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Characteristics and Anaerobic Digestion of fruits wastes from Ubungo-Urafiki market in Dar es Salaam

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ABSTRACT

Fruits are susceptible to mechanical damages during their transfer to the markets if they are not packed well in containers. Hence fruits wastes are generated in large quantities and because of their organic nature they decompose, which leads to environmental problems. The objective of this research was to quantify and characterize the fruits wastes generated from the Ubungo Urafiki Market in Ubungo Municipality and to establish the potential treatment of these wastes by anaerobic digestion. The data were collected in the field to establish the characteristics quantity of wastes generated in order to determine the potential degradation of fruit wastes using anaerobic digestion process. The market receives seven main kinds of fruits including pineapples, mangoes, water melons, avocados, oranges; paw paws and ripe bananas, which generate about 4.85 tons of fruit wastes per day. The leading fruits with higher percentage of wastes were water melons and oranges, which generated about 800 kg/day and 797 kg/day, respectively. The results of batch plants experiments showed that the reactor with fruit waste-cattle manure-wood ash mixtures had a maximum biogas yield of 34.2 liters while the reactor with fruit wastes-mixtures had lowest biogas yields of 0.1 liters. The reactor with fruit waste-wood ash mixtures had high volatile solid and total solid removal efficiencies of 8.0% and 14.3%, respectively. For the maximization of biogas production wood ash was recommended in order to raise the pH value of the fruit wastes. The batch reactor used in this study was limiting pH control and therefore activities of methanogenic bacteria. It is recommended to adopt a semi continuous or continuous reactor in order to limit excessive production of organic acids, which are responsible for inhibition of biogas production.

***Key words**: Anaerobic digestion, Biogas, Fruit Wastes.*

INTRODUCTION

Solid waste collection for disposal in Tanzania's largest city, Dar es Salaam is still a major problem. Dar es Salaam city generates about 4,161 tons of waste per day and only about 40% of the wastes generated are collected and transferred to Pugu dumpsite for the disposal (KMC, 2014; Maziku, 2014). The lower collection efficiency is due to budget constraints of the respective council budgets allocated to waste management (DCC, 2010). In accordance with Dar es Salaam City Council about 42 million US Dollars is estimated to be required for collection, transportation and disposal of about 70% of the wastes (DCC, 2010). Other reasons for the poor collection of wastes include; poor or no planning of solid waste collection routes, inadequate involvement of the residents, inaccessible roads, distant dumping sites and inexistence or inadequate design of temporary collection sites (Kirama and Mayo, 2016). With urbanization and increase of population, the generation of solid wastes is increasing. This will further pose continuous risk of contaminating the household environments, public areas and risking human health (Chengula *et al*., 2011; Kirama and Mayo, 2016).

The major compositions of solid wastes in Tanzania are organic fractions (Mbuligwe and Kassenga, 2004; Lohri *et al*., 2015). Several studies on organic wastes in Dar es Salaam city has been carried, although most of these studies focused on household wastes (Kassim and Ali, 2006; Lohri, 2009). On the other hand there are no comprehensive studies on market wastes and in particular fruit wastes although everyday tons of fruits of various varieties such as oranges, pineapples, water melons, bananas, to mention a few are offloaded daily at the markets for the city consumers. The problems of management of fruit wastes have been observed in Dar es Salaam city particularity in Ubungo-Urafiki market.

The high moisture and organic content in fruit wastes suggests that anaerobic digestion, which has been widely used for treatment of high strength organic wastes, can be a suitable treatment option (Velmurugan and Ramanujam, 2011). Anaerobic digestion involves the biochemical decomposition of complex organic material by various bacterial processes with the release of an energy rich biogas and the production of a nutritious effluent (Lohri, 2009). Collection of fruit wastes for biogas production may offset costs required for transportation of the wastes to treatment site for production and reducing the volume of fruit wastes to be sent to the dumping site. Several studies have shown the fruits wastes have the potential to produce biogas when treated anaerobically. According to Dilhan *et al*. (2012) a kg of organic wastes can generate up to 40-50 liters of biogas. Fruit wastes as the part of market garbage are reported to be producing up to 91 liters per kg (Kigozi *et al*., 2014). Sagagi *et al*., (2010) showed that a kg of pineapple and orange wastes have the potential of producing 4.8 liters and 3.06 liters, respectively.

Apart from having a broad spectrum of benefits, the application of anaerobic digestion has been reported to be having some drawbacks. A major limitation of anaerobic digestion of fruit and vegetable wastes is accumulation of volatile fatty acids (VFA), which inhibits activities of methane forming bacteria due to decreasing pH (Chen *et al*., 2008). This suggests that digestion process need to be enhanced by addition of other materials with high pH value. Different anaerobic reactors such as batch reactors, one stage reactors and two stage reactors are available for anaerobic digestion process. In batch systems, wastes are fed once with or without addition of seed materials, and allowed to go through all degradation steps sequentially. Longer retention times are required for these types of reactors. In one stage systems, all the reactions simultaneously take place in a single reactor, but in a two stage systems, two different reactors are used for acidogenesis and methanogenesis (Velmurugan and Ramanujam, 2011). This study focused on market fruits because fruits are more vulnerable to mechanical damages during their packaging, storage and transportation from the sites of production to the markets, which make them more susceptible to rotting.

MATERIALS AND METHODS

The study area

The study area is Ubungo-Urafiki market located in Ubungo Municipality, which was part of Kinondoni Municipality at the time this study was carried out (Figure 1). Kinondoni and Ubungo Municipals in total have about twenty four (24) markets, of which Ubungo-Urafiki market under study is the only pure fruit market with reliable data information on fruits. The market is a free market, not owned by the Municipality, and has its own leaders who are responsible for management of the market. These leaders serve as a means of communications with the Municipal Council as they collect taxes of items sold at the markets on the behalf of the Municipality. The large population inside the market and the heavy movement of traffic carrying items to be sold in the market hinders the daily collection and transportation of wastes to the Pugu dumpsite. Thus, the wastes are not collected daily and hence accumulate in huge piles inside the market premises before they are collected and transported to the dumpsite. This makes the area very unaesthetic and unhygienic particularly during the rainy seasons. The wastes are collected once or twice per months using a 7 tons trucks estimated to carry a 4.5 tons of wastes per truck.

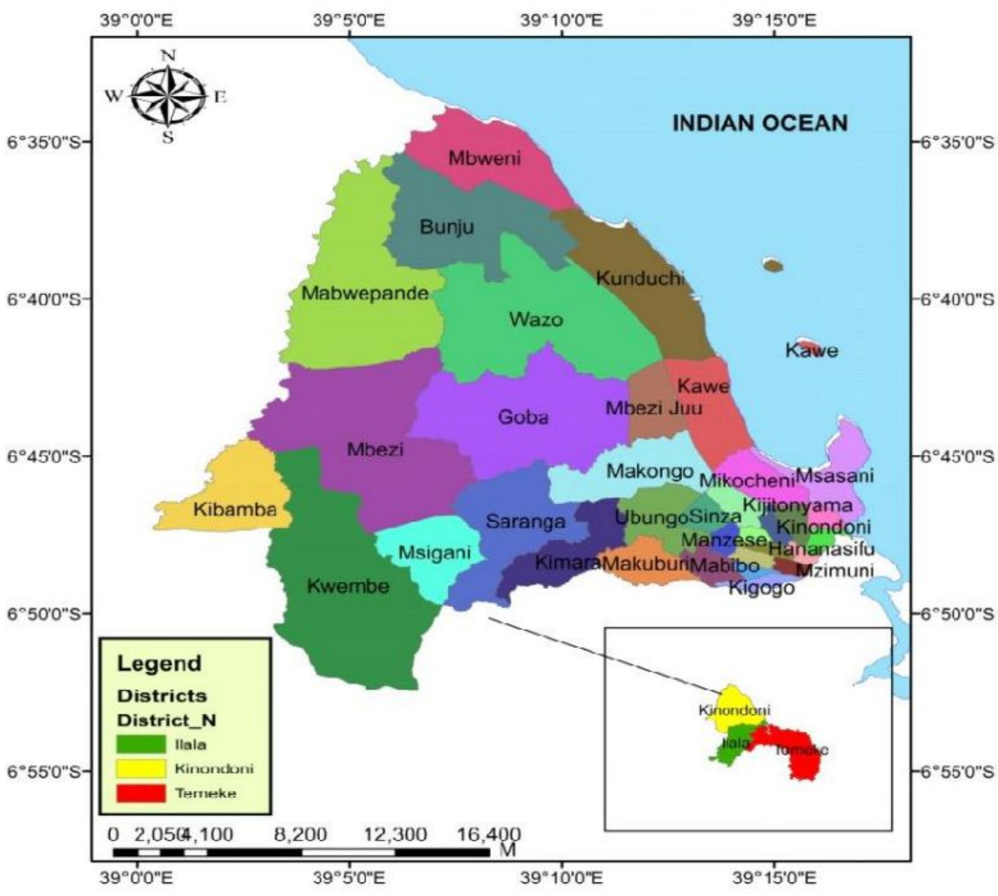

Figure 1: Map of the Ubungo Municipality (Source: National Bureau of Statistics, 2013

Inventory survey

The quantification of the individual fruit wastes were made based on the data collected in face-to-face interview with the fruit vendors. There are about 130 fruit vendors at the market out of which 98 vendors were interviewed. The sample size was determined using Equation (1) in accordance with Krejcie and Morgan (1970).

$$n = \frac{Z^2 \times p \times (1-p) \times N}{e^2(N-1) + Z^2 \times p \times (1-p)} \quad \text{........... (1)}$$

Where n is the required sample, Z is the confidence level (Z-value = 1.96 for 95%), N is population size (130), p is population proportion (expressed as decimal, assumed to be 0.5), e = margin error (0.05).

During the interview the individual fruit wastes per ton were estimated. Based on the records of different fruits supplied in the markets in the year 2015, the individual and total wastage per day of discarded fruits were estimated. The record of total wastes collected by trucks per month in 2015 were also estimated and compared with the estimates obtained from the interview. The information that was obtained during the inventory survey helped to determine the ratios of the mixed fruit wastes that were treated anaerobically in batch experiment.

Preparation of samples for anaerobic digestion of fruits for laboratory tests

The fruit wastes for laboratory tests were collected from Ubungo Urafiki market. Its contents included rotten fruits such as watermelons, oranges, ripe bananas, avocados, mangoes, pineapples and paw paws. All wastes were stored in closed buckets and used within 6 hours. Before characterization and feeding into reactors, substrates were sliced manually, grounded using mortar and pestle and then further blended into small pieces with a kitchen blender. The reduction of the particle sizes was done in order to increase their surface area for better bacterial digestion. A small portion of each grounded sample was measured using an electronic weigh balance. In the experiment the wastes were mixed in accordance with the daily generation in the market (Table 1).

Table 1: Fruit Wastes mixed composition ratios

S/no	Type of fruit	Percent	Weight composition (kg)
1	Water Melon	23	1.38
2	Oranges	23	1.38
3	Ripe bananas	20	1.2
4	Avocado	18	1.08
5	Mangoes	12	0.72
6	Pineapples	3	0.18
7	Pawpaw	1	0.06
8	Total	100	6

To quick start the digestion process three days old cattle manure, which was obtained freely from animal husbandry at Ukonga ward in Dar es Salaam, was used for the experiments after removing straw materials. According to Chukumwa *et al.* (2013) the cow dung when mixed at 50% with poultry droppings showed the quick start of gas production within 24 hrs. In this research the same ratios at 1:1 weight by weight was adopted. For the initial pH adjustment the wood ash was used as buffering material. Wood ash is cheap and locally available and has been reported to enhance biogas production (Adeyanju, 2008). The wood ash was collected from the kitchen at the University of Dar es Salaam. Wood ash was sieved in order to obtain the fine powder wood ash. To obtain the optimal fruit wastes to wood ash mixture, the wood ash was weighed using analytical weigh balance and its pH value was measured using pH meter (Sartorius, PT-15). The wood ash used had pH of 11.3 and was added slowly into the bucket containing the weighed fruit wastes mixtures and then mixed thoroughly to obtain the uniform mixtures. The pH values were recorded throughout the processes until the optimal mixture was recorded. The results showed that to obtain optimum pH value of 7.3 the fruit waste to wood ash should be mixed at the ratio 1 to 0.07 weight by weight, respectively.

Sample analysis:

Total solids and volatile solids were measured at the beginning of the experiment before adding the slurry into the reactors and at the end of the experiment using gravimetric method in accordance with standard methods for the examination of water and wastewater samples (APHA et *al.*, 2012). To determine total solids, a small portion of the substrate was weighed (W_2) in an empty crucible (W_1) and dried for 24 hours in an oven maintained at 105°C (W_3). The percentage of total solids (TS) was then calculated using Equation (2). To determine, volatile solids, an oven dried sample was weighed (W_3) in an empty crucible (W_1) and heated to 550°C for 1 hour in the muffle furnace to constant weight (W4). The percentage of volatile solids (VS) was then was calculated using Equation (3). The pH was determined using a pH meter (Sartorius, PT-15).

$$TS(\%) = \frac{W_3 - W_1}{W_2} x100 \qquad (2)$$

$$VS(\%) = \frac{W_4 - W_1}{W_3} x100 \qquad (3)$$

Experimental set up for biogas production

The experiments, which were run at mesosphilic temperatures (26°C-31°C), consisted of a bench scale set up with five batch plants with fruit wastes mixtures as detailed in Table 2. The wastes were fed through the inlet port located at the top of the reactor. Upon feeding the desired quantity, the same port was tightened with a delivery tube, which transfers gas into 1.0 liters capacity inverted bottle for gas collection (Figure 2). The 10.68 liter capacity glass flasks (Bell co glass, Inc USA) were used as batch reactors. The glass flask batch reactors used were of 20 cm diameter with 34 cm height, which were tapered at the top to 11 cm diameter mouth. The wastes were filled up to about 20 cm high from the bottom. The free space of about 14 cm high was left at the top to provide room for expansion of substrate under pressure. The biogas produced from the batch plants were collected using upward displacement methods in a 1.335 liter capacity inverted hard glass bottles containing distilled water, were rested in the experimental bench having dimensions of 10 cm diameter and the height of 17 cm. The top mouth of the bottle had the diameter of 3 cm and was covered with rubber stoppers fitted with inlet gas hose pipe and outlet hose pipe for displaced water from the container. The gas inside the inverted bottle was collected at the surface of water where it created pressure, which displaced the water equivalent to the volume of the gas collected. The displaced water was forced out through the needle into the tube and was discharged into the measuring cylinder under the tube. The volume of water was measured using measuring cylinder. The reactors were mixed daily by manually shaking the contents. The room temperature was recorded daily during the experiment period by using a mercury thermometer.

Table 2: Blended composition (kg/kg) of batch-plants

Run	Fruit Wastes	Cattle manure	Wood ash
1	100 %	0 %	0 %
2	50 %	50 %	0 %
3	93.5 %	0 %	6.5 %
4	48.3 %	48.3 %	3.4 %
5	0 %	100 %	0 %

Note: (6 kg wastes were used in the experiment, and fruit wastes were the mixtures as per ratio in table 1)

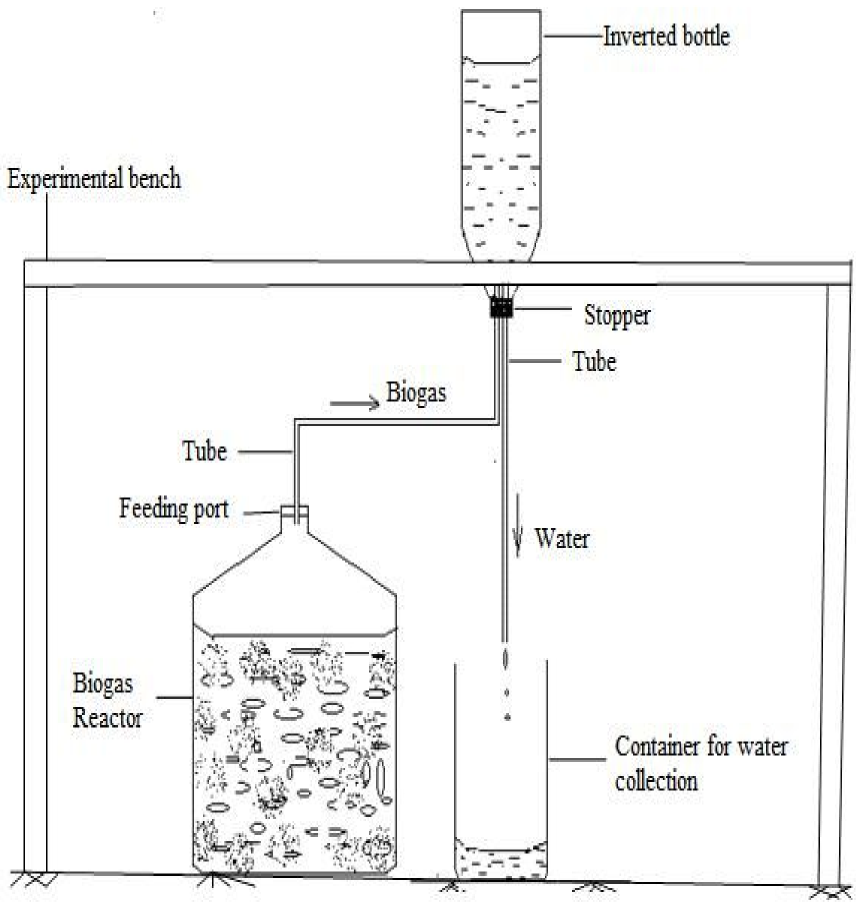

Figure 2: Layout of the experimental set up

RESULTS AND DISCUSSION

Quantification of the Fruits Wastes

The market has an estimate of 130 fruit vendors who are selling seven types of fruits including; pineapples, mangoes, water melons, avocados, oranges, paw paws and ripe bananas. For each kind of the fruits, 14 vendors were interviewed. These fruit wastes vary seasonally depending on the seasonality of supply of fruits in the market. The average weights of each type of fruit were determined to help estimate the quantity of the discarded fruit wastes. Table 3 shows the average numbers of discarded fruit wastes per numbers of fruits supplied at the market in accordance with fruits vendors. The result show that of the fruits supplied at the market; 7.1 %, 14.56 %, 21 %, 30 %, 22.39 %, 25 % and 10 % of pineapples, mangoes, watermelons, avocados, oranges, paw paws and ripe bananas, respectively are discarded. On the basis of these estimates, the quantity of fruit wastes generated per quantity of fruits supplied per day at Ubungo Urafiki market in the year 2015 were estimated (Table 4).

The result shows that the Ubungo-Urafiki market generates about 3.476 tons/day of the discarded fruit wastes. The leading fruits with higher percentage of wastes are water melons and oranges, which generate about 0.8 ton/day and 0.797 ton/day, respectively. Pawpaw is generating only 0.039 ton/day of wastes. Records of number of trucks per month used to transport wastes at Ubungo Urafiki market in the year 2015 were also reviewed. The 7 tons trucks each estimated to carry 4.5 tons of wastes were used for transportation of wastes. Table 5 shows the number of trucks per months used for transportation of wastes from Ubungo-Urafiki market and the estimates of the total wastes per day in the year 2015. The results show that the total wastes generated per day in the Ubungo Urafiki market based on the transported wastes from the market in the year 2015 was about 4.85 tons/day. In accordance with survey of discarded fruits wastes 3.476 tons of fruit wastes are produced daily. Therefore the difference of 1.374 tons/day is contributed by packaging materials such as wrapping leaves and worn out containers. The total wastes generated can be reduced if proper packaging containers are used.

Table 3: Average fruit wastes as per interview with fruits vendors

Fruits	Quantity of fruits	Quantity of discarded fruit wastes	Fruit average weight (kg)
Pineapple	5300	377	3.125
Mangoes	3270	476	1.125
Water Melons	500	105	8
Avocado	5250	1575	0.2
Oranges	15333	3433	0.2
Pawpaw	1000	250	1
Ripe bananas	100 bunches	10 bunches	37

Table 4: Average fruit wastes supplied in tons per day in the year 2015 and estimated discarded wastes

Fruits	Quantity of fruits	Quantity of discarded fruit wastes
Pineapple	1.546	0.110
Mangoes	2.761	0.400
Water Melons	3.811	0.800
Avocado	2.100	0.630
Oranges	3.558	0.797
Pawpaw	0.156	0.039
Ripe bananas	7.00	0.700
Total	**20.932**	**3.476**

Table 5: Estimated total wastes per month at Ubungo- Urafiki Market basing on the number of truck per month in the year 2015

Month	7 tons truck @4.5 tons of wastes	Estimated wastes (tons)
January	36	162
February	28	126
March	38	171
April	41	184.5
May	37	166.5
June	29	130.5
July	18	81
August	32	144
September	26	117
October	27	121.5
November	31	139.5
December	45	202.5
Total	**388**	**1,746**
Average tons/day		**4.85**

Characterization of the Fruits Wastes

The examination of the characteristics of the fruits wastes collected from Ubungo-Urafiki market was carried out in the Laboratory. The results as depicted in Table 6 shows that watermelon had maximum moisture content of 96.4% and lowest total solids content of 3.6%, and ripe bananas had lowest moisture content of 78.9% with the maximum total solids content of 21.1%. The maximum volatile solid value of 95.5% was recorded in mangoes and the lowest volatile solids value of 72.5% was recorded in ripe bananas. On average, the fruits wastes had the moisture contents of 86.8% and total solids of 13.2 %. Further analysis of the total solids indicated that 86.8% were volatile solids and 13.2 % was inert inorganic solids. These results are comparable to those of Asquer *et al.* (2013) who reported that the average total solids values of fruit wastes are in average of 14%. The characteristics of mangoes and avocados for this study are also comparable to those of Deresa *et al.* (2015) who reported the moisture contents and total solids of mangoes to be 88.9%, and 16.4%, respectively. The moisture contents and total solids of avocados were reported to be 79.9% and 26.8%, respectively. In accordance to Deresa *et al.* (2015), volatile solids of mangoes and avocados were 94.8% and 91.2%, respectively. The characteristics of fruit wastes in terms of moisture contents, total solids and volatile solids suggest that these fruit wastes are suitable feed stocks for anaerobic digestion.

The pH of the individual fruit wastes ranges from 3.91 (oranges) to 4.87 (ripe bananas), and that of the mixed fruit wastes as per generation in the market was 4.18 (Table 6). These pH values are lower than the optimum range of pH (6.6-7.6) for production of biogas, which suggests that pH must be adjusted in order to optimize production of biogas. The optimal mixed fruit wastes to wood ash ratio was determined as 1 kg of wood ash mixed with 14 kg of mixed fruit wastes of pH of 4.18, which gives the optimum pH of 7.3. The resulting pH values for the mixed fruit wastes and wood ash (pH =7.3) and that for the mixed fruit wastes, cattle manure and wood ash (pH= 6.6) were within the recommended values (pH =6.6-7.6) for the biogas production and were therefore used in the experiment (Table 7). The pH value for the mixed fruit wastes, cattle manure and the mixed fruit wastes and cattle manure were lower than the recommended values for biogas productions.

Table 6: Characteristics of the fruits wastes at Ubungo Urafiki Market

Name of Substrate	Total Solid (%)	Moisture Content (%)	Volatile Solid (%)	pH
Avocados	20.1	79.9	81.9	4.68
Mangoes	11.6	88.4	95.5	4.40
Oranges	16.1	83.9	91.4	3.91
Pineapples	6.7	93.3	89.9	4.39
Ripe bananas	21.1	78.9	72.5	4.87
Water melons	3.6	96.4	89.6	4.40
Mixed FWs	12.3	87.7	90.0	4.18

Table 7: Characteristics of the mixed fruit wastes

Run	Mixed Wastes	Total Solid (%)	Moisture Content (%)	Volatile Solid (%)	pH
1	Fruit wastes	12.28	87.7	90.0	4.18
2	Fruit wastes + wood ash	19.55	80.4	53.5	7.3
3	Fruit wastes + Cattle manure + wood ash	17.94	82.1	69.1	6.6
4	Fruit wastes + Cattle manure	13.85	86.2	86.3	5.04
5	Cattle manure	17.00	83.0	85.9	5.18

Efficiency of the bioreactors in biogas productions

Five runs of batch experiments were carried out to determine the effective method of biogas production from fruit wastes. In Run 1, which involved biogas production from mixed fruits wastes, only about 100 ml of biogas was produced after running the batch plant for 20 days. This biogas yields is relatively low and the main reason for low production of biogas was because of pH value of the mixed fruit (4.18), which further dropped to 3.88 after 20 days of the experiment. It is worth noting that acidic conditions are not favourable for the activities of methanogenic bacteria whose optimum pH is between 6.8 and 7.4 (Mao *et al.*, 2015).

In Run 3, which contained a mixture of mixed fruit wastes, cattle manure and wood ash, the total biogas produced in this reactor was about 34,200 ml (Figure 3). The maximum biogas production was recorded in day one (16.7 litres) and then it subsequently decreased to 9.6, 2.9, 1.3 and 1.1 litres in day two to five, respectively. In day one the production was high because the reactor had optimum pH value of 6.6 for anaerobic digestion by bacteria. Unfortunately the production of biogas ceased in day 20 of the experiment when pH in the reactor dropped to 5.13.

In Run 4, the contents of the reactor were mixed fruit wastes and cattle manure. The total biogas produced in this run was about 3,500 ml (Figure 3). The maximum biogas production was recorded in day two (1800 ml), but it subsequently decreased to 600 ml, 260 ml, 230 ml in day three to five, respectively. Although the starting pH value (5.04) was below the recommended values (6.6-7.6) in day one the biogas production was relatively higher than the rest of the days, as pH of the mixture kept on decreasing. The production of biogas ceased after sixteen days of the experiment when pH value in the reactor dropped to 3.99, which significantly inhibited biogas production. In Run 5, which was used as a control batch, only cattle manure was used for digestion. It was observed that only about 200 ml of biogas was recorded after 20 days of the experiment. The cattle manure had low pH of 5.18 and was three days old when collected. The cattle manure was further stored for 3 days in a closed bucket before putting in the reactors, and this might have affected the biogas production. According to Lehtomaki *et al.* (2004) the normal composting of 7 days accounts for 17% loss of the total biogas production.

Another factor which might have caused the lower biogas production in the reactor is high solid contents and this applies to all reactors since the experiments were run under dry anaerobic digestion processes. In accordance with Jha *et al.* (2011) a dry digestion takes place at solid concentrations higher than 10% and enables higher volumetric organic loading rate. To both reactors the solid concentration (TS) ranged from 12.3% to 19.6%. According to Deressa *et al.* (2015) one of the factors contributing to incombustibility of the biogas production in the digesters is the accumulation of the digested solids at the bottom of the digesters that allow scum formation at the slurry surface. This experience was observed in this reactor.

Efficiency of the biogas reactors in treatment of the mixed fruit wastes

The performance of the reactors was investigated based on the digestion of the organic matter, which was measured in terms of total solids and volatile solids before and after the digestion process. Table 8 shows the Total Solids (TS) and Volatile Solids (VS) removal efficiencies after 20 days of the experiment. Optimum initial pH values for fruit wastes -wood ash mixtures and fruit wastes-wood ash-cattle manure mixtures favoured the high removal efficiencies (14.6%, 11.4% TS and 54.8%, 43.0% VS, respectively). The reactor with mixed fruit wastes alone had the lowest removal efficiencies (7.6% TS, 36% VS) because of the acidic initial pH values (4.18), which further dropped to 3.88 after 20 days. The reactor with cattle manure alone had the highest TS removal efficiency (21.6%) with the VS removal efficiency of 38.0%. The reason behind this performance could be stable pH in the reactor (5.15), which was close to the initial pH value (5.18). In accordance with Lohr (2009), the market wastes (spoiled fruits and spoiled vegetables) removal efficiencies were 72% TS and 85.3% VS when digested for 67 days under controlled Semi continuous mode of digester (ARTI compact biogas system) with the daily load of 2 kg, which is an indication that control of pH was necessary to achieve high biogas production.

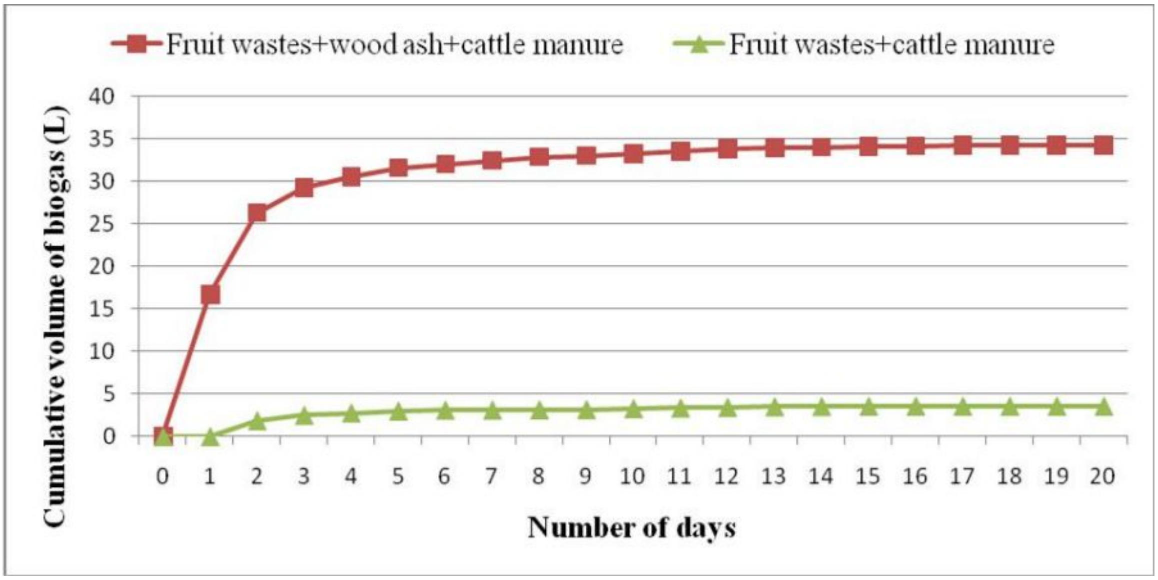

Figure 3: Temporal changes in cumulative biogas productions from (a) fruit wastes-cattle manure-wood ash mixtures (b) fruit wastes-cattle manure mixtures

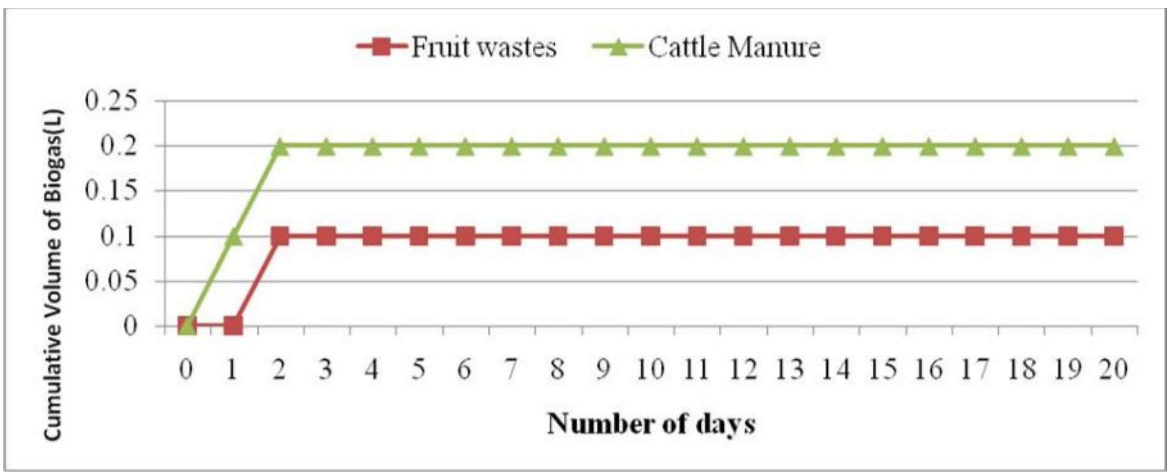

Figure 4: Temporal changes in cumulative biogas productions from (a) mixed fruit wastes mixtures (b) cattle manure

Table 8: Total Solids and Volatile Solids removal efficiencies

Run	Reactor Contents	Total Solids			Volatile Solids		
		Initial (g)	Final (g)	Reduction efficiency (%)	Initial (g)	Final (g)	Reduction efficiency (%)
1	Fruit wastes	12.28	11.34	7.6	11.29	7.22	36.0
2	Fruit wastes + wood ash	19.55	16.71	14.6	9.24	4.18	54.8
3	Fruit Wastes – Cattle manure + wood ash	17.94	15.90	11.4	16.37	9.33	43.0
4	Fruit wastes + Cattle manure	13.85	12.33	11.0	13.15	7.62	42.0
5	Cattle manure	17.00	13.33	21.6	10.92	6.77	38.0

CONCLUSIONS

This study showed that the total wastes generated per day in the Ubungo-Urafiki market was about 4.85 tons/day out of which the waste fruits (rotten, physically damaged) are generated at the rate of 3.48 tons/day and the other wastes (packaging materials etc) are generated at the rate of 1.37 tons/day. To reduce wastes from packaging materials, it is important to develop recyclable packaging containers in order to discourage the use of wrapping leaves and other disposable fruit packaging containers. The characterization of fruit wastes in terms of moisture contents, total solids and volatile solids has demonstrated that fruit wastes are eligible feed stocks for anaerobic digestion. The pH of the fruit wastes ranged from 3.91 to 4.87, which are lower than the optimum pH range of 6.6 to 7.6 for production of biogas. This suggests that pH must be adjusted in order to optimize production of biogas. Wood ash is recommended as buffering material because it is cheap (free) and is readily locally available. The performance of the batch plants experiments showed that; the reactor with fruit waste-cattle manure-wood ash mixtures had a maximum biogas yield of 34.2 litres while the reactor with fruit wastes-mixtures had lowest biogas yields of 0.1 litres. The high volatile solid and total solid removal efficiencies of 14.6% and 54.8%, respectively, were recorded in the reactor with fruit waste-wood ash mixtures. The batch reactor used in this study was limiting control of pH and therefore performance of the reactors. It is recommended to adopt a semi continuous or continuous reactor for further studies at longer duration time.

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