nutrient balance, particularly the C/N ratio, and increasing microbial activity. Water hyacinth acts as a carbon source, while cow dung serves as a nitrogen source and microbial inoculum. This combination creates a synergy that can accelerate the organic material degradation process and increase biogas production (Wahab & Ramli, 2022). However, the success of the co-digestion process is greatly influenced by the substrate ratio used. An inappropriate ratio can lead to a nutrient imbalance, which can impact microbial activity and biogas production. (Irianto & Mirwan, 2023) Too high a ratio in water hyacinth can slow the hydrolysis process due to its high lignocellulose content, while too high a ratio in cow manure can lead to excess nitrogen, potentially inhibiting the activity of methanogenic bacteria (Muddin et al., 2019; Riswanto & Sodikin, 2019). Therefore, determining the optimal substrate ratio is a key factor in improving biogas production performance. (Sarwono et al., 2018)

Various studies have been conducted to examine the effect of substrate ratio on biogas production from co-digestion of water hyacinth and cow manure. However, the results show significant variation, both in terms of biogas volume and operational conditions. These differences may be caused by variations in research methods, hydraulic retention time (HRT), environmental conditions such as pH and temperature, and the characteristics of the raw materials used. This indicates that more systematic studies are needed to comprehensively understand the relationship between substrate ratio and biogas production (Ajieh et al., 2020). Based on this background, this study was conducted to analyze the effect of the substrate ratio to biogas volume on the co-digestion of water hyacinth and cow dung using a Systematic Literature Review (SLR) approach. This approach allows for the systematic collection and synthesis of data from various studies to obtain a more comprehensive picture of optimal conditions for biogas production. The results of this study are expected to contribute to the development of organic waste-based biogas technology and serve as a reference for further research.

Method

This study used the Systematic Literature Review (SLR) method to examine the effect of substrate ratio on biogas volume production in the co-digestion of water hyacinth and

cow dung through anaerobic digestion. The SLR method was chosen to systematically and structuredly collect, evaluate, and synthesize relevant research results. The research process began with literature identification through searches of scientific databases such as Google Scholar, ScienceDirect, and national journal portals. Keywords used in the search included "biogas," "water hyacinth," "cow dung," "co-digestion," and "substrate ratio." The search was limited to publications within the last 5–15 years to ensure data freshness, but some older references were retained to support the theory.

Next, a literature selection process was conducted based on inclusion and exclusion criteria. Inclusion criteria included: (1) research articles discussing biogas production from water hyacinth and/or cow dung, (2) studies presenting data on substrate ratio and biogas volume, and (3) articles that were fully accessible. Meanwhile, exclusion criteria included: (1) review articles without experimental data, (2) articles irrelevant to the research topic, and (3) articles with incomplete or unclear data. Articles meeting the criteria were then analyzed and data extracted, including author, year of publication, substrate ratio, biogas volume produced, and operating conditions such as hydraulic retention time (HRT). The obtained data were then compiled in tabular form to facilitate comparison between studies. The final stage was descriptive-comparative data synthesis and analysis to identify patterns in the relationship between substrate ratio and biogas volume. The analysis was conducted by comparing the results of various studies and linking them to relevant theories to draw comprehensive conclusions.

Results and Discussion

Based on Table 1, the ratio of water hyacinth (WH) and cow dung (CD) substrates significantly influences the volume of biogas produced in the anaerobic digestion process. Variations in substrate composition affect nutrient balance, particularly the carbon-to-nitrogen (C/N) ratio, which plays a crucial role in supporting the activity of anaerobic microorganisms, particularly methanogenic bacteria, in producing methane gas.

Table 1. The Effect of Substrate Ratio on Biogas Volume on Co-digestion of Water Hyacinth and Cow Manure through Anaerobic Digestion

<i>Author (Year)</i>	<i>Water Hyacinth : Cow Dung Ratio</i>	<i>Biogas Volume (mL)</i>	<i>HRT (days)</i>	<i>Note</i>
Astuti (2013)	33 : 67	176.33	20	Optimum conditions
Roni et al. (2020)	50 : 50	302	21	Optimum conditions
Luthfiyah et al. (2022)	50 : 50	3,165	30	Highest volume
Dhaniswara et al. (2022)	33 : 67	11,233	33	Highest volume
Aziz (2025)	47 : 53	344	21	Optimum conditions

The analyzed research results indicate that a substrate ratio closer to balance tends to produce a more optimal biogas volume. In the studies of (Roni et al., 2020) and (Luthfiyah et al., 2022), a 50:50 ratio produced biogas volumes of 302 mL and 3165 mL, respectively. This indicates that the combination of water hyacinth as a carbon source and cow dung as a nitrogen source and microorganism inoculum creates ideal conditions for the anaerobic fermentation process. A balanced C/N ratio under these conditions supports optimal growth and activity of methanogenic bacteria.

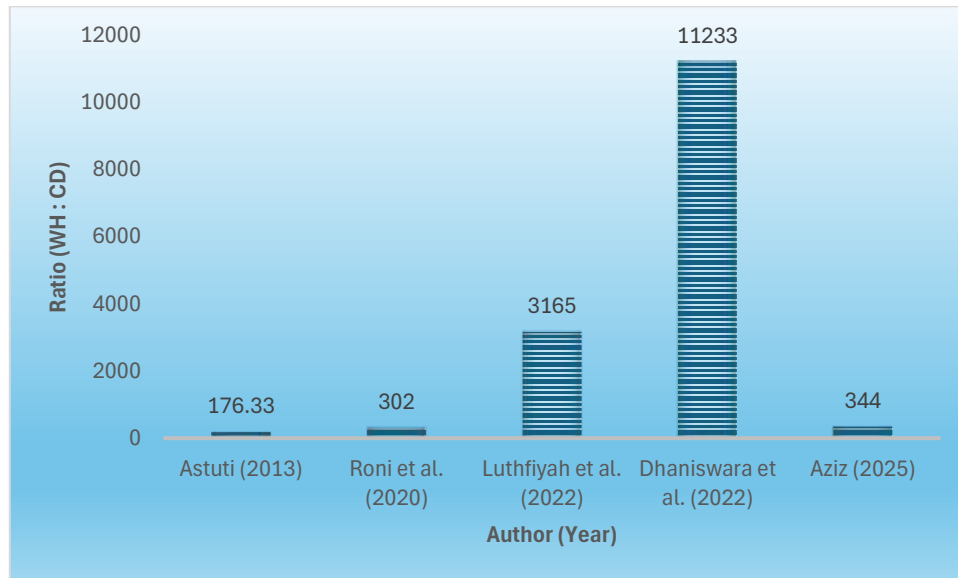


Figure 1. Biogas volume at various substrate ratios

Furthermore, (Aziz, 2025) research using a 47:53 ratio showed a biogas volume of 344 mL under optimum conditions. This ratio is still close to equilibrium, thus maintaining process stability and biogas production efficiency. This finding reinforces the idea that less extreme substrate ratios, whether dominated by water hyacinth or cow dung, are more beneficial in anaerobic digestion systems. Conversely, with an unbalanced ratio, such as 33:67 (WH:CD), the results showed significant variation in biogas volume. (Astuti et al., 2013) study produced a volume of 176.33 mL, while (Dhaniswara et al., 2022) study produced a much higher volume of 11,233 mL. This significant difference indicates that the substrate ratio is not the sole factor determining biogas production; other factors, such as hydraulic retention time (HRT), operating conditions, and reactor scale and design, play a role. The influence of HRT was clearly evident in (Dhaniswara et al., 2022), where the use of a 33-day HRT allowed for a more complete organic matter degradation process, resulting in a higher volume of biogas compared to studies with shorter retention times. The longer the retention time, the greater the opportunity for microorganisms to decompose organic matter into biogas.

In addition to HRT, differences in experimental conditions between studies also affect the results obtained. Differences in reactor scale, measurement methods, and environmental conditions such as pH and temperature can cause variations in the volume of biogas produced. Therefore, comparisons between studies must be made carefully, taking these factors into account. In terms of raw material characteristics, water hyacinth has a high lignocellulose content, particularly lignin, which is relatively difficult to degrade in anaerobic processes. If used in excess, the hydrolysis process is slowed, which can reduce biogas production. Conversely, cow dung contains active microorganisms and high levels of nitrogen, but if too dominant, it can cause a too low C/N ratio, potentially inhibiting the activity of methanogenic microorganisms.

Overall, the results of this study indicate a tendency that a substrate ratio close to balance, such as 50:50 or 47:53, produces more stable and optimal biogas production. Meanwhile, ratios that are too extreme, whether dominated by water hyacinth or cow dung, tend to produce lower biogas volumes or vary depending on other operating conditions. This indicates that the substrate ratio does not act alone but interacts with other parameters to determine the performance of an anaerobic digestion system. Therefore, optimizing biogas production depends not only on the substrate ratio but also requires controlling

other operational parameters such as retention time, environmental conditions, and feedstock characteristics. An integrated approach is essential to achieve maximum, stable, and efficient biogas production.

Conclusion

Based on the results of the study using the Systematic Literature Review (SLR) method, it can be concluded that the ratio of water hyacinth and cow dung substrates significantly influences the volume of biogas produced in the Anaerobic Digestion process. Substrate ratios that are close to balance, such as 50:50 and 47:53, tend to produce more optimal and stable biogas volumes than unbalanced ratios. A ratio that is too dominant in one of the substrates, such as 33:67, shows varying results and is influenced by other operational factors, such as retention time (fermentation duration), process conditions, and raw material characteristics. In addition, the combination of water hyacinth as a carbon source and cow dung as a nitrogen source, along with microorganisms, plays an important role in creating conditions that support biogas production. Thus, optimizing the substrate ratio is a key factor in increasing biogas production, but it needs to be supported by controlling other operational parameters to obtain maximum and sustainable results.

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