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Electricity Generation from Waste Tomatoes, Banana, Pineapple Fruits and Peels Using Single Chamber Microbial Fuel Cells (SMFC)

Kalagbor IA[1]*, Azunda BI[2], Igwe BC[2] and Akpan BJ[2]

[1]Research and Development Centre, Ken Saro-Wiwa Polytechnic, Nigeria

[2]Department of Science Laboratory Technology, Ken Saro-Wiwa Polytechnic, Nigeria

***Corresponding author:** Kalagbor Ihesinachi A, Research and Development Centre, Ken Saro-Wiwa Polytechnic, P.M.B 20, Bori Rivers State, Nigeria, Email: ksinachi@yahoo.com, kalagbor.ihesinachi@kenpoly.edu.ng

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Abstract

Green Chemistry is gaining prominence in environmental and technological processes. Generating electricity from agro wastes comprising of waste vegetables and fruits are new sources of clean energy. Scientists need to develop technological methods of converting these agro wastes to useful resources especially in developing countries. Fruit wastes are generated in large quantities globally from processing plants. Defective tomatoes rejected and damaged banana fruits as well as unusable pineapple fruits and peels constitute part of the agro waste biomass generated annually. Effective management of this biomass is still ongoing. This research focuses on the conversion of these agro wastes to bioelectricity (green energy) using single microbial fuel cells (SMFCs) technology. Fruits wastes of 5kg, 10kg, 15kg and 20k were used. Results showed that the higher the quantity of substrate, the higher the electricity produced. The maximum voltage outputs generated on day 1 were 4.2V, 3.1V and 3.0V from tomatoes, banana and pineapple (fruit and peel) wastes respectively. The values obtained for current readings were significantly proportional to the voltage readings. The physiochemical parameters; pH, Conductivity, BOD, COD and DO were consistent with those from similar studies. The conversion of tomatoes, banana and pineapple fruit waste to bioelectricity was achieved. Reduction of this biomass by biodegradation using the SMFC technology is one way of removing these agro wastes from the ecosystem to maintain a clean, healthy, pollution-free environment.

Keywords: Agro Waste; Fruits Waste; Biomass; Tomatoes; Banana; Pineapple; Bioelectricity; Microorganisms; Biodegradation

Introduction

Microbial fuel cell (MFC) is a new method in which organic waste is converted to energy using microorganisms. They are devices that use bacteria as the catalyst to oxidize organic and inorganic matter to generate current [1]. The electrons and protons released during the breakdown of organic biomass maybe harnessed by means of appropriate technologies for the production of bio-electricity. For many years, electricity has been mostly generated using fossil fuels, leading to high dependence on this source. The use of fossil fuels has exhibited many negative consequences to the environment. The pursuit of new trends in energy production which is sustainable, efficient and renewable is in progress [2] especially with agro waste biomass. These are also referred to as solid organic wastes (SOWs). Energy production studies have been carried out on some SOWs such as oil palm tree empty fruit [3,4], sugar cane wastes [5], wheat straw [6,7], corn stover biomass [8,9] and cocoa pod husks [10,11]. We have reported the generation of electricity from another type of agro wastes, the vegetables [12]. Fruit wastes are usually generated in huge quantities and dumped in areas where they begin to decay. They emit offensive odour, attract birds, rats and vectors responsible for spreading many diseases [13]. Tomatoes are rich in carotenoids and flavonoids which are redox-active molecules. The natural lycopene in them encourages the generation of electricity [14]. They also have high conductivity [15]. The quercetin in tomatoes has the potential to exhibit electrochemical activity in aqueous medium [16]. Bananas are tropical fruits that are available all year round. They have high carbohydrate content and contain other essential nutrients capable of enhancing microbial growth [17,18]. Banana biomass (fruit and peels) have been used as feedstock for the production of methane gas [19]. It has also found application in biofuel production [20,21]. It is reported by Gunaseelan [22] that using banana peels resulted in higher rates of methane production than most other fruit wastes. Banana wastes have also been known to produce very clean form of biogas [23]. The conversion of banana peel waste (BPW) into electricity using microbial fuel cells (MFCs) was investigated by Elviliana, et al. [24]. Their results showed that the BPW had a huge potency to be used as a feed stock. Large amount of unusable waste pineapples are generated during processing [25] and they contain high organic matter. The pineapple peel has a good amount of crude fiber [26] which is readily reduced by microorganisms. Pineapple fruit and peel have been utilized for the production of methane biogas [27-29]. They have also been used in the production of bio-hydrogen gas [30,31] and for bioethanol production . Banana and pineapple peel wastes have been successfully used for electricity generation using double chamber MFC [32]. Banana and other fruit wastes that have been discarded due to the imperfections are normally dumped as a huge mass of wastes, which over time; affect the environment and health of living organisms. These, according to Tock, et al. [33] can be put to good use by converting them to bio-energy and avoid the environmental problem due to their decomposition. This research focuses on the conversion of another form of agro wastes - the fruits, into bio-electricity (green energy) using the single chamber microbial fuel cell (SMFC). Defective tomatoes, rotten and overripe banana and pineapple fruits and their peels were used for this study. These fruits were chosen for their unique characteristics.

Materials and Methods

Construction of the MFC chambers

Constructions of the Microbial Fuel Cell single chamber, two electrodes Microbial Fuel Cell (MFCs) were constructed using rectangular plastic containers (28cmx42cmx25cm). The electrode was constructed using 10mm diameter PVC pipes. The electrode materials were obtained from discarded 1.5V dry cells which were picked, harvested, cleaned and air-dried before filling into the PVC pipes. The height of the anode electrode was 25cm and the cathode were 40.5cm and porous. These were held in place on the lid of the plastic container with 4-minute super glue. The two electrode terminals were connected by copper wires to 10,000Ω resistor. The generated electrons are transferred from the anode to the cathode through the external circuit (Figures 1-4).

Figure 1: Harvesting graphite from 1.5V dry cells.

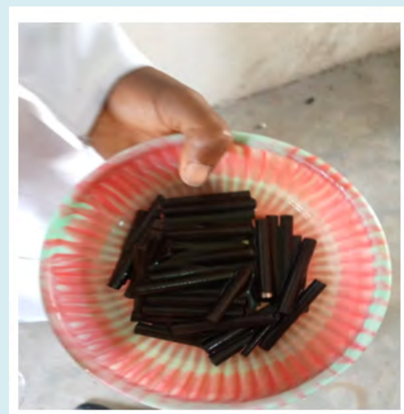

Figure 2: Graphite materials obtained and cleaned.

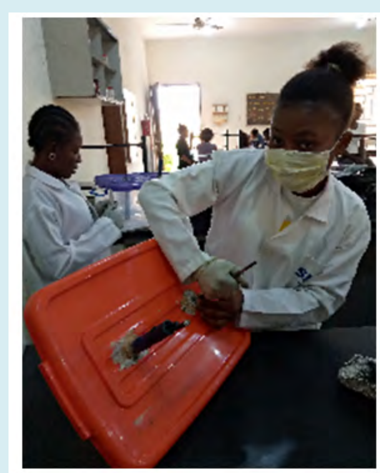

Figure 3: Fitting in the electrodes.

Figure 4: Fitted electrodes in the SMFC.

Sample Collection

The waste fruits and peels were obtained from the sellers in Bori market in Khana Local Government Area, Rivers State, Nigeria. They were incubated by wrapping them in polyethylene bags to facilitate degradation by the microorganisms. They were each weighed in varying amounts of 5kg, 10kg, 15kg and 20kg using a top scale. The fruit wastes were thoroughly smashed with hands and loaded into the constructed single chamber microbial fuel cells (SMFCs).

Figure 5: Weighing the Banana biomass.

They were then properly mixed by adding water up to the brim. Slurry of proper consistency was formed. The pH of the slurry was checked, samples were taken for BOD, COD and DO analysis. The lids having the electrodes were submerged in their respective chambers ensuring that the SMFCs were air tight. The bacteria present in the fruit wastes were used for this MFC operation, no external inoculums were added. Flexible wires were connected over the electrodes, having the positive terminals connected with a resistor and analog multimeter and was observed for period of 6 days intervals for each weight of study (Figures 5-10).

Figure 6: Mashed up Banana biomass.

Figure 7: Weighing the Tomato waste.

Figure 8: Tomato slurry in the SMFC.

Figure 9: Set up for Tomatoes.

Figure 10: Set up for Banana.

Results (Tables 1-12 & Figures 11-22)

Days	V	A	pH	Con	DO	BOD	COD
Initial					3.6	2.2	4.4
Day 1	1.6	1.2	5.1	2.03			
Day 2	1.3	1	4.9	2.08			
Day 3	0.8	0.8	4.8	2.27			
Day 4	0.5	0.3	4.4	2.49			
Day 5	0.3	0.2	4.2	2.86			
Day 6	0.2	0.2	4	3.56			
Final					3.5	2.7	4.8

Table 1: Values for the parameters measured for 5kg tomato waste.

Days	V	A	pH	Con	DO	BOD	COD
Initial					3.9	2.7	5.4
Day 1	2.6	2.2	5.7	2.28			
Day 2	2.1	1.8	5.4	2.76			
Day 3	1.6	1.3	4.9	3.64			
Day 4	0.9	0.6	4.8	3.8			
Day 5	0.6	0.2	4.7	4.32			
Day 6	0.4	0.2	4.4	4.74			
Final					4.2	2.9	5.8

Table 2: Values for the parameters measured for 10kg tomato waste.

Days	V	A	pH	Con	DO	BOD	COD
Initial					3.9	2.6	5.2
Day 1	3.7	3.2	6.2	4.78			
Day 2	3.4	2.9	5.3	5.02			
Day 3	2.9	2.6	5	5.13			
Day 4	2.4	2	4.7	5.22			
Day 5	1.9	1.6	4.5	5.2			
Day 6	1.4	1.2	4.3	5.41			
Final					3.3	2.2	4.4

Table 3: Values for the parameters measured for 15kg tomato waste.

Days	V	A	pH	Con	DO	BOD	COD
Initial					4.4	2.7	5.4
Day 1	4.2	3.7	6.7	6.47			
Day 2	3.6	3.2	5.4	6.51			
Day 3	3.1	2.8	5	6.53			
Day 4	2.7	2.4	4.7	6.54			
Day 5	2.3	1.8	4.8	6.62			
Day 6	1.6	1.4	4.4	7.42			
Final					4	2.5	5

Table 4: Values for the parameters measured for 20 kg tomato waste.

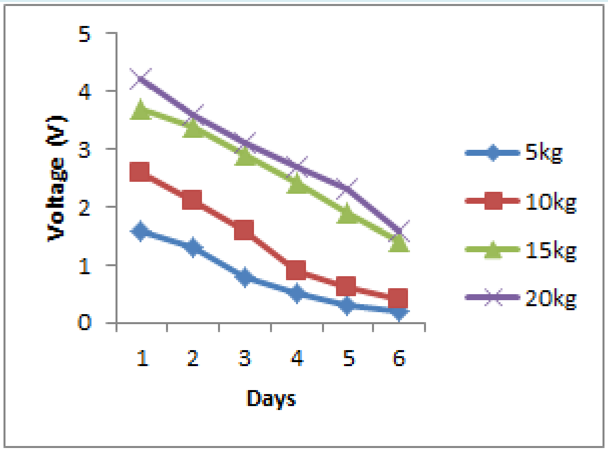

Figure 11: Plot of values for voltage (V) for 5kg, 10kg, 15kg, 20kg tomato waste.

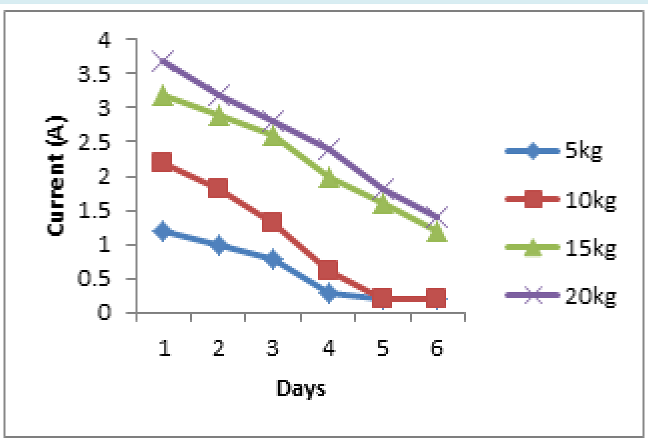

Figure 12: Plot of values for current (A) for 5kg, 10kg, 15kg, 20kg tomato waste.

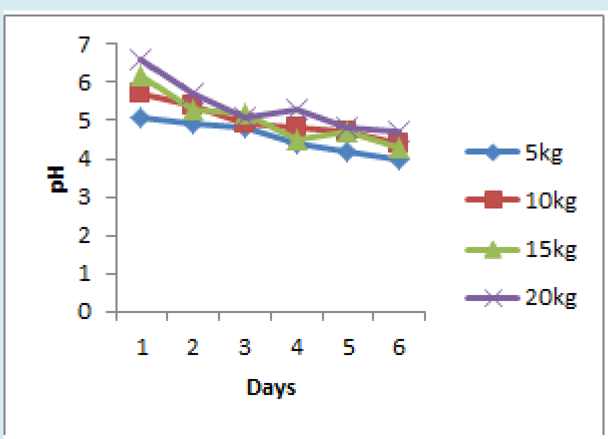

Figure 13: Plot of values for pH for 5kg, 10kg, 15kg, 20kg tomato waste.

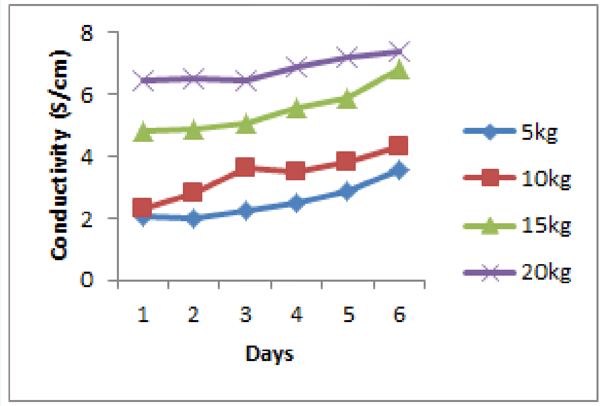

Figure 14: Plot of values for conductivity (S/cm) for 5kg, 10kg, 15kg, 20kg tomato.

Days	V	A	pH	Con	DO	BOD	COD
Initial					5.3	3.2	6.4
Day 1	1.2	1	3.4	2.6			
Day 2	0.7	0.5	3.8	2.69			
Day 3	0.4	0.3	4.2	2.41			
Day 4	0.6	0.2	5.1	2.5			
Day 5	0.2	0.1	5.4	2.3			
Day 6	0.1	0	6.1	2.21			
Final					4.8	2.8	6.1

Table 5: Values for the parameters measured for 5kg banana waste.

Days	V	A	pH	Con	DO	BOD	COD
Initial					5	3.4	6.8
Day 1	1.5	1	4.3	5.06			
Day 2	0.9	0.8	4.3	4.58			
Day 3	0.6	0.5	5.3	4.23			
Day 4	0.4	0.5	5.4	3.81			
Day 5	0.2	0.2	5.2	3.7			
Day 6	0.2	0.1	6.3	3.49			
Final					4.1	3.7	6.2

Table 6: Values for the parameters measured for 10kg banana waste.

Days	V	A	pH	Con	DO	BOD	COD
Initial					5	3.4	6.8
Day 1	2.5	2.5	5.6	5.01			
Day 2	2.2	2	6.1	4.6			
Day 3	1.7	1.3	6.1	4.23			
Day 4	1.4	1	6.2	3.8			
Day 5	0.9	0.7	6.4	3.11			
Day 6	0.6	0.4	6.5	3.11			
Final					4.8	2.9	5.8

Table 7: Values for the parameters measured for 15kg banana waste.

Days	V	A	pH	Con	DO	BOD	COD
Initial					5.3	3.9	3.9
Day 1	3.1	3.1	5.6	6.06			
Day 2	2.6	2.4	6.1	5.52			
Day 3	2.1	2	6.1	5.6			
Day 4	1.6	1.8	6.3	5.51			
Day 5	1	1.1	6.8	4.6			
Day 6	0.4	0.5	6.9	4.43			
Final					4.7	3.6	3.3

Table 8: Values for the parameters measured for 20kg banana waste.

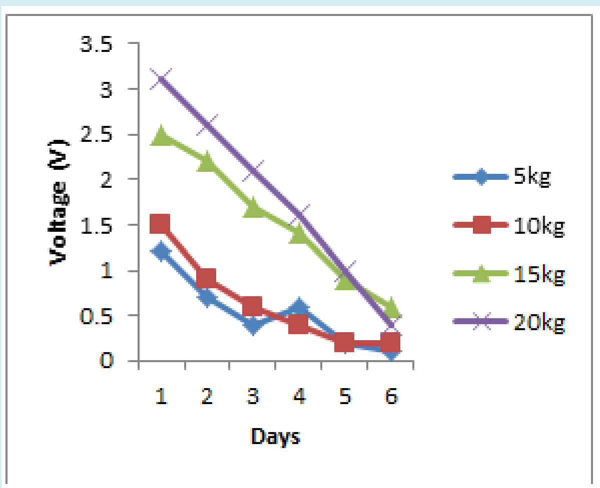

Figure 15: Plot of values for voltage (V) for 5kg, 10kg, 15kg, 20kg banana waste.

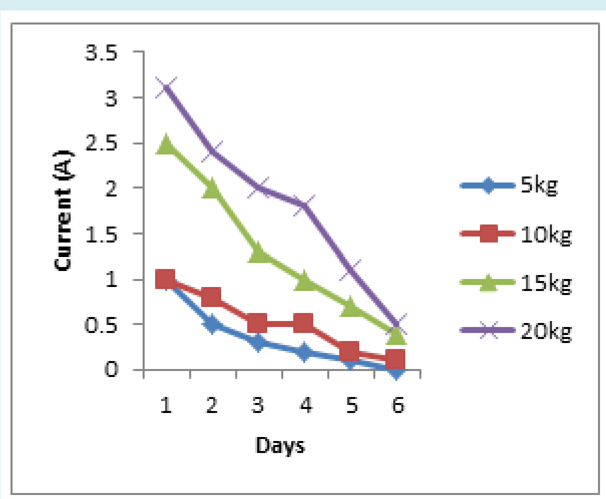

Figure 16: Plot of values for current (A) for 5kg, 10kg, 15kg, 20kg banana.

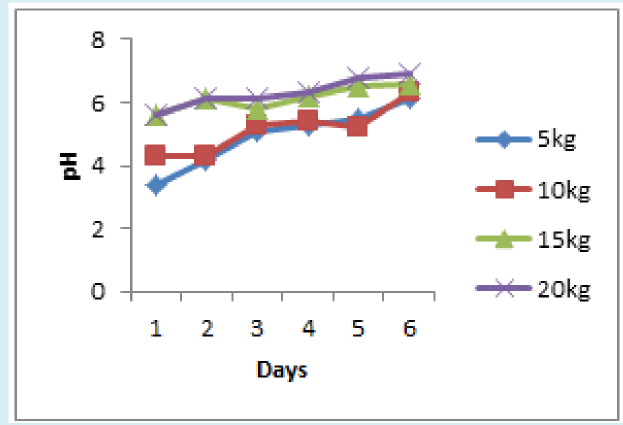

Figure 17: Plot of values for pH for 5kg, 10kg, 15kg, 20kg banana waste.

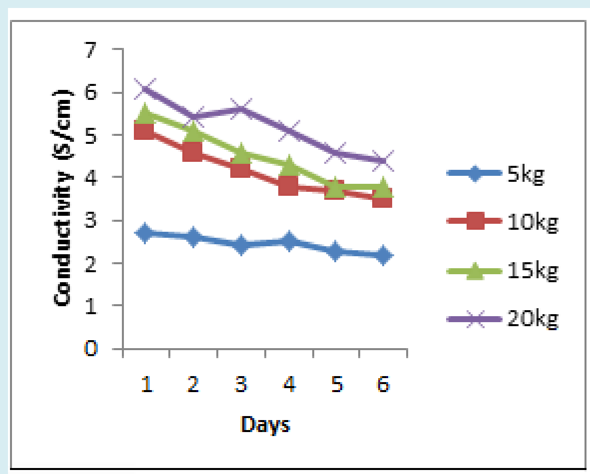

Figure 18: Plot of values for conductivity (S/cm) for 5kg, 10kg, 15kg, 20kg.

Days	V	A	pH	Con	DO	BOD	COD
Initial					4	2.6	5.2
Day 1	0.8	1	5.1	0.65			
Day 2	0.6	0.6	5.3	0.79			
Day 3	0.4	0.4	4.8	0.94			
Day 4	0.2	0.2	3.8	1.21			
Day 5	0	0.1	3.7	1.9			
Day 6	0	0	3.5	2.31			
Final					4.9	3.5	7.1

Table 9: Values for the parameters measured for 5kg pineapple waste.

Days	V	A	pH	Con	DO	BOD	COD
Initial					5.2	3.1	6.2
Day 1	1.6	1.8	5.3	1.23			
Day 2	1.2	1.5	5.1	1.38			
Day 3	1.9	1.3	5.1	1.62			
Day 4	0.7	1	4.6	1.68			
Day 5	0.4	0.8	4.6	2.3			
Day 6	0.2	0.5	4.4	2.62			
Final					5.8	3.7	7.4

Table 10: Values for the parameters measured for 10kg pineapple waste.

Days	V	A	pH	Con	DO	BOD	COD
Initial					3.9	2.1	4.2
Day 1	2.6	2.6	4.2	2.07			
Day 2	1.9	2.2	3.9	2.44			
Day 3	1.6	2	3.4	3.44			
Day 4	1.4	1.8	3.5	4.1			
Day 5	1.2	1.5	3.3	4.15			
Day 6	0.8	1	3	4.15			
Final					5.8	3.8	7.6

Table 11: Values for the parameters measured for 15kg pineapple waste.

Days	V	A	pH	Con	DO	BOD	COD
Initial					4.1	2.5	5.1
Day 1	3	3.2	4.3	2.65			
Day 2	2.6	3	3.7	3.04			
Day 3	2.2	2.5	3.7	3.42			
Day 4	2	2.1	3.1	4.6			
Day 5	1.8	1.6	3.1	4.93			
Day 6	1.4	1	3.1	4.98			
Final					4.3	2.9	8.9

Table 12: Values for the parameters measured for 20kg pineapple waste.

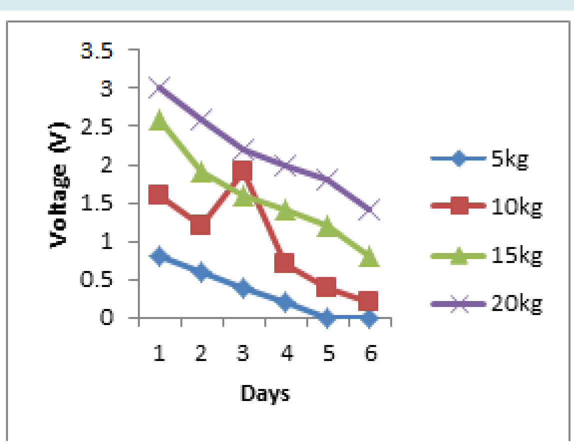

Figure 19: Plot of values for voltage (V) for 5kg, 10kg, 15kg, 20kg pineapple waste.

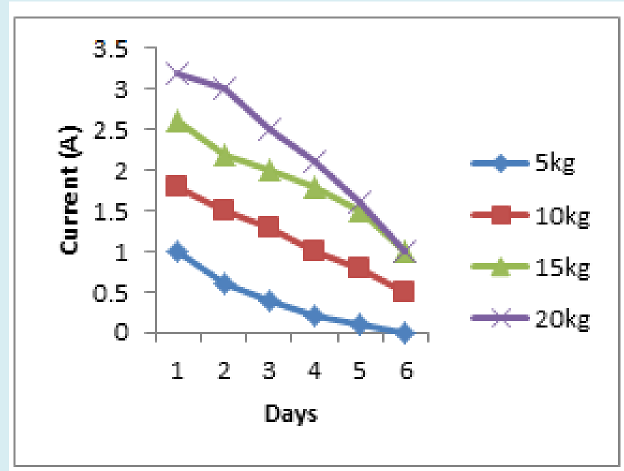

Figure 20: Plot of values for current (A) for 5kg, 10kg, 15kg, 20kg pineapple waste.

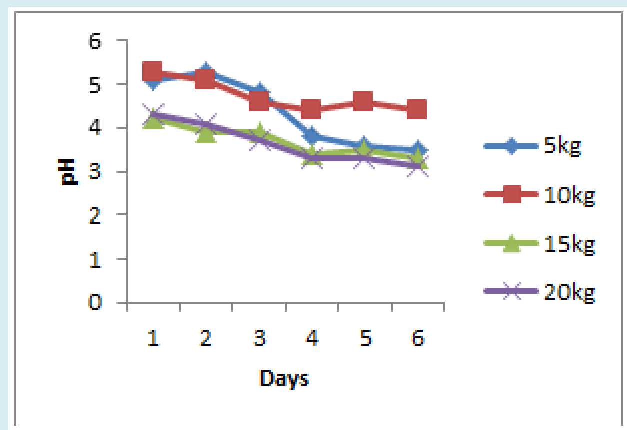

Figure 21: Plot of values for pH for 5kg, 10kg, 15kg, 20kg pineapple waste.

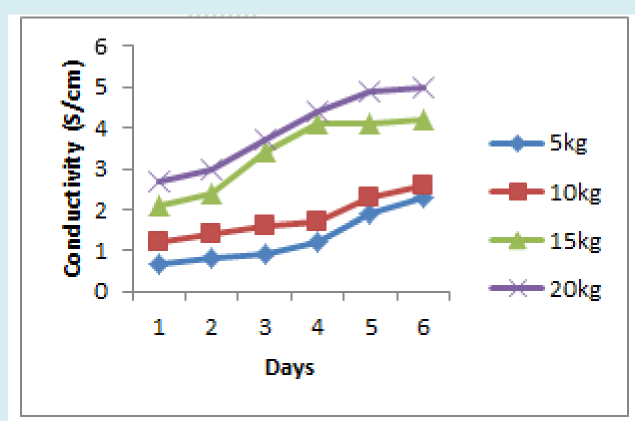

Figure 22: Plot of values for conductivity (S/cm) for 5kg, 10kg, 15kg, 20kg pineapple waste.

Discussion

Voltage

Voltage readings were taken daily using the multimeter connected to the terminals of the electrodes as shown in Figures 9 & 10. These were recorded each week for the various weights. The tomatoes waste had readings of 1.8V and 0.2V on day 1 and day 6 respectively for the 5kg. Increase in weights shared significant increase in voltages output with a maximum of 4.2V generated on Day 1 from 20kg. These readings are presented in Tables 1-4 and Figure 11. The output is high when compared with previous study [34] on bioelectricity generation from fruits. Similar results were obtained from banana waste (Tables 5-8) with the highest voltage of 3.1V generated from the 20kg substrate as shown in Figure 15. However, voltage readings from pineapple were low when compared to the other fruit wastes. On Day 1, only 0.8V was generated from the 5kg waste and 3.0V from the 20kg. These are presented in Tables 9-12 and in Figure 19. For all fruit wastes, a decreasing trend in voltage output was observed. This is as a result of reduction in the available substrate as reported in other studies [32,35].

Current

The values obtained for current were all significantly proportional to voltage readings. The 5kg fruit waste produced the least current while the 20kg produced current as high as 4.2A, 3.1A and 3.2A for tomatoes waste, banana waste and pineapple waste respectively. The readings are presented in Tables 1-12 and in Figures 12, 16 & 20. The gradual decrease in current production was observed from day 1 to day 6 and this is in accordance with the findings of Elviliana, et al. [24]. The type of substrate used has been found to affect the bacteria (microorganism) at the anode which ultimately influences the current generated [36]. Pineapple has the lowest values for current measured. This can be attributed to its high crude fiber content, lignin, cellulose and hemicellulose as indicated in reports by Nurhayati and Azuoma, et al. [26,37]. These low values are also in accordance with reports by Miran, et al. that higher cellulose fibers limit the microorganisms' ability for degradation. This was observed at the end of each process (at day 6) whereas the other fruit waste in their respective SMFCs reduced considerably leaving more water and little quantity of the decomposed substrate.

pH

The results for the pH values are presented in Tables 1-12 and in Figures 13, 17 & 21. For banana waste, the pH increased from day 1 to day 6 for all the weights as shown in Figure 7. However, for tomatoes and pineapples the values decreased from day 1 to day 6 (Figures 13 & 21). The fall in pH values for these fruit wastes could be as a result of hydrolysis and acidification as observed by Azuoma *et al* (2018) in their study. Banana slurry had pH range of 3.4 (day1) to 6.1 (day 6 for the 5kg and 5.6 (day 1) to 6.9 (day 6) for the 20kg as shown in Table 7. In Table 3, tomatoes had the reverse; 5.1 (day 1) to 4.0 (day 6) for the 5kg and 6.7 (day 1) to 4.4 (day 6) for the 20kg. Similar pH profile was obtained for pineapple (Table 11); 5.1 (day 1) to 3.5 (day 6) for 5kg and 4.3 (day 1) to 3.1 (day 6) for the 20kg. This trend shows that the banana medium tends to a neutral pH state as the days progress whereas the tomatoes and pineapple media tend to move down the pH scale to a more acidic state as the days progress. This confirms that fermented pineapple waste have been known to have high acidity than fresh waste [38].

Conductivity

Conductivity is the measure of the ability of a cell to produce current enough to generate voltage. The values recorded for tomatoes and pineapple presented in Tables 4 & 12 showed an increasing trend from day 1 to day 6 as shown in Figures 14 & 22. For tomatoes waste, the 5kg substrate recorded values of 2.03 S/cm on day 1 and 3.56 S/cm on day 6. The 20kg substrate had values of 6.62 S/cm on day 1 and 7.42 S/cm on day 6. Conductivity values for pineapple were lower though an increasing trend was observed as shown in Figure 22. The lowest value, 0.65 S/cm was recorded on day 1 for 5kg substrate and 2.31 S/cm on day 6. For the 20kg substrate, 2.65 S/cm was obtained on day 1 and 4.98 S/cm for day 6. A decreasing trend in conductivity values was recorded for the banana substrate from 2.61 S/cm (day 1) to 2.21 S/cm (day 6) for 5kg and 6.06 S/cm (day 1) to 4.43 S/cm (day 6) for the 20kg substrate. These are presented in Table 8 & Figure 18. This observation can be attributed to the pH condition of the medium. The tomatoes slurry has pH of 5.1-6.6 on day 1 and by day 6. It was 4.0-4.7. Pineapple had a pH from 5.1-4.3 on day 1 and by day 6 the values are 4.4-31. These acidic conditions facilitated the high conductivity value obtained during this study.

BOD and COD

These parameters measure the removal efficiency of the system. The results are presented in Tables 1- 12. For the tomato waste, the BOD and COD values were relatively constant. With the BOD values ranging from 2.2 to 2.9 mg/L for BOD and values of 4.4-5.8 mg/L for COD. The lower values in both parameters were obtained for the for the 5kg and 10kg substrates while there was a gradual increase in values for the 15kg and 20kg substrates. BOD values for banana waste were higher than those for tomatoes. The values were from 2.8 - 3.9 mg/L while the COD values were from 3.3-6.8 mg/L. Pineapples fruits are known to have high BOD and

COD values [39] and this was observed with the results from his study. The BOD values obtained were from 3.5-3.8 mg/L and the COD values were from 5.0-8.9 (for 20kg pineapple) being the highest recorded for the three fruit waste. This is quite significant as it corresponds with observations from other reports [40-43]. These values also demonstrate the effectiveness of the microbial fuel cell technology.

DO

The dissolved oxygen (DO) values presented in Tables 1-12 were fairly constant for three fruit wastes across the weights used for this study. DO values for tomatoes waste were 3.3-4.4 mg/L, for banana waste we obtained values of in the range of 4.1-5.3 mg/L and for pineapple, the DO values were in the range of 4.0-5.8 mg/L.

Conclusion

The conversion of tomatoes, banana and pineapple fruit waste to bioelectricity was achieved using the single chamber microbial fuel cells (SMFCs). Voltage and current generated were observed to increase as the weights of the fruit wastes were increased from 5kg to 20kg. This shows that these wastes can be utilized to generate bioenergy that can be applied to ameliorate the energy problems for small units and with subsequent scale-up, energy crises in developing countries will be a thing of the past. Environmental pollution and degradation caused by the dumping of these huge agro wastes will also be taken care of.

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