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Bioelectricity Generation from Plantain Peel Waste using *Saccharomyces cerevisiae* in a Low-Cost Microbial Fuel Cell

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ABSTRACT

This study investigates the potential of using plantain peel waste as a substrate in a microbial fuel cell (MFC) for bioelectricity generation. *Saccharomyces cerevisiae* was employed as the microbial inoculum, while kaolinite clay combined with starch was used to fabricate a cost-effective proton exchange membrane (PEM). The performance of the microbial fuel cell was monitored over a period of 13 days, during which a steady generation of electricity was observed, including current and voltage readings of 0.903 mA and 0.42 V; and 0.03 mA and 0.47 V on days 1 and 13 respectively. The maximum current density, power density, and voltage density were recorded as 1157 mA/m², 527.62 mW/m², and 289.5 V/m², respectively. The study demonstrated that plantain peel waste is a suitable substrate for electricity generation, and the clay-starch membrane functioned effectively as a proton exchange membrane, albeit with limited viability. This experiment also showcased the feasibility of creating a low-cost microbial fuel cell using locally available materials, which provides a potential avenue for sustainable and economically viable bioelectricity production to meet future electricity needs.

Keywords: Microbial Fuel Cell, Bioelectricity, Clean Energy, Proton Exchange Membrane

INTRODUCTION

The global demand for clean, sustainable energy has sparked a significant interest in bioenergy industries. The bioenergy is derived from biological sources and offers the potential for lower greenhouse gas emissions compared to fossil fuels. It encompasses a variety of energy forms, such as biogas, biohydrogen, biodiesel, bioelectricity, biochar, and bioethanol (Duarah *et al.,* 2022). Among these, bioelectricity generation through microbial fuel cells (MFCs) has emerged as a promising avenue due to its potential to generate clean energy while simultaneously addressing waste management challenges.

MFCs are bio-electrochemical devices that convert the chemical energy in organic substrates into electricity by harnessing the metabolic activities of microorganisms (Mohan *et al.,* 2008). Since Potter's discovery in 1911 of bacteria's ability to generate electricity, research into MFCs has significantly advanced over the last few decades (Adekunle & Raghavan, 2017). Although MFC technology is not yet commercially viable, its potential as an environmentally friendly energy source is compelling. The concomitant utilization of organic matter such as wastewater, plant waste, and animal waste, MFCs offer the dual benefits of waste treatment and renewable electricity production. The mechanism involves the oxidation of organic molecules by microorganisms in the anode chamber, releasing electrons that are then transmitted to the cathode chamber via an external circuit, where reduction takes place (Pant *et al*., 2010).

The microorganisms involved in MFCs play a crucial role in determining the system's efficiency, as different species vary in their electron transfer mechanisms and metabolic

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pathways. For optimal performance of the microorganism in generating electrons, the organic substrates must be fully oxidized to carbon dioxide, and the generated electrons must be efficiently transferred to the anode (Franks & Nevin, 2010). While most research has focused on bacterial species as biocatalysts for the generation of electricity, certain eukaryotes, such as the yeast *Saccharomyces cerevisiae*, have been shown to be promising biocatalysts. *S. cerevisiae* may serve as a biocatalyst for fuel cells if electron transfer occurs directly or without the use of a mediator (Gunawardena et al., 2008). Due to its low cost, ease of culture, and potential for MFCs, yeast has attracted a lot of scientific attention (de Oliveira et al., 2019) they can also grow in aerobic and anaerobic conditions. *S. cerevisiae*, offers several advantages as an MFC biocatalyst, including its ability to thrive in moderate temperatures (around 30°C) and its capacity for anaerobic respiration (Permana *et al*., 2015).

In addition to microorganisms, the proton exchange membranes (PEM) are components that are necessary for MFC operation. Protons are directed toward the cathode through the PEM. By the process of dissolution, electrolyte molecules separate into ions. Transporting positively charged ions, such as Na+, K+, Ca+, H+, etc., is made possible by the membrane's unique structure. In terms of being porous or semi-permeable membranes, separators differ from one to another. The triple roles of the polymeric membrane in the PEM fuel cells are as follows: charge carrier for protons, to separate the reactant gases, and electronic insulator for not passing electrons through the membrane (Peighambardoust et al., 2010). Common PEM materials include Nafion and other costly synthetic membranes. However, these materials present significant challenges in terms of economic feasibility, particularly for scaling up MFCs for broader applications. Thus, there is a need for more accessible, cost-effective alternatives to conventional PEMs.

Substrates used as fuel in MFCs include waste carbon-rich materials from both plant and animal sources. Plant waste, in particular, offers a readily available and cost-effective source of carbon. Among various plant wastes, such as orange peel, corncob, and watermelon rind, plantain peel waste (PPW) stands out due to its high carbohydrate and cellulose content. Plantain is a widely cultivated crop, especially in West Africa, where significant amounts of peel waste are generated as a byproduct of plantain production and consumption. In 2011 alone, West Africa produced 12.46 million metric tons of plantain, contributing to 32% of the world's production (Ayanwale *et al*., 2016). The improper disposal of this waste, often through incineration or dumping, leads to environmental pollution, highlighting the need for sustainable waste utilization strategies.

While much research has been conducted on microbial fuel cells, no prior studies have reported the use of plantain peel waste as a substrate for bioelectricity generation. Moreover, few studies have explored the use of locally available materials, such as clay, as a proton exchange membrane in MFCs. Addressing these gaps, this study investigates the feasibility of using plantain peel waste to generate bioelectricity and explores the potential of a clay-starch composite as a low-cost alternative to conventional PEMs such as Nafion 112 and Nafion 117, poly ethersulfone (PES), and polysulfone (Lim *et al*., 2012).

The novelty of this research lies in the integration of locally sourced materials including plantain peel waste as a substrate, *S. cerevisiae* as the microbial inoculum, and a clay-starch membrane as the proton exchange component to create a cost-effective microbial fuel cell. This approach not only addresses the

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need for cleaner energy generation but also provides a sustainable solution for waste management, particularly in West Africa where plantain peel waste is abundant. The use of clay, a locally available material, as a proton exchange membrane, offers a viable and scalable alternative to expensive synthetic PEMs, and the introduction of plantain peel waste as a novel substrate expands the range of biodegradable materials used in MFC research.

MATERIALS AND METHODS

Collection and Preparation of Substrate

Plantain fruits were sourced from Uselu market, Benin City. The peels were separated from the fruit, washed, and dried in an electric oven at 60°C for 2 hours to remove moisture. The dried plantain peels were then ground into a fine powder using the Hammer mill machine mechanical grinder. This powder was dissolved in a beaker using 500ml of distilled water and thoroughly agitated using a magnetic stirrer to ensure homogeneity. The resulting mixture was allowed to stand for a few minutes before use.

Preparation of Microorganism Inoculum

S. cerevisiae (baker's yeast) was selected as the microbial inoculum for this study. To prepare the inoculum, 2 g of glucose was dissolved in 10ml of distilled water and heated in a beaker to 45°C. Subsequently, 1 g of *S. cerevisiae* was added to the solution and stirred to ensure even distribution. A nutrient medium containing sodium bicarbonate (420 mg/L), 25 mL of calcium chloride dihydrate (0.021 g/L), and 30 mL of magnesium sulfate (0.25 g/L) was prepared and added to the inoculum. 5ml of this mixture was then measured and introduced into the anode chamber to initiate microbial activity (Miran *et al*., 2016).

Preparation of Proton Exchange Membrane

Clay was collected from the grounds of the University of Benin. The clay was dug out using hand trowels and placed in clean polyethylene bags, and taken to the laboratory. The clay was then dried, and ground into fine particles with the use of a mortar and pestle. The fine clay was sieved using a 100-micrometer mesh to ensure uniform particle size. Separately, 50 g of starch powder was dissolved in 50ml of distilled water to form a solution. This starch solution was added to 100 g of clay, followed by the addition of 50 g of sodium chloride (NaCl), which had been dissolved in distilled water. The mixture was heated to 120°C while stirring continuously until a gel-like consistency was achieved. The gel was then poured into a 3.2 cm diameter mold and allowed to cool. The 50ml of dissolved starch solution was added to increase the mechanical strength, hydration stability, and adhesive properties of the clay, while NaCl enhanced the cation exchange capacity and conductivity of the resulting proton exchange membrane (PEM) (Obasi *et al*., 2021). To prepare a suitable membrane it was ensured that the clay and starch mixture was maintained in a gel form. A suitable ratio was chosen to prevent the dissolution of the membrane into the cell (salt; starch; clay) (1:1:2).

Preparation of Electrodes

Anode Preparation: Zinc sheets, sourced from spent cell casings, were used as the anode material. The zinc sheets were cleaned, scraped, and cut to the appropriate size (35 mm by 45 mm) using a tin snip. They were then treated, washed, and soldered to copper wires for connection to the external circuit.

Cathode Preparation: Graphite rods, extracted from spent dry-cell batteries, were employed as the cathode material. The rods were

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carefully removed, cleaned, and their diameters were measured and recorded.

Construction of the Microbial Fuel Cell

The microbial fuel cell (MFC) was constructed using two plastic vessels, one serving as the anode chamber and the other as the cathode chamber. Circular openings were cut into both vessels to accommodate the proton exchange membrane (PEM), which was prepared as described in Section 2.3 and fitted into a 3.2 cm diameter pipe. The edges of the PEM were sealed with epoxy sealant to prevent any leakage.

The anode chamber housed the zinc sheet (35 mm by 45 mm), while the cathode chamber contained the graphite rod (8 mm in diameter). The anode and cathode were connected via copper wires to a digital multimeter, which measured the voltage and current. Both electrodes were suspended in their respective chambers to ensure full submersion and optimal contact with the electrolyte solution. A magnetic stirrer was used in the anode chamber to ensure continuous mixing of the substrate.

The anode chamber was sealed to maintain anaerobic conditions, and nitrogen gas was introduced to displace any remaining oxygen. In the cathode chamber, distilled water was used as the electrolyte, and an air pump was attached to provide a continuous supply of oxygen to act as the electron acceptor. The experimental set up is as shown in Figure 1.

Figure 1: Experimental setup of the microbial fuel cell.

Experimental Procedure for Electricity Generation

Once the microbial fuel cell was fully assembled, the anode chamber was inoculated with *S. cerevisiae* as described in Section 2.2. Initially, glucose was used as the substrate to facilitate the formation of a biofilm on the anode. A nutrient medium containing sodium bicarbonate (420 mg/L), 25 mL of calcium chloride dihydrate (0.021 g/L), and 30 mL of magnesium sulfate (0.25 g/L) was added to support microbial growth. After the formation of a stable biofilm, indicated by electricity generation, the glucose medium was replaced with plantain peel waste slurry.

Throughout the experiment, the anolyte in the anode chamber was continuously stirred using a magnetic stirrer to maintain a homogeneous solution. Nitrogen gas was periodically introduced to the anode chamber to prevent oxidation and ensure anaerobic conditions. The cell was maintained at room temperature, and low illumination was applied to avoid any photosynthetic interference (Miran et al., 2016b).

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Measurement of Voltage and Power Generation

The voltage generated by the MFC was measured across a variable resistor using a DT-830B digital multimeter. Power output was calculated using equation (1)

$$P = VI \quad (1)$$

Where P is power, V is the voltage, and I is the current generated.

The current, power, and voltage densities produced were calculated by dividing both parameters by the measured anode film area as shown in equations (2), (3), and (4) respectively (Logan et al., 2006).

The anode had a dimension of 35mm×45mm and an area of 1,575mm^2 (0.001575m^2).

$$\text{Current density} = \frac{I}{\text{anode surface area } (m^2)} \quad (2)$$

$$\text{Power density} = \frac{P}{\text{anode surface area } (m^2)} \quad (3)$$

$$\text{Voltage density} = \frac{V}{\text{anode surface area } (m^2)} \quad (4)$$

RESULTS AND DISCUSSION

The experimental data obtained from the microbial fuel cell (MFC) using plantain peel waste as the substrate was analyzed to determine the electrical output. The MFC's performance was monitored over a 13-day period, during which the current and voltage were measured and recorded, as shown in Table 1.

Table 1: Current and voltage generated from the MFC over 13 days.

Days	Current reading (m A)	Voltage (V)
1	0.903	0.420
2	1.360	0.473
3	1.575	0.478
4	1.525	0.474
5	1.545	0.416
6	1.552	0.436
7	1.603	0.508
8	1.560	0.474
9	1.731	0.444
10	1.823	0.456
11	1.310	0.418
12	0.010	0.341
13	0.030	0.470

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From these values, the current, voltage, and power densities were calculated using the anode surface area, revealing the performance of *S. cerevisiae* as the inoculum and kaolinite clay as the proton exchange membrane. The characteristics of the anode medium were measured and are shown in Table 2.

Table 2: Characteristics of anode medium in the MFC.

Parameter	Value
pH	7.0
TDS (ppm)	326
Conductivity (mS/m)	64.6
BOD (mg/L)	12

The conductivity of the medium was measured using a conductometer, and a value of 64.6 mS/m was recorded as the conductivity of the anode medium. In a study by (Najafgholi et al. 2015), they showed that an increase in conductivity caused an increase in the current and power density generated a conductivity of 44 mS/m^2 generated a current density of 319.08 mA/m^2 and a power density of 31.05 mW/m^2, with NaCl used to increase conductivity. In this study, the conductivity values were increased by the nutrient medium, which were mainly salts. The maximum values for current and power densities were 1157 mA/m^2 and 527.62m W/m^2.

The current density, power density, and voltage density were calculated using equations (2), (3), and (4) respectively. The graphs of these values were then plotted against time (days) as shown in Figures 2, 3, and 4 respectively. The results show a peak output on the tenth day, with a current density of 1157.46 mA/m^2, a power density of 527.62 W/m^2, and a voltage density of 289.5 V/m^2.

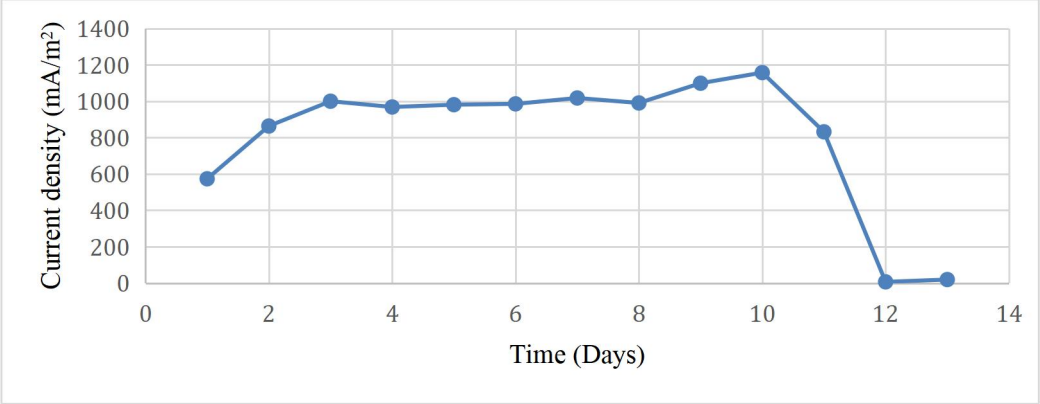

Figure 2: Graph of current density against time (days).

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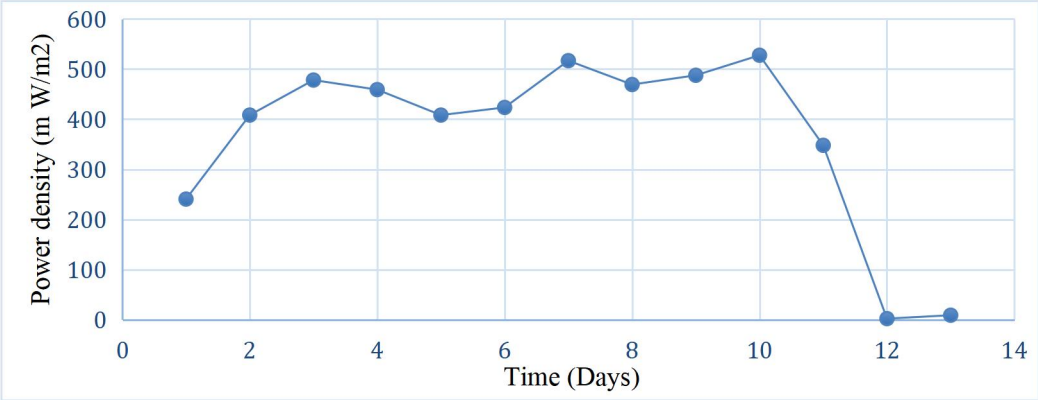

Figure 3: Graph of power density against time (days).

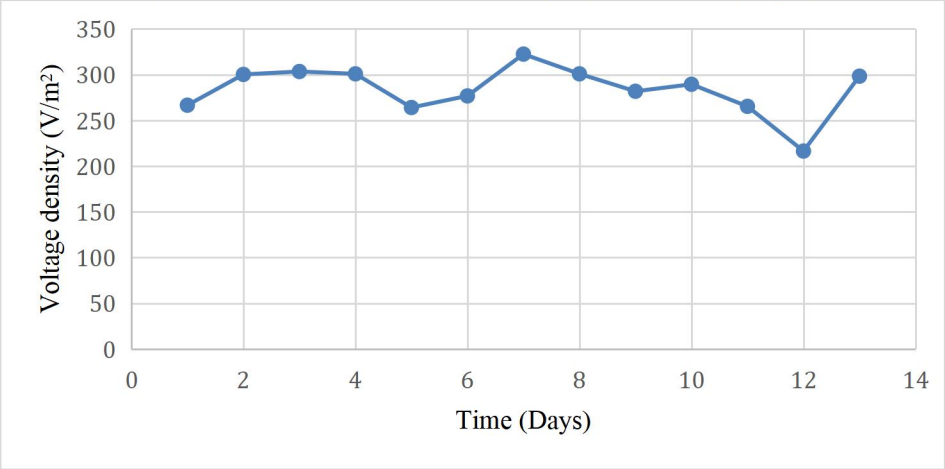

Figure 4: Graph of voltage density against time (days).

Effect of Inoculum

The formation of a stable bacterial community is crucial to the performance of the microbial fuel cell. *S. cerevisiae* showed power generation after hours of being introduced into the MFC. *S. cerevisiae* was able to form a biofilm around the anode and generate electricity without the use of chemical mediators. The formation of a biofilm required direct contact with the anode material, thus making the electron transfer mechanism of yeast a direct electron transfer whether by cell attachment or through nanowires. The results obtained also showed that yeast was capable of generating a substantial amount of electricity without the use of a chemical mediator. This was similar to the findings of Sayed & Abdelkareem (2017), who were able to generate a maximum power output of 3 mW/m^2 without using an external mediator.

Effect of Substrate

The viability of plantain peel waste as a suitable substrate for bioelectricity generation was tested using the microbial fuel cell. The results show a steady generation of electricity using the waste material. From a proximate analysis of plantain peel waste carried out by Igbokwe *et al*. (2016), PPW was reported to have a cellulose content of 46%. Elviliana et al. (2018) noted that a higher cellulose concentration limited the microorganism degradation of the waste in the cell thus reducing power generation. Pure compounds, which contain single organic molecules, are

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preferred for use in MFC due to ease of degradation, acetate a preferred compound used widely in MFC studies records a power density generation of 506 mW/m^2 from work carried out by Liu et al. (2004), complex materials may have to undergo chemical pretreatment before they can be suitable for use such as corn stover (Zhao et al., 2017) which must first undergo hydrolysis to produce simpler compounds. Plantain peel waste was suitable due to its moderately low cellulose content, it readily responded to bacterial decomposition as a current of 0.90 mA was recorded after a few hours of seeding the anode chamber with the ground plantain peel waste.

Proton Exchange Membrane

It was found that the proton exchange membrane performance was related to the extent of its proton conductivity, while the proton conductivity was also related to the extent of the humidity of the membrane. Nafion 117 membrane is a membrane that has gained wide use in the area of MFC studies, (Chae et al., 2008) using Nafion 117 was able to generate electricity for 50 days before biofouling of the membrane occurred. The high cost of Nafion membranes reduces the economic viability of microbial fuel cells. Work carried out by Rahimnejad et al. (2010) showed that the maximum voltage, current, and power density obtained using Nafion 117 and yeast as inoculum in a microbial fuel cell were 668 mV, 60.28 mA/m^2, and 9.95 mW/m^2. Although the clay-starch membrane had a shorter viability, its cost and fabrication were inexpensive compared to the Nafion membrane. From the experiment carried out, the starch-clay membrane recorded a maximum voltage, current density, and power density generation of 508 mV, 1157 mA/m^2, and 527.62m W/m^2 using yeast acting on plantain peel waste.

CONCLUSION

MFC technologies have the potential to assist the transition from fossil fuel-based technology to renewable energy dependence. Microorganisms that can achieve the oxidation of organic compounds and transfer produced electrons to electrodes offer the promise of self-sustaining systems that can convert bio-waste and renewable biomass to electricity. From the experiment, several factors that affect the generation of bioelectricity from an MFC, such as choice of substrate, PEM and choice of inoculum, were tested and evaluated extensively.

This experiment highlights the feasibility of constructing a low-cost MFC using locally available materials—plantain peel waste, yeast, and kaolinite clay. The successful generation of electricity with this setup underscores its potential for economic viability and scalability, especially for regions where these materials are abundant. This approach may contribute to sustainable energy solutions by providing a practical, affordable alternative for bioelectricity generation.

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