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Effect of Biochar Addition on Biogas Production Using Konjac Waste through Mesophilic Two-Phase Anaerobic Digestion

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Abstract

Purpose: This study aimed to investigate the influence of biochar supplementation in the mesophilic two-phase anaerobic digestion process for konjac waste. **Methods:** Reactors with a working volume of 60 ml were utilised to incubate cultures containing biochar. In the first phase, the cultures were maintained at 32°C and a pH of 5 to facilitate the production of hydrogen. In the second phase, the cultures were adjusted to 37°C and a pH of 7 to promote methane production. The concentration of konjac flour waste varied between 0 g/L to 500 g/L, while the ratio of biochar addition ranged from 0 g/L to 25 g/L. Biogas production was measured daily using the volume displacement method, and the pH of the cultures was monitored both before and after the experiment. **Results:** The findings show that using biochar has a beneficial effect on biogas production from konjac flour waste. During the initial phase of the experiment, incorporating biochar with a concentration of 15 g/L led to substantial improvements, elevating the maximum H_2 production rates by 9.6%. Furthermore, the addition of biochar led to an 84% increase in H_2 yield during the initial phase. Similarly, in the second phase, introducing biochar with a concentration of 15 g/L resulted in a 22.2% increase in the maximum CH_4 production rates and a 2.5 times increase in CH_4 yield. **Conclusions**: Overall, this work confirms the beneficial effects of biochar on the H_2 and CH_4 production from konjac flour waste using the mesophilic two-phase anaerobic digestion method for sustainable energy.

Keywords: Biochar; Clean Energy; Circular Economy; Konjac flour waste

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Introduction

Konjac Glucomannan is a food additive that has been used worldwide. During the production of Konjac flour, some of the products do not pass quality control and become waste. However, the waste can be utilised as an adhesive for particle boards (Dwiyono & Djauhari, 2019), biopellets (Saloko et al., 2020), and ethanol (Kapoor et al., 2024). Additionally, the Konjac flour waste can be converted into biogas, which can serve as a renewable source of energy to support Sustainable Development Goals (SDGs).

Biogas is a gas produced by decomposing organic substances with the help of microorganisms in an environment without oxygen (O_2). It mainly contains methane (CH_4), carbon dioxide (CO_2), and water (H_20) (Sugiarto et al., 2023). Conventional Anaerobic Digestion (AD) typically employs a single-phase digestion process to generate biogas. However, this approach is characterised by slow reaction time, poor reactor stability, and sensitivity to changes in both biological communities and reaction environment (Zhang et al., 2015). As a result, the quality of biogas produced from single-phase digestion is low, with high CO_2 content, low energy density, and poor combustion properties, leading to low heat and power generation (Sunyoto et al., 2016). A two-phase anaerobic digestion (TPAD) process was developed to overcome these issues. The TPAD process sequentially produces biogas enriched in hydrogen (H_2) and methane (CH_4), with hydrogen being produced in the first phase and methane in the second. By dividing the digestion process into two phases, specific microbial populations can grow under optimal operating conditions, which results in increased yields of both H_2 and CH_4.

One way to increase biogas production is by adding biochar, which can form biofilms and reduce ammonia inhibition. According to Sugiarto et al. (2023), the addition of biochar can accelerate the formation of granules in sludge (Sugiarto et al., 2023). According to recent research conducted by Salado et al. in 2022, adding biochar can improve anaerobic digestion(Salado et al., 2022). This is because biochar can increase the rate of methane production and maintain a pH level close to neutral. This pH level is favourable for the growth of methanogens and microorganisms, which can lead to faster methane production compared to the control group in experiments. Additionally, biochar plays a role in converting volatile fatty acids (VFA) into acetic acid, further contributing to the process. Moreover, biochar can increase methane production when there is high organic matter content. However, if the concentration of biochar in the Anaerobic Digestion (AD) process is too high, it could have the opposite effect, reducing methane production and damaging the whole system (Sunyoto et al., 2016). Therefore, it is crucial to consider the proportion or concentration of biochar while using it in biogas production.

This study adds value to Konjac flour waste by utilising it in biogas production within a circular economy framework based on a zero-waste approach. This study explores the impact of different concentrations of konjac flour waste on biogas production and also examines the effect of adding biochar to the mixture. Furthermore, the study presents a detailed analysis of how the addition of biochar helps to increase biogas production through mesophilic two-phase anaerobic digestion.

2. Experimental

Konjac flour waste, inoculum and biochar

Konjac flour waste was being used as a feedstock for AD. The konjac flour waste contains 8.09% moisture and 7.75% ash, making up a total solids content of 91.91%. Its elemental composition is as follows: 43.84% carbon, 6.59% hydrogen, 39.97% oxygen, and 1.52% nitrogen, resulting in a carbon-to-nitrogen (C/N) ratio of 28.84. Konjac flour waste also has a volatile solids content of 92.25%. The inoculum used in the research was taken from the local industry digester located in Malang (Indonesia). The sludge for anaerobic digestion contains a total solid of 1.09% and a total volatile solid of 99.45%. The biochar was produced from pine sawdust through pyrolysis at 650°C in an indirectly fired kiln reactor for a retention time of 20 minutes. The biochar was then ground down using a stainless-steel ring mill to a size fraction smaller than 25.9 μm and a median particle size (D50) of approximately 12 μm. Before use, the biochar was dried in an oven at 105°C. The biochar had a low moisture content of 1.64% and a high ash content of 79.17%. It contained 84.14% carbon, 1.57% hydrogen, 13.7% oxygen, and 0.58% nitrogen, with a high carbon-to-nitrogen (C/N) ratio of 145.06. The total solids content was 98.36%, with volatile solids at 20.83%.

Anaerobic digestion Experimentation

In this study, a 100 mL vial with a working volume of 60 mL was used. The vial contained Konjac flour waste, biochar, sludge, and distilled water. The concentration of Konjac flour waste was varied at 0 g/L, 16.67 g/L, 33.33 g/L, and 50 g/L. Additionally, 10 mL of sludge was added to the vial with 50 mL of distilled water. The pH level was adjusted to a range of 7 by adding either NaOH or HCl. The bioreactors were purged with high-purity nitrogen (>99.99%) at a flow rate of 20 L/min for 30 seconds to establish an anaerobic environment.

After that, the bioreactors were sealed with rubber plugs and covered with aluminium caps before they were incubated at 32 for 20 days in 1st phase. All the experiments were conducted in triplicates. After 20 days, the remaining culture in the reactor was used as the feed for biogas production in the second phase. The bottle was opened, and 10 mL of unheated sludge was added to adjust the pH to 7. Then, the bottle was sealed and incubated at 37°C for 77 days. After achieving the highest gas production from konjac flour waste at a specific concentration, a similar study was conducted to investigate the effects of adding biochar using the same method as the konjac waste experimentation for the 1st and 2nd phases. The biochar concentration ranged from 0 g/L to 25 g/L in the total working volume.

Analytical methods

The amount of CH_4 produced was measured every day using the water displacement method and then calculated into volumetric CH_4 production under standard temperature and pressure (STP) conditions (273K and 1 atm pressure) according to the ideal gas law [11]. The gas composition was analysed using Gas Chromatography (GC; Agilent 7980) with TCD (heater 200 ºC, reference flow: 7 mL.min-1, make-up flow: 3 mL.min-1), back detector thermal conductivity detector (TCD) (heater 250 ºC, reference flow: 10 mL.min-1, make-up flow: 5 mL.min-1), and flame ionisation detector (FID) (heater 200 ºC, hydrogen flow: 30 mL.min-1, airflow: 350 mL.min-1, make-up flow: 35.5 mL.min-1).

3. Results and Discussion

3.1 Effect of Konjac Flour Waste Concentration on Biogas Production

The concentration of Konjac flour waste can influence H_2 and CH_4 production in the 1st and 2nd phases, which can be seen in Figure 1, Figure 2, Figure 3 and Figure 4. The concentration variations used consisted of 4 concentration variations, namely 0 g/L as a control, 16.67 g/L, 33.33 g/L and 50 g/L. The results of these differences in concentration can be tested in comparison with controls that do not use additional substrate.

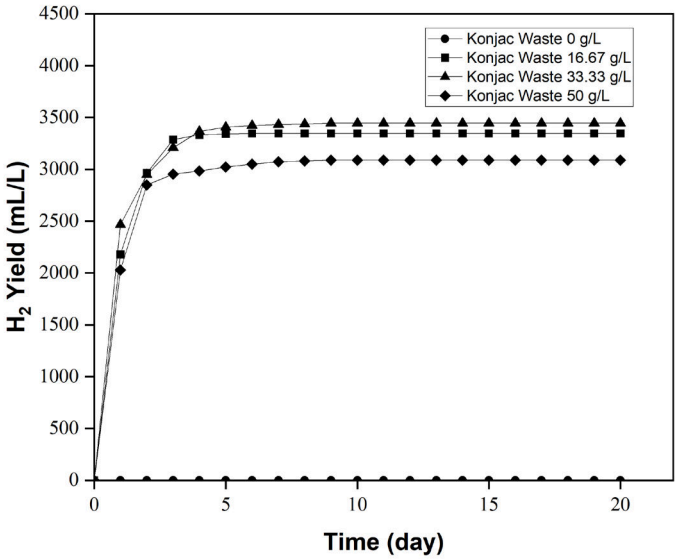


Figure 1. Effect of Different Concentrations of Konjac Flour Waste in the 1st Phase

Figure 1 illustrates that the presence of Konjac flour waste in sludge can lead to H_2 production. The graph indicates an increasing trend in H_2 production, with no H_2 being produced in the treatment without Konjac flour waste. The highest level of H_2 production was achieved at a concentration of 33.33 g/L of Konjac flour waste, resulting in 3446.3 mL/L of H_2 yield. However, when the concentration was further increased to 50 g/L, the H_2 production decreased to 3088.2 mL/L. This decrease is might be because of the accumulation of Volatile

Fatty Acids (VFA), which results from the degradation of more organic material. The accumulation of VFAs suggests an imbalance in the microbial communities responsible for various stages of anaerobic digestion. High concentrations of VFAs, such as acetic, propionic, and butyric acids, can decrease the pH of the system, leading to a more acidic environment (Sunyoto et al., 2017). Kaur et al. (2022) and Johnravindar et al. (2021) stated that high levels of VFA can hinder biogas production (Johnravindar et al., 2021; Kaur et al., 2020).

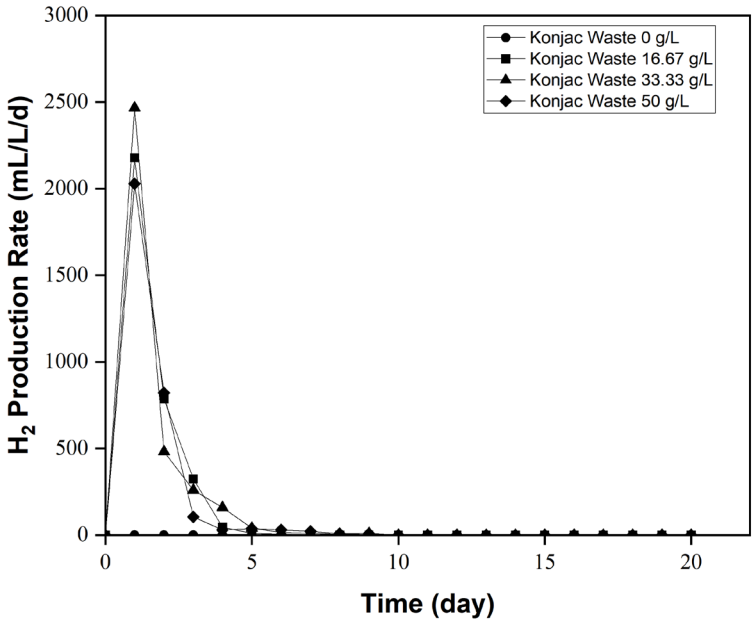


Figure 2. Biogas Production Rate with Different Concentrations of Konjac Flour Waste in the 1st Phase

Figure 2 shows that all of the treatments resulted in H_2 production on the 1st day. The treatment with no additional konjac flour waste concentration exhibited the lowest H_2 production rate. The addition of konjac flour waste in concentrations of 16.67 g/L, 33.33 g/L, and 50 g/L resulted in H_2 production rates on the 1st day. However, the rate of H_2 production

decreased from day 2 onwards. The highest H_2 production rate was observed at a Konjac flour waste concentration of 33.33 g/L, with a production of 2466.6 mL/L. The increase in H_2 production rate at a concentration of 33.33 g/L was 13.2% compared to a concentration of 16.67 g/L. This is in line with the findings of Sugiarto et al. (2023), which suggests that the production of H_2 follows a similar pattern(Sugiarto et al., 2021a).

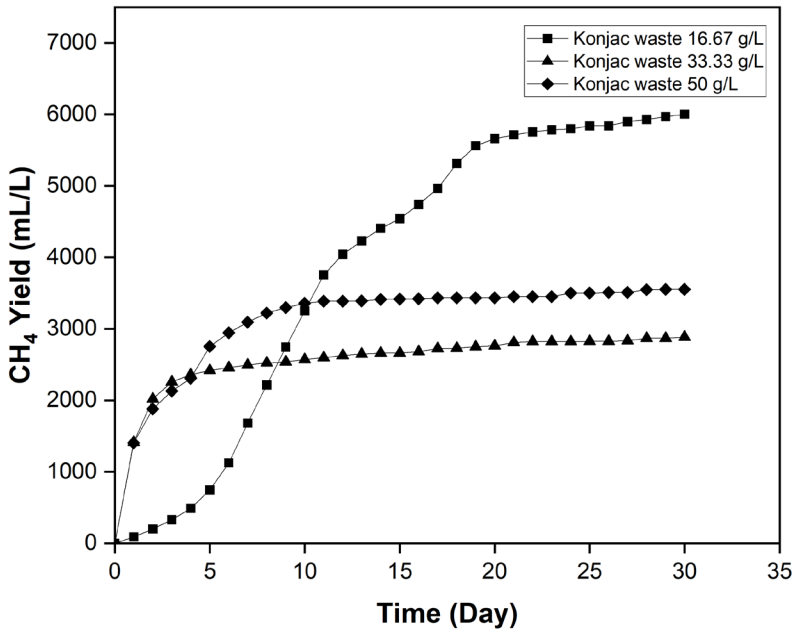


Figure 3. Effect of Different Concentrations of Konjac Flour Waste in 2nd Phase

Figure 3. shows that biogas production occurred in 2nd phase. The graph suggests that adding Konjac flour waste to the sludge can enhance CH_4 production. The highest CH_4 production occurred when Konjac flour waste was added with a concentration of 16.67 g/L, producing 6002.4 mL/L. Conversely, the lowest CH_4 yield was observed in the treatment without Konjac flour waste, which was only 144.2 mL/L. However, a decrease in CH_4

production was noticed at a concentration of 33.33 g/L and 50 g/L. The addition of Konjac flour waste at high concentrations resulted in a decline in CH_4 production. This is because high concentrations of waste in the bioreactor can increase the concentration of VFA, including acetate, butyrate, propionate, and long-chain acids. Studies have shown that high VFA concentrations can disrupt or suppress the activity of microorganisms, leading to a decrease in biogas production during anaerobic fermentation (Sugiarto et al., 2021a). Moreover, high VFA concentrations can hinder the performance of microorganisms and even lead to their death at the hydrolysis phase.

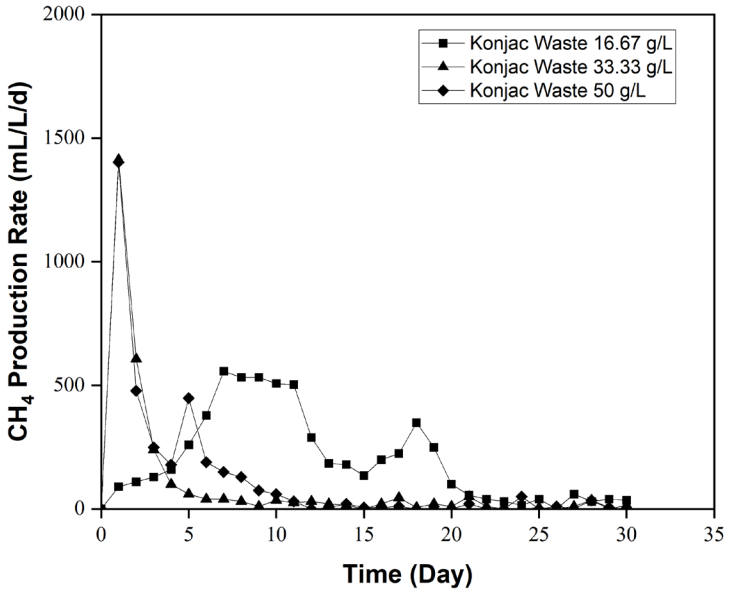


Figure 4. Effect of Different Concentrations of Konjac Flour Waste in 2nd Phases

In Figure 4, it is evident that the production of biogas began on the 2nd day. The rate of CH_4 production rate varied in samples with different concentrations of Konjac flour waste, i.e.

16.6 g/L, 33.33 g/L, and 50 g/L. The highest CH_4 production rate was observed at a concentration of 33.33 g/L, with as much as 1412.3 mL/L. However, the treatment without the addition of Konjac flour waste had the lowest CH_4 production rate, with only 79.6 mL/L being produced. Increasing the concentration of Konjac flour waste to 50 g/L caused a decrease in the CH_4 production rate, with a production rate of 1402.4 mL/L. The highest CH_4 production rate was observed on the first day at a concentration of 33.33 g/L. This may be attributed to respiration, which generates carbon dioxide (CO_2) (Sunyoto et al., 2019).

Effect of Biochar Supplementation on Biogas Production

The study investigates the impact of biochar on H_2 and CH_4 production by testing four different concentrations of 0 g/L, 5 g/L, 15 g/L, and 25 g/L. The experiment will compare the results from varying concentrations with controls without additional substrate and controls with substrates without biochar. The findings of the study are presented in Figure 5, Figure 6, Figure 7, and Figure 8, which illustrate the effect of adding biochar on H_2 and CH_4 production in the first and second phases.

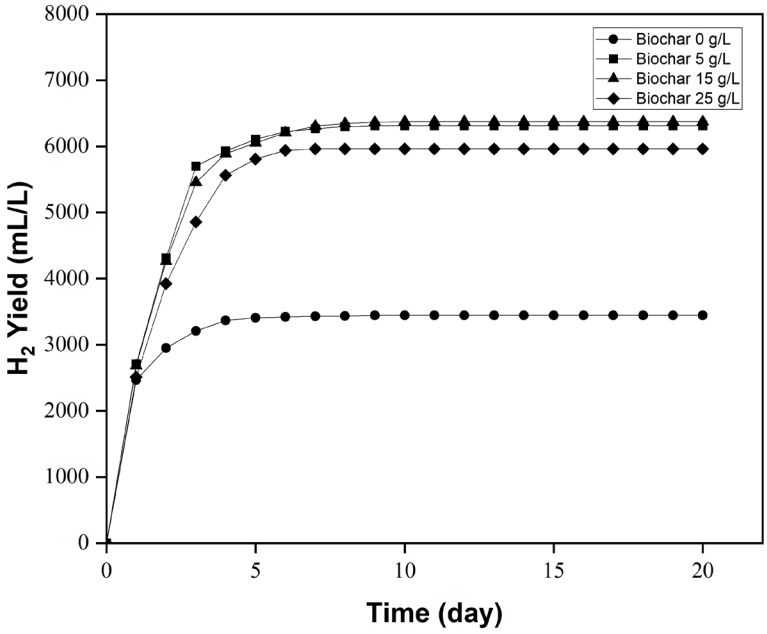


Figure 5. Effect of Different Biochar Concentrations in the 1st Phase

Figure 5 displays that the addition of biochar during the 1st phase can enhance the H_2 yield. The highest H_2 yield was observed when biochar was added at a concentration of 15 g/L, producing 6375.3 mL/L. This is an 84% increase compared to the sample without biochar at a substrate of 33.33 g/L, which produced 3446.3 mL/L of H_2. However, adding 25 g/L of biochar can lead to a decrease in H_2 yield, with only 5962.6 mL/L. According to Nemr et al. (2022), using the right concentration of biochar is essential as it does not always increase H_2 yield (El Nemr et al., 2022). Biochar is a porous carbon material obtained from agricultural waste, wood, excess sludge, and other biomass using thermochemical technology under suitable anaerobic conditions. It is an activated carbon precursor with the properties of solid carbon and rich surface functional groups. Biochar boosts microbial immobilisation, increases ion exchange

capability, and raises the pH of the microenvironment in the anaerobic digestion (AD) process. It also contains various redox components and has a more efficient direct electron transfer ability between species compared to granular activated carbon, even though it has lower conductivity(Liu et al., 2022).

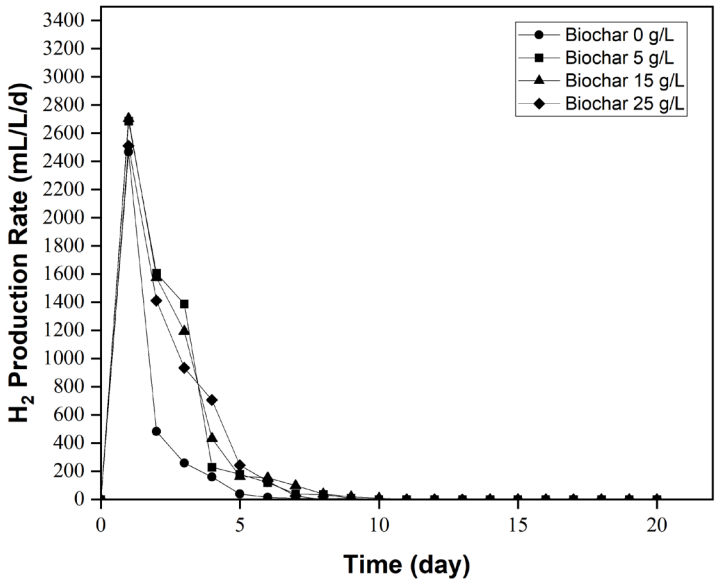


Figure 6. Effect of Different Biochar Concentrations on H_2 Production Rates in 1st Phase

In the 1st phase, the daily biogas production rate is shown in Figure 6. According to the figure, the production of H_2 begins on the first day. The highest H_2 production rate was observed when the biochar concentration was 15 g/L and the substrate concentration was 33.33 g/L. The recorded H_2 production rate was 2705.3 mL/L, which is 9.6% higher than the non-biochar treatment. On the other hand, the lowest H_2 production rate was observed in the treatment without the addition of biochar, which was 2466.6 mL/L. An increase in concentration of 15 g/L resulted in a decrease in H_2 production with a rate of 2685.4 mL/L,

whereas a concentration of 25 g/L produced 2511.3 mL/L.

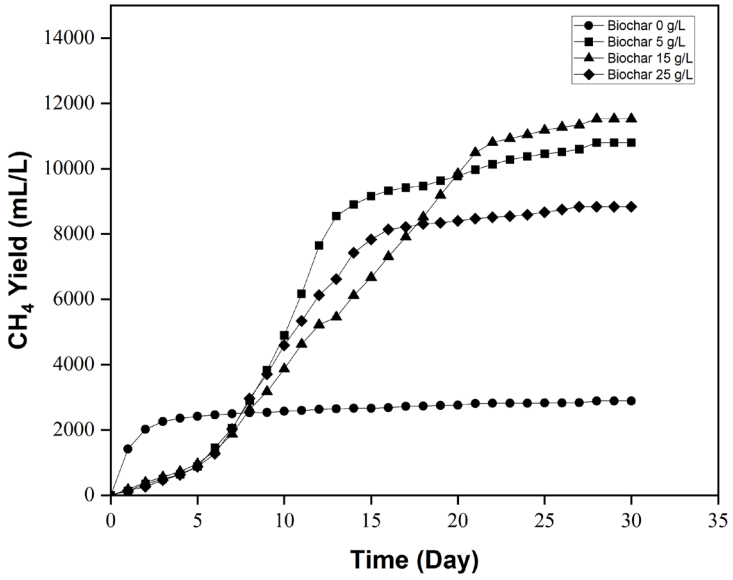


Figure 7. Effect of Different Biochar Concentrations on CH_4 Yield in 2nd Phases

In Figure 7, the impact of biochar on CH_4 yield is explained. According to the study, the lowest CH_4 yield occurred at a biochar concentration of 0 g/L. At a biochar concentration of 15 g/L, the highest CH_4 yield was obtained at a concentration of 11527.3 mL/L. However, at concentrations of 25 g/L, CH_4 yield decreased. According to Sunyoto et al. (2016), it was discovered that adding biochar in high concentrations does not necessarily result in increased biogas production. In fact, in the treatment where biochar was not added, the culture produced a CH_4 yield of 2884.3 mL/L. This suggests that adding an inappropriate concentration of biochar can even disrupt the biogas production process instead of enhancing it. However, biochar still plays a crucial role in Anaerobic Digestion by providing immobilised microbes, increasing ion exchange capabilities, and raising the microenvironment's pH level (Khalid et

al., 2021).

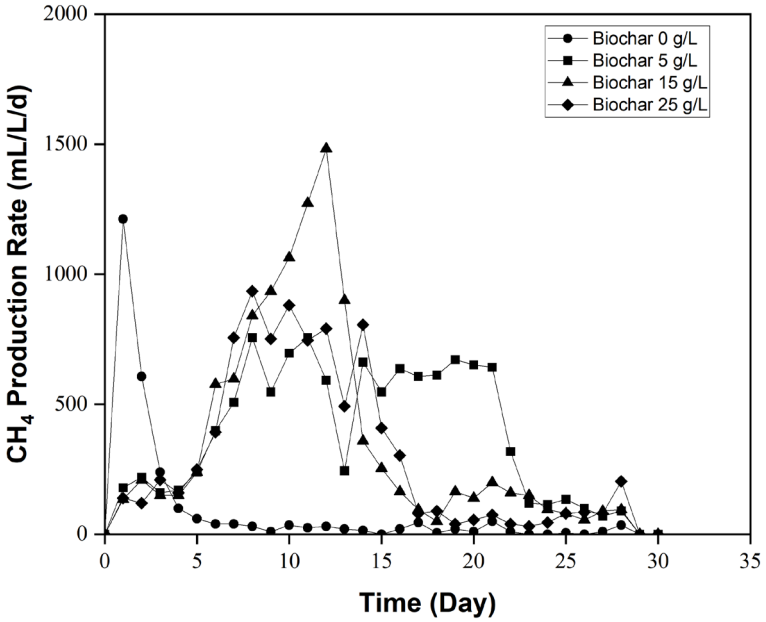


Figure 8. Effect of Different Biochar Concentrations on CH_4 Production Rate in 2nd Phases

Figure 8 depicts the biogas production rate in 2nd phase. As per the graph, CH_4 production began on the first day. The study found that the highest production rate of CH_4 was observed when the biochar concentration was at 15 g/L, which was 1481.9 mL/L on the 12th day. On the other hand, the treatment without biochar had the lowest CH_4 production rate, with only 1412.3 mL/L. Sunyoto et al (2029) stated that the initial 10 to 19 days were the peak of the degradation process (Sunyoto et al., 2019). However, the duration of the degradation process varied for each substrate.

Effect of pH during AD

Figure 9. shows the pH in the first phase of the experiment. On the first day, the pH conditions of the samples ranged from 6.99 to 7.06. By the 20th day, all samples underwent pH changes and tended to be within the range of 3 to 7. During this first phase, the samples tended to be acidic because of the acidogenesis process. This process leads to the production of acids, which makes the samples more acidic. The biogas samples experienced a decrease in pH on the 20th day, which made the pH conditions acidic. According to Sugiarto et al. (2023), in anaerobic digestion, the pH value decreases as volatile fatty acids (VFA) are produced (Sugiarto et al., 2021b). The decrease in pH is due to the acidification process, which is caused by the conversion of hydrolysis products into volatile fatty acids such as acetate, propionate, and butyrate.

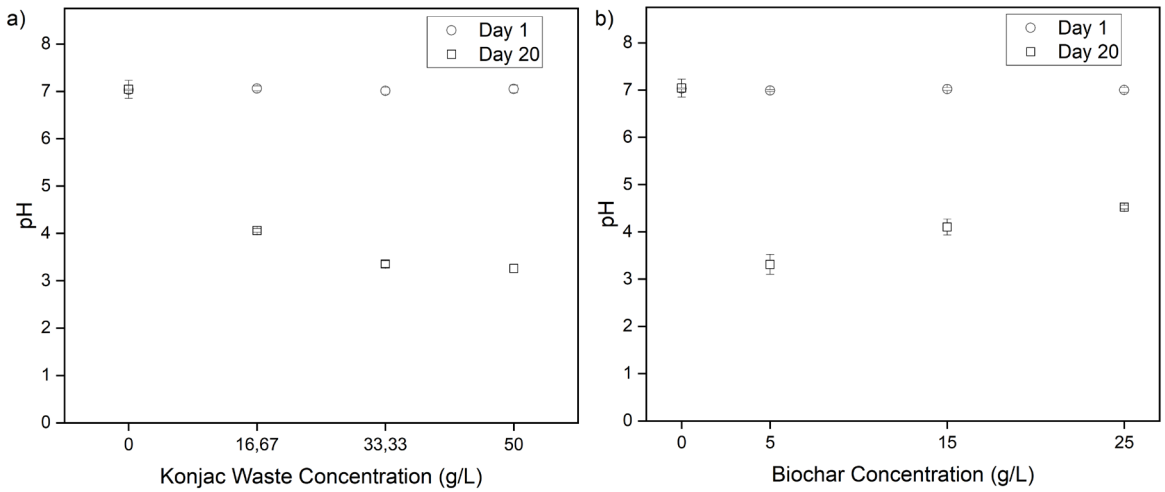


Figure 9. pH in the 1st phase of the experiment a) Various Konjac Waste Concentration b) Various Biochar Concentration

Figure 10. shows the acidity levels during the 2nd Phase. Based on the figure, it can be observed

that on the first day when the sludge is added, all the samples are conditioned to attain a neutral pH range of 7. On the 77th day, which is the final day, the samples exhibit a pH range between 5 to 7. The most effective treatment for producing biogas is adding biochar at a rate of 15 g/L. The figure depicts that the pH of this treatment is neutral, at 7.22. This indicates that the methanogenic bacteria work efficiently and produce the maximum amount of CH_4 from organic matter during the second phase (Sunyoto et al., 2016).

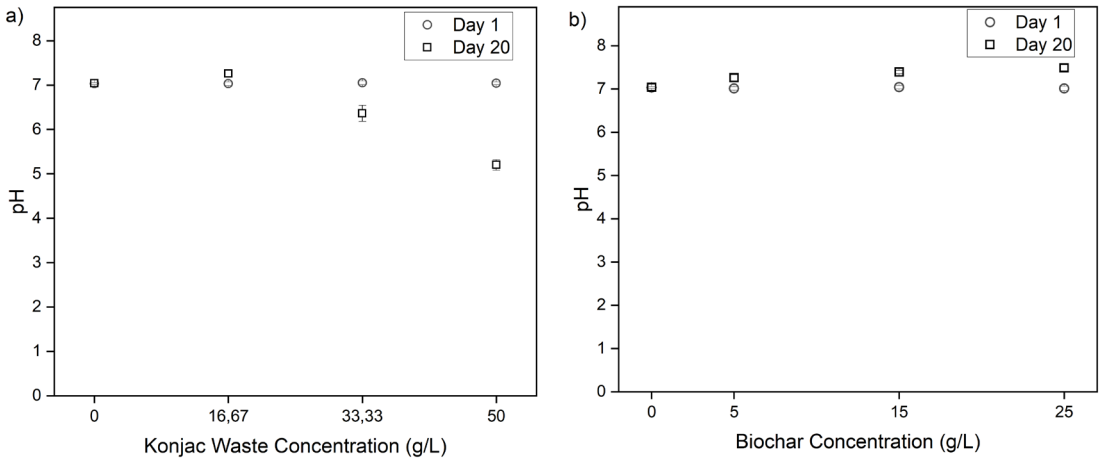


Figure 10. shows the pH in the 2nd phase of the experiment

Conclusions

The study has demonstrated that adding biochar to konjac flour waste had a positive impact on biogas production. In the first phase, adding biochar with a concentration of 15 g/L resulted in a significant enhancement, increasing the maximum H_2 production rate by 9.6%. The addition of biochar also increased the H_2 yield in the first phase by 84%. Similarly, in the second phase, the addition of biochar with a concentration of 15 g/L led to a 22.2% increase in the maximum

CH_4 production rate and 2.5 times increase in CH_4 yield. These results confirm the beneficial effects of biochar on H_2 and CH_4 production from konjac flour waste using the two-phase anaerobic digestion.

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Conflict of Interest

The authors declare no conflict of interest.

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