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# CHARACTERISATION OF FRUIT AND VEGETABLE WASTE WITH COW DUNG FOR MAXIMIZING THE BIOGAS YIELD

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## ABSTRACT

This work investigates the biogas production and methane ($CH_4$) enrichment for anaerobic digestion (AD) of fruit and vegetable waste (FVW). The effect of pH and temperature were studied using a lab scale batch anaerobic digester. The raw biogas was pebbled through water, NaOH, for biogas purification and CH4 enrichment. The results showed that mixed fruit waste (MFW) provides 10% more biogas yield than mixed fruit vegetable waste (MFVW). The use of NaOH, increased CH4 enrichment upto 5 %, Biogas having 71% CH4 contents with 28% reduced $CO_2$. Anaerobic digestion; vegetable and fruit wastes of high calorific contents can be transformed to a source of energy through the production of biogas in this day and age of energy insufficiencies. Role in maximizing the process of anaerobic digestion through speeding up hydrolysis and to compare production potentials of commonly available wastes in Addis Ababa for possible co-digestion in large scale production of biogas. Thermo-chemical pre-treatment was the most effective for speeding up hydrolysis with the co-digested substrates producing maximum biogas. The moisture content ranged between 67-83%. The pH reduced from 6.8-7.2 before digestion to 6.2-6.8 after digestion. The desired C: N ratio was between 18:1 to 32:1 for Anaerobic Digestion. The gas produced was found to contain 63.89% methane, 33.12% $CO_2$ and 3% other gases.

**KEYWORDS:** Anaerobic Digestion, Co-Digestion, and C: N Ratio, Hydrolysis, and Substrate Pre-Treatment

## INTRODUCTION

### Fruit and Vegetable Wastes

Anaerobic digestion is the breakdown of complex organic matter by the microorganisms in the absence of free oxygen producing methane, carbon dioxide, and ammonia, traces of other gases and organic acids of low molecular weight as end products of the process (Polprasert 1989). An anaerobic digestion of fruit and vegetable wastes are the rapid acidification due to the lower pH of wastes and the larger production of volatile fatty acids (VFA), which reduce the methanogenic activity of the reactor. The rate limiting step in fruit and vegetable wastes are methanogenesis rather than hydrolysis because methanogenic bacteria take long mass doubling time of 3-4 days in anaerobic reactors (Garba and Atiku, 1992). There are different types of reactors used for the bioenergy recovery from solid wastes like fruit and vegetable.

Fruit-processing wastes, especially banana waste is highly biodegradable because of their rich organic matter and high moisture content. It has been found earlier that biowaste residues with a moisture contents above 50% are more suitable for bio-conversion processes rather than thermal-conversion processes (Bardiya et al., 1996). The banana waste is a concentrated source of putrid organic waste, ideal for anaerobic digestion to produce energy while fermentation products can serve as fertilizer with high nutritional value, as well as a valuable energy source in form of biogas

(El-Mashad and Zhang, 2010).

Most fruits and vegetable wastes have high levels of volatile solids, easily biodegradable organic matter, but suffer from a deficiency of total solids. In most cases, they hydrolyze faster and lead to production of acids, lowering pH and thus causing inhibitions with the methanogens. Potentially, all organic waste materials contain adequate quantities of the nutrients essential for the growth and metabolism of the anaerobic bacteria in biogas production (Khan, *et al*., 2013). In genera biogas production had been maximized by adjusting the organic matter of the mixture for fruit and vegetable waste with cow dung in the laboratory level.

**Biogas Composition and Characteristics**

The composition of biogas largely depends on the type of substrate used for its formation. Generally, biogas consisted of methane (50-70%), carbon dioxide (30-40%) and hydrogen, nitrogen as well as hydrogen sulphide (Rahmat, *et al*., 2014). Biogas is a mixture of methane ($CH_4$) and carbon dioxide ($CO_2$) along with other trace gases. Methane gas, the primary component of natural gas (98%), makes up 55-90% by volume of biogas, depending on the source of organic matter and conditions of degradation. Moisture content, C:N ratio, and TS were found to have a bearing on the gas production and with establishment of thermo chemical pre-treatment and co-digestion as the best strategies for biogas production optimization from plant wastes, it is recommended that further research on the same be carried out and AD digesters on a larger scale embrace this technology.

## MATERIALS AND METHODS

**Feedstock (Inputs)**

Fruit and vegetables wastes (FVW) were collected from fruit and vegetable house and market and it cuts manually into small pieces and it grounds to use for digestion (physical pre-treatment, particle size reduction) and after shredding to small size and make relative very small size for the mixing and homogeneity in the digester, the raw FVW was used as feed to the reactor and kept at normal temperature until use.

**Physico-Chemical Properties of the Feedstocks**

**Total Solids**

Total dry solids (TS) are the solid substance present in the sample which contains both organic and inorganic matter. Freshly collected samples of each of 5 gm of cow dung, and FVW was weighed using electrical balance, and placed inside an electric hot air-oven maintained at 105°C using a crucible and it stayed in the oven for 24 hours and then taken out, cooled in a desiccator and weighed. The percentage of this total solid was calculated according to this formula:-

$$\%TS = \frac{MDS}{MFS} \times 100\% \quad \textbf{(1)}$$

(EPA, 2001). Where %TS=Percentage of total solid, MDS=Mass of dry sample and MFS=Mass of fresh sample.

**Organic Carbon (OC) Determination**

The OC was determined using the volatile solid data and calculated by the formula

$$\%OC = \frac{MDS - M(ASH)}{1.72MDS} \times 100\% \quad (2)$$

(Nelson and Sommers, 1996). Where 1.72 =the factor parameter

The determination of the carbon concentration in fruit and vegetable mixed with cow dung and alone was important indicator of the production of Biogas energy by methanogenises bacteria produced in the lab-level digester

**Sample Collection and Preparation**

Fresh fruit and vegetable collected from market of Ethiopia Addis Ababa and cow dung was collected from the lideta woreda 1 small enterprise farms in which the cows were fed with locally available resources. Fruit and vegetable and Cow dung samples were collected in container and preserved in a room temperature. After obtaining the samples, they were thoroughly mixed with fruit and vegetable each other and the cow dung took separately in the laboratory and the sample of fruit, vegetable and cow dung mixed in different ratio T1; 100:0, T2; 75:25 T3; 50:50, T4; 25:75, and T5; 0:100 i.e. 100 % of fruit and vegetable, 100 % of cow dung and in 3 sample treatment as different ration should be mixed with tap water at the ratio 1:1, and then fibers were screened through a sieve (0.5cm x 0.5cm) mesh size in a container. From the container, single composite sample was taken out and shifted to the glass bottle and sealed air tight. Then the samples were stored for further analysis.

**Experimental Digester Set-Up of Fruit, Vegetable and Cow Dung Mixture**

The experimental set up for the study using batch digestion consists of amber glass bottle with a plastic cover and all the fifteen anaerobic digesters were constructed at bench-scale experiments at where the degradation of the fruit, vegetable and cow dung was accomplished in sealed serum bottles with a capacity of 2.5 liters. Each bottle was sealed with its cover having two outlets. The first outlet was attached to an 8 mm internal diameter hose gas pipe and immersed up to a little above the bottom of the solution level in order to take samples without introducing air into the digester and indicate the quantity of gas produced inside the digester. Thus, a plastic tube was extended from the bottom of the substrate up to the plastic tube cover to prevent out flow of the substrate from the inside of the digester. The second outlet was above the top of the solution for gas collection. The whole cover and the hose gas pipe were sealed with gasket to protect air leakage from the environment. It was operated at ambient temperature in the hemophilic range (27-31°C), yet the temperature and moisture were monitored daily using thermo-hygrometer. A gas collector was provided for collection and determination of the amount of biogas. The content of methane concentration produced in the reactor was monitored daily. In the digesters' internal working temperature was maintained at the ambient temperature of the room using thick cover of sand and pH was regularly measured (every three days) throughout the digestion process.

**Figure 1: The Experiment Digesters Setup**

**Biogas Yield and its Quality**

The volume and methane content of the gas produced in the anaerobic reactors were measured by an indirect method and determination of the composition of biogas gas chromatography analysis is required, in this case an indirect method was employed to estimate both the amount of biogas produced and the methane content of the gas. First, the volume of water is displaced by the gas was measured by down ward displacement of water for each digester which corresponds to the amount of biogas produced. Subsequently, the methane content in the biogas was estimated by allowing the gas to pass through 10% NaOH solution as the $CO_2$ dissolves in it and form carbonate. Thus, the amount of NaOH displaced is approximately equal to the amount of methane in the gas. Other types of gases were dissolved in the solution.

**Digester Composition**

**Feed Stocks**

For the purpose of this study the amount of TS in digesters was fixed to be 100 g (taking the digesters volume into consideration) and the mass of dry samples of FVW and fresh cow dung was added to the 2.5L amber bottle digesters was calculated in this formula:-For cow dung: R=100S/%TSCD, Where: R= mass of fresh cow dung added to the digester, S= mass of total solid (dry matter) obtained from R after staying in an oven at 105°C. %TS**CD**= percentage of total solid of cow dung determined. For FVW: since it had already been dried the mass needed was directly weighed and added to the respective digesters. The weight of dung in the mixture was maintained greater than or equal to 50%. The treatment mixtures were as follows: T1; 100:0, T2; 75:25 T3; 50:50, T4; 25:75, and T5; 0:100

**Water Content**

Biogas production a total solid (TS) of 8% in the fermentation slurry should be adjusted. So the feed stocks were mixed with tap water to get 8% TS solution. The amount of water added was then determined by the formula:-MTS/A+B=8%, Where: MTS= mass of fixed total solid, A= mass of fresh cow dung + mass of dried sample of FVW added= mass of water added to get 8% total solid in the digesters and substituting 100 g in place of MTS gives us B = 1250-A which was applied to obtain the amount of water that was added to the respective digesters.

There are different types of reactors used for energy recovery from solid wastes, including batch reactors, one stage and two stage reactors. In batch reactors, wastes are fed in to the system and all the degradation steps are allowed to follow sequentially. In one stage systems which are commonly preferred for full scale anaerobic digestion of organic solid wastes in the world, all the reactions simultaneously take place in a single reactor. In two stage systems, two different reactors are used for acidogenesis and methanogenesis. One stage systems are preferred than the batch and two stage systems because of their easier and simpler designs and low in investment costs. In my study chose the one stage system

**Table 1: Treatment of the Sample**

| Treatment | Proportion (%) *(FVW*:CD) | Fresh CD (g) | Dried FVW (g) | Water Added (g) (for 8% TS) | Total Mass (g) |
|---|---|---|---|---|---|
| **T1 (control)** | 0:100 | 654.194 | 0 | 595.806 | 1250 |
| $\mathbf{T_2}$ | 25:75 | 163.55 | 81.465 | 1004.985 | 1250 |
| $\mathbf{T_3}$ | 50:50 | 327.096 | 54.31 | 868.5935 | 1250 |
| $\mathbf{T_4}$ | 75:25 | 490.65 | 27.155 | 732.195 | 1250 |
| $\mathbf{T_5}$ | 100:0 | 0 | 108.62 | 1141.38 | 1250 |

## RESULT AND DISCUSSIONS

### Characterization of Feed Stocks

The TS and VS content of both FVW and cow dung was determined with three replications and their average values are summarized. The total solid content of FVW for TS, VS and ash (fixed solid) of the substrate were, 78.85%, 90.602% and 11.11% respectively. And the VS content value 90.602% is more than the range of 75-80% stated by Steffen *et al.* (2000). This shows that large fraction of FVW is biodegradable and thus it can serve as an important feedstock for biogas production. For cow dung the TS was 18.24% within the range of 18-20% as reported by Rai (2004), the VS as percentage of TS is 92.02% and fixed solid as percentage of TS is 43.72%. The carbon to nitrogen ratio (C/N) of the feed stocks is another factor that affects the anaerobic digestion process. Methane yield and its production rates are highly influenced by the balance of carbon and nitrogen in the feeding material. The nitrogen content of FVW was 1.56 which is by far higher than the expected value as most fruit and vegetable matter contains lower nitrogen (higher C/N ratio). The C/N ratio of FVW and cow dung was 33:1 and 330:1, respectively which agree with Pyle (1978) which recommended for an anaerobic digester a value of 10 to 30 and C/N ratio of night soil, Cow manure, chicken manure, bagasse, wheat straw, oat straw and saw dust were 6 to 10, 18, 8, 150, 150, 48 and 200 to 500. This shows that FVW could serve as a substrate for biogas production even without mixing it with cow dung or other animal and human waste provided that it is available in the area. For the mixture treatments of these substrates, the possible ratio is still around 33:1. Thus, in both substrates the balance of carbon and nitrogen is good for the bacteria so that both could be used (their combination or each alone) for anaerobic digestion to produce biogas.

### Characteristics of Digesters

Many types of organic wastes such as sewage sludge, industrial waste, slaughter house waste, fruit and vegetable waste, manure and agricultural biomass have been digested anaerobically in a successful way either separately and or in co-digestion processes (Murto et al 2004). co-digestion process, different organic substrates combines to generate a homogeneous mixture as input to the anaerobic reactor in order to increase process performance (Zhang and Banks 2008) and avoid nutrient addition when a co-digested waste contains nutrients in excess (Neves et al 2009). Process requirements for anaerobic co-digestion are optimum mixing ratio of substrate and co-substrates, presence of macro and micronutrients, C/N ratio, pH, absence of inhibiting substances, availability of biodegradable organic matter, alkalinity and temperature after the finishing of the Laboratory:-

**Temperature**

Reasonable methane yields still can be expected from anaerobic digestion at low temperatures (14–23°C) if the organic loading of the digester is reduced by means of extending the hydraulic retention (Alvarez and Lidén, 2009). Both the mean temperature and the temperature fluctuations adversely affect the performance of a biogas digester. The day time temperature of the room where digestion took place was measured three times a day and the result is shown in Figure 1 below

It was found that the minimum and maximum day time temperatures were 18°C and 27°C, respectively. The mean daily temperature of the digestion room during the digestion period was 18-27°C. This means that there was a maximum fluctuation for 3 months of 2 to 9°C. This fluctuation was minimized by thick covering of the digesters with sand which brought the digesters, temperature fluctuation to less than 2°C as recommended by NRCS (2005). Practically, the changes in temperature during biogas production can be minimized by constructing the digester in underground as done by the NBPE for household users. In this experiment it can be deduced that it is possible to produce biogas in such temperature range (14-24°C), but it takes a longer hydraulic retention time (about 80 days in this case). Practically, the production in such temperature range can be compensated by using a digester having a larger volume rather than heating the reactor as it may need higher energy costs. The time of the first 3 days there was no temperature because of digestion process of the bacteria did not start to digest the biomass of the material.

**Table 2: The Temperature Different for Different Time of 80 Days**

| Morning (6-9. AM) | Noon (11AM-2PM) | Dusk (2.30:12PM) | Average |
|---|---|---|---|
| 18 | 19.5 | 21 | 19.5 |
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 |
| 20 | 21 | 22 | 21 |
| 19.5 | 21 | 20 | 20.17 |
| 20 | 21 | 22 | 21 |
| 20.5 | 19 | 21 | 20.17 |
| 19 | 20 | 21 | 20 |
| 18 | 19 | 22 | 19.67 |
| 19 | 22 | 19.5 | 20.17 |
| 21 | 22 | 19.5 | 20.83 |
| 22 | 21 | 20 | 21 |
| 20 | 19 | 22 | 20.33 |
| 21 | 20 | 22 | 21 |
| 20 | 22 | 21 | 21 |
| 22 | 21 | 20 | 21 |
| 18 | 22 | 19 | 19.67 |
| 20 | 19 | 22 | 20.33 |
| 19.5 | 22 | 20.5 | 20.33 |
| 19 | 21 | 22 | 20.33 |
| 21 | 20 | 23 | 21.33 |
| 22 | 20 | 19.5 | 20.5 |
| 21.5 | 22 | 19 | 20.83 |
| 20 | 23 | 21 | 21.33 |
| 18 | 19.5 | 22 | 19.83 |

**Table 2: Condt.,**

| Morning (6-9. AM) | Noon (11AM-2PM) | Dusk (2.30:12PM) | Average |
|---|---|---|---|
| 19 | 20 | 25 | 21.33 |
| 19 | 23 | 26 | 22.7 |
| 21 | 22 | 24 | 22.33 |
| 24 | 25 | 27 | 25.33 |

**3.3. 2.pH**

Most anaerobic bacteria including methane forming bacteria function in a pH range of 5.5 to 8.5, (Fang, 2010) but optimally at a pH of 6.8 to 7.6, and the rate of methane production may decrease if the pH is lower than 6.3 or higher than 7.8 (Gerardi, 2003). PH is another factor that affects digestion of substrates in reactors. Thus, the pH of all the treatments was measured in three days interval regularly. The initial pH of each input mixture of treatments, $T_1$, $T_2$, $T_3$, $T_4$, and $T_5$, were 5.08, 5.39, 4.48, 5.28 and 4.88 respectively. This is not in agreement with a pH range of 6.5 to 7.5 which is conductive for methanogenic bacteria to function properly as indicated by Rai (2004). These initial values changed throughout the digestion period that is initial acidic condition and at the end of the digestion period was also acidic the pH of all the five treatments went up at the beginning of the digestion period and remained declining up to the last day of fermentation. This may be due to the formation of acids by acidogenic bacteria during the incubation period (Wilkie, 2008), After 19 days, the pH of the treatments increased which is an indication of the digestion of volatile acid and nitrogen compounds, and more methane was produced. The production of acids and its digestion continued up to the fifth week of digestion and the pH remained more or less constant after the fifth week which may be due to the presence of larger number of methanogenic bacteria than acidogenic bacteria so that almost all the acid present could be digested to form methane and carbon dioxide gases (Dahlman and Forst, 2001). Generally, in this study the pH was above 5.00 which means there was a need for adjustment of substances like lime, ash or ammonia as the gas producing bacteria still can ferment the acid and restore balance as reported by Saxon (1998).

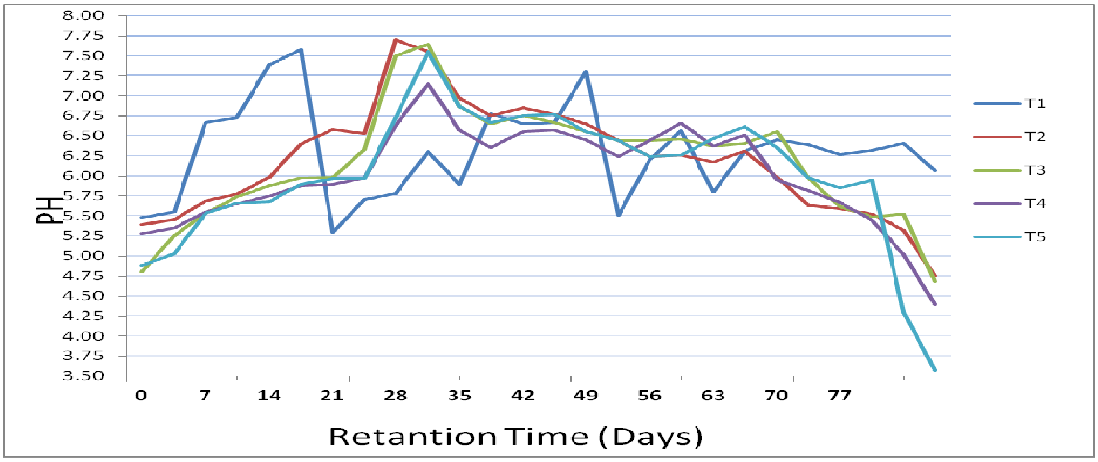


**Figure 2: Ph Treatment Verse Time**

**Table 3: pH of Each Treatment**

| Time | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ |
|---|---|---|---|---|---|
| Week | PH | PH | PH | PH | PH |
| 1st | 5.08 | 5.39 | 4.8 | 5.28 | 4.88 |
| | 5.55 | 5.45 | 5.25 | 5.35 | 5.03 |
| 2nd | 6.67 | 5.69 | 5.53 | 5.55 | 5.53 |
| | 6.73 | 5.77 | 5.74 | 5.65 | 5.66 |
| 3nd | 7.39 | 5.98 | 5.88 | 5.75 | 5.68 |
| | 7.58 | 6.4 | 5.97 | 5.88 | 5.89 |
| 4th | 5.3 | 6.58 | 5.98 | 5.89 | 5.96 |
| | 5.7 | 6.53 | 6.33 | 5.97 | 5.96 |
| 5th | 5.78 | 7.7 | 7.5 | 6.63 | 6.73 |
| | 6.3 | 7.55 | 7.65 | 7.15 | 7.55 |
| 6th | 5.89 | 6.97 | 6.87 | 6.57 | 6.87 |
| | 6.78 | 6.75 | 6.65 | 6.35 | 6.67 |
| 7th | 6.65 | 6.85 | 6.75 | 6.55 | 6.75 |
| | 6.67 | 6.77 | 6.67 | 6.57 | 6.77 |
| 8th | 7.3 | 6.65 | 6.55 | 6.45 | 6.55 |
| | 5.5 | 6.44 | 6.44 | 6.24 | 6.44 |
| 9th | 6.2 | 6.24 | 6.44 | 6.44 | 6.24 |
| | 6.56 | 6.26 | 6.46 | 6.66 | 6.26 |
| 10th | 5.8 | 6.17 | 6.37 | 6.37 | 6.47 |
| | 6.31 | 6.31 | 6.41 | 6.51 | 6.61 |
| 11th | 6.45 | 5.98 | 6.55 | 5.95 | 6.35 |
| | 6.39 | 5.63 | 5.97 | 5.82 | 5.97 |
| 12th | 6.27 | 5.59 | 5.62 | 5.67 | 5.85 |
| | 6.32 | 5.52 | 5.49 | 5.44 | 5.95 |
| 13th | 6.41 | 5.32 | 5.52 | 5.02 | 4.3 |
| | 6.07 | 4.75 | 4.68 | 4.39 | 3.57 |
| sum | 163.65 | 161.24 | 160.07 | 156.1 | 156.49 |
| **Average** | **6.294230769** | **6.201538462** | **6.156538462** | **6.003846154** | **6.018846154** |

**Amount (Quantity) and Quality of Biogas Production**

Biogas production and its methane content were measured for about 13 weeks of digestion period until gas production ceased. It was found that $T_2$ produced the highest (7552.67 ml) in the whole week of digestion. $T_5$ produced lowest of the five treatment 2652.84 ml of biogas production (Figure 4). $T_3$ and $T_5$ were produced 2752.17ml and 2652.83ml of the total biogas production of the whole week of the fermentation period respectively. The other treatments for methane production percentage $T_1$, $T_2$ and $T_4$ produced 78.354%, 67.942% and 74.0962%, respectively in this period of digestion. Thus, these three treatments especially, need extra days for more gas production. A lag phase of about one week was observed at $T_3$ which indicates that in the 1:1 ratio there should be sufficient period for acclimation in order to start up the digestion process. This supports the recommendation made by Rai (2004) i.e. keeping the cow dung proportion above 50% is essential for immediate and better volume of gas production in such a mixture. Though $T_5$ (FVW alone) produced maximum for the first week and the minimum in the middle and last week of digestion, its average methane content especially in the whole days was in average (mean 74.78%) (Figure 2) which means that about 25.22% of the gas constituents in this period was $CO_2$. The gas therefore cannot be used as an energy source directly during this period of digestion. The fact that no lag phase was observed at the beginning of the experiment, but only low methane content suggests a higher hydrolytic-acidogenic than methanogenic activity in the reactors of this treatment. After the first week, the methane content of the treatment, $T_5$, decreased and remained in the range 55 to 75 which agrees with the literature value of 50 to 75 (EEMBPM, 2006) and 55 to 80 (Jemmett, 2006). Therefore, it could be important to use FVW alone from the first week of digestion period to production stopped.

Methane content was between 55 to 75% during the whole digestion period as suggested by EEMBPM (2006). The reason could be the existence of more and more methanogenic bacteria conversion of acidic substances including $CO_2$ and $CH_4$ with digester $T_2$ and $T_4$ quality is better than $T_3$ (1:1) and $T_1$ best of all the treatments both in quality and amount of methane production. One way ANOVA test result 0.000 5% and 1% of level of significant which means that there is volume of biogas production Comparisons (least significant difference (LSD) method was employed biogas production of each treatment compared with the other treatments are significantly different at the 0.05 significance level. Thus, the combination which produced relatively maximum biogas (7552.67±28.6552ml) with maximum methane composition (67.94%) i.e. T2 (3:1 ratio of cow dung to FVW) can be used important in using it as a substrate for supplementing cow dung. $T_5$ (FVW *alone*) (2652.83±21.266 ml) could be the least as its biogas content and methane content is relatively lower than $T_1$ (the quality of $T_3$ was about 7% more than $T_2$ for the whole digestion period). So, using this mixture by scrubbing the $CO_2$ or by removing the biogas produced within the whole digestion period may contribute much in providing a significant amount of biogas production. In general, Statistical test for the mean difference of dependable variable pH of treatments except between $T_3$ and $T_5$ varies significantly at 0.05 levels. The result also showed that the biogas and methane content of the gas produced by $T_5$ vary significantly at 0.05 levels except with $T_1$and $T_3$. Finally, environmental, slurry and foreign currency benefits can be realized through fuel replacement value of the biogas produced by the five treatments

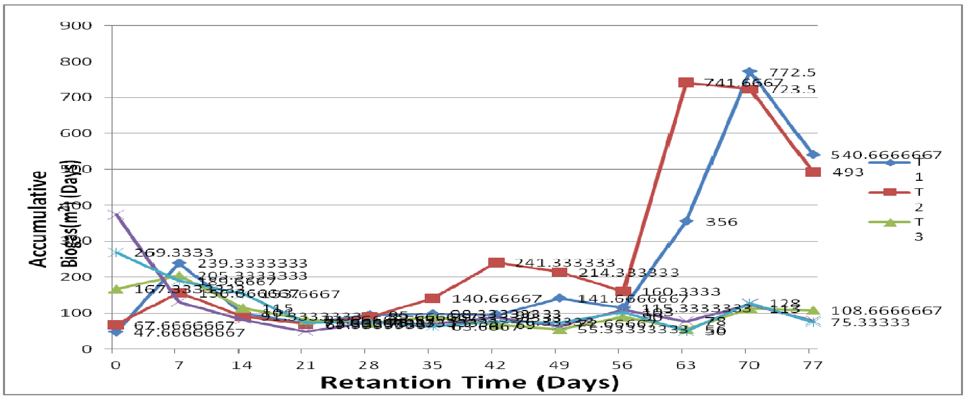


**Figure 3: Comparison of Biogas Production of Treatments**

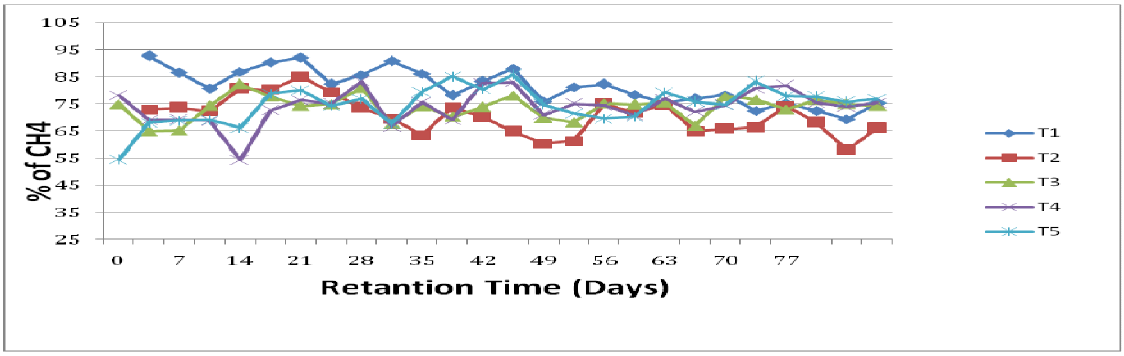


**Figure 4: percentage of Methane of Treatments**

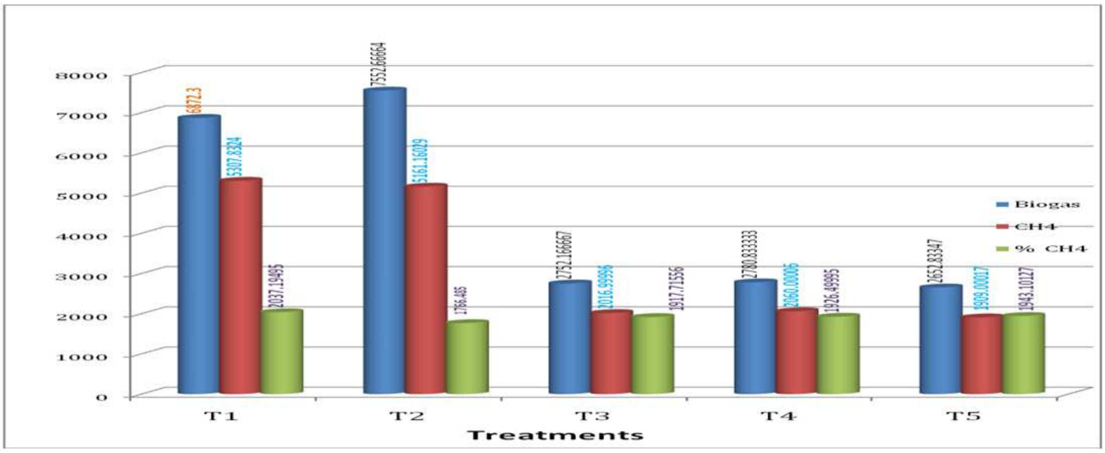


**Figure 5: The Total Biogas, Methane and its Overall Percentage of Treatments**

## CONCLUSIONS

The daily mean minimum and maximum ambient temperature during the phase of experiment were $18^0$C and $27^0$C, respectively. Hence, in this study biogas digesters were kept throughout in sand jacket to control temperature fluctuation. From this experiment the volume of biogas produced in all the digesters ranged from 2652.83ml to 7552.67ml. The maximum biogas was produced in a mixture of fruit and vegetables to cow dung at the ratio of 25:75($T_4$) which provided 7552.67ml in 80 days of retention time. The biogas produced from cow dung alone was 6872.3ml; next best biogas production and the Minimum production of biogas was 2652.83ml of $T_5$ and it is the study further revealed that those treatments ($T_1$ and $T_5$) that have C/N ratios within the range of 20-35 are found to perform better in biogas yield and methane production than those outside this range. The C/N ratio of $T_2$ and $T_4$ is beyond the optimum C/N value. This shows that fruit and vegetables biomass is highly organic having less nitrogen therefore might need to be mixed with feed stocks which are rich in nitrogen to be used as substrate for biogas production. The result also shows that the pH of the digesters throughout the retention time was under acidic condition. In this regard the pH of all the digesters of treatments were in the range of optimal level 5.00 to7.15 suitable for most methanogenic bacteria to function for biogas production. Finally, the quality of the biogas either from fruit and vegetables alone or with mixture of cow dung also were beyond 50% or were within the range of good quality biogas.

Again from the laboratory result, the VS content of the FVW was 92.602% of the TS. This shows that a large fraction of the fruit and vegetables is biodegradable. This implies that fruit and vegetables can serve as an important feedstock for biogas production. Biogas and methane production from $T_1$(100%CD), $T_3$(50%CD:50%FVW) and $T_5$(100%FVW) were not statistically significant at 0.5 level. Co-digestion of cow dung and fruit and vegetables biomass is therefore, one way of addressing the problem of lack of enough feedstock for biogas production. If suitable materials for co-digestion, such as manure, are not available; fruit and vegetables can be digested alone and create a good opportunity for poor people who have not livestock. Environmental, slurry and foreign currency benefits can also be obtained from biogas production of these feed stocks.

## RECOMMENDATIONS

Biogas technology has significant potential to mitigate several problems related to ecological imbalance, minimizing crucial fuel demand, improving hygiene and health, and thus, resulting in an overall improvement in the quality of life in rural and urban areas.

The condition of low pH also should be studied. Further work is also necessary to look at composition of organic matter (carbohydrates, proteins, lipids) and process state indicators (VFA, Ammonia level). Efforts should also be made to measures the methane quality of the different mixture by HPLT for very accurate measurements.

Awareness and skill development training on the sustainable use of fruit and vegetable as a substrate for biogas production and the slurry as a fertilizer for each household biogas users (potential users too) and companies is essential.

The conversion of fruit and vegetable wastes to biogas using anaerobic digestion process represents a viable and commercial one. But the rapid acidification of fruit and vegetable wastes tends to operate the reactor at a lower organic loading rate.

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