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BIOGAS RECOVERY AND WASTE REDUCTION FROM SELECTED KITCHEN FOOD WASTE (SHALLOTS AND CABBAGE) BY USING ANAEROBIC DIGESTION

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ABSTRACT. *Kitchen food waste is defined as food that is left over or wasted during the production, processing, distribution, procurement, preparation, and consumption processes. About 50% of all food waste is reportedly to originate from kitchens and since it can decompose, food waste is regarded as degradable kitchen waste. It is reported about 15,000 tonnes per day kitchen food waste generated in Malaysia and has the potential to produce hazardous gases, leachate, air pollution from food decay and quickly expanding landfills. In this study, kitchen food waste was used to recover biogas using anaerobic digestion. Additionally, the volume of waste reduced was also investigated to prove that anaerobic digestion is not only to recover resources, but also to reduce waste generation. The anaerobic digestion was performed at pH value of 6.8-7.2 and temperature 37ºC for 15 days. Two (2) different samples of kitchen waste were used namely, shallots and cabbage. The biogas recovery was determined using water displacement technique. Kitchen food waste was also characterised before and after anaerobic digestion in terms of total solids, volatile solids and pH value. It is found that the percentage of total solids for shallots and cabbage before anaerobic digestion were 19.9% and 16.8%, respectively, and the percentage of volatile solids before anaerobic digestion were 88.1% and 95.6%, respectively. After anaerobic digestion, the percentage of total solids for shallots and cabbage were 15.5% and 13.6%, respectively, and the percentage of volatile solids were 21.0% and 15.2%, respectively. This suggests that the total and volatile solids of shallots and cabbage were reduced with 22.11% and 19.5%, and 76.14% and 84.14%, respectively, after performing anaerobic digestion. While, 168mL and 52mL of biogas can be recovered from shallots and cabbage, respectively, throughout 15 days anaerobic digestion. This shows that anaerobic digestion is not only to recover biogas but also to reduce waste.*

INTRODUCTION

Biogas, produced through anaerobic digestion, has gained attention as a promising method for converting organic waste into energy. Biogas is a mixture of mostly methane, CH_4 (50%-70%) and carbon dioxide, CO_2 (30%-50%) with some trace gases (1%-5%) (Ramaraj & Dussadee, 2015). The methane in biogas can be used to produce renewable heat, electricity or cooling (Sibilo *et al*., 2017), thereby reducing dependence on fossil fuel energy.

Among the many sources of biogas, food waste stands out as a significant contributor to municipal solid waste, especially in urban households. According to the Food and Agriculture Organization (FAO), more than 30% of the food produced globally is wasted, contributing significantly to environmental issues (Safdie, 2023). In Malaysia, it is estimated 15,000 tonnes of food waste generated daily which mostly originating from households, including kitchen food waste (KFW) (Shukla *et al*., 2024; Abd Ghafar, 2017). KFW, a significant fraction of municipal solid waste, is primarily biodegradable. Improper disposal of KFW poses environmental risks, including the generation of methane and other harmful greenhouse gases, as well as soil contamination from leachate. Converting KFW into biogas offers a promising solution to these issues. KFW can be converted into biogas because it is rich in organic, biodegradable matter with high moisture content, making it ideal for anaerobic digestion by microbes.

Previous research highlights the potential of anaerobic digestion to reduce the environmental impact of food waste while simultaneously producing renewable energy (Xu *et al*., 2024). One of the widely studied method in converting waste into biogas is anaerobic digestion (AD) which includes four (4) prominent steps, namely, hydrolysis, acidogenesis, acetogenesis and methanogenesis. AD is a biological process that breaks down organic material in the absence of oxygen, transforms organic waste into biogas, composed mainly of methane (CH_4) and carbon dioxide (CO_2), and a nutrient-rich digestate. This process reduces the volume of waste sent to landfills and mitigates methane emissions, making it an environmentally friendly solution. The efficiency of AD depends on several factors, including the composition of the waste, temperature, pH, and moisture content. The AD process is increasingly being used worldwide to convert organic waste into biogas, which can be used as a source of energy for heating, electricity, or as vehicle fuel (Shukla *et al*., 2024). In addition, AD reduces greenhouse gas emissions by preventing the release of methane from landfills.

Therefore, this research aims to explore the potential of KFW for biogas recovery, focusing on shallots and cabbage, the commonly consumed food items at the café of Faculty of Science and Technology, Universiti Malaysia Sabah, where the samples were collected. This study assessed the production of biogas using anaerobic digestion over a 15-day period as well as the amount of waste reduced after performing anaerobic digestion. This research not only contributes to the growing knowledge on waste-to-energy solutions but also promotes the use of sustainable waste management practices.

MATERIALS AND METHODS

Sample Collection and Preparation

The kitchen food waste (KFW) samples, namely, shallots and cabbage were collected after lunch hour from the student's café of Faculty of Science and Technology, Universiti Malaysia Sabah, when needed. The samples were cleaned using tap water and ground using a mortar to make it ready for anaerobic digestion and were stored at 4°C prior to use (APHA, 2005). The sediment sludge was collected from a lake at Universiti Malaysia Sabah and used as inoculum for AD process. The sludge was stored in a Schott Duran glass bottles and allowed to degasify in a water bath at 37°C for seven (7) days. The level of the water bath was raised slightly above the level of sludge in the Duran bottle. The bottle top was opened at least once a day to allow any gas that might escape from the sludge. After the degasification process was completed, the sludge was kept in a water bath at 37°C until it was needed for the AD treatment (Wid *et al*., 2017).

Determination of Physical Properties of Kitchen Food Waste

The physical properties that were determined including total solids (TS), volatile solids (VS) and pH value. The total solids (TS) and volatile solids (VS) of the samples were determined using standard procedures outlined by APHA (2005). TS was determined by drying the samples at 105°C for 24 hours, followed by VS analysis by igniting the dried samples at 550°C for four (4) hours in a furnace. The determination of TS and VS were carried out before and after anaerobic digestion. While the pH of the samples was also determined according to the standard method of APHA (2005). The raw samples of KFW were placed in a 250mL of Duran and distilled water was added to the bottle in a ratio of 1:10. The Duran bottle was then shaken in an orbital shaker at 100rpm for 24h in room temperature. The pH of the solution was then measured.

Anaerobic Digestion Setup

The AD process was conducted using biomethane potential (BMP) method according to the procedures outlined by Owen *et al*., (1979) and Wid & Sualin (2018) with slight modification. 250 mL Schott Duran reactors were used, sealed with rubber stoppers to maintain anaerobic conditions. In total there were three sample bottles including shallots, cabbage and a control sample that contained only inoculum to create the resulting biogas formation that would be subtracted from the biogas production from the studied sample bottles (Figure 1).

Figure 1. The anaerobic reactors of shallots, cabbage and control samples used in this study

This study used the effective volume of 200 mL and ratio of 1.5:1 food waste to inoculum to increase the kinetic effect of biogas production (Selaman & Wid, 2019). The inoculum was used to maximise sample conversion into final products as it contains high number of microorganisms and bacteria present in the sludge. The reactors were placed in a water bath maintained at 37°C because it is a mesophilic temperature in the anaerobic digestion process and bacteria are very active at this temperature. The reactor was shaken daily to ensure an even temperature inside the reactor. The pH was controlled between 6.8 – 7.2 using sodium hydroxide (NaOH) and hydrochloric acid (HCl) (Li *et al*., 2024; Jiraprasertwong *et al*., 2019; Owen *et al*., 1979). Biogas production was monitored daily using water displacement method for 15 days (Wid *et al*., 2017).

RESULTS AND DISCUSSION

The determination of the physical properties is crucial in order to understand the organic and inorganic content of the sample to maximise the utilization of the sample during anaerobic digestion. This is also important to study waste reduction analysis after performing anaerobic digestion. While for pH, it is important to determine the value to make sure the anaerobic digestion process is carried out within the optimum conditions for anaerobic bacteria.

Total Solids, Volatile Solids and Waste Reduction

From this study, it was found that the initial total solids (TS) for shallots (before AD) was 19.9%, while cabbage had an initial TS value of 16.8%. After AD, these values reduced to 15.5% and 13.6%, respectively, indicating substantial degradation of the organic matter. Similarly, the volatile solids (VS) for shallots decreased from 88.1% to 21.0%, and for cabbage from 95.6% to 15.2%.

The initial TS values before AD indicate that KFW of shallots and cabbage were suitable to be used in AD. Recent studies have reported that TS contents between 15% and 25% support favorable microbial activity and biogas production, provided that VS content is sufficiently high (Akter *et al.*, 2021). However, some anaerobic digesters can handle total solids concentrations as high as 20% to 30% or more, depending on the type of digester and the specific substrate being used. According to Li *et al.*, (2024) TS content more than 8% is not only hindering dissolution but also leading to generation of antimicrobial by-products that significantly affect methane production. In addition, the increase in molecular weight of organic matter is an important reason for prolonging the start-up time of anaerobic digestion. While the high initial VS values indicate high organic content in the KFW samples. The reduction in TS and VS suggests the effectiveness of AD in breaking down organic materials. The higher initial VS in cabbage beans compared to shallots suggests that cabbage contained more organic material available for decomposition.

In terms of waste reduction, the TS values for shallots and cabbage were reduced to 15.5% and 13.6%, suggesting that 22.11% and 19.05% of waste reduction, respectively. While for VS, the organic content of shallots and cabbage reduced significantly with 76.14% and 84.14% reduction, respectively, after anaerobic digestion. This indicated that AD is able to reduce the amount of waste as well as stabilise organic wastes by degrading organic matter. This may divert waste from landfill, the most common disposal technique in Malaysia, by reducing the amount of waste sent to landfill. Consequently, preventing the release of greenhouse gases into the atmosphere. Similar VS reduction rates have been observed in recent studies on vegetable and kitchen waste digestion, where reductions above 80% are associated with high substrate biodegradability (Mehmood *et al.*, 2023; Mollah *et al.*, 2023). Additionally, the nutrient-rich digestate produced during AD can be used as fertiliser, further promoting sustainability by recycling nutrients back into the ecosystem.

Biogas Recovery from Kitchen Food Waste

The biogas recovery from kitchen food waste was measured over the 15 days of anaerobic digestion. Figure 2 illustrates the daily production of biogas from shallots and cabbage where biogas production from control was subtracted from both samples. Generally, there was a daily increase of biogas production from shallots and cabbage, with the highest production was 20mL and 7mL, at day 3 and 10, respectively. A high production at the early stage of AD for shallots primarily because of the rapid hydrolysis, acidogenesis, and methanogenesis of easily biodegradable carbohydrates in the food waste samples. Figure 2 also shows fluctuation in both samples which may tributed to the large fluctuation in the levels of methanogenic population bacteria, as volatile fatty acids were accumulated and then subsequently consumed. This may be due to the inconsistency of food waste composition or any sudden changes in pH values or carbon to nitrogen ratio during AD. Similar trends were reported by previous studies (Al-Wahaibi *et al.*, 2020; Griffin *et al.*, 1998).

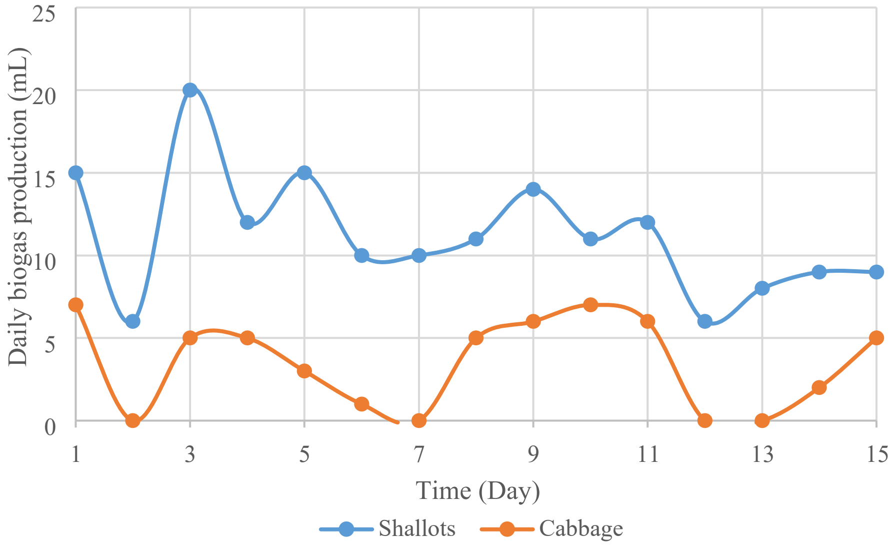

Figure 2. Daily biogas production of biogas throughout 15 days anaerobic digestion of shallots and cabbage

The cumulative biogas production is shown in Figure 3. The cumulative biogas production from shallots and cabbage were 168mL and 52mL, respectively. The cumulative production from shallots was higher than cabbage, and steadily increased until day 15, indicating that anaerobic digestion was not complete and still producing biogas. Therefore, it can be suggested that anaerobic digestion can be prolonged to allow more biogas production. The cumulative production from cabbage was lower, maybe due to suppression factors such as high fixed solid concentration and difficulty in digesting the composition present in the sample. This may also be attributed to the lower total solids content in cabbage, which may affect microbial activity and substrate instruction due to high moisture content. Shallots produced significantly more biogas (168 mL) than cabbage (52 mL), which is consistent with findings by Gulhane *et al.*, (2024), who noted that vegetables with higher carbohydrate content and lower acidity tend to produce higher methane yields. Overall, this finding shows both KFW samples were suitable to be used as a source for biogas recovery, though, the results were highly depending on the physical and chemical properties of the food waste substrates.

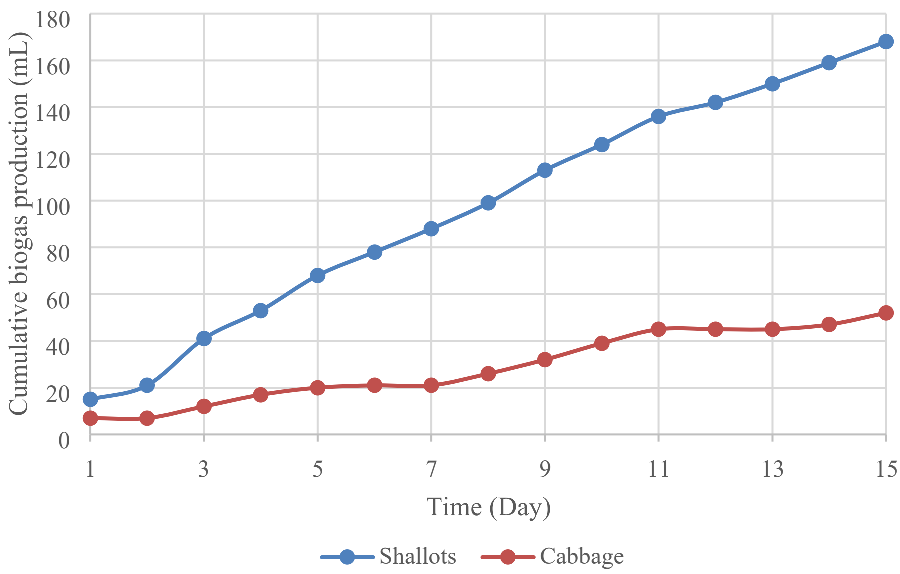

Figure 3. Cumulative production of biogas throughout 15 days anaerobic digestion of shallots and cabbage

CONCLUSION

Anaerobic digestion has drawn considerable attention due to its ability to convert waste into products. This study demonstrates the feasibility of biogas recovery from kitchen food waste over a 15-day anaerobic digestion (AD) period. The physical characterisation showed total solids (TS) and volatile solids (VS) contents of 19.9% and 16.8%, for shallots and cabbage, respectively, were within the optimal range for efficient anaerobic digestion, which supported by recent studies that this range is favorable for microbial activity and biogas production. Shallots produced significantly more biogas (168 mL) than cabbage (52 mL), which is consistent with previous findings, particularly for kitchen food waste with higher carbohydrate content. The reduction in total solids and volatile solids with 22.11% and 19.5%, as well as 76.14% and 84.14%, for shallots and cabbage, respectively, further supports the effectiveness of anaerobic digestion in breaking down and stabilising organic material. Overall, the results of this study underscore the potential of kitchen food waste as a renewable energy source. By adopting anaerobic digestion as a waste management strategy, this can reduce landfill waste, lower greenhouse gas emissions and promote sustainable environment. Future research should focus on optimising anaerobic digestion conditions, such as pre-treatment methods and co-digestion with other waste streams, to enhance biogas yields.

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