

Biogas Production from Co-Digestion of Poultry Manure and Orange Peel through Thermal Pre-Treatments in Batch Fermentation

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Abstract

Biogas production decreases environmental pollution through decomposing organic wastes and positively affects the socio-economy of the society. With the aim of producing biogas from co-digestion of Poultry Manure (PM) and Orange Peel (OP) a series of experiments were carried out for 21 consecutive days. Five different proportions of PM and OP (100%PM, 75%PM+25%OP, 50%PM+50%OP, 25%PM+75%OP, 100%OP) were used to obtain the suitable mix ratio (which gives maximum biogas production). Having determined the optimum mix ratio, temperature pre-treatment at 60 and 80 °C were applied to compare the results with those obtained with non-pre-treated waste. Cumulative biogas production obtained from 75%PM+25%OP was 768ml, whereas 218.33ml was measured from 100%OP. Increasing the proportion of OP above 25% decreased the amount of gas production, volatile solids (VS) and total solids (TS) reduction. This indicated that addition of PM to mix ratios improves biogas production. Thus 75%PM+25%OP mix was found to be the optimum mix ratio which resulted in high biogas yield. In thermal pre-treatments, maximum cumulative gas production was measured at 80 °C pre-treated substrate. It exceeded by 11.7% and 6.6% over the control and the 60 °C pre-treated sample respectively. Overall the results indicated that the biogas yield and VS and TS reduction of the 75%PM+25%OP mix ratio can be enhanced with the use of thermal pre-treatments prior to anaerobic digestion.

Keywords: Anaerobic Digestion; Biogas; Co-digestion; Pre-treatments; Total solids; Volatile solids; D-limonene.

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1. Introduction

Biogas technology is growing as a number of countries are accessing up biogas targets as a main approach for treating a variety of organic wastes. Biogas production decreases environmental pollution through decomposing organic wastes and positively impacts the socio-economy of the society [1]. Today, utilization of biogas as an alternative energy source is steadily increasing. It accounts for up to 20% of renewable energy consumption in the European Union. About 52% of the biogas plants produce biogas from agricultural wastes, and about 36% are utilizing sewage sludge and the remaining 12% are landfill treatment plants. Germany is by far the major biogas producer in the world [2].

For their economic progress, African countries need sustainable energy supplies. Unreliable energy supply may end up with low level of private investment in African continent. Therefore, improvement in the quality and magnitude of energy services in developing countries is required to meet developmental objectives including the Millennium Development Goals (MDGs). Although reliable regional energy statistics are not readily available, the existing estimates of energy use in Eastern and Southern Africa indicate that there is a significant and persistent dependence on traditional biomass energy technologies and limited use of modern, sustainable energy technologies [3].

Biomass in the form of mainly fuel wood and charcoal is the dominant energy source in Sub-Saharan Africa. Though it appears cheap, overexploitation of this biomass leads to serious negative environmental consequences. Fossil energy sources are the most widely used energy supplies in the world today. However, the increased prices of oil and increased awareness of climate changes is promoting the use of alternative environmentally friendly renewable energy sources such as biogas [4]. Traditionally, biogas has been used as fuel to support the process temperatures in anaerobic digesters. Another alternative use is that the gas is burned in an engine generator of combustion to produce electricity in biogas plants. It has also been used as fuel for cooking, light and vehicles [4].

Due to the complex physical and chemical nature of lignocellulosic substrates, their complete biodegradation cannot be achieved in anaerobic digesters to result in high biogas yield [5]. To overcome biodegradability problem, some pre-treatment methods can be employed [6]. Pre-treatments, for example, biological [7], mechanical [8], chemical [9], thermal [10] and combination of these treatments have been done to facilitate the biogas production by overcoming the limitation of hydrolysis, which include the solubilization and biodegradation of hemi-cellulosic and lignin parts of the substrates. Thermo-chemical pretreatments have a great impact on biogas production with a maximum enhancement of 78% for biogas and 60% for methane [5]. Thermal pretreatment also has effect on biogas production with a maximum enhancement of 28% for biogas and 25% for methane. This indicates that pretreatment of substrates urgently needs further investigation.

Biogas technology was introduced in Ethiopia as early as 1979, when the first batch type digester was constructed at the Ambo Agricultural College. In the last two and half decades around 1000 biogas plants, ranging in size from 2.5m³ to 200m³ have been constructed in households, community and governmental institutions in various parts of the country [11]. In Ethiopia, biogas production from different organic materials.

However, no research has been done on the effect of different pre-treatments of poultry waste and orange peel on biogas production.

General Objective was to:

- Examine the effect of thermal pre-treatments on biogas production from poultry manure and orange peel in sole or co-digestion.

Specific Objectives were to:

- [1]. Characterize poultry manure and orange peel in terms of the total solids (TS), volatile and fixed solids (VS), moisture content, organic Carbon and pH before and after anaerobic digestion.
- [2]. Evaluate the biogas yield of single and mixed substrates of orange peel and poultry manure.
- [3]. Assess the effect of thermal pre-treatments on biogas yield.

2. Material and Methods

2.1. Design of Experiments and Preparation of Substrates

The study was carried out by using two experimental phases: (i) anaerobic digestion of five substrates without pre-treatments and (ii) anaerobic digestion of the best performing substrate of first phase with thermal pre-treatment. The five substrates that were used for anaerobic digestion without pre-treatments were poultry manure (PM) and orange peel (OP) in sole or mixing at different proportions as follows; 100% PM, 75%:25% mix of PM: OP, 50%:50% mix of PM: OP, 25%:75% mix of PM: OP and 100% OP. For further experiment and second phase of experiment the highest biogas yielding substrate was selected and subjected by thermal treatment, i.e. anaerobic digestion after thermal pre-treatment. The experimental design was completely randomized design. That means the treatments were arranged randomly in the laboratory and done in three replicates.

2.2. Feedstock and Inoculum

Two types of lignocellulosic biomass, poultry manure and orange peel were used in this study. Poultry manure was obtained from Haramaya University animal farm, i.e. fresh manure about (4kg) was randomly collected. Orange peel waste (4kg) was collected from local market around Haramaya University washed with water and cut into pieces using scissors in the laboratory in order to make it easier for digestion. The prepared orange peels were added into poultry manure in different proportions and stored at 4°C for usage as feed.

To start up anaerobic process, rumen fluid was used as inoculum [13]. For this experiment, fresh rumen fluid was collected from the nearby slaughter house and filtered through a cloth of 0.5mm sieve diameter to separate solid content from slurry. Prior to use, the inoculum was starved for one week by incubating at 38 °C to remove the easily degradable VS present in inoculums [14].

2.3. Analyses of Physico-chemical Characteristics of Substrates

Both poultry manure and orange peel were analysed for TS, VS, moisture content and pH before and after AD process based on the Standard Methods for the Examination of Water and Wastewater [15].

2.3.1. Total solids

First a clean evaporating dish was oven-dried (at 105°C for 1hour), cooled in a desiccator and weighed immediately before use. Sample of substrate (10 g) was placed on the evaporating dish and put in an oven (Contherm 260M) at 105°C using a crucible to evaporate for 24 hours. After 24 hours, the crucible was taken out from the oven, cooled in desiccators and weighed using electronic balance (PB602). Thereafter, the percentage of TS was calculated using the following formula [15].

$$\%TS = \frac{mDS}{mFS} \times 100$$

Where,

%TS= percentage of total solids

mDS= mass of dry sample (final weight) in gram

mFS= mass of fresh sample in gram

Then percentage of TS removal was calculated using the formula indicated below.

$$\%TS \text{ removal} = \frac{TS_i - TS_f}{TS_i} \times 100$$

Where,

TS_i=initial total solids before digestion (%)

TS_f=final total solids after digestion (%)

2.3.2. Volatile and fixed solids

Once the TS was determined, the oven dried sample was ignited at 550°C in a muffle furnace (BiBBY, Stuart) for 3 hours to determine the volatile and fixed solids. The following formula was employed to calculate the percentage of volatile solids content of the TS [15].

$$\%VS = \frac{mDS - m(\text{ash})}{mDS} \times 100$$

Where,

% VS = percentage of volatile solids

mDS= mass of dry solids in gram

m(ash)=remaining mass after ignition =fixed solid in grams.

i.e., TS=VS + fixed solids

Then percentage VS removal was calculated using the equation below.

$$\%VS \text{ removal} = \frac{VS_i - VS_f}{VS_i} \times 100$$

Where,

V_{si}= initial volatile solids before AD (%)

V_{sf}=final volatile solids after AD (%)

2.3.3. Moisture content determination

To determine the percentage of moisture content (MC) in the samples, 10 g of fresh substrate was dried in an oven (Contherm 260M) at 105 °C for 24 hours and reweighed. The moisture content was then calculated as follows [15].

$$\%MC = \frac{W - D}{W} \times 100$$

Where,

MC = moisture content

W = initial weight of sample in grams,

D = weight of sample after drying at 105 °C in grams

2.3.4. Determination of pH

The initial pH of each sample was measured directly using digital pH meter before and after AD (HANNA HI 8314). In the case of before AD, an electrode was inserted into samples of substrate that was diluted using distilled water before inoculation of rumen fluid and the pH values of the contents of digesters were buffered between 6.8 and 7.4 which is the optimal range for methanogenic bacteria [16]. Measurement of pH after AD

was also done using pH electrode which was inserted into samples of substrate that is digested in AD process.

2.3.5. Organic carbon

The carbon content of the substrates was obtained from volatile solids data using an empirical equation [17].

$$\% \text{Carbon} = \frac{\% \text{VS}}{1.8}$$

Where, VS= Volatile solids

2.4. Anaerobic Digestion of Substrates without Pre-treatment

The experiments were conducted in batch mode in 0.5L digester from poultry manure and orange peel which were prepared in five different proportions as indicated above. Substrates were mixed with appropriate amount of distilled water and inoculum to achieve the recommended (8% w/w) total solids content in the fermentation slurry. The total amount of liquid (distilled water and rumen fluid) needed to be added to the digester was then determined by the formula [18];

$$Y = \frac{mTS - 8\%X}{8\%}$$

Where,

mTS = mass of total solids

X = mass of fresh substrate

Y = mass of fluid (distilled water and rumen fluid) to be added to get 8% total solids in the digester.

Then, by fixing the amount of inoculum (100mL) that was added finally to facilitate digestion, the amount of distilled water that has to be added was then determined using the formula;

$$Z = Y - 100$$

Where,

Z = amount of distilled water

Y = total amount of liquid (distilled water and rumen fluid).

The temperature of the bio-digester was kept at mesophilic condition (38°C) by keeping in oven [19]. The pH of the digesters was maintained between 6.8 and 7.4 by adding buffer solution. The digestion process lasted for

about 21 days and biogas yield was measured every day starting from the first day after the substrates were arranged for AD.

2.5. Thermal pre-treatment and digestion of high yielding substrate combination

Thermal pretreatment showed enhancement in the temperature range 50-100°C, with maximum enhancement at 100°C, having 28% biogas and 25% methane increases [5]. For this reason, the slurry containing the optimum non-treated substrate mix-ratio and the corresponding volume of distilled water were added into 0.5 L flasks. Since temperature below 60°C is usually considered as a pre-digestion step rather than pre-treatment, 60 and 80 °C were selected. After covering the flasks with plastic film, they were treated with temperatures of 60 and 80°C for 3 hours by keeping in water bath with intermittent gentle shaking to ensure the homogeneity of temperatures in the flasks [20]. The sample without thermal pre-treatment is used as control. Then all the slurry was kept for 24 hours in a refrigerator at 4°C before the addition of 100mL inoculum.

The total amount of liquid (distilled water and rumen fluid) needed to be added to the digester was then determined using the same formula indicated in section 3.5 and the same is true for pH and temperature.

2.6. Digester Configuration and Setup for Biogas Production

Twenty-one (15 for co-digestion without pre-treatment and 6 for thermal pre-treatment) anaerobic digesters (plastic bottle) were constructed for bench-scale experiments with which biogas was produced out of the degradation of substrates in 0.5L digester. Degradation of the substrate was accomplished in sealed three bottles each with a capacity of 0.5L which were arranged in order in such a way that the first bottle contained slurry, the middle contained acidified brine solution and the last was used for collecting the brine solution that was expelled out from the second container.

The acidified brine solution was prepared by adding NaCl to distilled water until a supersaturated solution was formed to prevent the dissolution of biogas in the water. Three drops of sulphuric acid were added using a dropper to acidify the brine solution. All the three containers were interconnected with a plastic tube having a diameter of 1cm. The tube connecting the first bottle to the second was fitted just above the slurry in the first bottle to help gas collection. Thus, the biogas produced by fermentation of the slurry was driven from the first bottle to the second bottle that contained a brine solution so as to displace a volume of the brine solution equivalent to the volume of biogas that was produced.

The lids of all digesters were sealed tightly using superglue in order to control the entry of oxygen and loss of biogas. Daily biogas production was measured following the method suggested by [21]. As biogas production was commenced in the fermentation chamber, it was delivered to the second chamber which contained the acidified brine solution. Since the biogas is insoluble in the solution, a pressure build-up provides the driving force for displacement of the solution. The displaced solution was measured to represent the amount of biogas produced. The temperature of all digesters was maintained at 38°C by keeping in an incubator, which represents mesophilic condition.

2.7. Data Analysis

Data were analysed by using analysis of variance (one-way ANOVA) using SAS version 9.1. Fishers Least Significant Difference (LSD) was used to investigate statistical significance between the different treatments, whereas paired samples T-test was used to investigate statistical significance within a treatment. The statistical significance level was selected at p-value < 0.05

3. Results and Discussion

3.1. Physicochemical Characteristics of the Untreated Substrates

The Physicochemical characteristics of both PM and OP in sole or mixed for AD were determined before and after AD, and among the different mix ratios.

Table 1: Comparison of pH, % organic carbon and %MC between before and after AD and among different mix ratios (values are mean ± SE, n=3)

Treatments	Parameters					
	pH		% C		%MC	
	Initial	Final	Initial	Final	Initial	Final
A	6.89±0.01 ^{Aa}	8.15±0.01 ^{Eb}	10.14±0.01 ^{Da}	8.52±0.01 ^{Db}	76.40±0.03 ^{Ea}	80.60±0.05 ^{Eb}
B	6.82±0.00 ^{Ba}	8.46±0.02 ^{Db}	10.69±0.01 ^{Ea}	7.68±0.00 ^{Eb}	76.20±0.06 ^{Da}	82.20±0.03 ^{Db}
C	6.51±0.08 ^{Ca}	8.64±0.02 ^{Cb}	11.36±0.01 ^{Ca}	8.87±0.01 ^{Cb}	74.90±0.03 ^{Ba}	78.80±0.01 ^{Cb}
D	6.13±0.04 ^{Da}	8.73±0.06 ^{Bb}	11.74±0.02 ^{Ba}	9.19±0.02 ^{Bb}	74.10±0.02 ^{Ca}	77.40±0.05 ^{Bb}
E	5.53±0.02 ^{Ea}	8.83±0.03 ^{Ab}	12.02±0.01 ^{Aa}	9.80±0.01 ^{Ab}	73.35±0.04 ^{Aa}	77.00±0.06 ^{Ab}

Means followed by different small letters in row are significant at 0.05 probability levels for paired samples T-test within treatment. Means followed by different capital letter in column are significantly different at 5% level of significance between treatments.

A=100%PM, B=75%PM+25%OP, C=50%PM+50%OP, D=25%PM+75%OP and E=100%OP.

pH is one of the factors that affect anaerobic digestion. It is important to adjust the pH-value in the optimal range because anaerobic performance is affected by slight pH deviations from the optimum. A significant decrease in growth rate of methane forming bacteria occurs if the value of pH is below 6.6. Furthermore, high alkaline pH can cause disintegration of microbial granules and consequently, result in the failure of anaerobic digestion [22]. The pH of 100% PM slurry before anaerobic digestion was about 6.89±0.01, whereas that of 100% OP was 5.53±0.02. So, pH of poultry manure alone is almost optimal for biogas production, but pH of OP

alone is not optimal for anaerobic digestion as it falls below 6.8. When the substrates were mixed, it resulted in the rise of pH compared to that of OP alone. The pH was found to increase significantly with increasing of PM proportion in the mix, suggesting that PM helps to maintain the pH to meet the optimum required. As volatile acid concentrations increase, the pH in the digester decreases. Thus, mixing of substrates is a good way of adjusting the pH value to the optimum [23].

Comparison of pH values between before and after AD showed that pH values are significantly increased for all treatments ($P < 0.05$) (Table 1). Maximum pH value was 8.83 whereas minimum value was 8.15. This indicated that as the proportion of OP increased within the sample, pH value also increased accordingly (Table 1).

The reason for the increment of the pH values after AD may be attributed to production of alkali compounds, such as ammonium ions during the degradation of organic compounds in the digester [24]. The pH value of the rumen fluid used in all experiments was relatively higher than both substrates (pH=7.51). This shows that the rumen content used may have high ammonia concentration. Thus, in addition to initiating the start up in the digestion process, the rumen fluids were used to adjust the pH of both single and mixed substrates, especially OP alone and mix ratios containing high content of OP.

The moisture content of 100% PM, 75% PM+25% OP, 50% PM+50% OP, 25% PM+75% OP and 100% OP before AD were $76.40 \pm 0.03\%$, $76.20 \pm 0.06\%$, $74.90 \pm 0.03\%$, $74.10 \pm 0.02\%$, and $73.35 \pm 0.04\%$, respectively. This indicates that PM contains high moisture content than OP and mixing of substrates might balance the moisture content of the digester. Significant differences were observed between before and after AD in all treatments (Paired samples T-test, $P < 0.05$).

The moisture content in all the substrates was found to be high to facilitate efficient degradation of the substrates as bacteria can easily access liquid substrate for relevant reactions to take place easily [25]. Since studies on the most favourable percentage of total solids for biogas productions suggest 8% as the optimum TS, the initial moisture content of substrates used for this study was not optimal for wet anaerobic digestion process [18]. Therefore, dilution is required to bring the total solids percentage to 8%.

There was a significant difference between treatments in both before and after AD in %C (Table 1). The study revealed that the percentage degradation of organic carbon for 75% PM+25% OP was higher than all treatments (from 10.69 ± 0.01 to 7.68 ± 0.00 , i.e., 30.1% reduction) (Table 1). Organic carbon can be removed in anaerobic digesters either by being converted to cellular materials for growth and reproduction of bacteria or through biogas production [24].

Therefore, the decrease in Carbon reflects the degradation process during anaerobic digestion [9]. The results also revealed that there were differences in percentage organic carbon in all mix ratios before and after AD ($P < 0.05$). This shows that mixing balances the percentage of organic carbon of substrates in the digester as the two substrates (PM and OP) contain different carbon content.

3.2. Analysis of TS and VS values of Untreated Substrates before and after AD

Table 2: Comparison of TS % and VS % between before and after AD and among the mix ratios (values are mean ± SE, n=3).

	Parameters			
	Initial TS	Final TS	Initial VS	Final VS
100% PM	23.55±0.02 ^{Db}	19.44±0.02 ^{Da}	18.25±0.02 ^{Da}	15.34±0.02 ^{Db}
75% PM+25% OP	23.82±0.34 ^{Db}	17.75±0.02 ^{Ea}	19.24±0.02 ^{Ea}	13.82±0.01 ^{Eb}
50% PM+50% OP	25.07±0.03 ^{Cb}	21.24±0.02 ^{Ca}	20.45±0.02 ^{Ca}	15.96±0.01 ^{Ca}
25% PM+75% OP	25.93±0.03 ^{Bb}	22.64±0.01 ^{Ba}	21.13±0.03 ^{Ba}	16.54±0.02 ^{Bb}
100% OP	26.45±0.02 ^{Ab}	23.04±0.01 ^{Aa}	21.64±0.01 ^{Aa}	17.64±0.01 ^{Ab}

Means followed by different small letters in row are significant at 0.05 probability levels for paired samples T-test within treatment. Means followed by different capital letter in column are significantly different at 5% level of significance between treatments. PM= poultry manure, OP= orange peel.

Significant differences were observed between treatments in % TS and % VS both in before and after AD (Table 2). Total solid content of all mixes before inoculation and digestion fall between 23.55±0.02% (i.e., 2.36 gram of TS from 10-gram sample) and 26.45±0.02%. Maximum TS was measured from 100%OP, but the minimum TS was recorded from 100%PM as shown in the table above (Table 2). The TS content of 23.55% of PM used in this experiment is in the range of 10 to 30% TS reported by [26]. Some agroindustry wastes may contain less than 1 % TS, while others contain high TS content of more than 20 %. Thus, the TS content of OP alone was in this range. This results in some substrates being able to be fermented only when mixed with other substrate or diluted.

After AD, values of TS significantly decreased in all substrate types (Table 2). However, high decrement was observed in 75%PM+25%OP which was 6.07. High reduction of VS was measured in 75%PM + 75%OP mix substrates compared to the rest of substrates after AD (Table 2). The TS and VS values before digestion was found to vary significantly ($P<0.05$) with increasing of OP proportion in the mix, suggesting that mixing helps to adjust the TS and VS. Removal of VS after AD suggests its conversion to biogas. Total solids and volatile solids destruction is a good parameter for evaluating the efficiency of anaerobic digestion [27].

3.3. Average Daily and Cumulative Biogas Production of Untreated Substrates

Even though the digesters contained different mix ratios of PM and OP, and the volume of biogas produced varied with substrate mixture, gas production was noticed from the very initial day of the experiment (Figure 1). Initially, the digester with PM alone and 75% PM + 25%OP produced higher amount of biogas than other digesters (Figure 1). This could happen due to the presence of higher amount of readily biodegradable organic matter and native anaerobic microbes in the PM [28]. Thus, biogas production is a function of the feedstock's organic content and its biodegradability [29].

Production of gas had gradually decreased starting from the first day in all digesters except in PM alone. This might be due to the declining of readily decomposable substrate [30] and/or an increase in ammonium concentration that may resulted in an increased pH values [31]. Gas production continued until day 19 and fallen sharply to 0ml after day 20 for digesters having PM alone and PM as co-substrate, but it stopped after day 17 for digester containing OP alone.

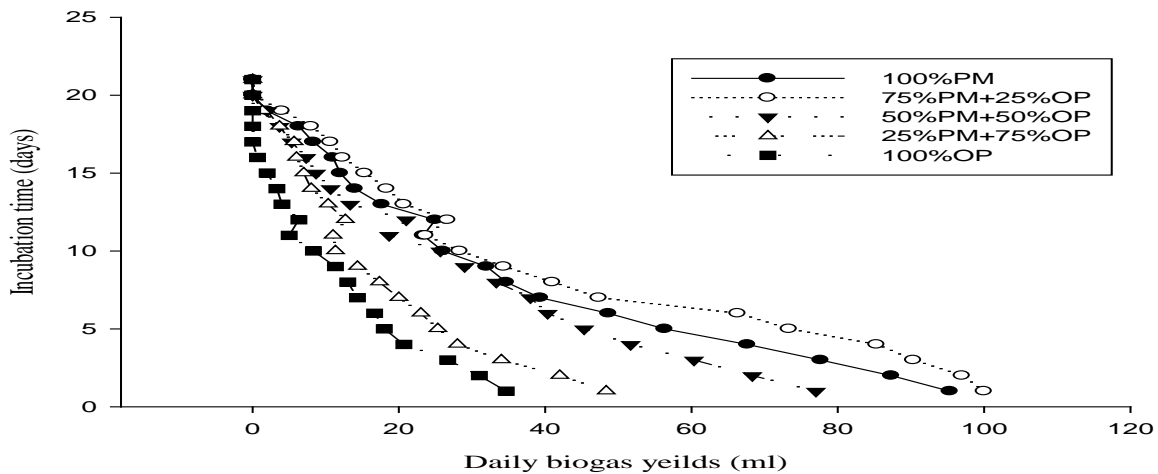


Figure 1: Daily mean biogas yield of the different substrate combinations.

There was a significant difference between the substrates in an overall biogas yield (Figure 2, $p < 0.05$) even though closer result was obtained from 100%PM and 50%PM+50%OP. High production of gas was recorded from a digester containing PM alone and other digesters having equal or more than 50% of PM as a co-substrate (Figure 2). However, the highest production of gas was observed from the mix ratio of 75% PM + 25% OP. From 10g (75%PM+25%OP), 768ml (Appendix table 1) of biogas was produced which was 549ml higher than 100%OP, that has produced 218.33ml of cumulative biogas. According to [32] the performance of digesters could be considerably improved by means of co-substrate addition and hence can be used to increase the efficiency of degradation and biogas production.

Low gas production obtained from digesters having high proportion of OP and the lowest production of gas was measured from OP alone. This may be due to the presence of an antimicrobial compound 'D-Limonene' in OP [33]. This chemical constitutes 90% of oranges essential oil as 2-3% of dry matter of the orange [34]. Limonene has been reported to be highly toxic to anaerobic digestion [33]. It causes ultimate failure of the process at concentration of 400 $\mu\text{L/L}$ on mesophilic digestion [36] and in the range of 450 to 900 $\mu\text{L/L}$ on thermophilic digestion [35]. Thus, it can be concluded that co-digestion of PM and OP is more productive with OP proportion not exceeding 25%. The higher production from the mixtures could be due to a proper nutrient balance, increased buffering capacity, and decreased effect of toxic compounds resulting from mixing of substrates [36]; [29;37;38].

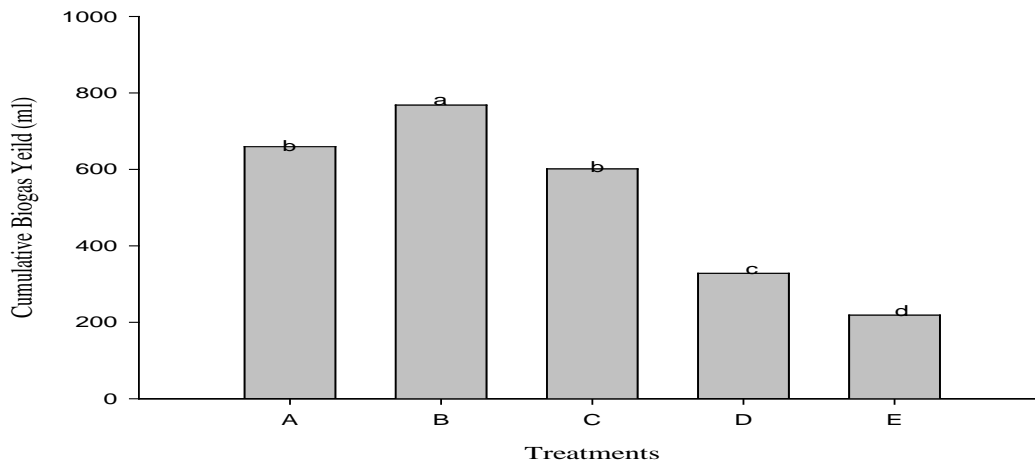


Figure 2: Cumulative biogas yield of the different substrate combinations (Values are mean \pm SE).

Bars with different letters indicate significant differences between means while those with same letters show no significant difference between means. A=100%PM, B=75%PM+25%OP, C=50%PM+50%OP, D=25%PM+75%OP, E=100%OP. (PM=Poultry manure, OP=Orange peel)

3.4. Physicochemical Characteristics of Temperature Pre-treated Substrate

pH values of the substrates for the three temperature treatments (control, 60 °C and 80 °C) was within the range of 6.82 ± 0.01 to 7.43 ± 0.01 before digestion (Table 3). This pH range is optimal for biogas production. Optimal pH for biogas production is neutral and when pH is < 6 or > 8 , fermentation process will be inhibited or ceased at all because of its toxic effect on the methanogenic bacteria, which produce methane gas [39]. The pH value of rumen fluid used in this experiment is almost neutral (7.51).

Table 3: Physicochemical features of blended PM and OP at 75%: 25% ratio for thermal pre-treatment test before and after AD (values are mean \pm SE, n=3).

Treatments	Parameters			
	Initial pH	Final pH	% initial organic C	% final organic C
Control	6.82 ± 0.01^{bA}	8.45 ± 0.01^{aA}	10.69 ± 0.01^{aA}	7.68 ± 0.01^{bA}
60 °C	7.41 ± 0.01^{bB}	8.45 ± 0.01^{aA}	10.56 ± 0.05^{aA}	3.65 ± 0.02^{bB}
80 °C	7.43 ± 0.01^{bB}	8.46 ± 0.01^{aA}	10.59 ± 0.03^{aA}	3.17 ± 0.01^{bC}

Means followed by different small letters in row are significant at 0.05 probability levels for paired samples T-test within treatment. Means followed by different capital letter in column are significantly different at 5% level of significance between treatments.

The result showed that the values of pH were slightly increased as the temperature of the substrate rose up from control to 80°C. This may be explained by the solubilisation of compounds such as proteins during thermal pre-treatment [40]. So, this indicates that temperature and pH are directly proportional to each other, i.e., as temperature increases pH increases and vice versa up to a certain point. There was no significant difference in pH values between the thermal treatments after AD ($P>0.05$) (Table 3). Before AD, pH value of the control showed significant difference than the two thermal treatments compared to initial pH ($p<0.05$). The final alkaline pH observed after digestion might be explained by the formation of $(\text{NH}_4)_2\text{CO}_3$ [41].

The result revealed that %C reduced in both thermal treatments (60°C and 80°C) before AD. The percentage reduction was 65.4% and 70% for 60°C and 80°C respectively. The results also showed that there are significant differences in percentage organic carbon in all treatment before and after digestion ($p<0.05$). The maximum reduction of carbon content observed in 80 °C thermal treatment (exceeded by 41.8% over the control) might be due to either by being converted to cellular materials for growth and reproduction of bacteria or biogas production [24]. The decrement of organic C indicates the effectiveness of degradation process during anaerobic digestion [42].

3.5. Effect of Thermal Pre-treatments on TS and VS Reduction

As shown in (Figure 3), there was no significant difference in TS between thermal treatments before digestion even though significant difference was observed after AD. TS of the substrates pre-treated by 60°C and 80°C temperature following digestion were significantly lower than the control (22°C), although there was no significant difference between 60°C and 80 °C pre-treatments (Figure 3). This reflects that increment of temperature of pre-treatment may reduce the TS value of substrate after AD and result in increased biogas production. TS was significantly reduced within each thermal treatment after digestion. This decrement in TS demonstrates that a large fraction of the substrates was broken down and digested. During anaerobic digestion, the TS of the substrate decreased due to its consumption for biogas production [24].

The initial value of TS showed that the moisture content of the substrates to be only 76.2%. Since studies on the most favourable percentage of total solids for biogas productions suggest 8% as the optimum TS, the initial moisture content of substrates used for this study was not optimal for wet anaerobic digestion process [18]. Therefore, 119.75 mL (100 mL inoculum+19.75 mL distilled water) is required to bring the total solids percentage to 8%.

There was no significant difference between temperature treatments in VS before AD. However, significant difference was measured in VS between treatments after AD (Figure 4). That is, VS of the substrates pre-treated by 60 and 80°C temperature following AD was significantly lower than that of control temperature, though there was no significant difference between 60 and 80 pre-treatments (Figure 4). Percentage reduction of VS for control, 60 °C and 80 °C pre-treated feed stocks were 28.2%, 61.1% and 64.3%, respectively. The observed volatile solid reduction could be due to an increment of soluble materials [45], due to thermal pre-treatment, which increases the availability of substrate for microbes during anaerobic digestion [40].

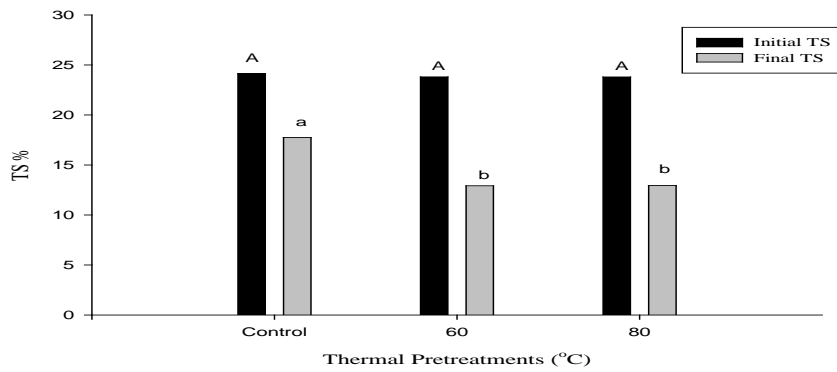


Figure 3: Values of TS for thermally pre-treated substrates before and after digestion.

Capital letters represent differences between %TS of the substrate under different temperature pre-treatments before digestion while small letters represent that of after digestion. Bar graphs with the same capital or small letters are not significantly different, whereas those with different capital or small letters are significantly different. TS=Total Solids.

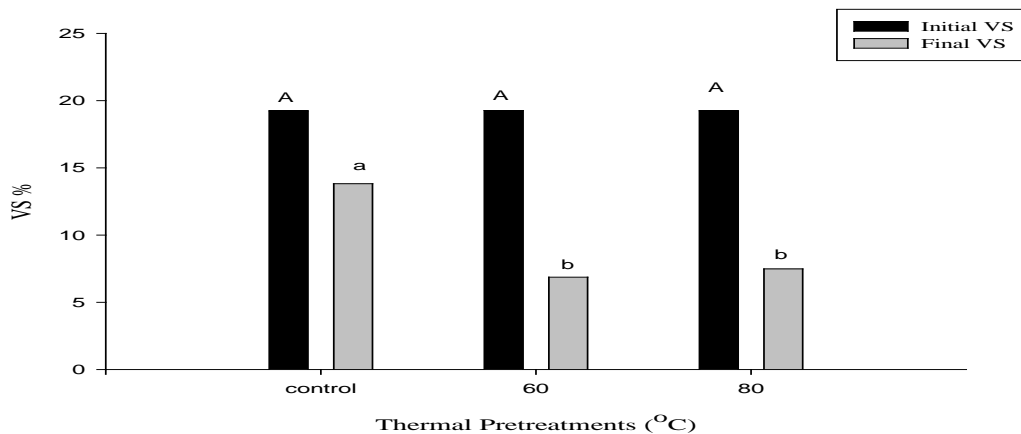


Figure 4: Values of VS for thermally pre-treated substrates before and after digestion.

Capital letters represent differences between %VS of the substrate under different temperature pre-treatments before digestion while small letters represent that of after digestion. Bar graphs with the same capital or small letters are not significantly different, whereas those with different capital or small letters are significantly different. VS=Volatile Solids.

3.6. Biogas Production from Thermally Pre-treated Substrates

The average biogas production of control and 60°C was almost closer to each other at day 1 and 2 even though the production was higher in case of the substrate pre-treated by 80°C (Figure 5). After day 3 production of biogas from control was less than those obtained from both thermally pre-treated substrates. This illustrates that

the substrate treated by 80°C is easily digestible by bacteria that take part in anaerobic digestion particularly hydrolytic bacteria at the early stage of the digestion. The production of gas gradually decreased from day 1 to day 17 and completely stopped starting from day 18 in all digesters containing thermally pre-treated substrate. Thus, pre-treatment does not only yield greater amount of biogas, but it also reduces hydraulic retention time needed for AD [43].

For thermally (60 and 80 °C) pre-treated samples more than 50% of biogas were measured within 5 days. This indicates that availability of more easily degradable organic materials for microbes within this short period of time. The increased initial biogas production is credited to the increased accessibility and degradability of substrate [5].

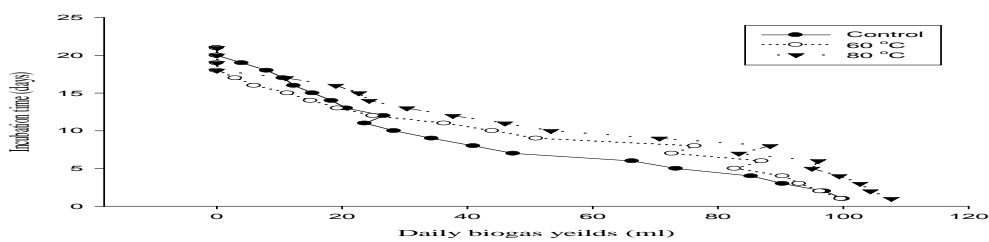


Figure 5: Daily mean biogas yield profile during batch fermentation of thermally pre-treated substrates.

Substrates pre-treated with 60 or 80 °C significantly increased cumulative biogas yield when compared with the control temperature ($P < 0.05$, Figure 6). The result also revealed that there was significant difference between 60 and 80 °C treated substrate in cumulative biogas yield ($P < 0.05$). Maximum cumulative gas production was measured for 80 °C pre-treated substrate. It was exceeded by 11.7% over the control and 6.6% over 60 °C pre-treated sample.

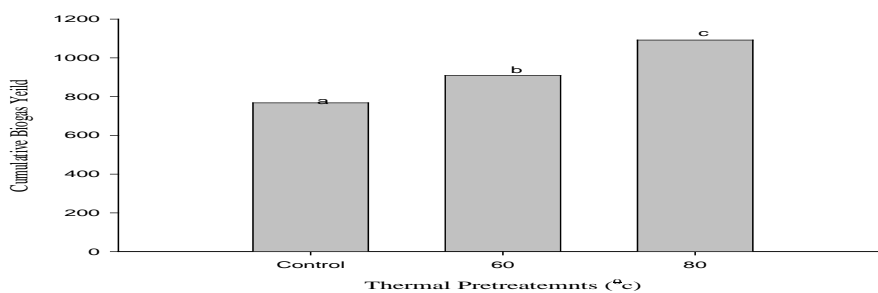


Figure 6: Cumulative biogas yield of the different level of thermally pre-treated substrates (means with the same letter are not significantly different).

4. Conclusion

The main aim of the study was to produce biogas from co-fermentation of poultry manure and orange peel at different mix ratio which took place under a series of experiments at mesophilic condition. This series of

experiments were taken place within 21 days. Anaerobic digestibility tests were carried out to get appropriate mix ratio for maximum biogas production from wet co-digestion of PM and OP at 5 different proportions. During the first phase of experiments, the mix ratio of 75%PM+25%OP resulted highest biogas yield compared to the rests, and selected for second phase of experiment. Then 75%PM+25%OP was pre-treated with temperature of 60°C and 80°C in order to identify the effect of pre-treatments on biogas production. Maximum production of biogas was obtained from a mix ratio treated by 80°C compared to control and a sample treated by 60°C. Cumulative biogas production from a sample treated with 80°C was 1091.67ml, while it was 768ml and 909ml from control and a substrate treated by 60°C respectively. Maximum reduction of TS and VS, and high degradation of organic carbon was noticed in a mix ratio subjected by 80°C. This may be due to the increment of degradability of substrate after pre-treatments. This in turn leads to high availability of nutrients for microbes, and finally improves biogas production. Generally, pre-treatments modify biogas production from different feed stocks as they speed up the activity of microbes.

5. Recommendation

Based on the finding of the study, the following recommendations are given;

- ✓ Ranking of mix ratios should be done based on reduction of TS, VS, organic Carbon, and producing the highest biogas yield in order to select a mix ratio for Thermal and Alkali pre-treatments.
- ✓ Other combination effective pre-treatments could be used to identify the most relevant one which improve the production of gas without eradicating the nutrients of the feed stocks, and initiating the activity of microbes.
- ✓ The five mix ratios could be characterized based on organic loading rate, Carbon/Nitrogen ratio and Carbon/ Phosphorous ratio to assess their effect on biogas production.
- ✓ Orange peel should be pre-treated by appropriate pre-treatments to reduce the inhibitory effects and optimize biogas production.

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References

- [1]. M. Lawrence (2012). Global biogas market to nearly double in size to \$33 billion by 2022.

- [2]. Bisipln. (2012). The Bioenergy System Planners Handbook. Available: www.bisiplan.bioenarea.eu/html-files-en/02-03.html [January 6, 2014]
- [3]. S. Karekezi. (1994). Disseminating renewable energy technologies in sub-Saharan Africa. *Annual Reviews* 19:387-421.
- [4]. S.K. Khanal. (2008). *Anaerobic biotechnology for bio-energy production*, John Wiley and Sons.
- [5]. R. Rafique, T.G. Poulsen, A.S. Nizami, Z.Z. Asam, J.D. Murphy and G. Kiely. "Effect of thermal, chemical and thermo-chemical pre-treatments to enhance methane production." *Thermal Energy*, vol.35, pp.4556-4561, 2010
- [6]. E. Bruni. "Improved anaerobic digestion of energy crops and agricultural residues," Department of Environmental Engineering, Technical University of Denmark, 2010
- [7]. W. Zhong, Z. Zhang, W. Qiao and M. Liu. "Renewable Energy. " Comparison of chemical and biological pretreatment of corn straw for biogas production by anaerobic digestion, vol.36, pp.1875-1879, 2011
- [8]. I. Angelidaki, and B.K. Ahring. "Methods for increasing the biogas potential from the recalcitrant organic matter contained in manure," *Anaerobic Digestion of Solid Wastes*, 1999, pp.23-32
- [9]. D.C. Devlin, S.S.R. Esteves, R.M. Dinsdale and A.J. Guwy. "The effect of acid pre-treatment on the anaerobic digestion and dewatering of waste activated sludge." *Bioresource Technology*, vol.102, pp.4076-4082, 2011
- [10]. Z. Mladenovska, H. Hartmann, T. Kvist, M. Sales-Cruz, R. Gani and B.K. Ahring. "Thermal pre-treatment of the solid fraction of manure: impact on the biogas reactor performance and microbial community." *Water Science Technology*, vol.53, pp.59-67, 2006
- [11]. EREDPC (Ethiopian Rural Energy Development Promotion Centre). 2008. *National Biogas Programme Ethiopia: Programme Implementation Document*) Accessed on October 11, 2014.
- [12]. FAO (Food and Agricultural Organization). 1990. *Food and Agricultural Organization of the United Nations Agrometeorology group, Remote Sensing Center Research and Technology Division*. Rome, Italy.
- [13]. S. Sunarso, Z. Johari and I.N. Widiassa. "The effect of feed to inoculums ration biogas production rate from cattle manure using rumen fluid as inoculums." *International Journal Waste resource*, vol. 2, pp.1-4, 2012
- [14]. B.S. Lo Niece Liew. "Solid state anaerobic digestion of lignocellulosic biomass for biogas production.

- “ MSc thesis, Ohio State University, USA, 2011.
- [15]. APHA (American Public Health Association). Standard methods for examinations of water and wastewater, 19th Edition. American Public Health Association, Washington DC, USA. 1999
- [16]. J.O. Arogo, Z. Wen, J. Ignosh, E. Bendfeldt and E.R. Collins. “Biomethane Technology,” College of Agriculture and Life Sciences, Virginia Polytechnic Institute and State University, pp. 442-881
- [17]. C.M. Badger, M.J. Bogue and D.J. Stewart. 1979. “Biogas production from crops and organic wastes.” *Journal of Science*, vol.22, pp.11-20, 2009.
- [18]. G. Tchobanoglous, H. Theisen and S. Vigil. “Integrated Solid Waste Management Engineering,”: Principle and Management Issues, McGraw-Hill U.S, Singapore, 1993.
- [19]. M. Knottier. “Integration of biogas technology, organic farming and energy crops.” The future of biogas in Europe, University of Southern Denmark, Denmark, 2003.
- [20]. A. Bonmatí, X. Flotats, L. Mateu and E. Campos. “Study of thermal hydrolysis as a pre-treatment to mesophilic anaerobic digestion of pig slurry.” *Water Science Technology*, vol.44, pp.109-116, 2001.
- [21]. I.N.Itod, E.B. Lucas and E.I. Kucha. “The effect of media materials and its quality on biogas yield.” *Nigerian Journal of Renewable energy*, vol. 3, pp.45-49, 1992.
- [22]. A.J. Ward, P.J. Hobbs P.J, Holliman. and D.L. Jones. “Optimization of the anaerobic digestion of agricultural resources.” *Bioresource Technology*, vol.99, pp.7928-7940, 2008.
- [23]. D. J. Hills and D.W. Roberts. “Anaerobic digestion of dairy manure and field crop residues.” *Agricultural Wastes* vol.3, pp.179-189, 1981.
- [24]. M.H. Gerardi.”The Microbiology of Anaerobic Digesters.”A John Wiley and Sons, vol.6, pp. 99-103, 2003.
- [25]. E. Buysman. “Anaerobic Digestion for Developing Countries with Cold Climates,” Utilizing solar heat to address technical challenges and facilitating dissemination through the use of carbon finance, University of Wagenigen, Environmental Technology, Wagenigen, 2009.
- [26]. R, P. Huber and J. Meyrath, “Ammonia toxicity in liquid piggery manure digestion.” *Biotechnology*, vol.3, pp.159-164, 1981.
- [27]. B. Abuabaker and N. Ismail. “Anaerobic Digestion of Cow Dung for Biogas Production.” *Journal of Engineering and Applied Science*, vol. 7, pp.69-172, 2012
- [28]. T.Y. Yeole, and D.R. Ranande. “Alternative feedstock for Biogas.” *Tropical Animal production*, vol.

9, pp.10-16, 1992.

- [29]. M. Macias-Corral, Z. Samani, A. Hanson, G. Smith, P. Funk, H. Yu and J. Longworth. "Anaerobic digestion of municipal solid waste and agricultural waste and the effect of co-digestion with dairy cow dung." *Bioresour Technology*, vol.99, pp.8288-8293, 2008.
- [30]. H. Ahn, M. Smith, S. Kondrad and J. White. "Evaluation of biogas production potential by dry anaerobic digestion of switch grass-animal manure mixtures." *Applied Biochemistry and Biotechnology*, vol. 160, pp.965-975, 2009.
- [31]. H.H Hansen, I. Angelidaki and B.K. "Ahring improving thermophilic anaerobic digestion of swine manure." *Water Resources*, vol. 33, pp.1805-1810, 1999.
- [32]. N. Kapraju and A. Rintala. "Thermophilic anaerobic digestion of industrial orange waste." *Environmental Technology*, vol.27, pp.623-633, 2006.
- [33]. M. Martín, A. Siles, F. Chica and A. "Martín. Biomethanization of orange peel waste." *Bioresour Technology*, vol. 101, pp.8993-8999, 2010.
- [34]. E. Mizuki. "Inhibitory Effect of citrus peel on anaerobic digestion." *Biological Wastes*, vol.33, pp.161-168, 1990.
- [35]. G. Forgács. "Methane production from citrus wastes: process development and cost estimation." *Biotechnology*, vol.8, pp.250-255, 2012.
- [36]. D. Fulford. "Running a biogas programme," a handbook. Intermediate technology Publications, London, pp.123-35, 1988.
- [37]. X. Li, L.Q. Li, M.X. Zheng, G.Z. Fu and J.S. Lar. "Anaerobic co-digestion of cattle manure with corn stover pre-treated by sodium hydroxide for efficient biogas production." *Energy Fuels*, vol.23, pp.4635-4639, 2009.
- [38]. T. Aragaw. "The effect of co-digestion of cattle manure with organic kitchen waste using rumen fluid as inoculum on the rate and amount of biogas production." M.Sc. thesis, Haramaya University, Ethiopia, 2012.
- [39]. S. Thy, T.R. Preston and J. Ly. "Effect of retention time on gas production and fertilizer value of biodigester effluent." *Rural Development*, vol.15, pp.1-24, 2003.
- [40]. H. Carrère, B. Sialve and B. Bernet. "Improving pig manure conversion into biogas by thermal and thermo-chemical pre-treatments." *Bioresour Technology*, vol.100, pp.3690-3694, 2009.

- [41]. D. Georgacakis, D.M. Sievers and E.L. Iannotti, Buffer stability in manure digesters.” Agricultural Wastes, vol.4, pp.427-441, 1982.
- [42]. M.A. Abdel-Hadi and S.A.M. Abd El-Azeem. Effect of heating, mixing and digester type on biogas production from buffalo dung.” Agricultural Engineering, vol. 25, pp.1454-1477, 2008.
- [43]. I. Ferrer., S. Ponsá, F. Vázquez and X. Font. “Increasing biogas production by thermal (70 °C) sludge pre-treatment prior to thermophilic anaerobic digestion.” Biochemical Engineering, vol.42, pp.186-192, 2008.

6. Appendices

Table 1: Daily mean biogas yields from co-digestion ± SE (mL) (n=3)

Days	Mix ratio				
	100% PM	75%PM+25%OP	50%PM+50%OP	25% PM+75%OP	100% OP
1	95.33±0.88	100±1.15	77±1.15	48.33±1.20	34.67±1.20
2	87.33±0.88	97±1.15	68.33±0.88	42±1.15	31±0.57
3	77.67±1.45	90.33±0.88	60.33±1.20	34±1.15	26.67±0.88
4	67.67±1.86	85.33±0.88	51.67±0.67	28±1.15	20.67±1.86
5	56.33±1.86	73.33±1.45	45.33±0.88	25.33±0.88	18±1.53
6	48.67±1.20	66.33±1.45	40.33±0.33	23±0.58	16.67±0.88
7	39.33±1.45	47.33±1.20	38±0.58	20±1.00	14.33±0.88
8	34.67±0.88	41±1.15	33.33±0.33	17.33±1.76	13.00±1.53
9	32±1.15	34.33±1.76	29±1.15	14.33±1.20	11.33±0.88
10	26±1.16	28.33±0.67	25.67±1.76	11.33±0.88	8.33±0.88
11	23.33±1.20	23.67±0.88	18.67±2.01	11±1.15	5±0.58
12	25±1.15	26.67±1.45	21±1.73	12.67±0.88	6.33±0.88
13	17.67±1.20	20.67±0.88	13.33±1.20	10.33±0.33	4±0.58
14	14±0.58	18.33±0.88	10.67±0.88	8±1.73	3.33±0.67
15	12±1.15	15.33±0.88	8.67±0.67	7±1.15	2±0.58
16	11±1.15	12.33±1.33	7.33±0.88	6±0.58	0.67±0.33
17	8.33±0.88	10.67±1.20	5.33±0.88	5.67±0.33	0±0
18	6.33±0.88	8±0.58	3.67±0.33	3.67±1.33	0±0
19	2±0.58	4±0.58	2±1.15	1.33±0.88	0±0
20	0±0	0±0	0±0	0±0	0±0
21	0±0	0±0	0±0	0±0	0±0
Total	659.33	768	601	328	218.33

Table 2

Days	Thermal Pre-treatment		
	Control	60 °C	80 °C
1	100±1.15	99.67±0.88	107.67±1.45
2	97±1.15	96.33±0.33	104.33±0.88
3	90.33±0.88	93±1.53	102.67±1.20
4	85.33±0.88	90.33±1.20	99.33±0.67
5	73.33±1.45	82.67±1.45	95±1.15
6	66.33±1.45	87±1.53	96±0.58
7	47.33±1.20	72.67±0.67	83.33±0.67
8	41±1.15	76.33±0.67	88.33±0.88
9	34.33±1.76	51±1.15	70.67±0.88
10	28.33±0.67	44±1.73	53.33±1.20
11	23.67±0.88	36.33±1.45	46±1.15
12	26.67±1.45	25±0.58	37.67±1.45
13	20.67±0.88	19.33±0.88	30.33±1.33
14	18.33±0.88	15±0.58	24.33±1.20
15	15.33±0.88	11.33±0.88	22.67±1.45
16	12.33±1.33	6±0.58	19±1.16
17	10.67±1.20	3±0.58	11±1.15
18	8±0.58	0±0	0±0
19	4±0.58	0±0	0±0
20	0±0	0±0	0±0
21	0±0	0±0	0±0
Total	768	909	1091.67

Appendix Table 3. Daily mean biogas yields from thermal pre-treatment test ± SE (mL) (n=3)