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# Electricity Generation from Waste Tropical Fruits - Watermelon (Citrullus lanatus) and Paw-paw (Carica papaya) using Single Chamber Microbial Fuel Cells

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***Abstract***

*Tropical fruits are often in abundance when they are in season with most of them ending up in dumpsites as wastes due to lack of technological processes and industries to convert the excess harvest into other useful forms. This study was aimed at converting these huge fruit waste into useable energy using a Single chamber Microbial Fuel Cell (SMFC). Different weights (1kg, 2kg, 4kg, 6kg, 8kg, 10kg, and 12kg) were used in this study for 7weeks with each weight per week. A digital multi-meter (Model: DT 9205A) connected to the SMFC was used to determine the voltage generated by the different weights of the fruit waste. The maximum voltage of 139.5mV and 222.9mV was generated by the 12kg substrate for watermelon and paw-paw respectively. Power densities generated for watermelon and paw-paw were 0.0955mW/cm$^2$ and 0.2452mW/cm $^2$ respectively. For watermelon, the value of $r^2$(0.976) and paw-paw (0.957) shows that the relationship between voltage and power density is significant. Results from the physicochemical analyses, showed that the highest values for pH, BOD, DO and conductivity was recorded from the 12kg substrate. The medium was mostly acidic for both fruits throughout the study. The DO and BOD values obtained showed that the medium was favorable for microorganisms to proliferate thereby resulting in the high amount of electricity generated. The results from this study have shown that a single chamber MFC is capable of generating electricity from waste tropical fruits. It is therefore recommended that a proper program be initiated to harness this vast resource to augment the epileptic and dearth of electricity supply in our urban and rural areas.*

**Keywords:** *Single Chamber Microbial Fuel Cell (SMFC), Watermelon, Paw-paw, Bioelectricity, Bio-degradation, Microorganisms, Fruit waste*

## 1. Introduction

A huge amount of the energy used globally comes from non-renewable sources and so there is the need for a renewable source as an alternative for energy production. The reliance on fossil fuels is unsustainable because of its finite, depleting supplies, and impact on the environment. An increase in human activities is consuming natural energy sources leading to the depletion of fossil fuels [1][2]. Energy demand worldwide will continue to be on the increase accelerating global crisis and environmental pollution. A Microbial Fuel Cell (MFC) is an advance device built to contend with three dimensional problems of fossil fuel based

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energy production with high cost and pollution generating unit. It is an emerging technology of wastewater treatment with energy production. It has the potential to utilize wastewater as feed substrate for microorganism and to generate bioelectricity [3]. The generation of electricity using Microbial Fuel Cells (MFCs) is one way of reducing dependency on fossil fuels as well as producing cleaner energy. This is a new method of simultaneously generating electricity from organic matter while degrading the same in a process most adeptly referred to as waste-to-energy. Microbial Fuel Cells (MFCs) are devices that use bacteria to generate electricity from organic matter and are considered as bioreactors that convert chemical energy stored in the bonds of organic matter into electricity through bio-catalysis of microorganisms [4]. These organic materials can be a source of energy when treated anaerobically through the conversion of carbohydrate present in waste products by the action of enzymes produced by these microorganisms. The idea of extracting electricity directly from organic matter through the catalytic reactions of micro-organisms emerged a century ago. A microbial fuel cell typically consists of several components primarily divided into two chambers; the anodic chamber and the cathodic chamber containing the anode and the cathode respectively. There are two main types of microbial fuel cells namely; the single chamber Microbial Fuel Cells (SMFC) and Dual-Chamber Microbial Fuel Cells (DMFC). A microbial fuel cell is a system in which microbes convert chemical energy produced by the oxidation of organic/inorganic compounds into ATP (Adenosine triphosphate) by sequential reactions in which electrons are transferred to terminal electron acceptor to generate an electric current [5][6]. Apart from bioelectricity generation and treatment of wastewater MFCs can also be applied in carbon capture, bioremediation, biosensing, biohydrogen production and desalination. This technology holds promise for a clean and green environment and its successful application would provide a new outlook for engineers and scientists [3]. The MFC containing separate cathodic and anodic chambers which are oftentimes separated by a proton exchange membrane [7] is referred to as the dual-chamber MFC while the one which contains both cathode and anode in a single chamber is called the single-chambered MFC [6]. SMFCs have some advantages over the DMFC in terms of the cheap cost for construction and its simple operation. Lemon, orange, and grapefruit are examples of biomass that are commonly known as citrus fruits and used for bio-energy generation [8][9], electricity has been generated from waste tomatoes, banana, pineapple fruits and peel using a single chamber microbial fuel cells [10] as well as waste vegetables (fluted pumpkin, waterleaf and cabbage) using microbial fuel cell [11] and can power a small device such as a calculator and LED clocks [12]. It has been reported by Oon [13] that under certain conditions, the citric acid contained in citrus fruit may act as an electrolyte which enables the generation of electricity just the same way as the galvanic battery. 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. 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 [10].

The eating habit of individuals around the globe is causing huge worldwide waste problem especially in Nigeria where organic wastes are carelessly dumped. These wastes have crowded dumpsites and roadsides thereby causing environmental pollution (land and air). Besides, the combustion of fossil fuel for the generation of electricity has been found to generate a lot of "greenhouse gases" such as $CO_2$, $SO_2$, $NO_2$, etc. which has shown alarming consequences such as global warming and acid rain on the environment. Hence this study seeks to address the energy crisis through the generation of electricity from huge fruit wastes that are building up all around us by employing the use of a cleaner and cost-effective technology - the Single chamber Microbial Fuel Cell (SMFC).

## 2. Materials and methods

### 2.1. Construction of the MFC

The single chamber Microbial Fuel Cells (SMFCs) were constructed using rectangular plastic containers (28cm x 42cm x 25cm). The electrodes were constructed using 10mm diameter PVC pipes. The electrode materials were obtained from used 1.5 V dry cells. The heights of the anode electrodes were 25cm and the cathodes were 40.5cm, the anode chamber was completely submerged inside the microbial fuel cell and was sealed totally with 4-minute gum thereby avoiding the passage of air. About 70% of the total length of the cathode was in the slurry of the waste fruits (watermelon and paw-paw) while the remaining 30% was exposed to atmospheric oxygen. The two electrodes terminals were connected by copper wires to 10,000Ω resistors and finally to the digital Multimeter (Model: DT9205A) for voltage readings. The generated electrons, according to [14] will be transferred from the anode to the cathode through the external circuit.

### 2.2. Method

The waste fruits were collected from the waste heap at the market dumpsite and kept in the laboratory for 3 days to decompose naturally (microorganism acting on it; which facilitates the generation of electricity). The waste fruits were each weighed using a top-loading weighing balance (Model: SP20kg; capacity: 20kg/40lb) before they were sliced and fed into the single chamber microbial fuel cell. The 1kg fruit waste was each loaded into plastic containers (the constructed SMFCs) and filled to brim with water and the terminal connected to a digital Multimeter. Initial readings were taken for voltage, pH, DO, and BOD. At the end of 7 days, the color change was noted before discarding the substrate solution. This process was carried out at room temperatures of 25 $\pm 2^0$C for 40 days with a day interval between each batch to enable us to wash and prepare the cell for the next batch (weight) of fruit wastes. The process was repeated for 2kg, 4kg, 6kg, 8kg, 10kg, and 12kg respectively for each week. Voltage readings were recorded every day for 7 days for each weight of waste fruits used. The study lasted for 7 weeks.

### 2.3. The microbial fuel cell procedure

The microbial fuel cells were monitored for 1 week (7 days) for each weight of waste watermelon and waste paw-paw used (1kg, 2kg, 4kg, 6kg, 8kg, 10kg, and 12kg), during which voltage generated and measured by the digital Multimeter (Model: DT9205A) was recorded for each day. A 24hourly (daily) readings of the voltage generated were measured using the digital Multimeter and were recorded in millivolts (mV). Power and power density values were calculated.

### 2.4. The physicochemical analysis of the electrolytes

50Cl of the electrolyte (waste watermelon and paw-paw) was collected and used to analyze its physicochemical characteristics which were pH, color, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD) and conductivity using standard laboratory methods as provided by American Public Health Association [15].

## 3. Results/Discussion

The average readings for voltage, power, power density, pH, DO, BOD, and conductivity for watermelon and paw-paw are presented in [Tables 1-4] and [Figure 1] and [Figure 2].

Table 1. Voltage, power and power density readings obtained from the different weights of waste watermelon

| Weight (Kg) | Voltage (mV) | Power (mW) | Power density ($mW/cm^2$) |
|---|---|---|---|
| 1 | 32.8 | 0.1076 | 0.0053 |
| 2 | 38.6 | 0.1490 | 0.0074 |
| 4 | 43.8 | 0.1918 | 0.0095 |
| 6 | 53.5 | 0.2862 | 0.0141 |
| 8 | 58.1 | 0.3376 | 0.0167 |
| 10 | 69.3 | 0.4802 | 0.0237 |
| 12 | 139.5 | 1.9349 | 0.0955 |

Electricity was generated by measuring the potential difference using a digital Multimeter and converting it to power. The microbes were the major active source of electricity generation.

[Table 1] shows the voltage output, power output and power density obtained at the end of the study, the voltage generated from the different weights of 1kg, 2kg, 4kg, 6kg, 8kg, 10kg, and 12kg of waste watermelon used were 32.8mV, 38.6 mV, 43.8 mV, 53.5 mV, 58.1 mV, 69.3 mV and 139.5 mV respectively. The power generated from the different weights of 1kg, 2kg, 4kg, 6kg, 8kg, 10kg, and 12kg of waste watermelon used were 0.1076 mW, 0.1490 mW, 0.1918 mW, 0.2862 mW, 0.3376 mW, 0.4802 mW and 1.9347 mW respectively in this study ranged from 0.1076mW - 1.9349mW. The power density obtained from the different weights of waste watermelon used in the study were 0.0053$mW/cm^2$, 0.0074 $mW/cm^2$, 0.0095 $mW/cm^2$, 0.01412 $mW/cm^2$, 0.0167 $mW/cm^2$, 0.0237 $mW/cm^2$ and 09551$mW/cm^2$ . The increase in the voltages, power, and power densities generated was weight dependent as an increase in weights of fruit resulted in a corresponding increase in the voltage, power, and power density generated. According to Logrono [16], SMFCs generated the highest output voltage with the device that contained more concentration of fruits as this criterion gives better conditions for oxidation-reduction reactions in the bio-electrogenic process. Their results showed that fruits produced more electricity because they contained more sugar which the bacteria cleaved to.

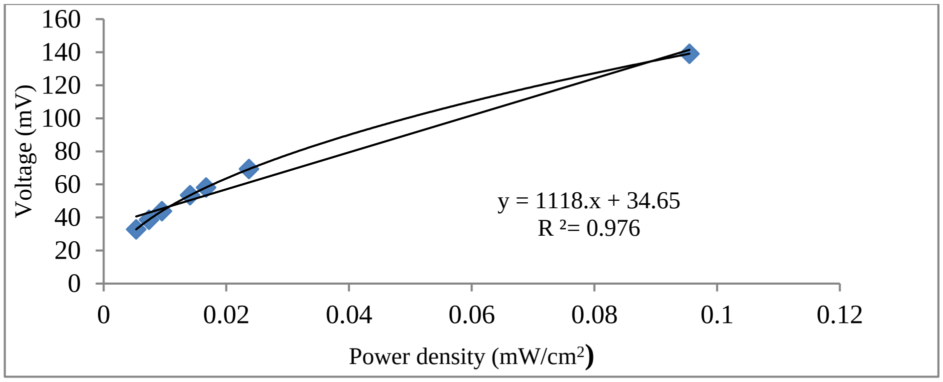


Figure 1. Plot of voltage (mV) against power density (mW/$cm^2$) for watermelon

The correlation between the voltage and power density for watermelon fitted a linear regression equation; y = mx + C. The values of $r^2$ for watermelon (0.976) from the plot above [Figure 1) show that the relationship between voltage and power density is significant.

Table 2. Voltage, power and power density readings obtained from the different weights of waste paw-paw

| Weight (Kg) | Voltage (mV) | Power (mW) | Power density (mW/$cm^2$) |
|---|---|---|---|
| 1 | 46.70 | 0.2181 | 0.0108 |
| 2 | 51.80 | 0.2683 | 0.0132 |
| 4 | 69.71 | 0.4859 | 0.0240 |
| 6 | 95.53 | 0.9126 | 0.0450 |
| 8 | 111.46 | 1.2423 | 0.0613 |
| 10 | 132.67 | 1.7601 | 0.0868 |
| 12 | 222.96 | 4.9711 | 0.2452 |

[Table 2] shows the voltage output, power output and power density obtained at the end of the study, the voltage generated from the different weights of 1kg, 2kg, 4kg, 6kg, 8kg, 10kg, and 12kg of waste paw-paw used were 47.70mV, 51.80 mV, 69.71 mV, 95.53 mV, 111.46 mV, 132.69 mV and 222.96 respectively. The power generated from the different weights used in this study was 0.2181mW, 0.2683 mW, 0.4859 mW, 0.9126 mW, 1.2423 mW, 1.7601 mW and 4.9711 mW. The power density obtained from the study revealed that substrates 1kg, 2kg, 4kg, 6kg, 8kg, 10kg, 12kg had values of 0.0108mW/$cm^2$, 0.0132 mW/$cm^2$, 0.0240 mW/$cm^2$, 0.0450 mW/$cm^2$, 0.0613 mW/$cm^2$, 0.0868 mW/$cm^2$ and 0.2452mW/$cm^2$ respectively. Paw-paw fruit waste generated a higher voltage, power, and power density than watermelon. This is due to the high amount of the sugar content in paw-paw when compared to that of watermelon; this implies that the higher the sugar content of the fruits the higher the voltage generated. According to [16], SMFCs generated the highest output voltage with the device that contained more concentration of fruits as this criterion gives better conditions for oxidation-reduction reactions in the bio-electrogenic process. Their results showed that fruits produced more electricity because they contained more sugar which the bacteria cleaved to.

 

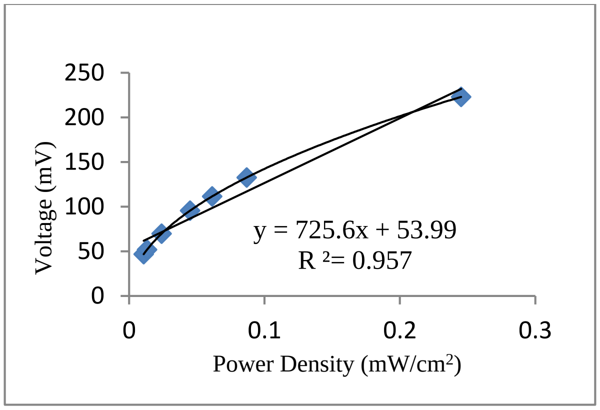


Figure 2. Plot of voltage (mV) against power density ($mW/cm^2$) for paw-paw

The correlation between the voltage and power density for paw-paw fitted a linear regression equation; y = mx + C. The values of $r^2$ for paw-paw (0.957) from the plot above [Figure 2] show that the relationship between voltage and power density is significant.

Table 3. Physicochemical properties of waste watermelon water

| Weight (Kg) | pH | DO (mg/L) | BOD (mg/L) | Conductivity µS/cm | Color |
|---|---|---|---|---|---|
| 1 | 6.8±0.04 | 7.9±0.28 | 5.4±0.67 | 189.4±34.45 | Cloudy, then became clear |
| 2 | 7.3±0.07 | 6.6±0.07 | 4.2±0.39 | 207.3±27.56 | Cloudy, then became clear |
| 4 | 3.9±0.40 | 5.3±0.13 | 5.5±0.44 | 235.0±38.47 | Cloudy, then became clear |
| 6 | 4.1±0.40 | 6.3±0.14 | 5.9±0.60 | 557.4±374.21 | Cloudy, then became clear |
| 8 | 4.3±0.40 | 6.7±0.14 | 5.9±0.56 | 1027.9±679.25 | Cloudy, then became clear |
| 10 | 4.5±0.37 | 7.0±0.26 | 6.1±0.56 | 1067.4±697.82 | Cloudy, then became clear |
| 12 | 4.6±0.37 | 7.7±0.59 | 6.2±0.53 | 1327.6±742.21 | Cloudy, then became clear |

The results presented in [Table 3] show the physicochemical properties (pH, DO, BOD, conductivity, and color) of waste watermelon water. For all the weights of the sample, the pH varied between 3.9 - 7.3. The pH values of watermelon wastewater for substrate 1kg, 2kg, 4kg, 6kg, 8kg, 10kg, 10kg and 12kg were 6.8±0.04, 7.3±0.07, 3.9±0.40, 4.1±0.40, 4.3±0.40, 4.5±0.37 and 4.6±0.37 respectively. From these values, it showed that the medium was slightly acidic. Comparing the values obtained from voltage to that of pH, viz-a-viz the weight of waste used it is observed that the voltage generated was higher in the weights of the samples that had low pH values, which is an indication that microorganisms which aid the generation of electricity thrive more in acidic medium than weak acidic or alkaline medium. This, therefore, implies that the lower the pH the greater the chances of obtaining higher values for the voltage which also goes to show that fruits with lower pH values have the potentials of generating more electricity when compared with those with higher values of pH. Fruits with an alkaline pH would not generate a good amount of electricity since microorganisms that aids the generation of electricity do not proliferate in an alkaline medium. Dissolved Oxygen (DO) is an important parameter in this study as it is the measure of the amount of gaseous oxygen ($O_2$) dissolved in aqueous solution. Oxygen gets into water by diffusion from the surrounding air, by aeration and as a waste product. From the results presented in Tables 3, the DO reading obtained from 1kg, 2kg, 4kg, 6kg, 8kg, 10kg and 12kg substrate of watermelon wastewater were 7.9±0.28 mg/L, 6.6±0.07 mg/L, 5.3±0.13 mg/L, 6.3±0.14 mg/L, 6.7±0.14 mg/L, 7.0±0.26 mg/L and 7.7±0.59 mg/L respectively. The pattern showed that DO had a fluctuating trend (increasing and decreasing simultaneously) for watermelon. The DO values of wastewater of paw-paw 5.3 - 7.9 mg/L. The Dissolved Oxygen (DO) values from the waste water sample of watermelon were found to be relatively high which is a pointer that the higher the amount of dissolved oxygen in the sample the higher the proliferation of the microorganisms aiding the process which results in a higher quantity of electricity generated. Biochemical Oxygen Demand (BOD) is a measure of the amount of Dissolved Oxygen (DO) that is used by aerobic microorganisms when decomposing organic matter in water. The greater the quantity of organic matter available for oxygen-consuming bacteria, the higher the BOD value. The BOD values of watermelon wastewater for substrates of 1kg, 2kg, 4kg, 6kg, 8kg, 10kg and 12kg were 5.4±0.67 mg/L, 4.2±0.39 mg/L, 5.5±0.44 mg/L, 5.9±0.60 mg/L, 5.9±0.56 mg/L, 6.1±0.56 mg/L and 6.2±0.53 mg/L respectively. An increase in the weight of the substrate results in a corresponding increase in the BOD values. The value of the BOD is an indication that the medium was favorable for microorganisms to thrive thereby resulting in an increased electricity generation. Conductivity is another very important parameter. It measures the water's ability to conduct electricity. The conductivity readings for substrates of 1kg, 2kg, 4kg, 6kg, 8kg, 10kg and 12kg for watermelon wastewater were 189.4±34.45 µS/cm, 207.3±27.56 µS/cm, 235.0±38.47 µS/cm, 557.4±374.21 µS/cm, 1027.9±679.25 µS/cm, 1067.4±697.82 µS/cm and 1327.6±742.21 µS/cm respectively. The color of the solution which was initially cloudy at the start of the research work became clearer at the end. It, therefore, shows that microbial fuel cells serve dual purposes which are the generation of electricity as well as the treatment of wastewater.

Table 4. Physicochemical properties of waste paw-paw water

| Weight (Kg) | pH | DO (mg/L) | BOD (mg/L) | Conductivity µS/cm | Color |
|---|---|---|---|---|---|
| 1 | 3.1±0.23 | 6.6±0.98 | 3.9±0.19 | 787.6±475.89 | Cloudy, then became clear |
| 2 | 3.2±0.15 | 6.8±1.00 | 4.0±0.25 | 851.7±450.56 | Cloudy, then became clear |
| 4 | 3.3±0.13 | 7.0±1.01 | 4.1±0.22 | 931.4±484.68 | Cloudy, then became clear |
| 6 | 3.7±0.00 | 7.3±2.09 | 4.6±0.09 | 1083.4±481.76 | Cloudy, then became clear |
| 8 | 4.1±0.20 | 7.5±0.90 | 5.3±0.08 | 1162.9±486.68 | Cloudy, then became clear |
| 10 | 4.3±0.29 | 8.2±1.80 | 5.8±0.16 | 1077.1±654.57 | Cloudy, then became clear |
| 12 | 4.6±0.38 | 9.1±0.80 | 6.4±0.11 | 1282.9±492.94 | Cloudy, then became clear |

The results presented in [Table 4] show the physicochemical properties (pH, DO, BOD, conductivity, and color) of waste paw-paw water. The values of pH for substrate 1kg, 2kg, 4kg, 6kg, 8kg, 10kg and 12kg were 3.1±0.23, 3.2±0.15, 3.3±0.13, 3.7±0.00, 4.1±0.20, 4.3±0.29, 4.6±0.38. From these values, it showed that the medium was acidic. It was observed that the voltage generated was higher in the weights of the samples that had low pH values which implies that the lower the pH the greater the chances of obtaining higher values for the voltage as observed in the case of watermelon. From the results presented in Table 4, the DO values obtained for paw-paw wastewater for the different weights used were 6.6±0.98 mg/L, 6.8±1.00 mg/L, 7.0±1.01 mg/L, 7.3±209 mg/L, 7.5±0.90 mg/L, 8.2±1.80 mg/L and 9.1±0.80

 

mg/L, the pattern showed that DO had an increasing trend for paw-paw wastewater. The BOD values of paw-paw wastewater for substrates of 1kg, 2kg, 4kg, 6kg, 8kg, 10kg and 12kg were 3.9±0.19 mg/L, 4.0±0.25 mg/L, 4.1±0.22 mg/L, 4.6±0.09 mg/L, 5.3±0.08 mg/L, 5.8±0.16 mg/L and 6.4±0.11 mg/L respectively. An increase in the weight of the substrate results in a corresponding increase in the BOD values. The value of the BOD is an indication that the medium was favorable for microorganisms to thrive thereby resulting in an increased electricity generation. Conductivity is a measure of the water's ability to conduct electricity. The conductivity readings for substrates of 1kg, 2kg, 4kg, 6kg, 8kg, 10kg and 12kg for paw-paw wastewater were 787.6±475.89 µS/cm, 851.7±450.56 µS/cm, 931.4±484.68 µS/cm, 1083.4±481.76 µS/cm, 1162.9±4876.68 µS/cm, 1077.1±654.57 µS/cm and 1282.9±492.94 µS/cm respectively.

## 4. Conclusion

This study evaluated the performance and effectiveness of Single Chamber Microbial Fuel Cells (SMFC) in the generation of electricity using various weights of watermelon and paw-paw fruit waste. The performance of the SMFC increased with an increase in the quantity of the substrates (the fruit waste). The results obtained from this study showed that electricity can be generated from waste watermelon and paw-paw through Single Chamber Microbial Fuel Cells (SMFCs). An increase in voltage output and conductivity was observed. The highest values were obtained from the 12kg on day 7 with a maximum of 239.5 mV and 250.4 mV from these fruits. The electricity generated was as a result of the microorganisms that were present in the waste watermelon and paw-paw. The decomposition of these waste tropical fruits resulted in the release of electrons. This study has shown that the use of Single Chamber Microbial Fuel Cells (SMFCs) is a promising technology in electricity generation and biodegradation of fruit waste as well as the treatment of wastewater.

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