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Experimental investigation on the anaerobic digestibility of selected vegetable wastes for biogas production

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Abstract

Due to the inefficient transportation and inability to preserve those agricultural products can be rotten and wasted. As a solution, to determine the viability of the selected vegetable wastes co-digested with cow and pig manure as a feedstock to produced biogas. The experiment conducted in a batch-type anaerobic co-digestion process under the mesophilic condition for 30 days of digestion. Agricultural products such as cabbage, Chinese cabbage, and lettuce are mixed with cow and pig manure subject to different particle sizes of 2.00 mm, 4.00 mm and 6.35 mm. Based on the experiments, it was observed that the temperature of the digester over the 30 days digestion period was 28 – 31 °C. Moreover, the effect of smaller particle size shows the highest biogas volume production of 1733.70 ml than the other particle sizes. In addition, the carbon dioxide concentration recorded as 14 – 16%, as well as the hydrogen sulfide concentration of 6 – 18 ppm. Furthermore, the effect sodium hydroxide buffer solution improves the pH concentration of the substrate but it does not reach the required pH values for methane formation which is 7.0; and other vegetable wastes such as lettuce, cabbage resulted in the failure of biogas production due to ammonia inhibition that affects the methane production process. Thus, the biogas production from these wastes can be used as an energy source for cooking, heating, and power generation applications.

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Introduction

In the present day scenario, both the energy crisis and climate changes are the main issues all over the world. Due to the scarcity of energy supply throughout the world, some countries have been investing hugely in different corners to get access to the new sources of energy, like renewable energy instead of using underground fossil fuels. The use of fossil sources (crude oil, lignite, hard coal, and natural gas) as the primary energy source has led to environmental degradation, global climate change, and human health problems. Global climate change will inevitably lead to drought, flooding, and possibly global warming.

Despite rapid globalization, the Philippines is one of the third world agri-based countries. Among the total annual harvest, a significant portion of land is devoted for vegetable cultivation across the country. However, because of the inefficient transportation and preservation of the vegetables have been wasted, firstly in the land where it was grown and then in the public and private market as municipal waste. Due to their high moisture, high organic contents and biodegradability, the green wastes are major contributors to the emissions of greenhouse gases and volatile organic compounds. From the standpoint of pollution control, green wastes are not hazardous materials but their disposal in landfill poses serious environmental problems. Therefore, security of energy supply, especially development of sustainable energy and reduction of CO_2 emission are priorities on agenda worldwide. In this regard, biogas is a renewable energy resource appears to be one of the most efficient and effective solutions. It is carbon neutral colorless, flammable gas produced from animal, plant, human, industrial and municipal wastes amongst others, to give mainly methane (50-70%), carbon dioxide (20-40%) and traces of other gases such as nitrogen, hydrogen, ammonia, hydrogen sulfide, water vapor etc.

Biogas is produced by the decomposition of organic matter in the absence of oxygen. For typical biogas systems, this organic matter can include manure or plant substrates like crops waste, for example, vegetables. These inputs are fed into an anaerobic digester where microbes in the presence of heat and absence of oxygen break down organic matter and produce biogas (composed of methane and other gases). In addition to biogas, the solids that have been digested are also products of anaerobic digestion.

This study aims the management of the selected biodegradable wastes by converting it into biogas by determining the viability of the selected vegetablewastes as a feedstock to produced biogas; aside from that, the effect of varying particle sizes on various mixture proportions of the vegetable waste with cow manure in biogas production.

Materials and methods

Substrate preparation

This research addresses the performance and analysis of vegetable wastes with cow dung for biogas production. Also, to examine the performance of biogas by using reduction of particle sizes as shown in Fig. 1.

The waste materials were collected at West Bound, Carmen, Cogon, and Agora market. Vegetable wastes (comprising cabbage, lettuce, and Chinese-cabbage) for this study were collected from market vendors. The waste materials were hand-picked and utmost care was taken to ensure that just a particular type of waste will be used.

The cow manure was collected from Manresa Butterfly Garden (Nature & Wildlife) at upper carmen across SM City Uptown which was within Cagayan de Oro City vicinity. All manures were freshly taken from the area, tightly sealed to ensure safety during transport. Then used immediately due to the lack of chiller for storing slurries.

Each class of vegetable wastes (comprising cabbage, lettuce, and Chinese-cabbage) were cleaned. The cleaned samples were then weighed with the aid of a weighing scale by taking 1.5 kg of the municipal solid wastes, then mixed by 1.5 L of water. The mixtures and ratios are presented in Table 1.

As shown in Table 2, three different set-ups of particle sizes (comprising 6.35mm, 4mm, and 2mm) experiment, 1.5 kg of vegetable wastes were taken (consisting of 150 g each of cabbage, Chinese-cabbage, lettuce) and then cut using different sizes of grater hole to accomplish the reduction of particle sizes, then mixed by 750 g of cow dung and 750 mL of water.

Analysis of Data

The pH of the slurry was determined using a pH meter (digital). Moreover, the temperature of the ambient and inside digester was measured on daily basis using a microprocessor thermometer with a temperature Range -200.0 to 1370.0 °C; Resolution: 0.1°F or °C (up to 100 degree, after that 1-degree steps). Then, the water displacement method was used where the volume of water displaced into the empty plastic container equal the volume of biogas produced. The volume of water displaced was measured and recorded on daily basis. The gas produced is analyzed by the gas analyzer (Model: IRCD4). The manometer is attached in the digester for the water difference. The indicated height in the manometer will be used to calculate for its pressure. Water is used as fluid of the manometer. By getting the default density of the water, we can finally solve for the pressure using empirical formulas.

Results and discussion

Viability of the selected vegetable wastes as a feedstock to produced biogas

One of the goals of this study is to determine the viability of vegetable wastes as a feedstock to produced biogas.

The experiment conducted in 30 days retention time. The ambient temperature and the temperature inside the digester as shown in Fig. 2 was monitored and measured on a daily basis. It was observed that the temperature throughout the 30 days retention time was between 28°C to 30.9°C for ambient temperature and 27.4ºC to 30.2ºC inside the digester on the various substrate. According to Moset *et al.,2015*, the anaerobic digestion process can take place at mesophilic thermal stage ranged from 25°C - 45°C.

Table 1. The substrate used in the experiment of vegetable wastes with cow and pig manure.

Wastes	Mass (g)	Manure	Mass Manure (g)	Volume of Water (L)	Total mass (kg)
Vegetable	750	Pig	750	1.50	3.00
	750	Cow	750	1.50	3.00
	750	Cow and Pig	750	1.50	3.00

It was also observed that there are small changes in the temperature inside the digester than the ambient temperature daily. Deublein, and Steinhauser, 2011stated that small changes in temperature can cause a significant decrease in activity of microbial and gas production up to 30%; therefore, the temperature should be kept exactly in the range of +/- 2ºC.

Furthermore, a low value of pH was observed at the beginning of the experiment by measuring the vegetable and substrate, 5.3 for lettuce, 3.3 for cabbage, and 5.7 for Chinese cabbage. It was shown in Fig. 3 that the pH values of the Chinese cabbage are much higher than the pH values lettuce and cabbage. Throughout the 30 days digestion time, the pH values of all varieties of vegetable wastes are still below 6.0. In order to obtain the best-optimized condition for biogas production, where the methane-producing bacteria exist, the pH value of the input mixture in the digester should be between 6.0 and 7.0 (Aslanzadeh and Özmen, *2009*).

Further, it was observed that there is a difference between the pH values of the different slurries ranging from 5.4 – 6.8 pH. It was also observed that on the 2nd day of the experiment the pH values of all set-ups started decreases. Throughout the 30 days retention time, the pH values of all particle sizes and mixed slurries was still below to 7.0. Esposito *et al.*, *2012* indicated that pH values below 6.0 – 6.5 inhibit the methane archaea activity. It is also indicated, when large amounts of organic acids are produced at the beginning of the fermentation, the pH inside the digester might decrease below 5.0 (Aslanzadeh, and Özmen, *2009*). Since the digester has a high concentration of volatile acids the methane fermentation process in the digester will be inhibited and even stopped.

Table 2. The substrate used in the experiment of vegetable wastes with cow dung varying the effect of particle size.

Mass of vegetable wastes (Kg)	Mass of cow manure (Kg)	Volume of water (L)	Particle size (mm)	Total mass (Kg)
0.75	0.75	1.5	6.35	3
0.75	0.75	1.5	4	3
0.75	0.75	1.5	2	3

The medium with low pH (below 6.5) will have a toxic effect on the methanogenic bacteria. The pH is a parameter that provides information on the stability of the process of fermentation; its variation is to change of phase of the anaerobic digestion. In addition, the daily gas production was measured as shown in Fig. 4. For the experiment on the selected vegetable waste, it was observed that throughout the 30 days retention time Chinese cabbage got the highest total volume displaced of 432.8 mL followed by lettuce with 194.2 mL, and cabbage with 178 ml.

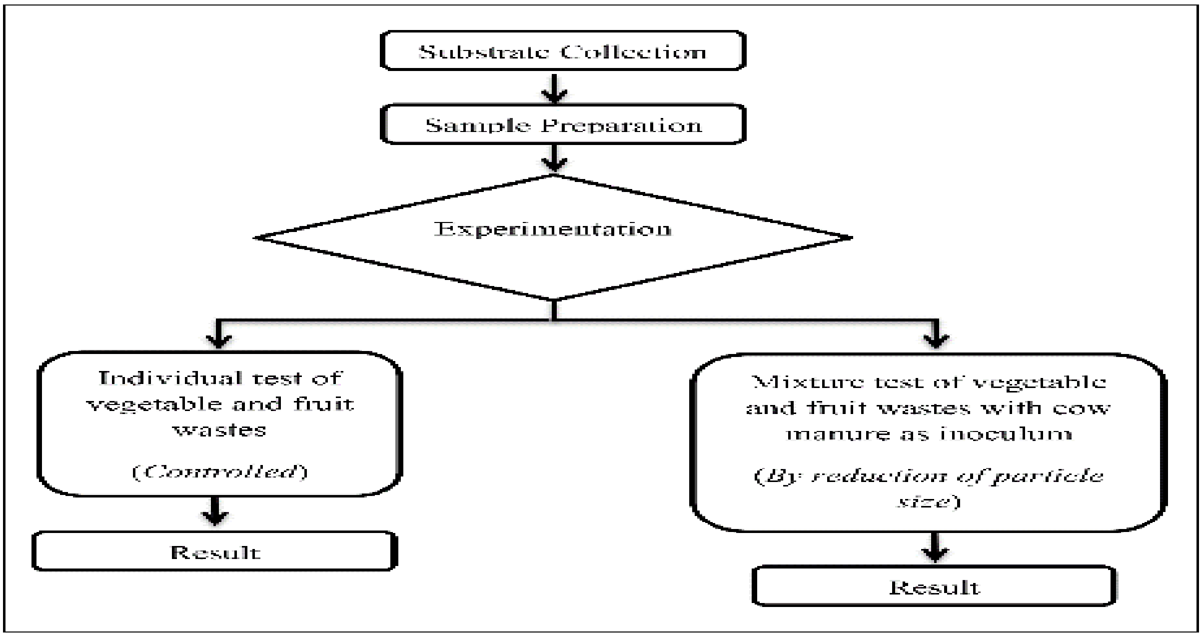

Fig. 1. Process flow chart implemented in this study.

There are types of substrates determines the rate of the digestion process, and lack of substrate ends the metabolism of the microorganism as well as determining the time of digestion since more complex substrate will take longer time for degradation by microorganism (Anti, *2012*). It suggests that all biological processes require sufficient supply of nutrients particularly carbon and nitrogen as well as other elements are also required in trace quantities (Anunputtikul, and Rodtong, *2004*). The lack of specific elements required for microorganism growth will limit the production of biogas. Nutrients are assigned by the ratio of carbon and nitrogen (approximate 20-30:1).

As shown in Fig. 5, the gas composition was measured for five (5) consecutive days prior the gas analyser malfunctioned due to water molecules affecting the gas detector. The substrate from vegetable wastes which produced the most abundant amount of carbon dioxide among the others was the Chinese cabbage.

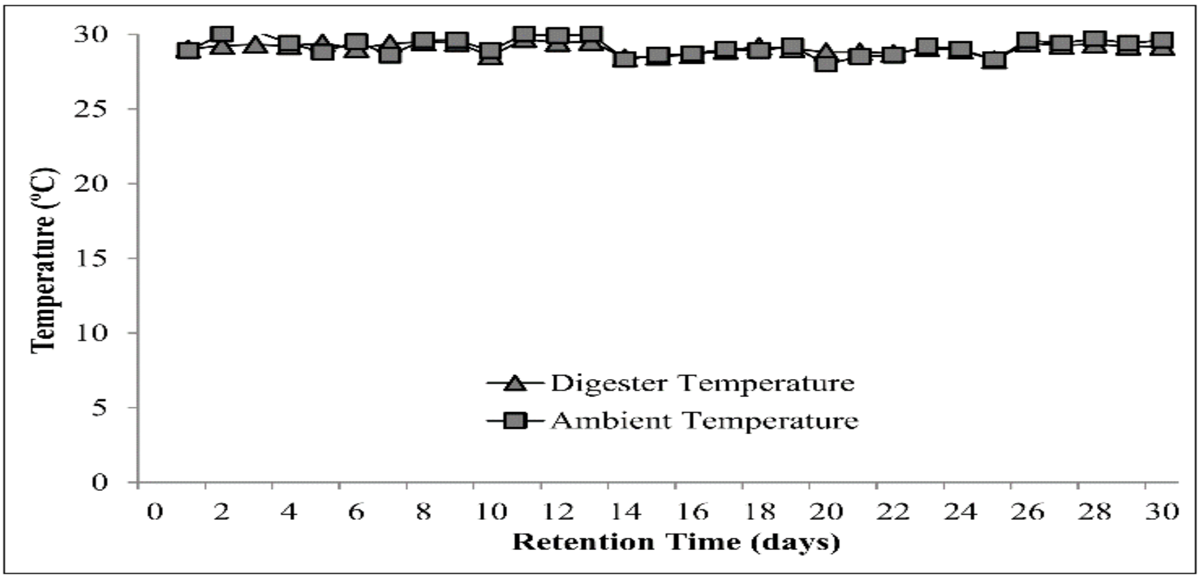

Fig. 2. The average temperature inside the digester of the vegetable wastes digester and the ambient temperature.

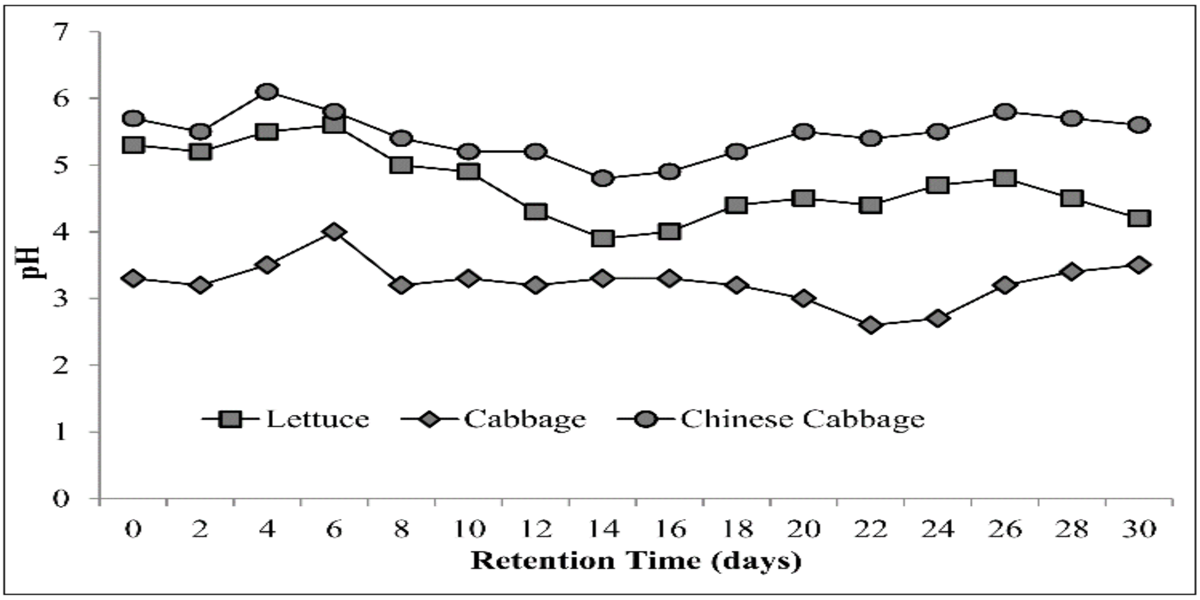

Fig. 3. pH values of each of the selected vegetable wastes.

It was observed from the previous result shown in Fig 5 that Chinese cabbage got the highest gas production than the other vegetable substrate.

It was also observed that there is a failure in methane production in all vegetable wastes substrate. It was shown in Fig. 3 that the pH value of all vegetable substrate is below 6.0. Further, the medium with low pH (below 6.5) will have a toxic effect on the methanogenic bacteria (Aslanzadeh, and Özmen, 2009).

Effects of reduction of particle sizes in biogas production

The ambient temperature and the temperature inside the digester in the vegetable wastes with cow dung set-ups varying particle sizes (comprising 6.35mm, 4mm, and 2mm) was also measured and observed in 30 days retention time are shown in Fig 6. Throughout the 30 days retention time, the temperature readings range from 28ºC to 30ºC. The experiment was conducted in the mesophilic thermal stage.

As shown in Fig 7, it was observed that there is a difference between the pH values of the different particle sizes. 6.35 mm particle size has the higher pH value of 5.9, followed by the 4 mm particle size which has the pH value 5.8 and lastly the 2 mm particle size which has the pH value of 5.6.

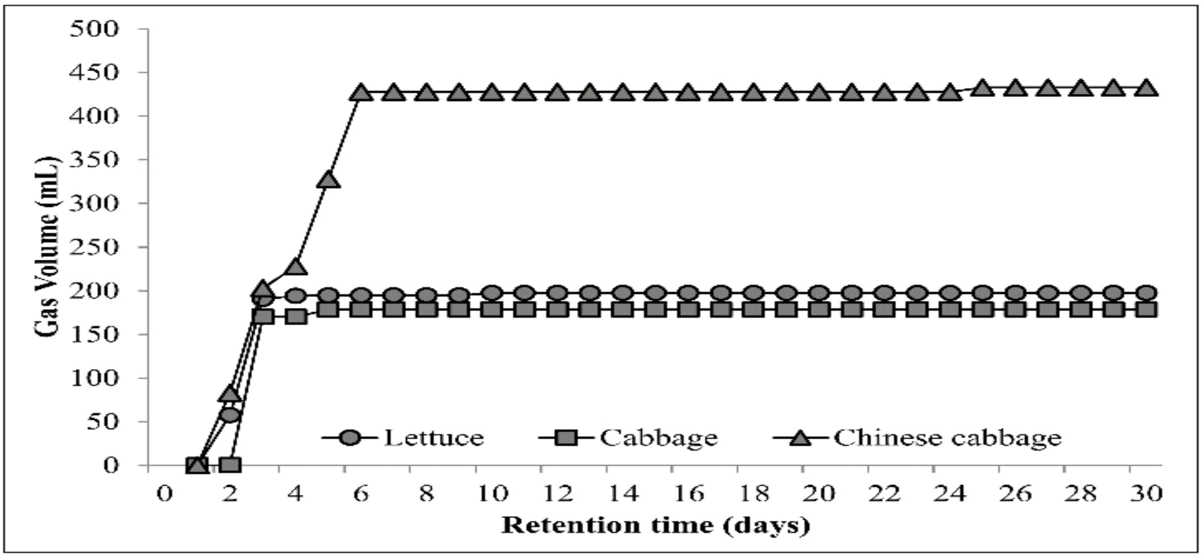

Fig. 4. Volume displacement of each of the selected vegetable wastes.

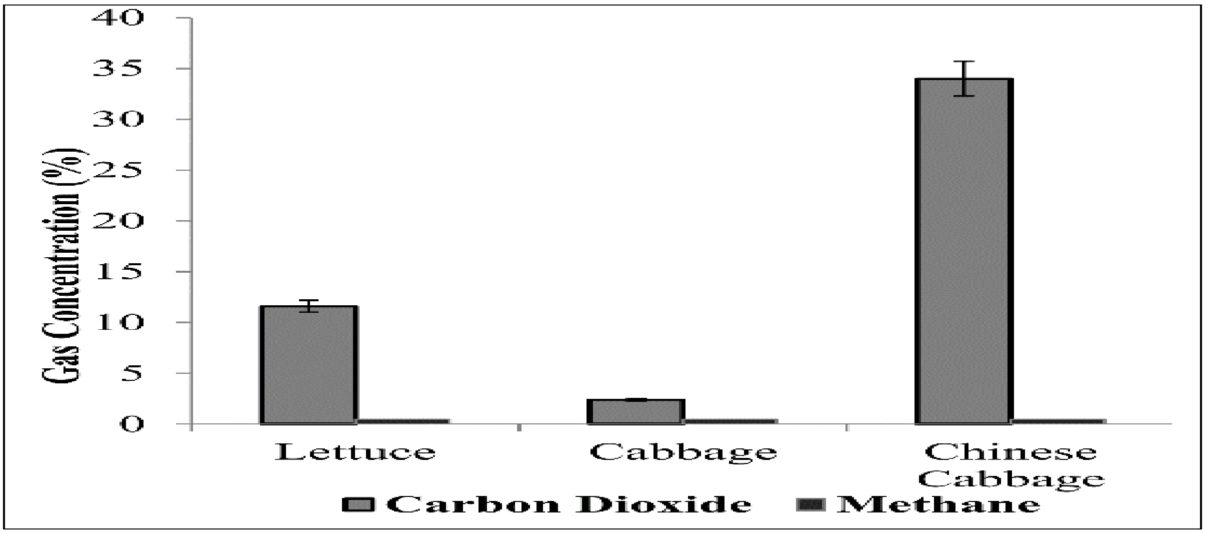

Fig. 5. Gas Concentration of each of the selected vegetable wastes.

It was also observed that on the 2nd day of the experiment the pH values of all particle size set-ups started decreases. Throughout the 30 days retention time, the pH values of all particle sizes experiment were still below 6.0. It was indicated that pH values below 6.0 – 6.5 inhibit the methane archaea activity (Esposito *et al., 2012*).

In addition, it was indicated that when large amounts of organic acids are produced at the beginning of the fermentation, the pH inside the digester might decrease below 5.0 (Aslanzadeh, and Özmen, *2009*). Since the digester has a high concentration of volatile acids the methane fermentation process in the digester will be inhibited and even stopped.

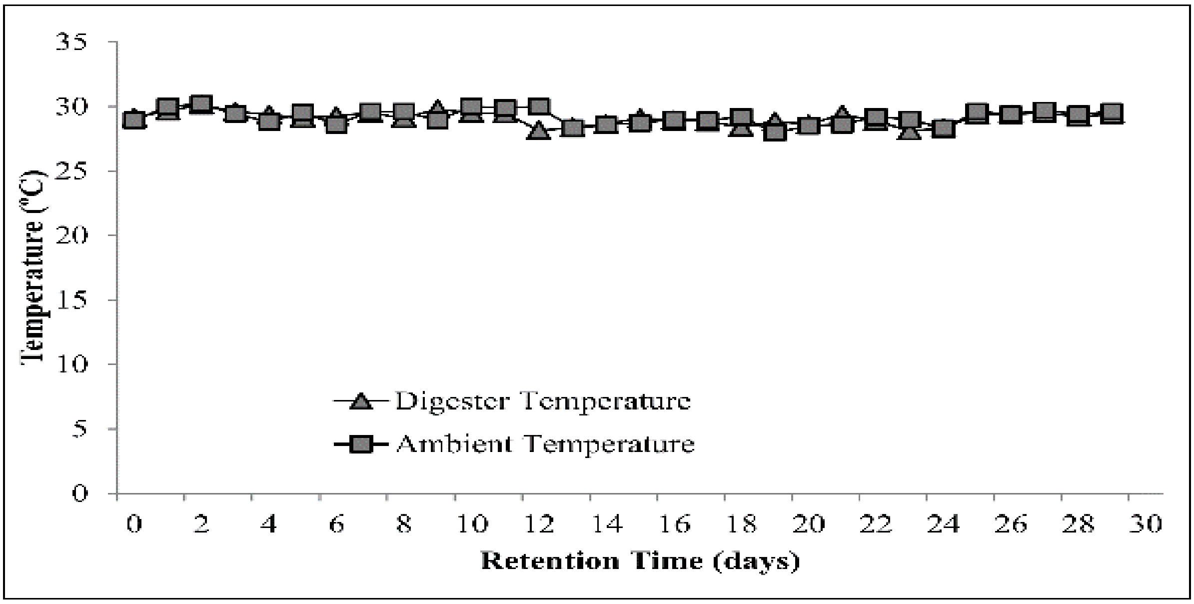

Fig. 6. The average temperature inside the digester of different particle sizes and ambient temperature.

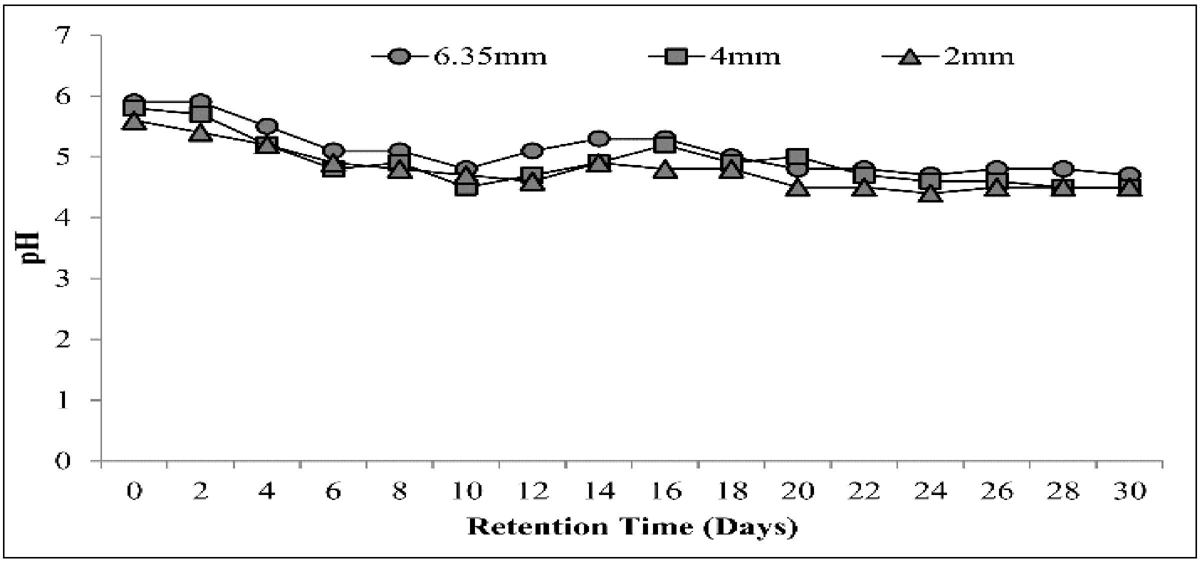

Fig. 7. pH values of different particle sizes.

The pH is a parameter that provides information on the stability of the process of fermentation; its variation is to change of phase of the anaerobic digestion. Mixed set up has a low pH. From the results from their study of Muyiiya, and Kasisira, *2009* shows that co-digestion of cow dung with pig manure increased biogas yield as compared to pure samples of either pig or cow dung. Comparing to samples of pure cow dung and pig manure, the maximum increase of almost seven and threefold was respectively achieved when mixed in proportions of 1:1.

The volume of gas produced on a daily basis was monitored and measured. Gas production began on the 2nd day for all particle sizes feedstock.

It was observed that there was a linear decrease in the gas produced from 4th to 30th day of the experiment.

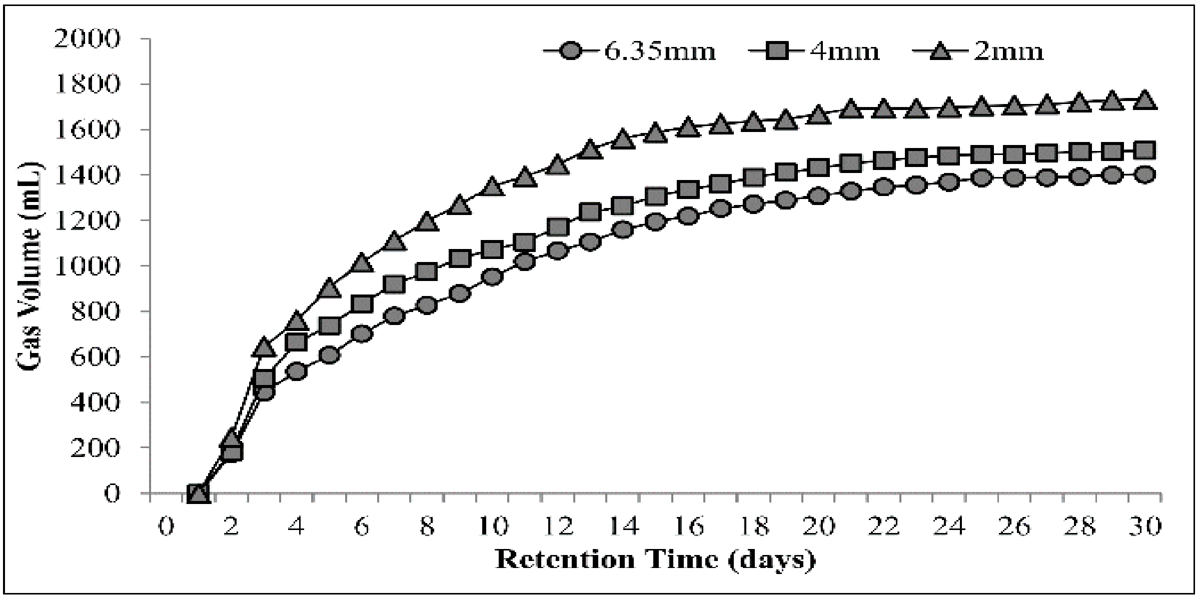

Fig. 8. Volume displacement of the particle sizes.

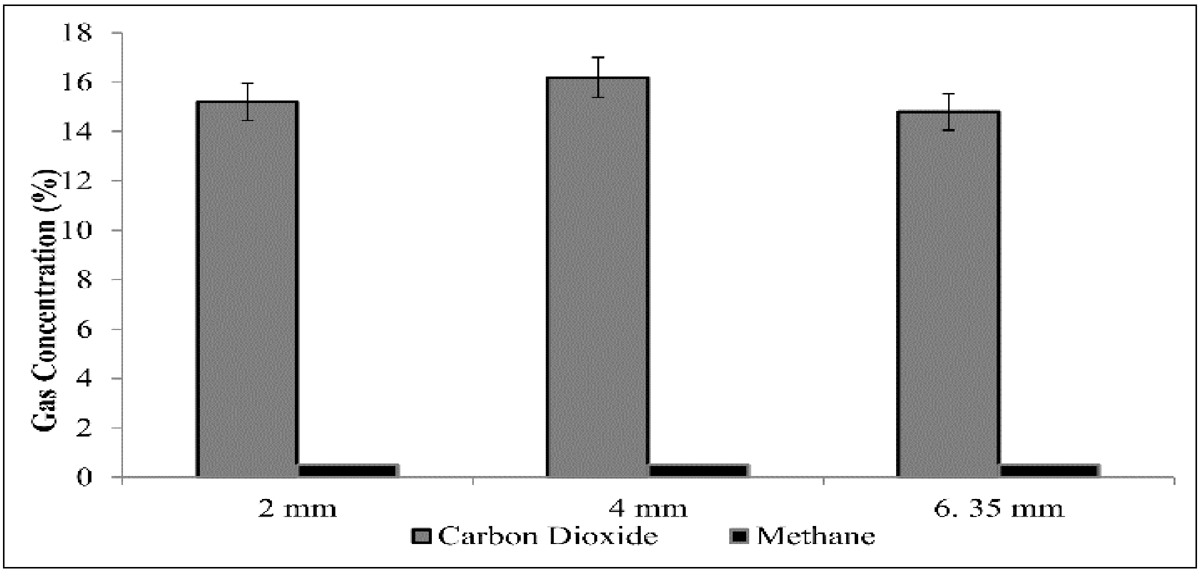

Fig. 9. Average Carbon Dioxide and methane at varying particle sizes.

Throughout the 30 days retention time of the experiment, it was observed that the smaller particle among the three, which is 6.35 mm got the highest total volume displaced of 1733.7 mL than 4 mm that got 1507.1 mL and 2 mm that got 1402.4 ml. Moreover, smaller particles would provide a large surface area for adsorbing the substrate that would result in increased microbial activity and hence increased gas production (Tenagne, *2016*). Furthermore, out of five particle sizes (0.088, 0.40, 1.0, 6.0 and 30.0 mm) as shown in figure 8, the maximum quantity of biogas was produced from raw materials of 0.008 and 0.40-mm particle size (Sreekrishnan, *et.al, 2004*). Large particles could be used for succulent materials such as leaves.

However, for other materials such as straws, large particles could decrease the gas production. The results suggested that a physical pretreatment such as grinding could significantly reduce the volume of digester required, without decreasing biogas production.

As shown in Fig 9, it was measured that 4 mm produced more carbon dioxide than 6.35 mm and 2 mm.

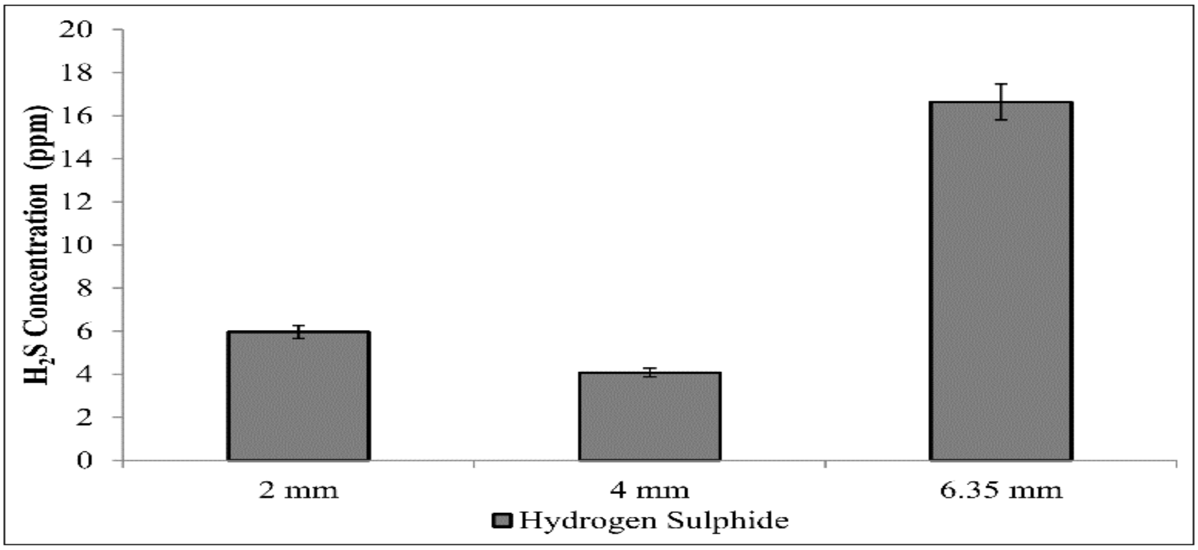

Fig. 10. Average hydrogen sulphide concentration at varying particle sizes.

The amount of carbon dioxide and volatile fatty acids produced during the anaerobic process affects the pH of the digester contents (Sreekrishnan, Kohli, and Rana, 2004).

It was also observed that there is a failure in methane production in all particle sizes due to the low pH values are shown in Fig. 7. The medium with low pH (below 6.5) will have a toxic effect on the methanogenic bacteria (Aslanzadeh, and Özmen, *2009*).

The graph in Fig 10., shows the result of the average hydrogen sulfide content in parts per million (ppm) in just 5 days due to the availability of the gas analyzer. The particle which produces the largest presence of Hydrogen Sulphide was the 6.35 mm particle size. The reason for the high H_2S content was the death phase of the bacteria resulted from nutrient depletion and high execution of methane in this reactor which lowers the conversion of the gas to form H_2S (Sebola, *et.al., 2015*).

Conclusion

Based on the data obtained and gathered through experiments, the following conclusions are derived. The viability of the selected vegetable wastes resulted in the failure of biogas production due to low pH values that have a toxic effect on the methanogenic bacteria. Followed by a pre-treatment of substrates by the reduction of the size of the particles has led to an improvement of the performance of the process results in an increase in the volume displacement. The smaller the particle the higher gas produced.

In order to guide or direct future studies of the study initiated, the following recommendations are being made, such as Keeping the pH values of the substrate in a neutral range condition for methane production by using chemically treated buffer system for strong acidification and ammonia-ammonium buffer system for weak acidification. Another study can be done on the reduction of particle size using another potential feedstock.

Acknowledgment

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