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Investigation of Biogas Production and its Residue with Fertilization Effect from Municipal Waste

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Abstract: This study was aimed to investigate the production of methane gas from three different types of food waste (vegetables waste, fruit waste and grain waste) using batch type anaerobic digestion method. The digestion process was conducted by using temperature range of 27 to 36°C and pH 6.5 to 7.5 to yield an optimum condition for the digestion process. The digestion was continued for a period of two weeks with the aid of cow dung as the inoculums. It was found that the grain waste yielded the highest methane 2546 mL due to the high content of carbohydrate. At the mean time, the fruit waste produced the second highest methane gas with 2000 mL as well as the vegetable waste generated the lowest methane gas with volume of 1468 mL. The vegetable waste produced the lowest methane gas because the vegetables waste contains high fibres and cellulose walls but low in glucose amount. For the fertilization test, fruit waste demonstrated the best observation for the growth of plant due to high content of potassium and followed by vegetable waste. The least effective fertilizer was grain waste due to less content of nutrients essential for plants growth.

Key words: Anaerobic digestion, biogas, municipal waste

INTRODUCTION

It is well known that municipal waste is one of the largest component occupied the landfill. Municipal waste is generated by households and industrial area which consist of food wastes, papers, unwanted containers and other solid wastes (Zain *et al*., 2011). In the early times, the disposal of human and other wastes did not cause a significant problem as the amount of waste generated was rather small compare to the land area available for the assimilation of waste. During that time, economists have defined waste as a material that is cheaper to throw than to reuse/recycle. At present, worldwide municipal solid waste generation is about two billion tons per year, which is predicted to increase to three billion tons by 2025 (Charles *et al*., 2009). In order to handle such large volume of waste generated by human being, many valuable forest lands have been cleared for landfill purpose. According to Elango *et al*. (2007), the modern societies are facing the space constraints and losses of valuable lands mainly due to landfilling occupancy.

Many methods can be employed for waste management. Gasification is a process where organic wastes are heated in an organic-starved environment to produce a medium or low calorific gas. Pyrolysis is a process where wastes are exposed to a very high temperature in the absence of air, causing the wastes to decompose. Lastly, incineration is a combustion process of organic matters in waste. It uses heat to convert the wastes into ash. Waste management using above techniques have been employed since very long time ago. The typical way of dumping waste to landfills contributes to climate change. The application of incineration, gasification and pyrolysis techniques in disposing waste could cause severe harmful impact to human health and environment by releasing acid gases, nitrogen oxides, lead, sulphur dioxide and etc. Meanwhile, the heating process as applied in theses technique also requires huge amount of energy usage and thus increase the cost. Landfilling and other waste management methods tend to harm the earth by polluting the air and water. Related to this, odour and taint issues are also a concern and these methods do not provide satisfied solution.

Since decades ago, the increasing of demands for petroleum fuels consumption and energy prices have increased attention of the society to develop alternative

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renewable energy technologies. Thus, conversion of waste into energy or also called as waste-to-wealth is believed to bring plenty of energy, environmental and public health benefits (Nouri *et al*., 2006). Hence, it is believed that cost can be saved and a green method can be applied. According to the case study as conducted by Golusin *et al.* (2012) on the form located Vizelj, Serbia, the profitability of the biogas electricity plant is acceptable and they suggest the biogas-to-electricity technology can be well applied in any corner of the world. Generally, anaerobic digestion method is one of the green methods that can be applied and use to manage waste. Ghani and Idris (2009) mentioned that anaerobic digestion is a method of decomposition of organic matters in the absence of oxygen to produce biogas as fuel gas and generates odour-free residues rich in nutrients. It produces a large scale of methane and small scales of other by products. Biogas with its main component methane (CH_4) and sub component of carbon dioxide (CO_2) is a gas which is produced from the digestion of organic matters and without the presence of oxygen (O_2). Basically, biogas is consisted of 48 to 65% of methane, 36 to 41% of carbon dioxide, up to 7% nitrogen, less than 1% of oxygen, 32 to 169 ppm of hydrogen sulphide and other gases emission (Ward *et al*., 2008). Biogas is defined as the by product generated during biological breakdown of waste and also known as swamp gas, marsh gas and Gobar gas which is the side product (Akinrinde and Lawal, 2006). Biogas is a high quality renewable energy source that can be substituted with other costly energies and needed for developmental activities. Biogas energy therefore can reduce cost and also generate power (Charles *et al*., 2009).

Up to date, few articles on the production methane gas by using various digestion methods have been published. However, none of these researches has been focused on investigating the different types of kitchen waste in producing biogas with anaerobic digestion method. The anaerobic digestion of waste is mainly to produce biogas and the mass residue after the digestion process also could be used as fertilizer (Bajwa *et al*., 2002).

MATERIALS AND METHODS

Materials: Three types of waste were used i.e. vegetable waste, fruit and grain waste (mixture of rice and bread). The vegetable and fruit waste were collected from the market in Genting-Klang area of Kuala Lumpur, Malaysia. Meanwhile, the bread and rice waste were collected from Pistachios Bakery and other restaurants in Genting-Klang area of Kuala Lumpur, Malaysia. Each waste was weight around 3 kg and was collected according to grab samples method from the Standards Methods for the Examination of Water and Wastewater. Grab samples are single samples collected at a specific spot over a short period of time. Sodium hydroxide (NaOH) with the purity of 99% was supplied by PROCHEM. Polyethene tarpaulin with the mesh size 16×11, weight 170 g m^{-2} was supplied by Kong Hui Canvas Manufacturer and nitrogen gas grade with purity of 99.5% was supplied by MOX-Linde Gases. Cow dung was used as inoculums in this study. Cow dung was collected from a cow farm in Sentul Farm, Kuala Lumpur, Malaysia. Cow dung was collected only during the day of experiment to provide fresh inoculums for efficiency purpose.

Design of anaerobic digester: A 8 L batch type anaerobic digester was constructed using a plastic container with two openings as shown in Fig. 1. The openings of the digester were drilled and fixed with valves. The first opening was specialized for nitrogen gas purging purpose. The other opening was drilled to enable the biogas to flow out from the digester. The opening was connected with a 1 cm diameter rubber piping to a container. Nitrogen gas was purged to fill up the whole system. The container was further connected to a water container where the methane gas pushes the water into the last container to show the level of methane was produced.

Sample preparation: The waste collected were sorted and chopped into smaller sizes to allow ease of bio-degradation and also to reduce chocking problems. Collected wastes were refrigerated until the experiment started to avoid decomposition by the bacteria at early stage. Two kilo gram of each types of collected sample were weighted and mixed with 1 L of inoculums and 1 L of water.

Fig. 1: Design of anaerobic digester, 1: Digester (V = 8 L) capacity, 2: Feed inlet, 3: Gas opening, 4: Water displacement jar, 5: Gas outlet and 6: Measuring jar

Anaerobic digestion process: The mixed sample was fed into the digester and the pH of the mixed sample was measured with a pH meter. The pH of the mixed sample was monitored in the range of 6.5 to 7.5 by adding sodium hydroxide. Then, the digester was sealed and covered with polyethylene tarpaulin. After that, the sealed digester was purged with gas nitrogen for 20 min to eliminate the presence of oxygen in the digester. Oxygen molecules were avoided from entering the system to provide anaerobic condition. In addition, the purged digester was connected to the container filled 3 mol dm^{-3} sodium hydroxide (NaOH). The purpose of sodium hydroxide is to dissolve all gases such as carbon dioxide and all hydrogen sulphide (H_2S) which passed through the container. The digester was operated at room temperature varying from 27-36°C. This was the optimum condition for the anaerobic digestion for high biogas generation (Chua *et al*., 2008). From the waste feed onwards, the methane generation was monitored. The digester tank was shaken for 1 min once a day to provide stirring aid for optimal methane production. The volume of methane produced during the decomposition of the organic wastes was determined by measuring the volume of water displaced in the measuring cylinder.

Fertilization process: The residues in the digester after two weeks were examined for fertilization purpose. The residues from the digester were dried using a tray dryer with model Lotus Scientific (LS-32008, 220/415 VAC). Initially, the fruit waste was evenly spread on the tray and dried at 65°C for 10 h. Then, the dried waste residues was placed into a blender and blended into smaller units. The blended and dried waste residues were used as fertilizers. These fertilizers then were used for the plants. These procedures were also repeated for both vegetable and bread waste. Each fertilizer was used for one plant respectively. Thus, there were three plants representing each waste with another plant used as control. The plants were fertilized once a week and watered twice per day while the control plant was watered the equal amount without any fertilizers added. In total, there were four plants and their growth was compared.

Scanning electron microscopy (SEM): The surface of fresh wastes (vegetables, fruit and grain) was observed and scanned using a Hitachi Scanning Electron Microscopy with model of BS 340 TESLA. With the aids of SEM, the morphology of different types of fresh waste were compared and related to the yield of biogas. Initially, the waste samples were cut into smaller pieces and then these samples were placed and mounted onto the copper stub with the surface is facing up. Before the SEM testing, the samples were coated with gold using EMITECH SC7620 Sputter Coater for three to four minutes and it was ready for scanning. The samples were scanned under the magnification of 8500×with the electron beam voltage of 15 kV. Papaya, rice and spinach were chosen as representation of the fruit, grain and vegetable waste respectively. The morphology of each waste was observed and compared.

RESULTS AND DISCUSSION

Methane production from waste: The methane gas production from the various types of waste using anaerobic digestion method was showed in Fig. 2. According to Fig. 2a, the production of methane gas for grain waste has reached the highest on the Day 3 of fermentation in compared to fruit and vegetables waste with 1032 mL of methane gas. Fruit waste produced the second highest of methane gas amount on Day 2 of fermentation with 610 mL of methane gas, while the vegetable waste showed the lowest amount of methane production. In this study, a combination of rice and bread waste was used to prepare the sample for grain waste. Basically, the grain waste contains a high level of carbohydrates which are complex substances with long chain hydrocarbon. At the early of anaerobic digestion (Day 1 and Day 2), the hydrolysis process would take place to convert the carbohydrates with long chain hydrocarbon into sugar or monosaccharide with smaller chain hydrocarbon (Linke, 2007). The sugar was further transformed into intermediate products such as acetic acid, propionic acid butyric acid and ethanol. The cleavage of acetic acid molecules during the digestion process could generate carbon dioxide and methane gases (Arsova, 2010). The high hydrolysis of grain waste could also produce more methanogens (methane producing bacteria) to assist the digestion process (Holm-Nielsen *et al*., 2009). The methanogens are very helpful in producing the biogas from the acetate. Thus, the amount of methane produced was directly proportional to the amount of carbohydrate and consequently, the grain waste could produce higher amount of methane gas in compared to fruit and vegetable waste. This result was also found to be consistent with the study conducted by Diaz *et al*. (2008), where they observed that the waste with high carbohydrates produced the highest methane gas. Besides that, they also observed that the waste with high carbohydrates could produce the highest biogas amount at the first three days of fermentation.

On the other hand, papaya, pineapple, mangoes and bananas were the fruits contained in the waste of this

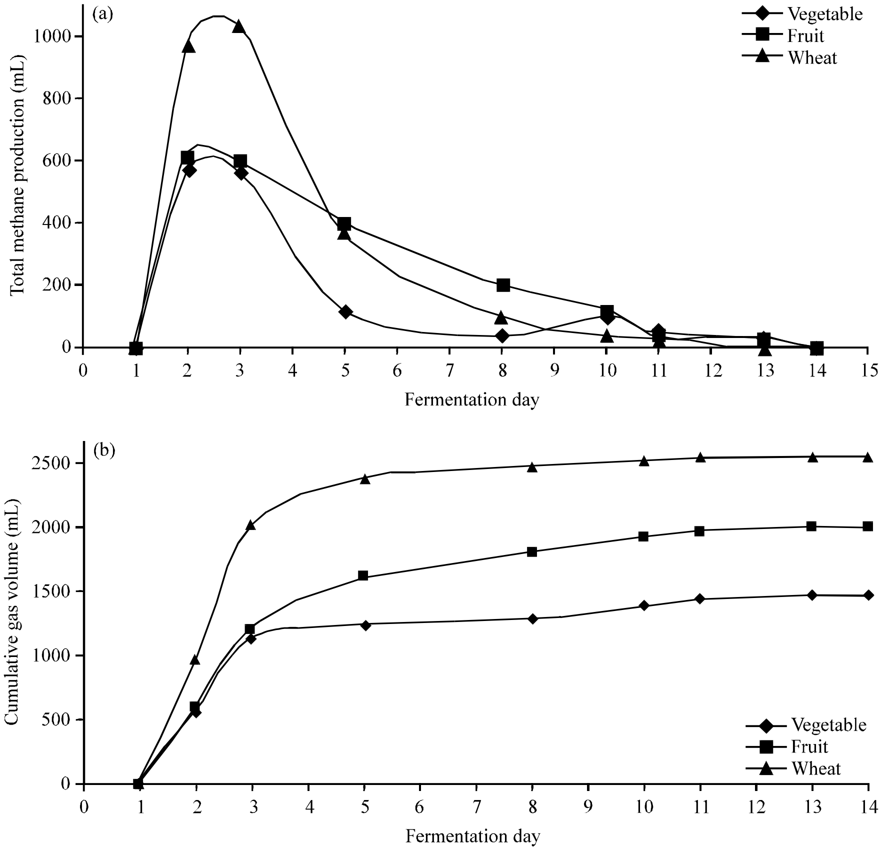

Fig. 2(a-b): (a) Total daily amount of methane gas produced from grain, fruit and vegetable waste and (b) Total cumulative methane gas volume produced from grain, fruit and vegetables waste

study. Fruit waste contains a low amount of carbohydrates and natural glucose. The low carbohydrates amount in fruit waste caused the fruit waste to generate a lower amount of methane gas than the grain waste. The occurrence of natural sugar in fruit waste also contributed to better digestion than vegetable waste with the aid of acetogenens (bacteria which digest sugar into simple organic acids, carbon dioxide and hydrogen) (Sagagi *et al*., 2008). As discussed earlier, the cleavage of the organic acid (acetic acid) could generate the methane gas. On the other hand, the vegetables waste that was used in this study was consisted of tomatoes, onion, spinach, cucumber and brinjal. Vegetable waste mainly contains high in fibres and cellulose but very low in carbohydrates and glucose which consequently lead to lower production of methane than grain and fruit waste. After that, the production started to decrease in further digestion process. From Day 8 to Day 11 for fermentation, the production of methane gas for vegetable waste was marginally increased again as shown in Fig. 2a. This was attributed to the digestion of fibre and cellulose in vegetables waste which needed longer time to breakdown into simpler units (Diaz *et al*., 2008; Sagagi *et al*., 2008; Mshandete *et al*., 2004; El-Mashad and Zhang, 2010). By referring to Fig. 2a, the production of methane gas for all types of waste was gradually decreased from Day 4 to Day 14 of fermentation. This is due to most of the content in waste had been utilized and digested during the beginning of digestion process. Thus, the production of methane gas has been reduced. From Fig. 2b, the cumulative methane gas production for all types of waste was rapidly increased from Day 1 to Day 3. As observed in Fig. 2b, the increment rate of cumulative methane gas production for all types of waste was greatly reduced from Day 3 to Day 11. However, the increment of cumulative methane gas production for all types of waste was observed to be insignificant. The cumulative methane gas of grain, fruit and vegetable waste on Day 14 was found to be constant at a total volume of 2546, 2000 and 1468 mL, respectively. As discussed in earlier, the grain waste sample contains a very high amount of carbohydrate which contributed to methane production.

Thus, the grain waste provided the highest value in cumulative methane gas volume. The total cumulative of fruit was found to be the second highest due to natural sugar content in fruits as mentioned earlier. The high fibre and cellulose content and low carbohydrate and glucose content in vegetable waste had contributed to low yield of methane as this waste need longer time to digest.

All the three wastes have a rapid production of methane at starting of the digestion period (Day 1 to Day 3) as showed in Fig. 2. After that, the methane production rate was gradually decreased after day 3 of fermentation. This could be attributed to most of the carbohydrate and glucose in the waste had been digested. Beside that, for batch type fermentation process, the inoculums and waste were only fed into the digester once in the beginning of the process. Thus, the aid of inoculums was very significant at the beginning of fermentation process. Hence, the digestion process was rapid and intense during the first five days for all the types of waste. The inoculums which consisted with a lot of methanogens which could help the digestion process by converting the complex structures into simpler ones as mentioned earlier. At Day 2 of fermentation, the inoculums (methanogens) have entered exponential growth phase by multiplying rapidly and reached a maximum growth rate (Shuler and Kargi, 2002). After 4 to 5 days, the amount of methanogens reduced momentously causing the methane production to reduce as well. This is due to the inoculums reached a stationary state where they were stopped from growing, eventually caused the digestion rate to decrease. Shuler and Kargi (2002) also reported such observation where the amount of methane produced was proportional to the amount of inoculums left. Furthermore, the inoculums have reached the death phase from Day 9 to Day 14. This was attributed to the depletion of waste substrates or toxic product accumulation in the digester which could lead to lower the pH of the waste to acidic. Since the inoculums used for anaerobic digestion are very sensitive to pH change, the lowering of pH to acidic could kill the inoculums and thus diminished the methane production (Chua *et al*., 2008).

Morphologies observation: Figure 3 shows the overall surface morphologies of a sample of rice with the magnification of 300 and 10000 times, respectively. The cook rice surface structure was observed to be uneven where the agglomeration of starch is rapid on the surface. The starch which contains high carbohydrates had contributed to the massive production of methane gas. The structure of rice also observed to be porous like the structure was magnified to 10000 times as in Fig. 3b. These porous could increase the water absorption into

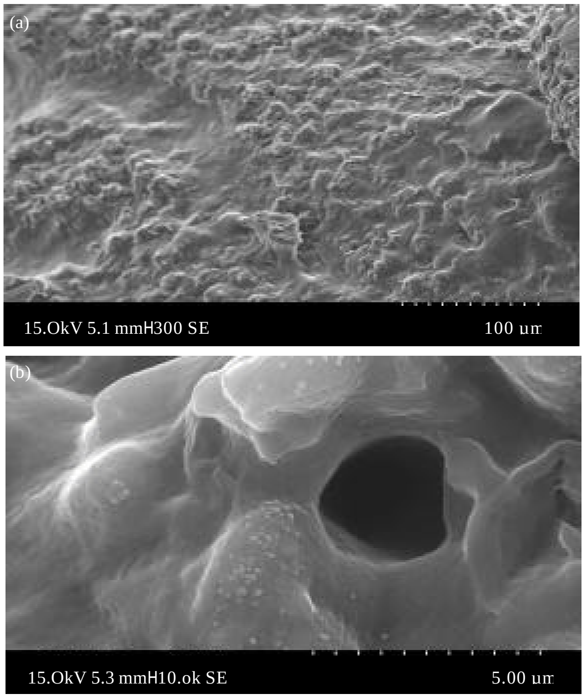

Fig. 3(a-b): Surface morphology of rice under magnification of (a) 300 times and (b) 10000 times, respectively the rice structure and further ease the inoculums to enter deep into the rice wastes and consequently the inoculums could consume the carbohydrate of the waste easier and then convert it into simple form. The water absorbed into the porous region ultimately weakens the strength of the structure. Thus, this could further enhance the digestion of inoculums.

In this study, papaya analyzed to find out fruits surface structures as shown in Fig. 4. By referring to Fig. 4a, the surface of papaya contains small porous regions. Such porous structure will enable the inoculums and water to penetrate depth enough to induce the occurrence of digestion process. In other words, this porous surface has further increased the total surface area that the digestion process would take place. Thus, the methane gas production of fruit waste can be optimized. Meanwhile, the surface structure of vegetables waste (spinach) was observed to be consisted of an uneven fibres and cellulose wall structure which are thick and strong as shown in Fig. 5. The cellulose wall of vegetables waste was observed to be thicker than the cellulose of fruit waste, which it could slow down the digestion of the inoculums (Babaee and Shayegan, 2010). Thus, the vegetables waste needed longer time for digestion. Besides, there are no porous regions were observed on the surface structure of vegetable waste and the inoculums had been prevented to enter the spinach structure and digest the waste.

Fertilization test: In this study, the residues from the anaerobic digestion were further used as fertilizers after being dried and blended. *Lxora coccinea* is the species of the plants used for fertilization test. The digestion residues from different wastes were used to fertilize these three plants respectively while a plant was used as control. At the beginning of this test, all the plants were approximately the same height and branching. After one month fertilization process, the total growth and branching of plants was observed and recorded in Fig. 6 and Table 1. Among all the plants, the plant which was fertilized by fruit waste showed the highest growth of 15 cm and branching. The growth of vegetable fertilized plant demonstrated the second highest reading with 11 cm

Table 1: Total Growth of Plant after 1 Month Duration

Plants	Height obtained after 1 month (cm)	Branching obtained after 1 month
Fruit waste fertilized	15	High
Vegetable waste fertilized	11	Moderate
Grain waste fertilized	7	Low
Control (not fertilized)	5	Low

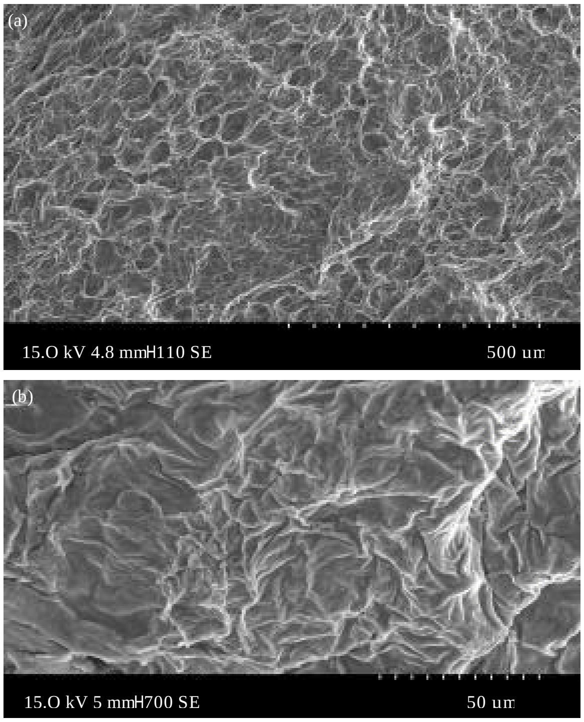

Fig. 4(a-b): Surface morphology of papaya under magnification of (a) 110× and (b) 700× respectively

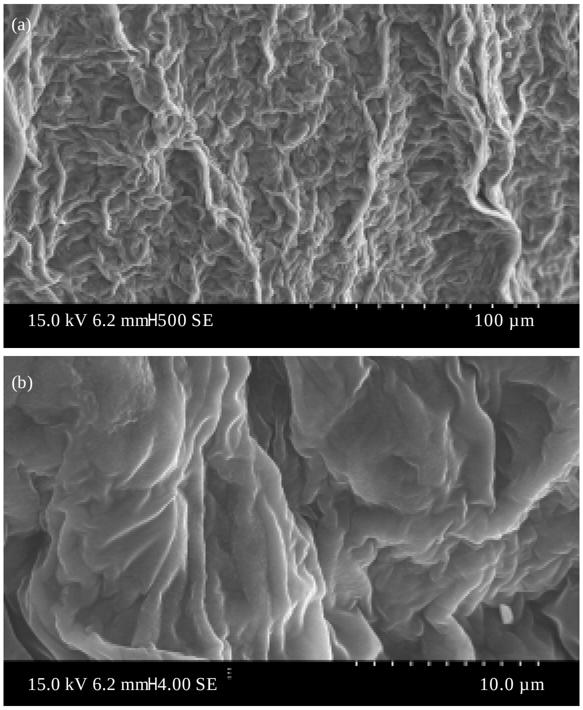

Fig. 5(a-b): SEM observation of spinach leaf under magnification of (a) 500 x and (b) 4000 x, respectively

Fig. 6(a-b): (a) Initial growth and branching of plants and (b) Final growth and branching of plants for one month duration with moderate branching while the grain fertilized plant showed the smallest growth with 7 cm and low branching. It is postulated that the residue of fruit waste consisted with the highest potassium, calcium and zinc in compared to the residues of vegetables waste. Thus, the plant growth and branching of fruit waste fertilized plant was better and higher than vegetables waste fertilized plant (Olowolafe, 2008). According to Olowolafe (2008) and Hart *et al*. (1997), the plant growth is mainly contributed by up-taking of potassium, calcium and zinc. The absence of potassium and calcium in the residue of grain waste (rice and bread) had led to the lacking nutrients in helping the growth of plant. Hence, the grain waste fertilized plant showed the lowest plant growth and branching.

CONCLUSION

In conclusion, grain waste had produced the highest methane gas production with 2546 mL of methane gas. The fruit waste produced the second highest methane gas with 2000 mL while the vegetable waste generated the lowest methane gas with volume of 1468 mL. The highest production of methane gas was contributed by the highest amount of carbohydrates and sugar in grain waste. For the plant fertilization test, the fruit fertilized plant showed the highest plant growth of 15 cm and also branching due to high potassium, calcium and zinc nutrients in residue of fruit waste. Vegetable fertilized plant showed the second highest in plant growth and moderate branching. It is postulated that the lack of potassium and calcium in residue of grain waste had led to the lowest plant growth and low branching.

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