Utilization of Onion Solid Waste as Feedstock for Biogas Production

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ABSTRACT--- ***Utilization of onion solid wastes such as onion leaves and unmarketable onion bulbs as potential feedstock for biogas production was investigated. Response surface methodology (RSM) was used to optimize the interactive effects of temperature, lime concentration and reaction time for the maximum biogas and methane yield, and biodegradation.***

Results showed that the optimum pretreatment conditions established for red creole bulb are: lime concentration of 4%, temperature of 118°C and reaction time of 5 hours; yellow granex bulb – lime concentration of 6.5%, temperature of 102°C and reaction time of 2 hours; red creole leaves – lime concentration of 12%, temperature of 118°C and reaction time of 6 hours; and yellow granex leaves – lime concentration of 12%, temperature of 118°C and reaction time of 5 hours. Red creole bulb produces the highest biogas yield (373.4 ml/g VS and 60.3% CH_4), followed by yellow granex leaves (366.6 ml/g VS and 58.5% CH_4), red creole leaves (331ml/g VS and 59.6% CH_4) and yellow granex bulb (350ml/g VS and 60.7% CH_4). The regression equation established for biogas yield was found to be adequate for the prediction of independent variables applied. Moreover, the highest and lowest biodegradability of 59.1% and 39% were obtained for Red creole bulb and leaves, respectively. Onion bulb wastes containing easily-degradable substrates had relatively higher methane production potential and biodegradability than onion leaves which have more fiber content.

Keywords---- onion waste, biogas, pretreatment conditions, biogas yield, biogas yield

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1. INTRODUCTION

The Philippines is mainly an agricultural country with 47% of total land area devoted to agricultural crops. Onion is one of the most important commercial vegetable crops grown in the Philippines. The country's total onion production has recorded 203,651 metric tons in 2014. The most commonly grown onion varieties are Red Creole (64%), Yellow Granex (7%) and Shallots or multiplier (29%) (BAS, 2015).

Onion production in October to December 2015 was estimated at 9.73 thousand metric tons, 3.5 percent lower than 2014 production of 10.09 thousand metric tons. The decline in production was attributed to occurrence of pests such as thrips, onion fly, and bulb rot due to failure to adopt some control measures such as good field sanitation by removing onion residuals from the field (BAS, 2015). Plant debris should be removed and disposed of immediately following harvest to reduce the dispersal of any emerging maggots in onion (Welbaum, 2015).

During harvesting, losses at the farmer's level of about 5% which accounts for the unmarketable rejects (removed and left at the farm) were reported by DA-BPRE and UPLB-PSSD (2009). Such circumstances increase the amount of onion waste generated in the field. Furthermore, Calica *et. al.,* (1999) reported a high total losses from harvesting to storage for red creole onion bulbs (16%) and yellow granex bulbs (18%).

Disposal of agricultural by-products create economic and environmental problems due to lack of proper utilization. When dumped in open spaces or in landfills, agricultural wastes being rich in organic matter get easily decomposed by the action of various microbes. This produces different gases like methane and carbon dioxide both of which contribute to the greenhouse effect leading to global warming (Brown and David, 1994). Open air incineration also generates noxious gases causing air pollution. Apart from this, the open decomposed organic matter acts as breeding ground of various disease causing organisms and their vectors thereby leading to a spread of air borne diseases at an alarming rate. Leachate from dumped waste contain high amount of total dissolved solid, ammonia, nitrate, phosphate, calcium, sulfate, and iron, as well as numerous heavy metals which have the potential to cause water pollution of surface and ground water (Salem *et. al.,* 2008), hence, necessitating the application of alternative strategies to convert these wastes into a usable form.

One viable solution is to manage the agricultural waste not as a waste product, but as a feedstock in a process that can produce biomethane. Crop residues have potential to be utilized for biomethane production. There are various methods available for the treatment of organic waste but anaerobic digestion appears to be a promising approach (Lee *et. al.*, 2009).

Anaerobic digestion is a controlled biological degradation process that allows for efficient capturing and utilization of biogas (approximately 60% methane and 40% carbon dioxide) for energy generation. This process happens naturally when bacteria breaks down organic matter in environment with no oxygen. It is a well-studied technique for organic waste biodegradation (Mata-Alvarez *et. al.*, 2000). The digestate from anaerobic digesters contains many nutrients and can thus be used as plant fertilizer and soil conditioner.

Recent Life Cycle Assessment (LCA) studies have demonstrated that biogas derived methane is one of the most energy efficient and environmentally sustainable vehicle fuels (Kapdi *et. al.*, 2005). LCA is a tool to assess the potential environmental impacts and resources used throughout a product's lifecycle, i.e., from raw material acquisition, via production and use phases, to waste management (Chen, *et. al.*, 2003). Due to increasing needs for renewable energy generation and diversion of organic residuals to reduce the greenhouse gas emissions and other environmental impacts, treatment of agricultural waste using anaerobic digestion technologies has become a more significant method for organic waste management. Biogas technology offers a very attractive route to utilize the agricultural waste and at the same time, provide biogas for heating, electricity and organic fertilizer or carrier material for biofertilizers.

Hence, the study explored the potential of utilizing onion solid wastes (e.g. leaves, unmarketable bulbs, sprouted onions) as feedstock for biogas production through anaerobic digestion.

2. MATERIALS AND METHODS

Collection and Preparation of Experimental Samples

The onion leaves left in the field after harvesting were collected from the farm at Science City of Muñoz, Nueva Ecija, while the onion bulb rejects were collected at KASAMNE, a cold storage facility in Palayan City, Nueva Ecija. These onion wastes were brought to Bioprocess Engineering Division (BPED) Laboratory-PHilMech for sorting and labeling. To ensure the availability of samples for the entire duration of the experiment, the fresh leaves samples were sundried to a moisture content of ≤ 10 % (wb). The dried onion leaves were ground to pass through a 2mm sieve. The ground onion leaves samples were kept in air tight container and stored at ambient temperature until use.

On the other hand, fresh effluent from a mesophilic anaerobic digester of the Dee-Y Farm in Cauayan, Isabela was collected and used as inoculum. Dee-Y Farm is a hog contract grower of Monterey that operates six (6) units of eight (8) cubic meter capacity anaerobic digester to treat their manure and to supplement the farm's electricity requirement. The inoculum was transported to BPED laboratory in 20-liter containers within 48 hours, following the handling procedure described by Hansen and co-workers (2004). Prior to use, the inoculum was acclimated at 37°C for one week.

Physico-chemical Analyses

Before the onset of the anaerobic process, the onion wastes were characterized in terms of moisture content (MC), volatile solids (VS), total solids (TS), and fixed solids (FS). Similarly, the entire content of the reactor were measured for VS, TS, FS, volatile fatty acids (VFA) and pH following the standard methods for the examination of water and wastewater (APHA, 1998). Moreover, the TS, VS, and FS content of the inoculum used were also determined.

In order to determine the characteristics of the experimental samples, the concentration of protein, fat, fiber, carbohydrates, calories and ash were analyzed. Ultimate Analysis was also conducted to determine the elemental Carbon, Hydrogen, Nitrogen and Sulfur content of the onion wastes. The measurement of physicochemical parameters was done as follows:

Determination of elemental composition and proximate analysis

The elemental composition (C, H, N, S) and Phosphorus were determined using Combustion Method (LECO Organic Application Note) and Official Methods of Analysis (AOAC, 2005), respectively. The proximate analysis was carried out using Block Digestion, Kjeldahl, Direct Ether Extraction (AOAC, 2005). All analyses were conducted by the Standards and Testing Division of ITDI-DOST. The crude fiber content was determined using Weende Method at DOST-III Regional Standards and Testing Laboratory.

Determination of Moisture Content

The moisture content of the onion bulb samples was determined using standard oven method at 130°C for 50 minutes (ASAE 1982). Initial weight and final weight after oven drying were recorded. Moreover, the moisture content of the dried onion leaves samples was monitored weekly using Moisture Analyzer (PMB202, Adam, United Kingdom).

Measurement of pH

The initial and final pH of the slurry was measured using digital pH meter (WD-35419-11, Oakton, USA).

Measurement of Total Solids (TS), Volatile Solids (VS) and Fixed Solids (FS)

Clean evaporating dishes were heated at 550^{o}C for 1 hour in a muffle furnace and were stored and cooled in desiccator until needed. The evaporating dishes were weighed immediately before its use.

Measurement of total solids in onion wastes samples before digestion

The onion leaves samples were ground and the onion bulb samples were minced to maintain homogeneity. The yellow granex and red creole onion varieties were used in the analysis. Ten (10) grams of onion leaves and twenty-five grams of onion bulb samples were weighed in separately prepared evaporating dishes. The samples were dried for at least 1 hour in an oven at 105°C. The evaporating dishes were cooled in a desiccator to balance temperature, and weighed again. The cycle of drying, cooling, desiccating, and weighing was repeated until the constant weight was obtained, or until weight change was less than 4% of previous weight or 50 mg, whichever is less (APHA, 1998). All samples were analyzed in duplicate.

Measurement of total solids in slurry

The total solids content were determined following the standard method by APHA (1998). Samples from each reactor at the end of the digestion trial were used in the analysis. A measured volume of well-mixed sample was pipetted to a pre-weighed evaporating dish. The samples were stirred during transfer to maintain homogeneity of samples. The samples were evaporated to dryness in the oven at 90^{o}C to prevent splattering of the liquid portion. The evaporated samples were dried for at least 1 hour in an oven at 105°C. The evaporating dishes were cooled in a desiccator to balance temperature, and weighed again. The cycle of drying, cooling, desiccating, and weighing was repeated until the constant weight was obtained, or until weight change was less than 4% of previous weight or 50 mg, whichever is less. All samples were analyzed in duplicate.

Measurement of volatile and fixed solids in onion wastes samples and in slurry

The volatile solids and fixed solids content were determined following a standard method (APHA, 1998). The dried residue from onion wastes samples and slurry were transferred to a cool muffle furnace. The muffle furnace were heated to 550^{o}C and ignited for 1 hour to remove volatile organics. They were then cooled in desiccator to balance temperature and then weighed. The samples will be ignited again for 30 minutes in the muffle furnace at 550^{o}C, cooled, desiccated, and weighed. The cycle was repeated until until the weight change is less than 4% or 50 mg, whichever is less.

<u>Experimental Set-Up</u>

The experimental set-up consists of a temperature controlled rectangular water bath maintained at 37 $\pm$ 0.5^{o}C (Fig. 1). Three thermocouple wires attached to a data logger were fixed on each end and middle of the water bath to monitor the water temperature. A water circulation pump was installed to maintain uniform temperature of water inside the water bath. Storage media bottle of 500 ml capacity sealed with open top screw cap with septa were used as bioreactors. The effective volume of each reactor was determined by weighing the water contained in the reactor. The biogas produced was measured and collected using liquid displacement method.

Leak test was conducted in each reactor and gas collection bottle prior to digestion test to ensure the anaerobic environment of the set-up and prevent escape of biogas. The leak test was done using water immersion bubble test method and soap solution bubble test.

a b

Figure 1. The experimental set-up include a water bath with reactors and gas collection bottles (a) and temperature controller (b)

Biomethane Potential (BMP) Assay

BMP Assay for Waste Onion Leaves

In each batch test, ten (10) grams of dried and ground onion leaves (both for yellow granex and red creole onion) was loaded in the reactor. A water loading of 5 grams of water per gram of dry onion leaves was applied. Alkali pretreatment was carried out for delignification using the commercially available hydrated lime or calcium hydroxide [$Ca(OH)_2$]. Three lime loadings equivalent to 4%, 8% and 12% of the amount of dried onion solids were investigated. The lime was mixed with water and the mixture was poured into the reactor containing dried onion leaves. It was mixed until the ground onion leaves were soaked. The mixture was heated to three temperatures (80^{o}C, 120^{o}C and 160^{o}C) with heating durations of 2 hours, 4 hours and 6 hours. After pretreatment, the reactors were allowed to cool. A fixed inoculum concentration of 20% (v/v) was added to each reactor to initiate digestion. The total solid concentration was kept at 2.5%. The reactors were flushed with nitrogen for 3 minutes to ensure anaerobic conditions in the headspace and then sealed with screw cap. The reactors were wrapped with aluminum foil and placed in the water bath maintained at 37 ± 0.5°C.

BMP Assay for Waste Onion Bulbs

Yellow granex and red creole onion bulb samples were minced. In each batch test, one hundred thirty (130) grams of yellow granex onion bulb and sixty five (65) grams for red creole onion bulb samples were loaded in the reactor. Similar to the pretreatment of waste onion leaves, alkali pretreatment was carried out for delignification using the same lime used with onion leaves. For the pretreatment of yellow granex onion bulb wastes, three lime loadings equivalent to 2.1%, 4.3% and 6.5% of the amount of onion solids were tested. As for red creole onion bulb wastes, lime loadings equivalent to 1.2%, 2.6% and 4% of the amount of onion solids were tested. The lime was poured in the reactor containing minced onion bulbs and thoroughly mixed. The mixture was heated to three temperatures (80^{o}C, 120^{o}C and 160^{o}C) with heating durations of 2 hours, 4 hours and 6 hours. After pretreatment, the reactors were allowed to cool. Seed inoculum of 20% (v/v) was added to each reactor to initiate digestion. The headspace of the reactors were flushed with nitrogen for 3 minutes and then immediately sealed with screw cap to maintain strict anaerobic conditions. The reactors were wrapped with aluminum foil and placed in the water bath maintained at 37 ± 0.5°C.

Control

For the control, the assigned reactors were loaded only with inoculum and were incubated at the same temperature conditions as described by Angelidaki and co-workers (2009). Control runs were done in triplicate.

Mixing

The reactors were carefully shaken manually once a day before the measurement of displaced barrier solution to ensure efficient transfer of organic material for the active microbial mass. Moreover, mixing was done to release gas bubbles trapped in the mixture and to prevent sedimentation of denser particulate material.

Monitoring

Monitoring and measurement of the barrier solution displaced to each container was measured daily. Experimental set-up, which did not displace barrier solution was tested for leaks to ensure that no gas produced has escaped.

BMP Assay Duration

Preliminary digestion tests were carried out for 60 days incubation period to ensure full degradation of the degradable organic matter. In the succeeding tests, incubation period for onion leaves were carried out for 45 days and 15 days for onion bulb samples. After the incubation period, samples were taken on each reactor for the determination of final pH, TS, VS, FS and VFA concentration.

Preliminary Tests

A preliminary study was done to investigate and to narrow the experimental factors and its corresponding ranges before the application of statistical design. One of the most important parameters for anaerobic digestion batch test design was the load of the total solid substrate introduced into the digester. Different total solid concentrations (4%, 6% and 8%) were initially investigated at a fixed temperature of 120^{o}C, reaction time of 4 hours & lime loading of 0.075 g/g of dry biomass. The conditions employed were determined by earlier study for the pretreatment of corn stover for biogas production (Karr *et. al.,* 2000).

Gas Measurement, Characterization and Calculation

Fig. 2 illustrates a Gasometer set-up. Gas productions were measured by water displacement method at a fixed time each day after mixing. Daily gas production were recorded and converted to standard conditions. All the gas productions were evaluated after deducting the mean value of the gas production from the inoculum control. Data on gas production volumes were converted at standard temperature (0 ^oC (273.15 K)) and pressure (101.325 kPa (1 atm) set by the International Union of Pure and Applied Chemistry (IUPAC) (Calvert, 1990).

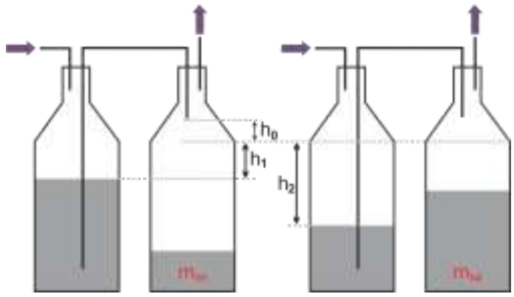

Figure 2. The Bottle Gasometer Set-up

Gas concentrations were determined once a week by a gas chromatograph (Shimadzu GC 2014, Japan) equipped with a thermal conductivity detector and an 8 ft x 1/8 in Hayesep D column. The carrier gas was helium (30ml/min), and injection volume was 0.5 mL. Injector and detector temperature was 140 ^oC, and oven temperature was 100 ^oC.

Gas samples of 0.5ml were taken from the headspace of the reactors through the septum using a gas tight syringe with pressure lock (VICI Pressure-Lok Precision Analytical Syringe, USA). The pressure lock was closed after the needle of the syringe had penetrated the septum and was inside the reactor headspace, making it possible to sample a fixed volume of gas at the actual pressure in the reactor. The syringe was redrawn and the sample was injected directly into the gas chromatograph where the concentrations of methane (CH_4), carbon dioxide (CO_2) and hydrogen sulfide (H_2S) were measured. A gas calibration curve was made using gas calibration standard composed of 95% methane and 5% hydrogen sulphide. The formula generated by the trend line of the calibration curve was used to calculate the gas concentration, given the peak area generated by the gas chromatograph. A 100% carbon dioxide standard gas was also used to verify the carbon dioxide concentration.

Data on the elemental compositions collected on each substrate was used to create theoretical methane yields using the Buswell equation. The Buswell equation is a method to determine the maximum biomethane potential (BMP) yield of substrates by converting all available volatile solids to methane and carbon dioxide. This stoichiometric equation however assumes all donated electrons are used entirely for metabolic energy.

Theoretical methane yield (TMY) was computed based on elemental compositions of the onion wastes. Methane yield expressed in ml CH_4/g VS feedstock was calculated as the volume of methane gas produced per g of VS loaded into the reactor at start-up corrected by subtracting the methane yield obtained from the control reactor (Angelidaki *et. al.*, 2009).

Anaerobic biodegradability (BD), which indicates how well a substrate can be degraded based on the experimental methane yield (EMY) and theoretical methane yield (TMY) (Elbeshbishy *et. al.*, 2012).

Experimental Design

Response surface methodology (RSM) using Box-Behnken design (BBD) was employed to obtain an optimal pretreatment condition that exhibits the highest biogas yield. Three factors were used: lime concentration (F1), reaction temperature (F2), and pretreatment time (F3). Tested conditions for onion bulb wastes varied lime concentrations of 1.2-6.5%, temperatures of 80-160^oC, and reaction times of 2-6 hours at fixed total solid concentration of 2.5%. Correspondingly, waste onion leaves were investigated at varied lime concentrations of 4-12%, temperatures of 80-160^oC, and reaction times of 2-6 hours at fixed total solid concentration of 2.5%. Data analysis was carried out via Minitab Statistical Software (Version 17.0).

3. RESULTS AND DISCUSSION

Physical and elemental compositions of onion wastes

Physical and chemical properties of biomass feedstocks and fuels are of great importance in any biomass-to-energy conversion process. Table 1 shows the physical and elemental compositions of onion wastes. The carbon to nitrogen ratio (C/N) of red creole leaves, yellow granex leaves, red creole bulb and yellow granex bulb were 19.56, 25.07, 29.73 and 11.83, respectively. On the other hand, the carbon to phosphorus ratio (C/P) of creole leaves, yellow granex leaves, red creole bulb and yellow granex bulb were 147.33, 174.63, 158.73 and 101.12, respectively. The C/N and C/P ratio of onion wastes obtained in the present study were found to be appropriate for anaerobic bacteria and therefore there is no need to add more nutrients to the raw onion waste to achieve optimum growth of bacteria. The total solid content of red creole leaves was significantly higher (85.23%) compared to the yellow granex bulb (5.37%).

Table 1. Physical and elemental compositions of onion wastes

Parameters	**Onion Wastes**			
	Red Creole Leaves	**Yellow Granex Leaves**	**Red Creole Bulb**	**Yellow Granex Bulb**
Total Solids (TS), %	85.23 ± 0.01	85.04 ± 0.07	13.11 ± 0.01	5.37 ± 0.00
Volatile Solids (VS), % TS	71.05 ± 0.02	83.70 ± 0.03	62.91 ± 0.04	62.55 ± 0.03
Fixed Solids (FS), %	28.95 ± 0.00	16.30 ± 0.00	37.09 ± 0.01	37.45 ± 0.01
C:N Ratio	19.56 ± 0.04	25.07 ± 0.04	29.73 ± 0.05	11.83 ± 0.04
C:P Ratio	147.33 ± 0.03	174.63 ± 0.02	158.73 ± 0.01	101.12 ± 0.01
Carbon %	35.8 ± 0.01	35.1 ± 0.01	7.73 ± 0.07	2.72 ± 0.02
Hydrogen, %	5.35 ± 0.02	5.28 ± 0.03	9.58 ± 0.01	10.10 ± 0.01
Nitrogen, %	1.83 ± 0.06	1.40 ± 0.01	0.26 ± 0.04	0.23 ± 0.03
Sulfur, ppm	5,540 ± 0.29	6,520 ± 0.50	880 ± 0.00	130 ± 0.29
Phosphorus, %	0.24 ± 0.01	0.20 ± 0.07	0.04 ± 0.00	0.02 ± 0.06

Proximate Properties of Onion Wastes

Generally, any type of biomass contains carbohydrates, proteins, fats, cellulose as main components, they can be used for biogas production. Table 2 shows the proximate properties of onion wastes. The yellow granex bulb was found to have the highest moisture content of 94.50 %. This could be the reason why yellow granex has the lowest amount of proteins, carbohydrates and fats. Likewise, methane production from organic substrates mainly depends on their content of substances that can be degraded to methane and carbon dioxide.

Table 2. Proximate Properties of Onion Wastes

Parameters	**Onion Wastes**			
	Red Creole Leaves	**Yellow Granex Leaves**	**Red Creole Bulb**	**Yellow Granex Bulb**
Moisture & Volatile Matter, %	12.20±0.02	11.80±0.04	85.10±0.01	94.50±0.00
Crude Protein, %	15.00±0.01	14.30±0.21	1.98±0.07	0.804±0.01
Crude Fiber Content, %	3.97±0.09	3.35±0.23	3.15±0.01	1.53±0.04
Total fat, %	4.30±0.21	3.60±0.17	0.129±0.20	0.125±0.03
Ash, %	18.10±0.11	19.30±0.25	0.517±0.08	0.534±0.14
Carbohydrates, %	50.40±0.05	51.00±0.01	12.20±0.03	4.08±0.12
Food Energy, Kcal/100g	300.00±0.00	294.00±0.06	58.10±0.07	20.70±0.01

Optimization of pretreatment conditions for maximum biogas yield

The response surface plots and it corresponding contour plots of biogas yield are generated with lime concentration kept at its optimum level, and varying the temperature and reaction time within the experimental range. These responses demonstrate the interactive effect temperature, and reaction time with the predicted best lime concentration on biogas yield. The interaction of temperature with reaction time showed that the maximum biogas yield could be around 118 ^{o}C and 5 to 6 hours reaction time for red creole bulb (Fig. 3a), red creole leaves (Fig. 3c) and yellow granex leaves (Fig. 3d). While pretreatment temperature of 102 ^{o}C and reaction time of 2 hours could yield the highest for yellow granex bulb (Fig. 3b). Biogas yield of red creole onion wastes increased with increasing reaction time. Moreover, the elliptic characteristic demonstrates that reaction time is more influential for biogas yield than lime concentration and temperature. Reaction time is an important factor which significantly affects solubilization.

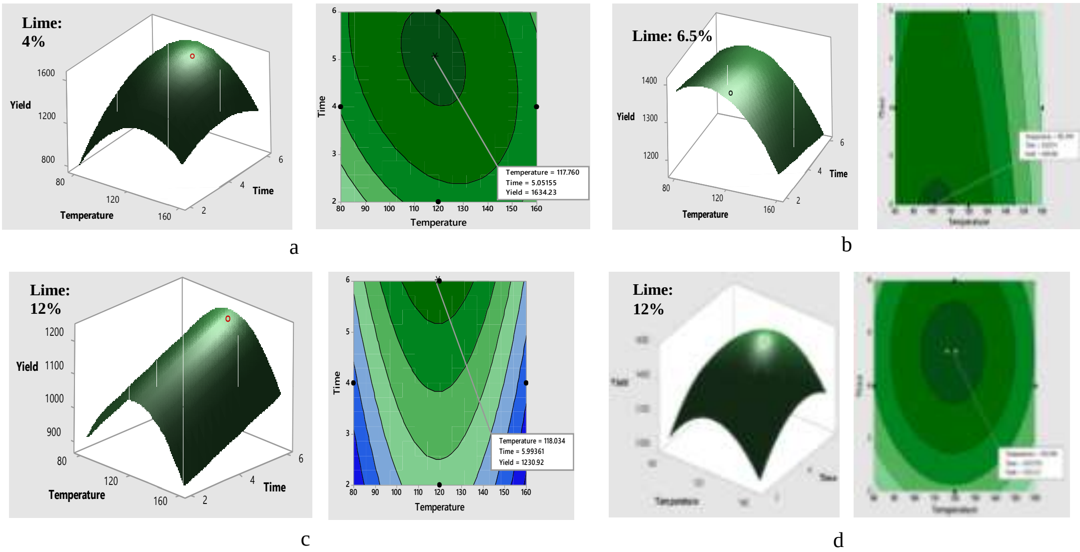

Figure 3. The surface response plots of the effects of lime concentration, temperature and reaction time on the biogas yield: (a) red creole bulb, (b) yellow granex bulb, (c) red creole leaves, (d) yellow granex leaves

<u>Response surface regression</u>

Table 3 shows the result of response surface regression and verification trials. The verification trials employing the optimized conditions for various onion wastes showed that the experimental biogas yields are within the range of the predicted values. The regression equation constructed for biogas yield was found to be adequate for prediction within the range of independent variables applied.

Table 3. Results of Response Surface Regression and Verification Trial

Onion Wastes	Regression Equation	95% Prediction Interval, ml	Verification Yield, ml	R^2
Red Creole Bulb	Yield = -6309 + 1165 Lime + 72.6 Temperature + 793 Time - 0.2162 Temperature*Temperature - 36.4 Time*Time - 5.08 Lime*Temperature - 105.0 Lime*Time - 1.69 Temperature*Time	802 – 2,219	1,867	83.4
Yellow Granex Bulb	Yield = -2281 + 562 Lime + 20.11 Temperature + 147.3 Time - 23.20 Lime*Lime - 0.0579 Temperature*Temperature - 0.970 Lime*Temperature - 18.7 Lime*Time	956 – 1,857	1,605	90.5
Red Creole Leaves	Yield = -1439 + 698 Lime + 27.03 Temperature + 37.5 Time - 0.1136 Temperature*Temperature	776 – 1,686	1,655	85
Yellow Granex Leaves	Yield = -2503 + 997 Lime + 34.17 Temperature + 348 Time - 0.1434 Temperature*Temperature - 37.5 Time*Time	1083 – 1988	1,833	89

<u>Biomethane Potential and Biodegradability of Onion Wastes</u>

The theoretical and experimental methane yield of onion wastes as well as the biodegradability and methane concentration are presented in Table 4. After 15 days of digestion for onion bulbs and 45 days of digestion for onion leaves, red creole bulb showed the highest methane yield and concentration of 225.2 ml CH_4/g VS and 60.3%, respectively, while red creole leaves showed the lowest methane yield and concentration of 197.3 ml CH_4/g VS and 60.7%. The high methane yield obtained can be credited to the type of digester used (APS) which has a separate hydrolysis reactor and biogasification reactor; thus, maintains appropriate pH for the methane-producing microorganisms.

In terms of biodegradability, onion bulbs yielded the highest value (red creole= 59.1% and yellow granex = 58.8%) compared to onion leaves This can be attributed to the lower fiber content of onion bulbs compared to onion leaves. Li *et. al.*, (2013) reported that feedstocks containing easily-degradable substrates had relatively higher methane production potential and biodegradability than onion leaves which have more fiber content.

Table 4. Theoretical and experimental methane yield of onion wastes

Onion wastes	Biogas Yield (ml/g VS)	Theoretical methane yield (ml CH_4/g VS)	Experimental Methane Yield (ml CH_4/g VS)	Biodegra-dability (%)	Methane Concentration (%)
Red Creole Bulb	373.50 ± 5.60	380.8	225.20 ± 3.38	59.14 ± 0.008	60.30 ± 0.10
Yellow Granex Bulb	350.00 ± 1.00	361.6	212.50 ± 0.61	58.75 ± 0.002	60.70 ± 0.10
Red Creole Leaves	331.00 ± 3.60	505.7	197.30 ± 2.15	39.01 ± 0.004	59.60 ± 0.17
Yellow Granex Leaves	366.60 ± 4.26	500.9	214.50 ± 2.49	42.82 ± 0.005	58.50 0.10

4. CONCLUSIONS

- Red creole bulb produces the highest biogas yield of 373.5 ml/g VS (60.3% CH_4), followed by yellow granex leaves of 366.6 ml/g VS (58.5% CH_4), red creole leaves of 331ml/g VS (59.6% CH_4) and yellow granex bulb with biogas yield of 350 ml/g VS (60.7% CH_4).

- The optimum pre-treatment conditions to obtain the highest methane gas from onion wastes were established as follows:
  - red creole bulb-lime concentration of 4%, temperature of 118^{o}C and reaction time of 5 hours
  - yellow granex bulb - lime concentration of 6.5%, temperature of 102^{o}C and reaction time of 2 hours
  - red creole leaves - lime concentration of 12%, temperature of 118^{o}C and reaction time of 6 hours
  - yellow granex leaves -lime concentration of 12%, temperature of 118^{o}C and reaction time of 5 hours

- The biogas produced from the treatment of onion waste can be used as source of fuel for cooking, lighting and electricity generation.

5. ACKNOWLEDGEMENT

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