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Anaerobic Digestion of Paddy Husk and Dried Coconut Leaves: A Pathway to Renewable Energy

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ABSTRACT

Recent research has focused on anaerobic digestion (AD) for resource recovery from waste. AD generates biogas, primarily methane, which can be used as a renewable energy source for electricity and heat. This study examines the physical properties and biogas production of paddy husk (PHU) and dried coconut leaves (DCL) through anaerobic mono and co-digestion techniques. Standard methods were used to measure the physical characteristics of both wastes, which included total solids (TS), volatile solids (VS), and pH. The biogas production experiments were conducted in Duran bottles at a mesophilic temperature range of 26°C - 32°C with a set inoculum-to-sample ratio. Biogas production was measured using the water displacement method, with daily records taken over ten days. The TS values for PHU and DCL were 5.08% (± 0.05) and 93.21% (± 0.04), respectively. While the VS values for PHU and DCL were 75.80% (± 0.05) and 91.29% (± 0.07), respectively. This finding shows the suitability of both substrates to undergo the AD process. The pH value shows both wastes in an alkaline state. Results for biogas recovery found that co-digestion between PHU and DCL recovered the highest amount of biogas with 858.0 mL (±0.05), and the optimum time for digestion was on day 9. Meanwhile, single digestion of PHU and DCL recovered biogas with 187.0 mL (±0.12) (Day 8) and 197.0 mL (±0.05) (Day 8), respectively. The findings reveal significant biogas production potential from both PHU and DCL, with mixing digestion yielding higher biogas output and greater process stability. Mixing digestion enhanced the AD process by increasing biogas production and achieving a more balanced nutritional profile. This study provides insights into optimizing AD systems for renewable energy production and sustainable waste managements.

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INTRODUCTION

Agricultural residues such as paddy husk (PHU) and dried coconut leaves (DCL) are typically left on fields after harvests and are often utilized as animal feed, disposed of in landfills, or burned in various regions (Meegoda et al., 2018). Both offer unique characteristics and potential for biogas production. PHU, a common by-product of rice milling, is rich in silica and organic matter, which also can support effective biogas production (Zamuji et al., 2019). Meanwhile, DCLs are notable for their high organic content, durability, and richness in cellulose and lignin, making them suitable for AD (Mrosso et al., 2023). Both wastes are cost-effective and readily available, promoting their use in renewable energy generation and sustainable waste management (Kim et al., 2019; Selaman & Wid, 2016). Anaerobic digestion (AD) is a process where microorganisms degrade organic nutrients without oxygen, and it contains four stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. These stages are crucial for converting complex organic substances into simpler compounds, resulting in biogas, which is a mixture of carbon dioxide and methane (CH_4) and digestate, a nutrient-rich byproduct (Selaman & Utomo, 2024). This technology offers a favourable opportunity for biogas production by emphasising the importance of optimizing sample ratios and process parameters. Besides that, AD not only benefits in generating renewable energy but can also reduce greenhouse gas emissions (GHGs) to the surrounding area as the process is done in a closed system. Heading towards increasing biogas production, anaerobic mixing digestion is one of the most efficient methods that have been applied nowadays. It is a process in which two or more types of samples are combined in one closed system. According to Marina et al. (2021), anaerobic mixing digestion is a versatile and efficient method for producing biogas by combining various organic materials. By leveraging the strengths of different wastes, it enhances biogas production, improves process efficiency, and provides a more comprehensive approach to waste management. Additionally, a study by Rabii et al. (2019) also reported mixing digestion eventually improved the nutrient balance and better microbial activity. As it can help maximize the breakdown of organic materials, and reduce process inhibition. Thus increasing biogas yield. Due to this, this study focused on determining the physical characteristics of PHU and DCL that could indicate that the samples are suitable for the AD process while also investigating the anaerobic single and mixing digestion of both wastes in increasing the yielding of biogas productions (Bhat & Tao; 2020; Mohammed et al., 2021).

METHODOLOGY

Sample Collection and Preparation

Raw PHU was collected at Kampung Kuhom Mawang in Serian, Sarawak. While DCL was collected from the UiTM Sabah branch, Kota Kinabalu, Sabah (Figure 1). Both samples were cut to a small size of about 3-5 mm before being analyzed. The purpose is to facilitate the AD efficiency process. The sludge that was used in this experiment was collected from the septic tank, Indah Permai, Kota Kinabalu. Sabah and it were kept in an anaerobic state at 35^{o}C (±1) in an incubator for one week before being used. This activated the facultative anaerobic bacteria in the sludge (Wolfgang Buckel, 2021).

a

b

Figure 1. Paddy husk (PHU) (a) and Dried coconut leaves (DCL) (b)

Determination of physical properties of PHU and DCL.

The standard procedure for determining the physical properties of the raw materials was done according to Selaman and Wid (2016). This study aimed to identify whether the samples could be used to undergo the AD process.

a. Determination of Total Solids (TS)

Firstly, an empty crucible was weighted using an analytical balance. Then, the crucible was filled with a PHU sample and then weighted. All the weight was recorded. Next, the PHU sample with the crucible was placed in an oven and heated at 105^{O}C. This process was done for 24 hours. Next, the PHU sample was placed in a desiccator to prevent the re-absorption of moisture by the sample. To increase the reliability of the measurement, PHU samples were tested in triplicate. The TS was calculated using Equation 1. This procedure was repeated for DCL.

TS (%) = [(A-B) / (C-B)] x 100% (Eq. 1)
TS is referred to as Total Solid (%)
A = crucible weight + dry sample weight (g)
B = crucible weight (g)
C= crucible weight + wet sample weight (g)

b. Determination of Volatile Solids (VS)

To determine the VS, a PHU sample from section (a) was placed in a muffle furnace at 550^{0}C for a total of 4 hours. Then, the sample was placed into a desiccator and weighted (APHA, 2010). Once the procedure was completed, the percentage of VS was calculated using Equation 2. This procedure was repeated for DCL.

VS (%) = [(A-C)/ (A-B)] x 100% (Eq..2)
VS is referred to as Volatile solid (%)
A = crucible weight + dry sample weight (g)
B = crucible weight (g)
C= crucible weight + ash sample weight (g)

c. Determination of pH

The ratio of the PHU sample to distilled water was set at 1:10 (w/v). The PHU sample was placed in a bottle and shaken using an orbital shaker at 130 rpm for 24 hours. In order to determine the pH, the FW sample was filtered using a vacuum filter, and the liquid part was taken to determine the pH. The pH was measured by using a pH meter. This procedure was repeated for DCL.

Operation start-up for AD process

The experimental work was performed using a Duran bottle with a working volume of 400 mL. Digestion tests were performed in an incubator. The sample-to-sludge ratio was fixed at 1.0:2.0. The temperature was used at mesophilic conditions at 26°C - 32°C. The Duran bottle was charged with sample PHU and DCL. The mixture of substrates of both wastes is also used. The pH was controlled at 6.8 to 7.2 by using 1.0 M HCl and 1.0 M NaOH. The digestion time for each digester was set up for 30 days. During the experiment, the gas was released once a day. Gas recovery was determined using the water displacement technique (Selaman & Utomo, 2024). The volume of gas recovery was calculated using Equation 3.

$$\text{Volume of gas recovery (mL)} = \text{Volume of distilled water displaced (mL)} \qquad \text{(Eq. 3)}$$

Data Analyses

Data obtained from the experiments were analyzed in the IBM SPSS Statistic 22.0 statistical software package. The results were given as mean ± standard deviation for the summary statistics. The Shapiro-Wilk normality test assessed the normal data distribution's appropriateness. For the comparison of different parameters applications, one way-ANOVA, and for multiple comparison test, Student-Newman-Keuls test were used. $P < 0.05$ was considered as the statistical significant value.

RESULTS AND DISCUSSIONS

a. Physical Properties of PHU and DCL

Table 1 shows that this study's TS values of PHU and DCL were 5.08% (±0.05) and 93.21% (±0.02), respectively. Both waste TS values demonstrated notable differences. The PHU indicated a relatively low solid content, and this suggested that the PHU contains a higher proportion of moisture, potentially affecting its handling and pre-treatment requirements. (Zamuji et al., 2019) While the DCL value implies lower moisture content, which could impact the digestion process by requiring different operational adjustments to maintain optimal conditions. Besides that, Firmo et al. (2022), stated that TS values of more than 30.00% suggest high TS, which can influence producing a high amount of biogas. Additionally, Adjovu et al. (2023) reported that a high TS indicates that the waste is not suitable for landfilling as it can undergo the AD process in an open space and will consequently contribute to the release of GHGs. A high TS value also represents a high volume of waste; thus, it will need more space for landfilling. The present TS value from other study results showed a difference from the studies by Abd Hammid et al. (2019), Mrosso et al. (2023) and Selaman et al. (2024) (Table 1). The difference in the value could be due to the different types and compositions of samples used in the studies.

The VS values for the PHU and DCL were 75.80% (±0.03) and 91.29% (±0.06), respectively. Both values were considerably different. According to Wid et al. (2017), the higher VS value indicates a greater proportion of organic matter available in the waste, which can influence the efficiency of biogas production. As higher VS content typically correlates with a higher potential for biogas generation. However, a study by Andrede et al. (2022) has stated that waste that contains a high VS value, which is about 70 -100%, is suitable to be treated under the AD process, as it contains high organic content. Therefore, this suggests that both PHU and DCL can be used in the recovery of biogas as compared with the other studies in Table 1.

Table 1. Physical properties data for current and previous studies

References	Types of Waste	TS (%)	VS (%)	pH
Current study	PHU	5.08 ± 0.05	75.80 ± 0.04	7.25±0.03
Current study	DCL	93.21 ± 0.02	91.29 ± 0.06	8.52 ± 0.04
Abd Hammid et al. (2019)	Banana peels	17.18 ± 0.00	85.56 ± 0.00	5.61 ± 0.00
Mrosso et al. (2023)	Kitchen Waste	36.20 ±2.34	96.36 ±1.73	4.00 ±0.00
Selaman et al. (2024)	Protein-Rich Food Waste	34.16±0.08	88.5 6± 0.04	3.67±0.12

According to Mohammed et al. (2021), the pH level of the wastes is a critical parameter because it affects the microbial activity and overall efficiency of the digestion process. The pH of the samples can influence how well the digestion process proceeds, especially in terms of biogas production and stability. The current study shows the PHU and DCL were 7.25 (±0.03) and 8.52 (±0.04), which are alkaline. However, the values are still close to the optimal value, which ranges from 6.8 to 7.2 for biogas recovery. Compared with other studies (Table 1), the value from others studies were in an acidic state. The difference in the value could be due to the different types and compositions of samples used in the studies (Xu et al., 2022).

Biogas Recovery in PHU, DCL and mixing of (PHU and DCL)

Figure 2 illustrates the results of biogas recovery in PHU and DHL, as well as the mixing of PHU and DHL. The results showed that the mixing between PHU and DCL contributed to the highest biogas recovery value with 858.0 mL (±0.05) at day 9 of AD. From the graph, it showed that biogas production was gradually increased starting from day 1 until day 9 of digestion and then significantly decreased until day 10 of digestion. Meanwhile, PHL and DCL recover the highest biogas with values of 185.0 mL (±0.08) and 187.0 mL (±0.09), respectively. During the AD process, it can be seen that biogas production is slightly increasing from day 1 until day 8 and then continuing to decrease until day 10. The decrease in biogas production could be due to the production of acids that lead to instability in digestion performance and methanogenesis bacteria activity (Hedge et al., 2019; Mohammed et al*.,* 2021).

The data also show that the mixing of PHU and DCL eventually produced the highest value of biogas recovery, which could be due to the combination of both producing better synergistic effects between both facultative anaerobic bacteria during the digestion process, which in turn helped in enhancing biogas production from the samples (Mohammad Kelif et a*l.,* 2022). Besides that, Rabii et al. (2019) also mentioned that mixing digestion in one AD process could help increase the efficiency of the process as the co-substrates will help supply the missing nutrients in the digestion medium. This finding indicates that mixing PHU and DCL can significantly enhance the anaerobic digestion (AD) product. The results revealed that the optimal duration for biogas recovery during the digestion process was longer for mixed digestion compared to single digestion. Nevertheless, the yield of biogas production was around 78.0%.These results showed that the appropriate composition of organic matter in one reactor would affect the growth and performance of bacteria in increasing biogas recovery by 120.3 mL (±0.05).

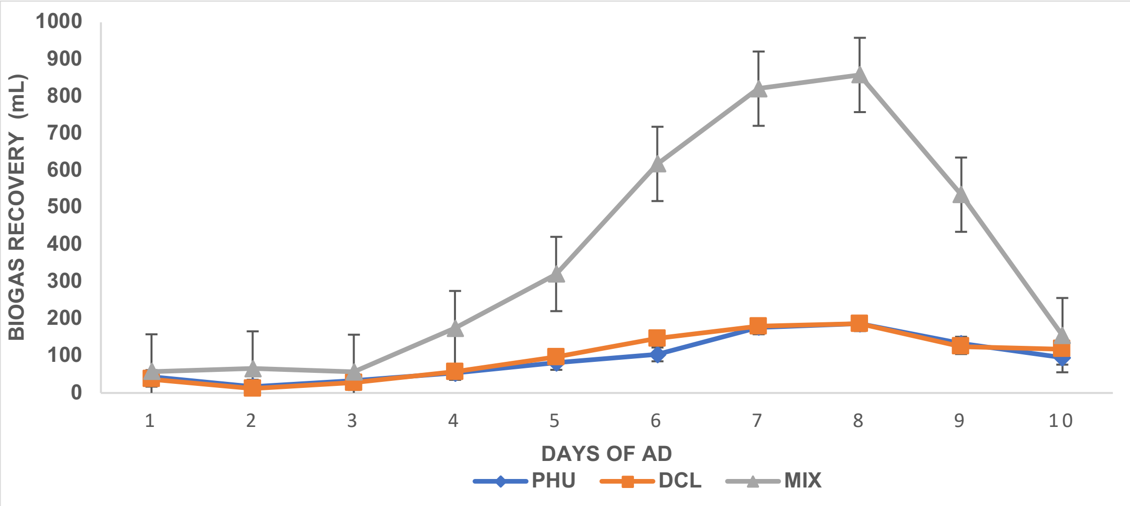

Figure 2. AD substrates (PHU, DCL and MIX) at 10 days of digestion time

Meanwhile, Table 2 shows the comparison of biogas recovery from current and previous studies. The data showed that different AD methods give different values of biogas recovery. Mixing digestion shows the highest value of biogas recovery. This could be due to the method balancing the nutrient content and improving the overall biodegradability of the waste mixture (Mohammad Kelif et al.,2022). Combining organic wastes can also enhance microbial activity and reduce the occurrence of inhibitory substances that might be present in single-type waste digestion. Additionally, the variability in biogas recovery observed across different studies and methods suggests that the efficiency of AD can be greatly influenced by the characteristics of the input materials (Selaman & Utomo, 2024; Vidal-Antich et al., 2022).

Table 2. Comparison of biogas recovery from current and previous studies.

References	Types of waste	Method used	Biogas recovery (mL)
PHU-DCL (Current study)	Paddy husk & Dried coconut leaves	Mixing digestion	858.0 ± 0.05
Abd Hammid et al. (2019)	Banana Peels	Single digestion	136.6 ± 0.00
Xu et al. (2022)	Food waste & Paper waste	Mixing digestion	238.00 ±0.00
Selaman et al. (2024)	Protein Rich Food waste & Pond Sludge	Single digestion	120.3±0.05

CONCLUSIONS

In conclusion, this study highlights the effectiveness of AD for resource recovery from PHU and DCL. The analysis showed that both substrates are well-suited for AD, with alkaline pH levels favourable for digestion. Generally, mixing digestion of PHU and DCL resulted in significantly higher biogas production, yielding 858.0 mL by day 9, compared to lower yields from single digestion. This indicates improved biogas recovery, process stability, and nutrient balance with a mixed substrate approach. Overall, the findings offer valuable insights for optimizing AD systems for renewable energy generation and promoting sustainable waste management through the use of diverse organic materials.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

All the authors contributed to the final write-up of manuscripts. Below is breakdown:

1. Rafidah binti Selaman : Provided the concept of analysis, suggested parameters, wrote results and data analysis, writing and editing.
2. Alexandra Dudy Clarence Anak Gaup : Collecting sample, performed the experimental work, wrote the introduction and methodology.
3. Nurfatin binti Jaafar: Collecting sample, performed the experimental work, wrote the introduction and methodology.

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