BIOELECTRICITY OF COCOA POD WASTE AS A SUBSTRATE IN A DOUBLE CHAMBER MICROBIAL FUEL CELL

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ABSTRACT

Currently, the utilization of cocoa pods has not been maximized, resulting in waste and foul odors that disturb the environment. However, cocoa pods contain a relatively high amount of cellulose compounds that serve as an energy source or nutrition for bacteria to carry out metabolic activities, thus holding the potential to be used as a substrate in microbial fuel cells (MFC). Based on this, the aim of this research is to investigate the bioelectricity generated by an MFC using cocoa pod waste as a substrate in order to determine the potential of cocoa pod waste as an electrical energy source. In this study, a double-chamber MFC consists of an anode chamber and a cathode chamber, which are separated by a salt bridge. Bioelectricity testing involved measuring the voltage, current, and power density produced by the MFC over several days. The results of measurements over 6 days indicate that the voltage, current, and power density generated by the MFC fluctuated, decreasing from the first day to the fifth day and increasing again on the sixth day. Additionally, the maximum voltage, current, and power density from the MFC were as follows: 36.0 mV, 0.19 mA, and 456 mW/m^2, respectively.

Keywords: *Bioelectricity, cocoa pod waste, microbial fuel cell*

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1. INTRODUCTION

Electricity in Indonesia is currently predominantly sourced from fossil fuels. The increasing use of fossil energy has led to a depletion of oil reserves and an increase in greenhouse gas emissions. This rise in greenhouse gases has had repercussions on climate instability, resulting in higher global temperatures and rising sea levels [1]. These conditions have also been accompanied by an increase in flooding and other environmental challenges. One solution to address these issues is transitioning from fossil energy to more environmentally friendly renewable energy sources.

One potential source of renewable energy for generating electricity is organic material. This organic material can be converted into electricity using Microbial Fuel Cell (MFC) technology. MFCs can convert the chemical energy stored in organic compounds into electrical energy through catalytic reactions facilitated by microorganisms [2]. Typically, an MFC system consists of an anode where anaerobic biocatalytic reactions occur and a cathode where aerobic biocatalytic reactions take place. On the anode, microbes or bacteria oxidize organic substrates, releasing electrons, which create a potential difference between the anode and cathode, resulting in an electrical current [3]. This process also produces protons that are transferred to the cathode through a salt bridge.

The type of substrate used in microbial fuel cells also influences the electrical energy generated. Organic compounds present in substrates such as glucose, cellulose, and hemicellulose serve as a source of nutrition for microbes to carry out metabolic activities, resulting in the production of electrical energy. MFC systems have the potential to generate electricity through the processing of organic waste as substrates, such as vegetable and fruit waste, offering a promising prospect for addressing energy crises and environmental pollution caused by waste [4]. Some of the vegetable and fruit waste materials that have been studied for MFC applications include orange peels, which achieve peak voltages of 4.6 V [5], avocado peels, which achieve peak voltages of 0.74 V [6], banana peels, which achieve peak voltages of 1.455 V [7], papaya peels which achieving peak voltages of 0.736 V [8], tomatoes which achieving peak voltages 3.43 V [9], potato waste [9], and corn cobs which achieving peak voltages 0.9059 V [10].

Cocoa (Theobroma cacao) is one of Indonesia's agricultural commodities that can be processed into chocolate products. The cocoa processing produces cocoa waste, primarily in the form of cocoa pods. In most cases, cocoa pod waste is left to decompose and is not fully utilized [11]. Allowing this waste to continue to decompose without proper handling can lead to environmental problems due to the unpleasant odor it produces. Apart from that, so far, cocoa pod waste has only been used as fertilizer [12]. However, cocoa pod waste contains high levels of organic compounds, such as 5.9% protein, 14.6% lignin, 6.1% pectin, 35% cellulose, and 11% hemicellulose [13]. This relatively high cellulose content can be used as an energy source for microorganisms or bacteria in their metabolic activities to generate electricity using microbial fuel cell (MFC) technology.

Based on the background information provided, the researcher proposes a study on the utilization of cocoa pod waste as substrate in anode chamber to generate electricity through MFC technology. This research aims to determine the bioelectricity generated by the Microbial Fuel Cell (MFC) using cocoa pod waste as a substrate, including voltage, current, and power density, in order to assess the potential of cocoa pod husk waste as an electrical energy source. The reactor used in this study is a Double Chamber Microbial Fuel Cell, which consists of two chambers, an anode chamber and a cathode chamber. Subsequently, measurements of the bioelectricity generated by the MFC, including current, voltage, and power, will be conducted.

2. RESEARCH METHOD

2.1 Research Flow Diagram

Figure 1 below shows the research flow diagram:

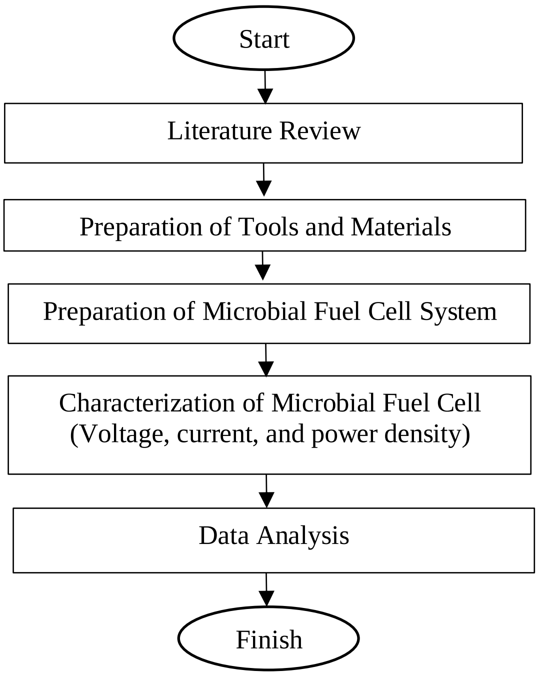

Figure 1 Research Flow Diagram

2.2 Tools and Materials

The main materials used in this research is cocoa pod waste as subtrat and Saccharomyces Cerevisiae bacterium as catalyst. Other tools and materials used include acrylic chamber as anode and chatode chamber, distilled water (H_2O), electrode (copper and zinc), cables, digital multimeter, analog multimeter, resistor (100 Ω), ammonium sulfate [$(NH_4)_2SO_4$], potassium dihydrogen phosphate [KH_2PO_4], and potassium chloride (KCl).

2.3 Construction Of Double Chamber Microbial Fuel Cells

The microbial fuel cell (MFC) created in this research employs a double-chamber system at a laboratory scale, consisting of two chambers: the anode chamber and the cathode chamber, as depicted in Figure 2. Each chamber is made of acrylic material and measures 11 cm x 11 cm x 17 cm. The anode chamber is filled with Saccharomyces cerevisiae bacteria and cocoa pod waste, while the cathode chamber is filled with permanganate ($KMnO_4$) as an electron mediator. Both of chambers are connected with salt bridge as proton exchange membrane which was placed inside a 12 cm long plastic tube. This MFC is also equipped with two electrodes; that is, copper (Cu) electrodes are used for the anode, while zinc (Zn) electrodes are used for the cathode. Each electrode has 4 cm x 3,75 cm size and an area of 15 cm^2. Both electrodes are connected with an external resistor of 100 Ω

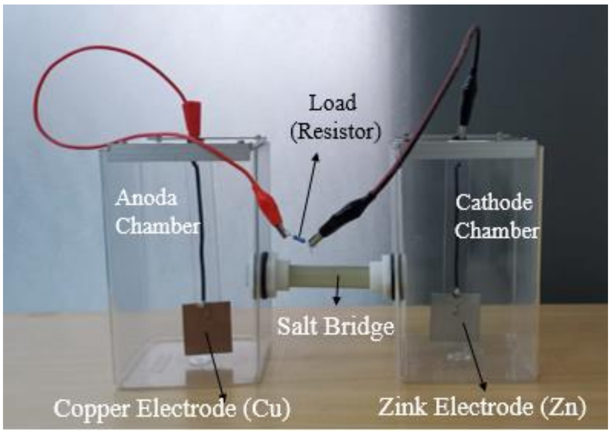

Figure 2 Double chamber microbial fuel cell (MFC)

2.4 Preparation Of Solution For The Anode Chamber

The microorganism most commonly utilized as a catalyst in the anode chamber microbial fuel cells is the Saccharomyces Cerevisiae bacterium, which belongs to the yeast genus. This is because the Saccharomyces Cerevisiae bacterium is more adaptable to various types of substrates, allowing for stable performance in microbial fuel cells. Some studies related to microbial fuel cells that employ Saccharomyces Cerevisiae bacteria include Utami et al., who used papaya peel as a substrate and achieved a maximum power density of 121.70 mW/m^2 [14], Yogaswara et al., who used POME waste as a substrate and achieved a maximum power density of 103.15 mW/m^2 [15], and Permana et al., who used glucose as a substrate and achieved a maximum power density of 2.12 mW/m^2 [16].

In this study, the crushed cocoa pod waste is soaked in water for 12 hours. Subsequently, 1000 ml of the soaked cocoa pod waste is mixed with 1 gram of Saccharomyces Cerevisiae, 1 g of peptone, 3 g of ammonium sulfate [$(NH_4)_2SO_4$], and 3 g of potassium dihydrogen phosphate [KH_2PO_4] which then placed into the anode chamber.

2.5 Proton Exchange Membrane Preparation

The Proton exchange membrane used in this research is a salt bridge. This salt bridge was made from 2 g of KCl plus 100 g of agar and 100 mL of H_2O, which was placed inside a 12 cm long plastic tube.

2.6 Preparation Of Solution For The Cathode Chamber

The solution for the cathode chamber in this research is made from 1000 ml of water and 31,6 g of $KMnO_4$.

2.7 Characterization of Microbial Fuel Cell

Bioelectricity testing is conducted by measuring the voltage, current, and power density generated by the microbial fuel cell during 6 (six) days. Voltage measurements are performed using a digital multimeter, meanwhile the current is measured with analog multimeter. This tool is then connected to resistance 100 Ω. Data collection is taken according to variations time. Data in the form of current strength and voltage processed into a power density value (mW/m^2), namely power per electrode surface area. Power density of microbial fuel cell is calculated using the following equation:

$$P = \frac{V \cdot I}{A} \tag{1}$$

Where:
P = power density (mW/m^2)
V = voltage (V)
I = current (mA)
A = electrode surface area (m^2)

3. RESULT AND DISCUSSION

3.1 Result of Bioelectricity Measurement

In this study, the electricity production of MFC from cocoa pod waste was observed by measuring the current and voltage generated by the MFC. The results of these current and voltage measurements were subsequently used to calculate the electrical power generated by the MFC. The design of the current and voltage measurements can be seen in Figure 3.

Figure 3 Voltage and Current Measurements in Cocoa Pod Waste MFC

The voltage measurement was conducted using a digital multimeter connected to both electrodes in the MFC reactor parallel. In measuring electrical voltage, the negative pole of the multimeter is connected to the anode of the MFC, while the positive pole of the multimeter is connected to the cathode of the MFC. The results of the current measurements generated by the MFC during 6 (six) days can be seen in Table 1 and Figure 4.

Table 1 Results of Voltage Measurements of Cocoa Pod Waste MFC

Time (Days)	Voltage (mV)
1	36.0
2	28.5
3	25.7
4	24.5
5	23.2
6	23.5

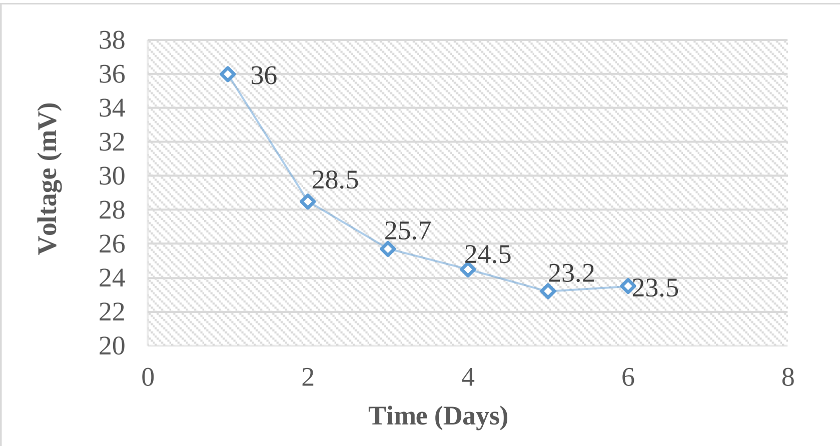

Figure 4 Graph of Voltage Measurement Results of MFC during 6 days

Figure 4 depicts the changes in electrical voltage over the course of 6 days of measurement. At the beginning of the observation, the multimeter immediately showed a voltage of 36 mV, but the electrical voltage decreased until the fifth day to 23.2 volts and increased to 23.5 volts in the sixth day.

Apart from measuring voltage, this research also carried out current measurements. Electrical current measurements of the cocoa pod waste MFC were conducted using an analog multimeter. The positive pole of the multimeter is connected to the MFC cathode, while the negative pole of the multimeter is connected to the resistor on the MFC.

Table 2 and Figure 5 show the changes in electrical current intensity obtained during 6 days of operation of the cocoa pod waste MFC reactor. At the beginning of the observation, the generated electrical current value was 0.19 mA. However, the the electrical current continued to decrease until fifth day to 0.75 mA and increased to 0.8 mA at sixth day.

Table 2 Results of Current Measurements of Cocoa Pod Waste MFC

Time (Days)	Current (mA)
1	0.19
2	0.14
3	0.10
4	0.09
5	0.75
6	0.80

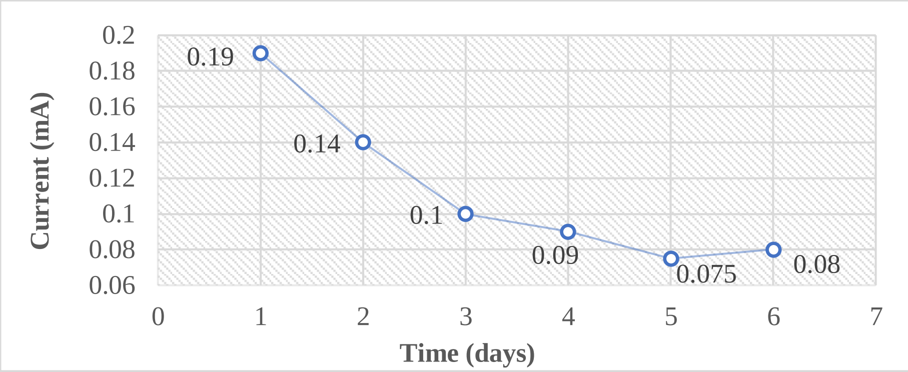

Figure 5 Graph of Current Measurement Results of MFC during 6 days

The results of electrical current and voltage measurements conducted were subsequently used to calculate the electrical power generated by the cocoa pod waste MFC. The calculated power output of the cocoa pod waste MFC in this study can be seen in Table 3 and Figure 6. Based on Figure 6, it can be observed that the maximum electrical power density generated by the cocoa pod waste MFC during 6 days of observation was 456 mW/m^2, occurring at first day. The electrical power continued to decrease in tandem with the decrease in voltage and electrical current values until the fifth day observation and increase at sixth day.

Table 3 Results of Electrical Power Measurements of Cocoa Pod Waste MFC

Time (Days)	Voltage (V)	Current (mA)	Power Density (mW/m^2)
1	36.0 x 10^{-3}	0.19	456
2	28.5 x 10^{-3}	0.14	266
3	25.7 x 10^{-3}	0.10	257
4	24.5 x 10^{-3}	0.09	221
5	23.2 x 10^{-3}	0.75	174
6	23.5 x 10^{-3}	0.80	188

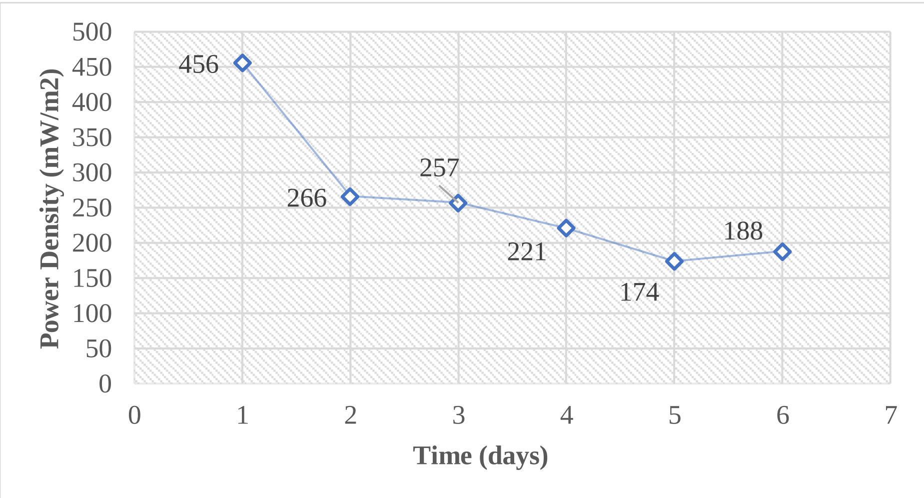

Figure 6 Graph of Electrical Power Density Measurements of MFC during 6 Days

3.2 Discussion

In this study, the anode chamber of MFC was maintained in anaerobic conditions by sealing it with acrylic glass. Microorganisms derived from the decomposition of cocoa pod waste and yeast would oxidize the papaya waste substrate in the anode chamber to produce electrons and protons, along with carbon dioxide as the oxidation product. Electrons would be bound to the anode (negative electrode), flowing to the cathode (positive electrode) through an external circuit, while protons would migrate through the salt bridge, and in the cathode chamber, they would combine with electrons to form water, with the oxygen source being provided by $KMnO_4$. As the substrate oxidizes in the anaerobic conditions of the anode chamber to produce electrons, the potential decreases. At the same time, the potential in the cathode chamber increases during the reduction of the reagent. The difference in potential caused by substrate oxidation at the anode and reduction at the cathode results in electrical current. The reaction equation occurring at the anode is given below:

$$C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24e^- + 24H^+ \quad (2)$$

On the cathode, there is KMnO4 which serves as an electron acceptor originating from the anode. The reaction occurring at the cathode, using KMnO4 as the cathodic agent in an acidic environment, is given below:

$$MnO_4^- + 4H^+ + 3e \rightarrow MnO_2 + 2H_2O \quad (3)$$

Based on the measurements conducted during 6 days, there is a noticeable decrease in voltage, current, and power density from first day until fifth day. According to Utami, the decrease in voltage, current, and power density values is mainly due to the microorganisms are in the lag phase or adaptation phase, where in this phase the microorganisms are adjusting to the new environment. In the initial processing process, the energy produced from the metabolism of organic materials is mostly used to form biofilms[3]. At the sixth day, both voltage, current, and power density are increased. This phenomenon might be due to the formation of an electrochemically active biofilm on the anode surfaces [5].

4. CONCLUSION

Based on the conducted research, the following conclusions are obtained:

a. Cocoa waste, as a source of renewable energy, has the potential to be an electricity generator using Microbial Fuel Cell (MFC) technology.
b. The measured values of maximum voltage, maximum current produced, and maximum power (at the first day) from the reactor are obtained in the following order: 36.0 mV, 0.19 mA, and 456 mW/m^2, respectively.
c. Over the course of 6 days of observation, there is a decrease in the voltage, current, and power density produced by the cocoa pod waste MFC from first day until fifth day because the microorganisms are in the lag phase or adaptation phase. At the sixth day, both voltage, current, and power density are increased due to the formation of an electrochemically active biofilm on the anode surfaces.

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