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Assessment of Quantum of Electricity Generation of Selected Plants from Middle Belt of Nigeria

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ABSTRACT: The prevailing energy needs globally is a major sign that can create energy crisis in the future. The objectives of the research was to find out the quantum of electric potentials that can be generated from some selected tropical plants. The use of living plants to obtain electrical energy through living plant bio-energy fuel cells was studied as a mechanism that can supply electrical energy, especially in rural areas of the world. In this study, the voltage produced by living plant bio-energy fuel cells was measured using a digital multi-meter connected to different electrolytic paired electrodes of copper, iron, aluminium, silver and zinc inserted into stems of plants at a height of 50cm above ground level and at different distances of 0.5m, 1m and 1.5m away from plant. The multi-meter probes, Black probe connected electrodes on plant stems (cathodes), and Red probe connected to electrodes on the ground (anodes). The voltages and currents measurements were carried out for 10 minutes at an interval of every 2 minutes. The selected plants belonging to the species of; Mango, Boabab, Gmelina, Cactus, Pawpaw, Palm tree, African Fan Palm and Hospital too far. They were selected for their availability, great fluid contents and fibrous nature of root systems, all within the tropical region of Nigeria. The higher voltages measured were of Pawpaw, Gmelina, Mango and African Fan Palm with voltages using silver-zinc electrode pairs; 1.042V, 818mV, 756mV and 745mV respectively. From the findings, it was discovered that plants can be good sources of electrical energy at varying magnitudes as there was significant differences among electrical potentials generated by some selected tropical plants. There was also significant difference among electrical potentials generated by some selected pairs of electrolytic electrodes. Therefore, it was recommended amongst others that the use of living plant bio-energy fuel cells have the potentiality of generating electrical energy. Scientists should be encourage to fully develop plant bio-energy fuel systems that could generate bigger quantum of electrical energy.

Keywords: Renewable Energy, Electrical Potentials, Electrodes, Electrochemistry, Living plant Bio-energy fuel Cells, Plant Microbial Fuel Cells.

I. INTRODUCTION

Electricity as a major source of power globally for over a century, the rate of electricity infrastructural development is very low and its supply remains inadequate. The availability of functional electricity has been an impending problem to developing countries of the world with particular reference to Nigeria. There are numerous sources of electricity but to have a source that is reliable and cheap has always been a problem. Electricity as a form of energy has been developed from various renewable sources, including sunlight, wind, chemical reactions, bioenergy, and others [32]. Electricity energy production in Nigeria over the last 40 years varied from gas –fired, oil – fired, hydroelectric power stations to coal-fired with hydroelectric power system and gas – fired system taking the lead [29]. Currently, most energy is generated by conversion of fossil fuels. The major setback of using fossil fuels is pollution of the environment by emission of carbon dioxide, nitrogen oxides, sulphur dioxide, volatile organic compounds, heavy metals, and fine particles, moreover fossil fuels are not renewable in a time scale for many decades [1]. The need for electricity in remote areas rich in vegetation can be met through energy generation from living plants throughout the tropics. The source of electrical energy from living plants comes from plants' interaction with soil microbes [28]. Plants process solar energy through photosynthesis. The process produces a variety of materials needed to support plant development. The process is a series of biochemical reactions that produce electron releases. The electrons released during the reaction can be captured with electrodes placed around tree roots to harvest electrical energy. The generation of electrical energy can continue for as long as plants live [24]. The process of harvesting electricity does not produce pollution which shows that it is one of the most reliable source of energy.

The procedure through which environmental energy is drawn into a system and transformed into useful electrical power is known as energy harvesting [36]. The planet's most plentiful source of energy is the sun. However, only a very small portion of solar radiation is transformed into usable energy globally. This study was based on microbial solar cell (MSC) which is a new collective name of biotechnological systems that integrate photosynthetic and electrochemically active organisms to generate in situ "green" electricity or chemical compounds, such as hydrogen, methane, ethanol and hydrogen peroxide [13]. Microbial Solar Cell is a recent development that builds on the discovery of electrochemically active bacteria and subsequent development of microbial fuel cells (MFCs) [2]. MFC technology converts organic matter into electricity. This study used selected plants from the middle belt of Nigeria to note the variations in the nature of electrodes and the distance between the electrodes in measuring electrical potential that can be generated from plants selected. This study's results provided knowledge related to the development of innovations in the field of renewable energy by utilizing living plants as a source of electrical energy to reduce dependence on hydro-power or fossil energy.

1.1 Problem Statement

All appliances at homes, businesses and industries are running because of electricity. Over the decades, the power generation industry faces a daunting challenge in meeting global energy needs. By 2030, electricity use will double globally and triple in developing countries [37]. The severe problem facing the world today is energy crisis caused by the depletion of fossil energy reserves. Electricity as a major source of power globally as well as in Nigeria for over a century, the rate of electricity infrastructural development in the country is very low and its supply remains inadequate [29]. The central challenges of the Nigerian power sector was the intentional monopoly of the government in power generation, transmission and distribution. The outcry of the masses called for reforms. In terms of electricity access, 46.09 percent of the Nigerian population remains unconnected to national grid, representing 83.98 million people. In terms of energy use, Nigeria has the lowest in the world [25], and so this prompted the need for utilizing living plants to become sources of electrical energy to reduce dependence on hydro-power or fossil energy.

1.2 Objectives of the study

The objectives of the study were to;

i. Find out the quantum of electric potentials that can be generated by some selected tropical plants.
ii. Examine the differences in the electrolytic conducting potentials of some selected pairs of electrodes.
iii. Determine the difference of electric potentials measured between anode electrodes into soils at different distances away from fixed inserted cathodes on plants.

1.3 Hypotheses of the Study

The study was guided by the following null hypotheses at $P \leq 0.05$ level of significance:

HO_1: There is no significant difference among electrical potentials generated by some selected tropical plants from the middle belt of Nigeria.

HO_2: There is no significant difference among electrolytic conducting potentials of some selected pairs of electrolytic electrodes in living plant bio-energy fuel cells.

HO_3: There is no significant difference among electrical potentials measured of anode electrodes into soils at different distances away from fixed inserted cathodes on plants.

II. THEORETICAL FRAMEWORK

2.1 Electrochemistry

Electrochemistry is a science that deals with the physical and chemical properties of ionic conductors as well as phenomena occurring at the interfaces between ionic conductors on one hand and electronic conductors or semiconductors, other ionic conductors (including gases and vacuum) on the other hand [18]. Both properties and phenomena in electrochemical systems are studied under equilibrium condition, when there is electric current flow in a system. The electrons produced by plants involve electrochemical processes as observed by Fitch [10], which are chemical reactions that produce potential electrical energy. Electrons move from electron source to anode as cathode releases electrons to ions to be discharged

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mounted at different poles in electric energy potential system. Based on the studies of Muladi [23], electrode material selection is based on the electrochemical series or Volta series and electrodes often used are Zn, Ni, Sn, Ca, Li, Ba, Na, K, Mg, Fe, Mn, Pb, Al (H), Hg, Au, Cu, Ag, Pt. Electrodes used for this study were made up of Zn, Fe, Al, Cu and Ag.

2.2 Plant-Microbial Fuel Cells and Principle

A plant-microbial fuel cell (P-MFC) is a bioreactor that uses electrochemically active bacteria as a catalyst to oxidize organic and inorganic matter to generate current [12]. Its operation is really based on the use of microorganisms naturally present in the soil to convert a biodegradable substrate into electricity. The fuel comes from the organic matter continuously released by plants during photosynthetic process as observed by Srivastava [33] and it is summarized in the following reaction:

$$6H_2O + 6CO_2 \rightarrow C_6H_{12}O_6 + 6O_2$$

In this process carbon dioxide and water are converted into chemical bonds of glucose. Part of this chemically stored energy is transferred via phloem vessels of plants and deposited into soils [26]. This energy transported into the soils are captured by electrochemical active bacteria. Micro-organisms do oxidize the organic matter of a given soil and transfer energy rich electrons to inserted electrode. The energy carried by the electrons can be used as electrical energy, after which the electrons react at another electrode with oxygen to form water. This technology is called Plan Microbial Fuel Cell (PlantMFC) [11].
According to the study of Shaikh [31], P-MFC in simple terms is based on two important processes: Rhizodeposition of organic compounds produced during photosynthesis carried out by plants and the generation of electricity from organic compounds within cell chloroplast. For any P-MFC system, the anodic oxidation due to electrochemically active bacteria as a function of rhizodeposits present in the soil can be defined according to the following half-reaction:

$$C_6H_{12}O_6 + 12H_2O \rightarrow 6HCO_3^- + 30H^+ + 24e^-$$

The cell potential (driving force for current generation) is the difference between cathode and anode potential. The maximum potential difference between cathode and anode potential is determined by the difference between Nernst potential of cathode and anode [4]. The Nernst potential is determined by the reduction and oxidation process. Ideally, the reduction process in the cathode is, oxygen reduction into water as follow;

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

From which the Nernst potential can be calculated as;

$$E_{cath} = E_{cath}^0 - \frac{RT}{4F}\ln\left(\frac{1}{pO_2\left[H^+\right]^4}\right)$$

Where E_{cath} is = cathode Nernst potential (V), E_{cath}^0 = standard cathode potential (V), pO_2 = partial oxygen pressure (Pa), [H+] = proton concentration in moldm^{-3}. The standard cathode potential with oxygen reduction is typically +0.805 V versus standard hydrogen electrode [13]. Ideally, the MFC with oxygen reduction at the cathode would have a maximum cell voltage of 1.1 V [27].
Similarly, the oxidation process at the anode in most MFCs is acetate oxidation as follow;

$$CH_3COO^- + 4H_2O \rightarrow 2HCO_3^- + 9H^+ + 8e^-$$

And from which the Nernst potential can be calculated as;

$$E_{an} = E_{an}^0 - \frac{RT}{8F}\ln\left(\frac{\left[CH_3COO^-\right]}{\left[HCO_3\right]^2\left[H^+\right]^9}\right)$$

Where E_{an} is = anode Nernst potential (V), E_{an}^0 = standard anode potential (V), [CH_3 COO^-] = acetate ion concentration in moldm^{-3}, [H_2O] = water concentration in moldm^{-3}, [H^+] = proton concentration in moldm$^{-3,}$ [HCO_3^-] = bicarbonate ion concentration in moldm^{-3}. Since the concentration and composition of the organic substrate in MFC are mainly unknown, the precise Nernst potential of the anode is hard to determine. Hence, standard open cell potential of anode E_{an}^0 is used which is typically -0.289 V versus standard hydrogen electrode [13]. The maximum cell potential is defined as the difference between the cathode Nernst potential and the anode Nernst potential represented as;

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$E_{cell} = E_{cath} - E_{an}$.

The maximum cell potential is reached when no internal potential losses occur and is approached by the open circuit potential (when no current is generated) [22]. A simplified process of rhizodeposits in P-MFC is described in Fig.2.1.

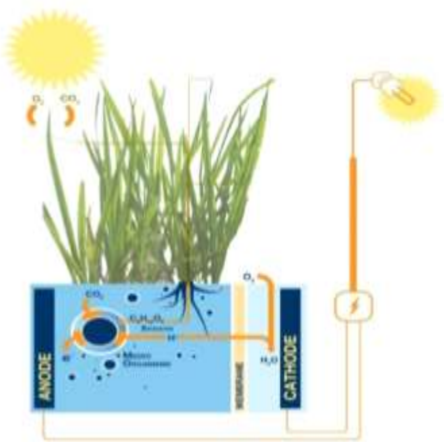

Fig.2.1. The reaction of rhizodeposits in P-MFC Strik et.al (2008).

2.3 Living Plant Bio-Energy Fuel Cell

Aside microbial fuel cell, trees have been discovered to have electrical properties [38], making it an interesting source of energy to harvest from. This was started by Cainan and colleagues [6], they claimed to have obtained electricity of 0.8V – 1.2V by inserting half an inch of aluminium roofing nail to tree and copper water pipe seven inches into the ground which was later supported by Choo and Dayou [7] as illustrated in Fig.2.2. These voltage differences have been used in attempts to monitor plant activity and have been discovered to be due to various sources, most prominent of which appears to be the ‘‘streaming potential’’ mechanism [20]. As a result, speculation of the report instantly became the driving force for researchers to reveal the sustainability of the renewable energy sources from plants.

2.4 Harvesting Electric Energy from Living Plants

Every green plant has chlorophyll and undergo a process called photosynthesis. Photosynthesis which is the process of converting solar energy into chemical energy by the use of sunlight, water, and nutrients from the soil, and carbon dioxide from the air to produce glucose or sugar and oxygen as a byproduct [14]. Plant energy is one of a kind of renewable energy resource, utilizing living plants to solve the lack of availability of power supply in remote areas. Hence, the potential of plants has been recognized and experimented by researchers with different types of variables and still researchers are extensively ongoing developing green energy as substitutions to fossil fuel [8]. From the categorization of renewable energy, there is a certain concept that can be implemented to get energy from plants. Research to utilize the organic material left over from photosynthesis from the plant has been carried out by a group of Dutch scientists who were members of Plant-e Company. They managed to harvest electricity from living plants, without affecting its growth or destroying it. This breakthrough nicknamed Plant Microbial Fuel Cell (Plant-MFC) make use of natural bacteria and plants to produce electricity. The Glucose produced from plants during photosynthesis is not all used up by plants, as much as 70 percent of photosynthesized products are thrown away through plant roots [15]. The organic matter which is discharged into the soil decomposed by microorganisms naturally into carbon dioxide, protons, and electrons (e-) [30]. Harvesting electrical energy is done by capturing these electrons by using electrolytic electrodes. Electrons released will be wasted if not utilized, so the electron capture process does not interfere with plant development. Energy harvesting can continue, and plants can grow naturally so that this energy source becomes renewable and environmentally friendly.

This research was carried out by placing two electrodes and functioned as anode and cathode. The anode inserted into soil to attract electrons (e-) generated by microbial activities and flow towards cathode to become a source of electrical energy in the same direction. Electrical energy is used by cathode embedded in plants to attract protons that combine with oxygen. This cycle can continue all the time, both at night and during the day, while plants still being alive. It was discovered that the experiment can produce a power of 0.4W per square meter within a plant radius [14]. Diagrammatic presentation of the insertions of electrodes is illustrated as fig. 2.2.

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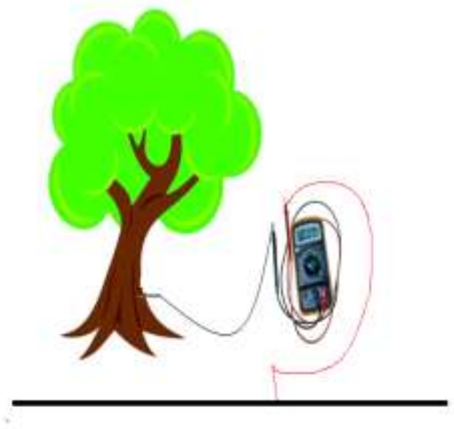

Figure 2.2: Connection of Electrodes to Plant, Soil and Multimeter.

2.5 Factors Affecting Performance of Living Plant Bio-Energy Fuel Cells (PBEFC)

Many factors can affect the performance of living plant bio-energy fuel cells, some of which include the following:

a. **Plant species**: Plants in electro-biotechnology serve as driving forces and a triggering mechanism in the generation of bioelectricity under the action of solar energy which launches the light phase of the chemical synthesis of ATP and the associated dark phase of photosynthesis of organic compounds [28]. The type of plant used in the PBEFC can impact its performance. For example, aquatic plants that grow in seawater can generate more bioelectricity than those that grow in freshwater.

b. **Soil properties**: The type of soil can affect the amount of bioelectricity generated. Organic soil contains more microbes and food for bacteria than sandy soil, so it can generate more bioelectricity.

c. **Temperature**: Maintaining optimal temperature range is essential for efficient electrochemical reactions. Temperatures that are too high or too low can lead to decreased efficiency, performance degradation, or even irreversible damage to the fuel cell components. Sustainability and resilience of P-MFC also tested in the Netherlands under the natural condition on rooftops [16], after a period of 221 days suggesting weather climate change causing a big influence on the power generation. Helder also supported that increase in solar radiation and temperature would likely increase power output [17].

d. **Ionic strength and salinity:** Higher salinity and ionic strength can increase the conductivity of the substrate and enhance MFC performance. However, salt can negatively affect microbial growth. From papers written by de Toledo and colleagues claimed that mobility of ions in plant tissue will increase the conduction with each different size and at its own rate by given electrochemical gradient [9]. Another finding is the effective resistance of apoplast along the midrib of leaves was inversely proportional to the width of leaves [19]. As the leaves dry up, resistance rises sharply. This means that resistance is higher when no water is present in a plant.

e. **Substrate inlet flow rate:** Increasing flow rate of sap can destroy biofilm and make it difficult for electron transfer process. Transroot potential occurs when charged ion gradients like H^+ , K^+ , and Ca^{2+} [5] reacting inside xylem sap. K^+ activity can cause an increase of 50mV in transroot potentials [39], also to glucose and H^+ when moving in opposite direction.

f. **Nature of Electrode:** Using inexpensive materials for electrodes and membranes can lead to a more cost-effective design for scalable wastewater treatment and high power generation. Characteristics of electrode are commonly considered as the key factors for improving the performance of MFCs. Electrode is the site of bacterial community attachment and growth and electrochemical reactions. Electrode architecture affects the performance of MFCs in electrical and mechanical perspectives such as internal resistance, inoculum spacing, fluid dynamics and so on. The efficiency of fuel cells varies with electrodes [21].

Other factors that affect microbial growth include: PH, moisture, and oxygen levels. Referring to researches conducted so far in this area of study, it is convinced that trees have the potential to generate electricity. By using the right electrode material to generate a significant amount of energy to be harnessed by low powered electronic devices.

III. RESEARCH METHODS

The study was conducted using experimental methods in several places within the tropical region of Nigeria where there were many plant species. Experimental design was considered most appropriate because it enabled the researcher to collect relevant data for a research of this nature. The study adapted the work of Muladi [23] where

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tropical plants were used. A survey was carried first. In the selection of plants, the aspects considered in selecting plants were; the easy insertion of electrodes into stems of plants, moisture condition and PH of soils.

3.1 Sample of the Study

The sample of the study comprised of eight selected tropical plant species within the middle belt of Nigeria which were; Mango, Boabab, Gmelina, Cactus, Papaya, Palm tree, African fan palm Mango (Mangifera Indica), Boabab (Adansonia digitata L.), Gmelina (Gmelina arborea Roxb), Cactus (Opuntia ficus-indica), Pawpaw (Carica papaya), Palm tree (Elaeis guineensis), African Fan Palm (Borassus aethiopum Mart.) and Hospital too far (Jatropha tanjorensis). The tree plants were selected because of their abundance within the tropical zone, their sap content and fibrous nature of root systems.

3.2 Apparatus and Instruments.

The technical devices that were used for the study include; Digital Multimeter, Electrolytic Electrodes (Copper, Iron, Aluminium, Zinc and Silver), Electrical Cables, Stopwatch, pH Meter and Measuring Tape.

3.3 Experimental Procedure

The experimental procedure involved series of stages. First, determining the moisture and PH of soils around tree plants, measurement of point on tree trunk, namely at the height of 50cm from the ground and the negative electrode (cathode) to be inserted 2cm deep. Determining the measurement point at ground level for the insertion of the positive electrode (anode) at a distance of 0.5 m, 1 m, and 1.5 m from plants. The two electrodes were connected to a digital Multimeter probe, black probe connected to electrode on tree trunk (cathode), and red probe connected to electrode on the ground (anode) as illustrated in figure 1. The voltage and current measurements using the digital multimeter were carried out one before another for 10 minutes by recording the values of the two parameters every 2 minutes and the averages calculated. The electrodes cleaned with water to remove adhered sap before being used for next measurement. The electrodes used were copper (Cu) with iron (Fe), silver (Ag) with zinc (Zn), and silver (Ag) with aluminum (Al).

IV. RESULTS AND DISCUSSION

The study investigated the quantum of electricity generation of selected plants from middle belt of Nigeria. The analysis essentially involved statistical testing of hypotheses at level of significance adopted $p \leq 0.05$ which form the basis for retaining or rejecting each of the null hypothesis stated, ANOVA statistical tool was used for the analysis. A summarized sample of the study of readings taken at a distance of electrode 0.5m away from tree trunk is given in Table 4.1.

Table 4.1: Summary of Electrical Parameters of Selected Tropical Plants from Middle Belt of Nigeria, Readings of Cathode 50cm Height on Plant / Anode 0.5m away from Plant.

S/N	Plant	Average Voltage			Average Current		
		Cu//Fe (V)	Ag//Al (V)	Ag//Zn (V)	Cu//Fe (mA)	Ag//Al (mA)	Ag//Zn (mA)
1	Mango Tree	0.706	0.279	0.756	0.032	0.004	0.260
2	African Boabab	0.643	0.384	0.723	0.112	0.203	0.504
3	Gmelina	0.743	0.301	0.818	0.136	0.001	0.145
4	Cactus	0.567	0.138	0.601	0.026	0.000	0.003
5	Papaya	0.720	0.383	1.042	0.155	0.127	0.205
6	Palm tree	0.635	0.406	0.289	0.181	0.119	0.045
7	African fan palm	0.646	0.446	0.745	0.123	0.146	0.220
8	Hospital too far	0.414	0.308	0.630	0.049	0.025	0.081

From the average voltages in Table 4.1, the histogram is presented as Figure 4.1

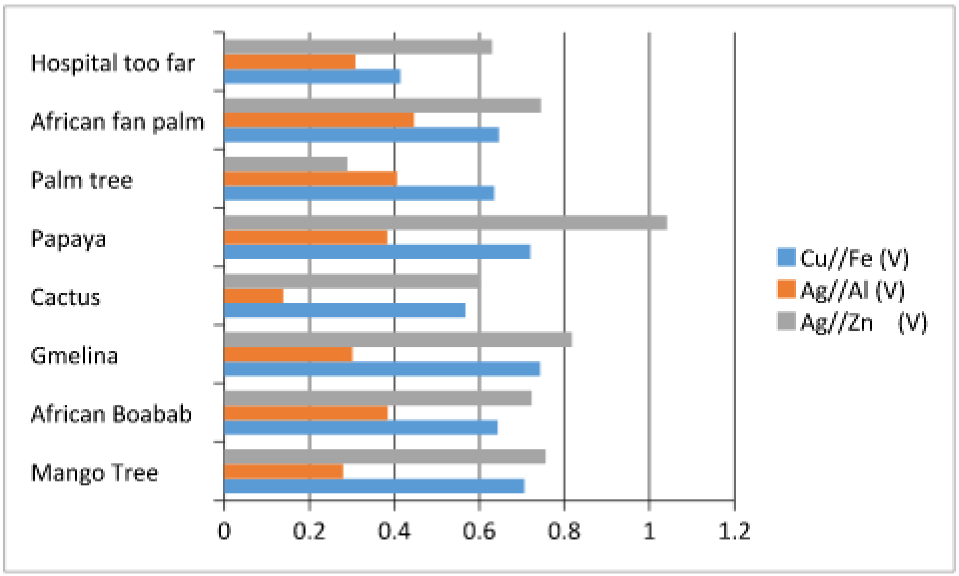

Figure 4.1: A histogram of averaged voltages of Selected Tropical Plants

4.1 Analysis of Null Hypotheses

To find the potential difference based on the nature of plant species, the following hypothesis was tested;

Effect of Plant Species

Null hypothesis HO_1: There is no significant difference among electrical potentials generated by some selected tropical plants from the middle belt of Nigeria.

Table 4.1: ANOVA Results of Electrical Potentials Generated by Selected Tropical Plants Using Different Pairs of Electrodes.

Electrode Pair	F – statistics	p – value	Decision (at α=0.05)
CU//Fe	4.53	0.009	Rejected H0
Ag//Al	3.89	0.014	Rejected H0
Ag//Zn	5.27	0.005	Rejected H0

Significant at P<0.05 Level.

Table 4.1 shows ANOVA results of electrical potentials generated by selected tropical plants. The p – values were 0.009, 0.014, 0.005 for the pairs of electrodes; Cu//Fe, Ag//Al and Ag//Zn respectively for the sampled plant species. Since the p-values obtained were less than 0.05 level of significance for each pair of electrodes, the null hypothesis that states that there is no significant difference among electrical potentials generated by some selected tropical plants from the middle belt of Nigeria stands rejected. This indicates that there was significant difference among electrical potentials generated by some selected tropical plants from the middle belt of Nigeria. These differences could be as a result of the physiology of different species, geographic conditions (soil, weather etc.), time of measurement, type and purity of the electrode material used and method of measurement [23]. This research was in line with the research conducted by Cainan [6], where they claimed to have obtained electricity of 0.8V – 1.2V by inserting half an inch of aluminium roofing nail to a tree and copper water pipe seven inches into the ground which was later supported by Choo and Dayou [7].

Effect of Electrode Variation

Similarly, to test for the effect of nature of electrode the following hypothesis was tested;

Null hypothesis HO_2: There is no significant difference among electrolytic conducting potentials of some selected pairs of electrolytic electrodes in living plant bio-energy fuel cells.

Table 4.2: ANOVA Results of Electrical Potentials Generated by Selected Pairs of Electrodes in Living Plant Bio-energy Fuel Cells.

Electrode Pair	F – statistics	p – value	Decision (at α=0.05)
CU//Fe Ag//Al Ag//Zn	14.10	0.0001	Rejected H0

Significant at P<0.05 Level.

Table 4.2 shows ANOVA results of electrical potentials generated by selected pairs of electrodes in living plant bio-energy fuel cells. The p – value 0.0001 obtained was less than 0.05 level of significance, the null hypothesis that states that there is no significant difference among electrolytic conducting potentials of some selected pairs of electrolytic electrodes in living plant bio-energy fuel cells was therefore rejected. This indicates that there was significant difference among electrical potentials generated by some selected pairs of electrolytic electrodes in living plant bio-energy fuel cells. These differences could be as a result of the sensitivity of different pairs of electrolytic electrodes used. In the study of Lin [21], they also observed that the efficiency of fuel cells varies with the nature of electrodes use.

Effects of Electrode Distance

To also test for the effects of electrode distance from plants, the following hypothesis was tested.

Null hypothesis HO_3: There is no significant difference among electrical potentials measured of anode electrodes into soils at different distances away from fixed inserted cathodes on plants.

Table 4.3: ANOVA Results of Electrical Potentials Measured of Anode Electrodes at Different Distances in Living Plant Bio-energy Fuel Cells.

Anode Distance	F – statistics	p – value	Decision (at α=0.05)
0.5 Meter 1 Meter 1.5 Meter	12.39	0.0003	Rejected H0

Significant at P<0.05 Level.

The electrode distance effect was investigated by placing the electrodes at a distance of 0.5, 1.0, and 1.5 meters from tree trunks. From Table 4.3, the p – value 0.0003 obtained was less than 0.05 level of significance, the null hypothesis that states that there is no significant difference among electrical potentials measured of anode electrodes inserted into soils at different distances away from fixed inserted cathodes on plants was therefore rejected. This shows that there was significant difference among electrical potentials measured of anode electrodes inserted into soils at different distances away from fixed cathodes on plants. These difference could be as a result of the microbial activities taking place at a given distance away from plant stand which had a profound effect on the voltage produced. Similarly, the research conducted by Muladi [23], the results showed that electrode distance effects of 0.5, 1.0, and 1.5 meters from tree trunk had a profound effect on the voltages produced.

V. CONCLUSION

This research sought to promote the possibility of using plants in both rural and urban areas to produce electrical energy through living plant bio-energy fuel cells to take advantage of electrons in the soil to generate electricity. Harvesting electrical energy from living plants was carried out using several electrode pairs indicated by the voltages obtained through a measuring instrument, multimeter, where voltages generated were measured. Silver and zinc electrode pairs produce the highest voltage, while Silver and Aluminium electrode pairs produce the lowest. While from the species of plant sampled, pawpaw produce the highest voltage compared to other plants. The distance between the electrodes measured from the rod to the electrodes on the ground also played significantly influence on the voltages measured. The electrode pairs tested in this study produce a stable voltage for the duration of the measurement to continuously produce electrical energy. This research needs to be further developed by studying the effects of soil chemistry, microbial activities in the soil within tropical regions of the world and how to boost current that can be generated from living plant bio-energy fuel systems for greater power output.

5.1 Recommendations

Based on the findings from this study, the following recommendations were made:

1. The use of living plant bio-energy fuel cells have the potentiality of generating electrical energy. Scientists should be encourage to fully develop plant bio-energy fuel systems that could generate bigger quantum of electrical energy.
2. For effective electric energy harvest, the used of sensitive electrode pairs should be employed.
3. To achieve success, government of nation could provide the enabling environment in terms of policy formulations and provisions of funds for scientists to have the materials needed for this development.

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