LAB SCALE BIOGAS PRODUCTION FROM MARKET WASTES AND DAGORETTI SLAUGHTERHOUSE WASTE IN KENYA

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ABSTRACT: *In this study, fruits and vegetable market wastes were used as substrates in biogas production under psychrophilic, mesophilic and thermophilic conditions. Slaughterhouse waste consisting of blood and diluted rumen fluid mixture was used as inoculum with seven days retention time. Influence of C: N ratios of the unique mixtures of vegetables found in the market were investigated. On average, the vegetable wastes found at the market contained >86% moisture, 5 - 12% volatile solid and 0.46 – 2.06% ash matter on a wet basis. The protein range was between 0.57 – 3.49% with high-fat content being recorded in avocado (Persea americana) wastes at 9.03%. The highest cumulative biogas was recorded in wastes mixture at 3500ml on seventh day while low biogas yield was registered for wastes with C: N ratios greater than 35:1 like avocado and lower than 10 like coriander and courgette wastes. The optimum operation pH was in the range of 6.80 – 7.2.It can be concluded that the highest cumulative biogas was generated from fruits/vegetable mixture at 3500ml in mesophillic conditions. This study recommends pH adjustment to 6.8 – 7.2 in market wastes and C: N ratios of 20 – 25 for large scale biogas production of wastes found in the Dagoretti Market.*
KEYWORDS: biogas, market wastes, inoculum, proximate properties

INTRODUCTION

Food wastage occurs in any stage of production, from pre-harvest to post-harvest losses at some point in processing, distribution, retailing and consumption and is estimated to be around 1.3 billion tonnes (Banks *et al.,* 2018). Food waste is either avoidable or unavoidable. The unavoidable waste comprises of un-consumable elements, (for example, shells, bones and strips) (Bellemare *et al.,* 2017; Chaboud and Daviron, 2017). The nature of fruits and vegetables makes them deteriorate fast producing a foul odor (Velmurugan and Alwar, 2011). The EU Parliament and the Member States endorse that the definition of food loss and waste to encompass both edible and inedible meals cloth. They outline food waste as meals meant for human intake, both in fit for human consumption or unfit popularity, withdrawn from the manufacturing or supply chain (EU Parliament, 2017; CEC, 2017). Banks *et al.,* 2018 reported that there has been improvements in market trends to preventing and minimize food waste.

Anaerobic digestion offers the quality possibilities for fruits and vegetable waste management and energy recoveries and therefore, it is the primary method considered in instances of market wastes. This is advised by the high levels of moisture and organic matter in these wastes (Velmurugan and Alwar, 2011). The theoretical methane capability of a feedstock may be predicted from the biochemical and elemental compositions of a substrate from the proximate and ultimate analysis. The biochemical composition study is explained in the IEA Bioenergy 2018 record based on batch

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examination for dung gas capability evaluation (Weinrich *et al.,* 2018). The methane potential of these wastes can be calculated based on the organic matter fraction in them. The calculations are based on the equation 1(Angelidaki and Sanders, 2004). The fractions of proteins, carbohydrates and crude fats are quantified as per the analytical procedures.

$$BMP_{CHNO} = 415 * \%carbohydrates + 496 * \%proteins + 1014 * \%lipids \ldots\ldots (1)$$

Pengfei *et al.,* 2018 reported that there is little work done on quantification and modeling of biochemical methane potential of fruits and vegetable wastes. They also noted that that little is known on the kinetics of fruits and market waste degradation.
The current method of dealing with waste is by using old fashioned psychrophilic anaerobic ponds. Nearby, there is a big market with vegetable waste. If a biogas digester can be built to utilize this market waste and abattoir waste, biogas which can be used for heating, and fertilizer for agriculture use be obtained. Therefore, in this study, biogas was recovered from twenty different market wastes using rumen fluid as inoculum at mesophillic temperature range. The influence of pH, C: N ratio and temperature were also investigated.

METHODOLOGY

Sampling

The feedstock used in this study was obtained from Kangemi market and Wakulima market in Nairobi County while slaughterhouse waste was obtained from Dagoretti slaughterhouse in Kiambu County. The sampling sites are shown in figure 1.

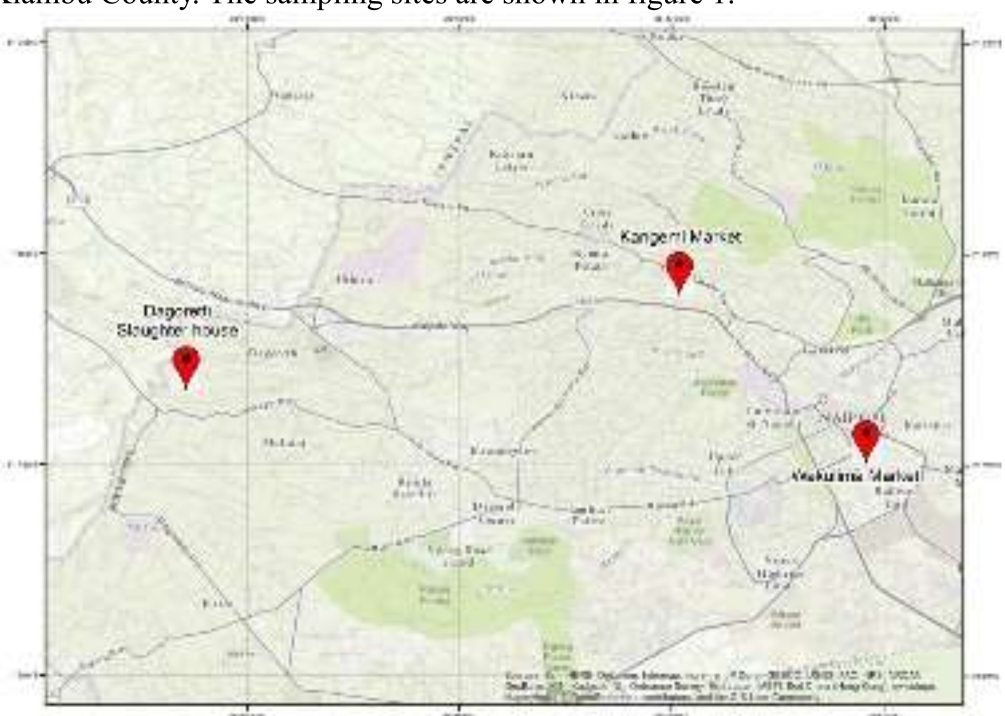

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Figure 1: The sampling sites map

Analytical analysis
Ash, moisture and fiber contents were determined using AOAC method (1990). Fat, crude nitrogen and protein contents were determined using Soxhlet extraction and Kjedhal methods described in Pearson (1976). Energy content was carried out as per the AOAC method described by Onwuka, 2005) while Renewable technologies (2005) method (Onwuka, 2005) was employed in determination of total and volatile solids. The pH was measured using a portable digital pH meter.

Biogas production

About 200ml of blended cabbage (*Brassica oleracea capitata*), Coriander (*Coriandrum sativum*.), Spinach (*Spinacia oleracea*), Kales (*Brassica oleracea acephala*), Papaya (*Carica papaya*), Pumpkin Leaves (*Cucurbita maxima*), Kahurura (*Cucumis ficifolia*), Pigweed (*Amaranthus spp*.), African Nightshade (*Solanum nigrum*), Togotia (*Erucastrum arabicum*), comfrey *(Symphytun officinale)*, Banana (*Musa spp*), Avocado (*Persea americana*), Sweet Potato (*Ipomoea batatas*), Cucumber(*Cucumis sativus*), Watermelon (*Citrullus lanatus*), Tomato (*Lycopersicon lycopersicum*), Potato (*Solanum tuberosum*), Mango (*Mangifera indica*) and Courgette (*Cucurbita pepo)* were loaded into the biodigester shown in figure 2. The rumen fluid inoculum (200ml) was added to the wastes and biogas production initiated at mesophilic conditions. The operating pH and the temperature were varied as stated.

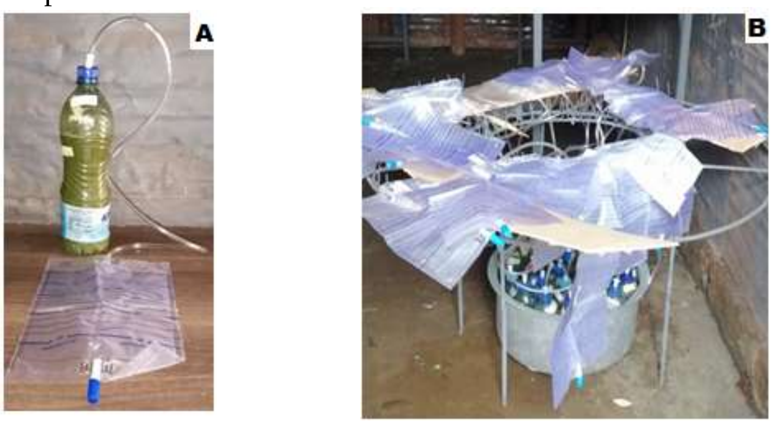

Figure 2: Biogas production setups (a) digester fitted with a urine bag (b) water bath setup
The setups in figure 2(a) were immersed in a sufuria with water, and the temperature maintained at 37^{0}C for the entire retention time. The cumulative biogas produced was recorded daily for seven days. The experiment was run in triplicate and the mean used in plotting the graphs using Minitab 17 or origin 8 statistical software or Microsoft excel 2013-2016.

RESULTS AND DISCUSSIONS

The total solids and degradable solids of the digestible portion of the market waste were found to be in the range of 4.14 - 37.95% and 4.64 - 36.89% respectively for the wastes on a fresh weight basis as shown in appendix table 1. Similar results had been obtained for vegetable wastes as reported in Pengfei *et al.,* 2018. The moisture content in tomatoes was in the range of 84.30 – 95.16%. Similar results had been obtained for tomato fruits by Wei *et al.,* 2014 who reported moisture content of 82.69%. Further, the pH of all the fruits and vegetables was in the brackets of

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4.87 – 7.32 which agreed with some previous results obtained for similar substrates observed by Xue *et al.*, 2015 observed at 3.98 -7.54. The degradable matter was relatively high based on the carbohydrate levels obtained in this study. The time series obtained when cumulative biogas produced was plot against retention time for room temperature biogas production is shown in figure 3. The trend was similar for all the substrates with gas production starting immediately. For most wastes, the upward trend was observed for the first five days with production platooning thereafter. This is explained by the changes in pH resulting from the breakdown of the substrate matter. The highest cumulative biogas was obtained for the market waste mixture substrate at 390ml which is explained by the high level of carbohydrates and C: N ratio of 20 – 24. Similar results had been reported for cucumber waste by Pengfei *et al.*, 2018 with the highest production being 40ml of CH_4 which compares with this study at 20 -80ml raw biogas and methane levels less than 54%.

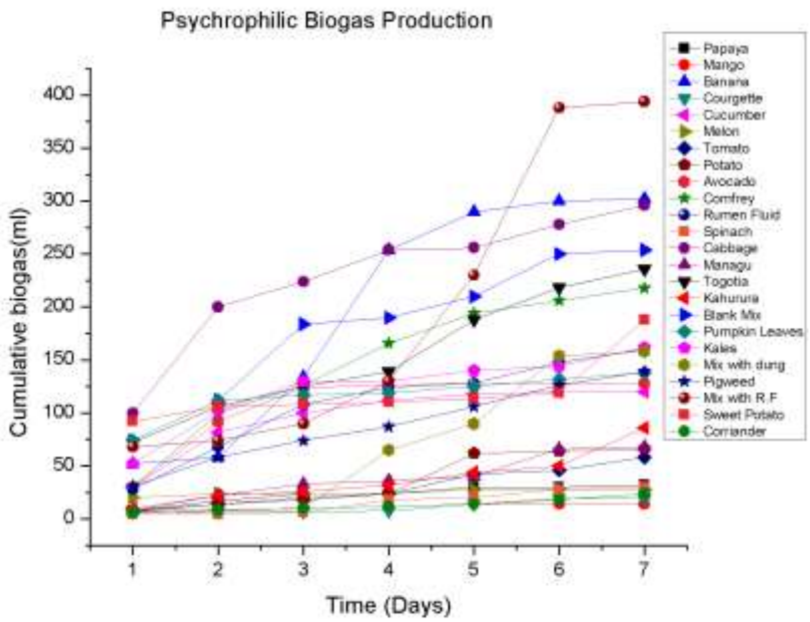

Figure 3: Psychrophilic biogas produced

In the mesophilic setup, biogas production studies were done at $37^{0}C$ which has been reported to favor some methanogens. The overall biogas production was higher in mesophilic conditions compared to psychrophilic conditions. High digestion rates were also observed based on the fact that biogas production started immediately after setting up the digester. On day 0, biogas produced was 600ml compared to 68ml at room temperatures in market waste mixtures. The bar graphs shown in figure 4 shows daily biogas production from market wastes. As observed in psychrophilic setup, the overall production was highest in the waste mixture at 3500ml.

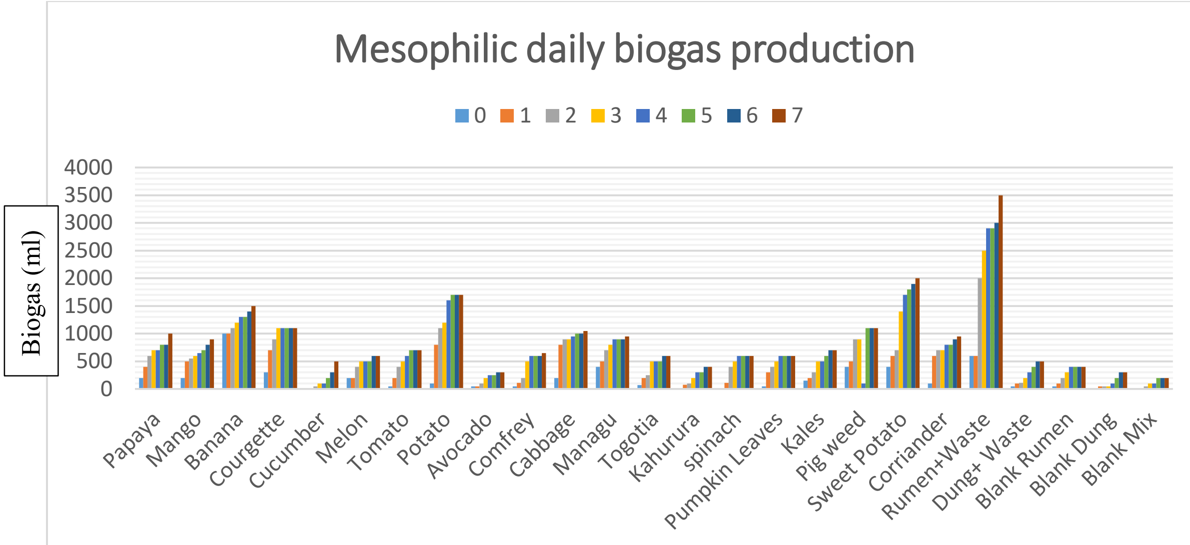

Figure 4: Bar graphs of biogas produced from wastes at mesophillic conditions

At thermophilic conditions, the temperature is maintained at 55^{0}C using a water bath. High substrate breakdown rate is observed compared to both mesophillic and psychrophilic biogas recoveries. For instance, the production at day 0 was 900ml at thermophilic setup compare to 600ml and 65ml at mesophilic and psychrophilic production respectively. The cumulative biogas yield is shown in figure 5.

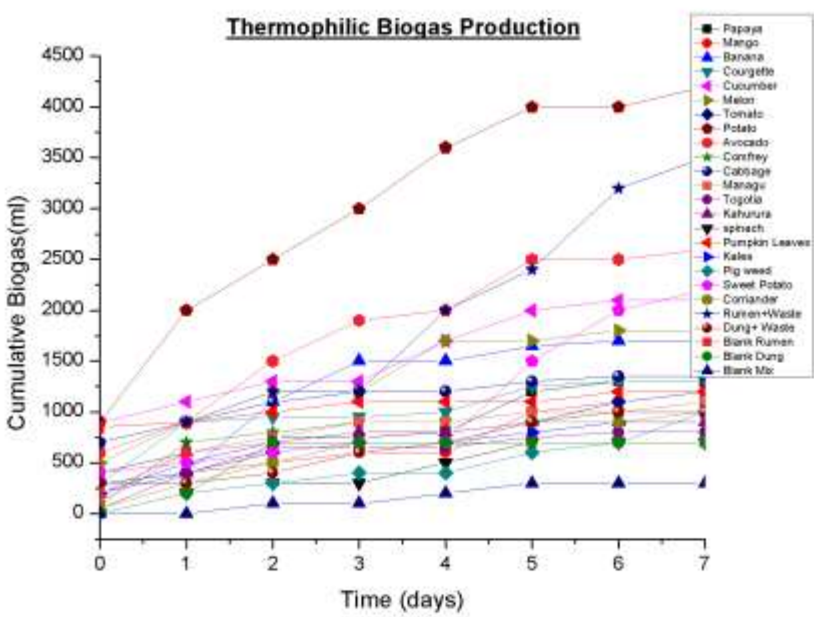

Figure 5: Thermophilic biogas production

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Biochemical methane potential

The calculated biochemical methane potential for the twenty wastes is shown in appendix table 1. It was in the range of 217.15 ml/g.VS in pigweed to 581.70 ml/g.VS in avocado fruit wastes. The BMP varied with varying levels of moisture, carbohydrates, crude proteins and crude fat. The levels of crude carbohydrates and fat largely influence the biochemical methane potential of a substrate.

Effects of C: N ratios

In this case, we considered coriander, courgette, Banana, potato and avocado wastes who's C: N ratios were 5.23, 9.00, 15.86, 24.36 and 38.92 respectively. The biogas production at mesophilic conditions for the five wastes is shown in figure 6. Similar results were reported by Musa *et al.,* 2104 who observed that increasing the C/N ratio of food waste from its initial value of 17 to 26 and 30 by anaerobic co-digestion with fruits and vegetables resulted in increased yield of biogas methane from 0.352 to 0.4465 and 0.679l/g.VS respectively (Musa *et al.,* 2104)

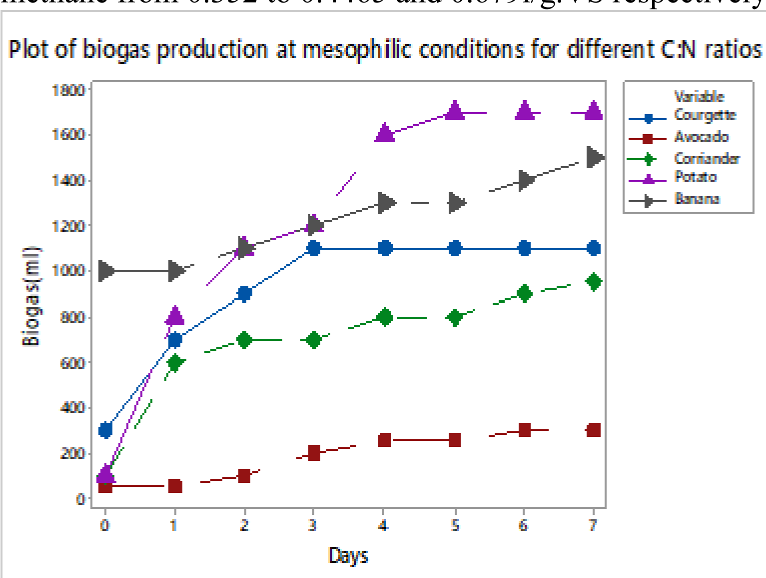

Figure 6: Biogas production at mesophillic condition at different C: N ratios

On employing substrates with different C:N ratios, it was observed that the best working range was between 20-30:1 as earlier reported by Guarino *et al*., 2016 and Garba *et al.,* 1998. The avocado wastes with the highest C: N ratio of 38.92 had the lowest biogas production at mesophillic conditions ranging from 50-300ml while at thermophillic conditions, the volume was 600 - 2600ml. On the other hand, potato waste with 24.36 C: N ratio recorded the highest biogas production as shown in figure 6. The methane levels in biogas is direct proportional to C/N ratio. The methane level of 55% was obtained in the process of avocado waste digestion with C/N ratio of 38.92. This had earlier been observed by Musa *et al.,* 2104 who reported methane levels of 85% from a feedstock with 31 C: N ratio.

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Influence of pH on biogas production

Most fruits and vegetables have a weak acidic pH ranging from 4.63- 6.04 (Xue *et al.*, 2015). The pH of all the substrates in this study was within 5.63 -7.64. Anaerobic degradation of waste is highly influenced by operation pH. The microbial activities in the digester entail process which frequently alters the pH. The initial pH of the feedstock was low during the preparation of the feed since wastes are acidic and thus buffer solution was used to adjust the pH. The results obtained when then initial pH was varied are shown in figure 7.

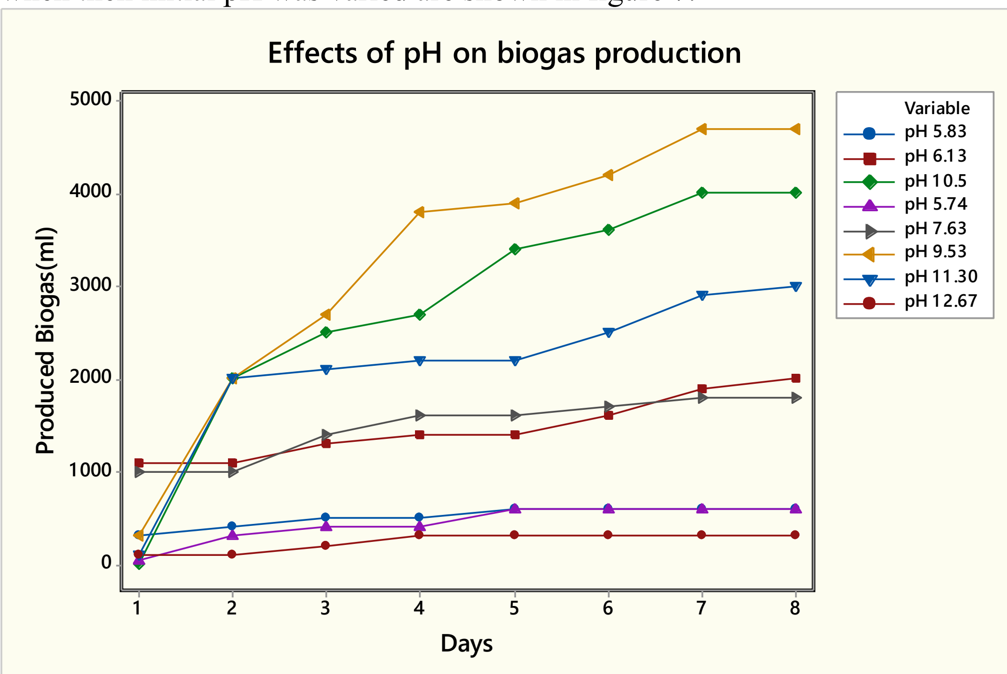

Figure 7: Influence of initial pH on biogas production

The general observation from figure 7 is that, pH below 6.20 and above 10.12 leads to low biogas generation from the wastes. Liu *et al.*, 2008 reported that pH is a major factors which influences digester performance. pH drop has been reported to inhibit methanogenesis and lead to less biogas production (Chen *et al.*, 2014). Yang *et al.* 2015, proposed that adjusting the digester pH leads to an increase in biogas production (Eramati & Ossein, 2017). This is because acetogenic microbes convert organic matter to weak organic acids (Velmurugan and Alwar, 2011).

Effects of temperature

Anaerobic microbes operate at three different temperatures; these are, under psychrophilic (<20°C), mesophilic (25−40°C) or thermophilic (50−65°C). Most digesters are operated at mesophilic conditions. The effects of different temperatures on biogas production are shown in figure 8. Biogas generation at elevated temperatures reduces retention time of a substrate ad also ensures greater destruction of pathogens (Ravuri, 2013).

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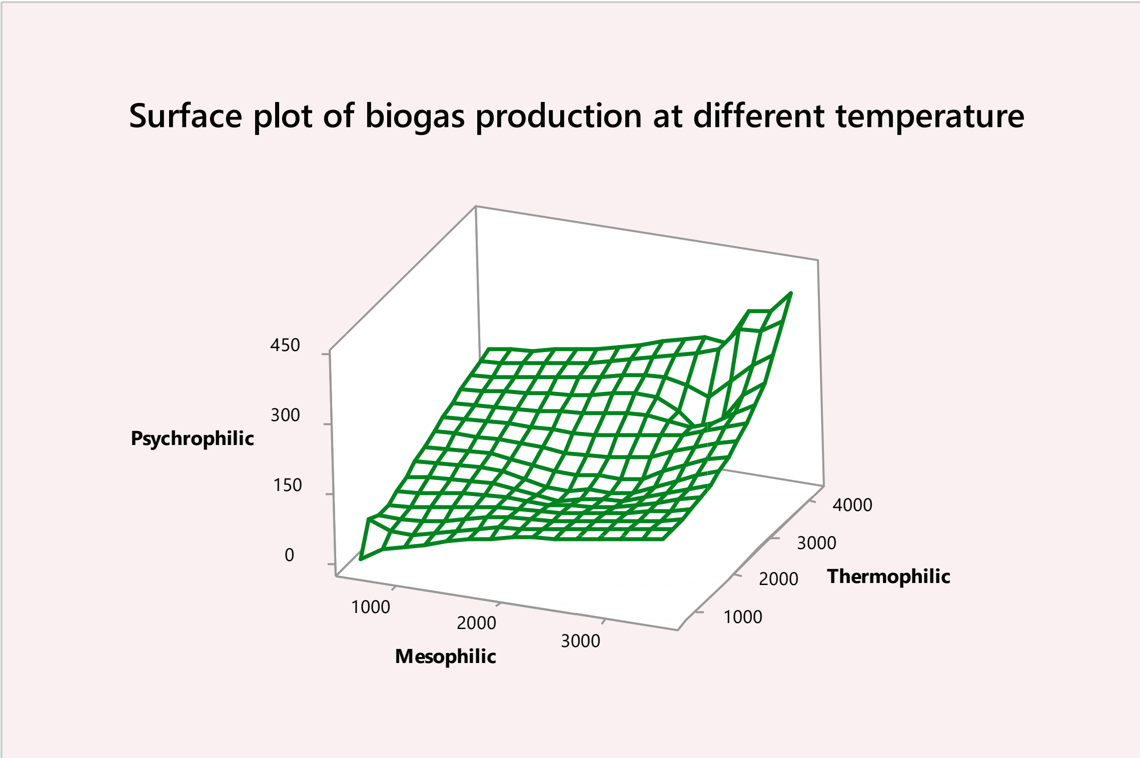

Figure 8: Surface plot of biogas production at different temperatures

High cumulative biogas was observed at thermophillic conditions and then mesophillic conditions and finally psychrophilic setups. Different microbes are activated at various temperatures with sudden fluctuations killing the bacteria. The observed production was three and ten folds higher in thermophilic compared to mesophillic and psychrophilic digestion respectively.

CONCLUSIONS

The market waste management via anaerobic digestion is essential since the waste consists of high moisture content which favors renewable energy recovery in anaerobic digestion. The high volatile solids content meant that there is enough organic matter which can be converted to biogas. The waste is rich in proximate properties which translate to high biogas production. The study showed that pH, C: N ratios and temperature play an essential role in anaerobic digestion, and thus, the optimum pH should be maintained throughout the process. The highest cumulative biogas was generated from fruits/vegetable mixture at 3500ml in mesophilic conditions. This study recommends pH adjustment to 7.0 – 7.2 in market wastes and C: N ratios of 20 – 25 for optimum biogas production.

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1 APPENDIX

Table 1: Physical and proximate properties of the market wastes

Sample	**% Moisture**	**% Total Solids**	**% Ash Content**	**% Protein**	**% Fat**	**% Fibre**	**% Carb.**	**BMP$_{CHNO}$ (ml/g.VS)**
Kales	89.85	10.15	1.94	2.27	0.34	1.57	4.03	269.33
Cabbage	94.87	5.13	0.49	0.83	0.05	0.54	3.22	329.18
Pumkin Leaves	90.78	9.22	2.06	2.27	0.18	0.94	3.77	268.84
Cucumis ficifolia	86.62	13.38	2.34	3.49	0.33	1.48	5.74	276.70
Pigweed	88.64	11.36	2.86	2.61	0.21	2.06	3.62	217.15
Erucastrum arabicum	89.37	10.63	1.99	2.82	0.19	1.68	3.95	260.02
Coriander	92.12	7.88	1.91	2.6	0.09	1.12	2.16	256.97
A. Nightshade	88.15	11.85	1.97	2.68	0.26	2.73	4.12	232.47
Spinach	93.27	6.73	1.73	1.53	0.17	0.92	2.38	257.08
Comfrey	85.04	14.96	3.46	3.24	0.29	2.07	5.9	228.89
Tomato	95.16	4.84	0.46	0.57	0.12	0.76	2.93	315.02
Potato	83.78	16.22	0.81	1.41	0.54	1.74	11.72	336.58
Sweet Potato	62.05	37.95	1.06	1.67	1.54	1.51	32.17	257.24
Pawpaw	89.22	10.78	0.5	0.68	0.34	1.31	7.95	324.52
Banana	74.3	25.7	1.67	3.05	0.5	1.24	19.24	282.54
Avocado	82.83	17.17	0.84	1.32	9.03	2.61	3.37	581.70
Courgette	95.34	4.66	0.72	1.06	0.25	0.69	1.99	320.72
Cucumber	95.86	4.14	0.46	0.52	0.21	0.78	2.17	315.11
Mango	86.82	13.18	0.44	0.87	0.68	1.28	9.91	342.74
Water Melon	92.85	7.15	0.74	0.9	0.33	0.76	4.42	314.80
NB: Experiments were done in triplicate and only mean is shown								