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The Effect of Nutrients in Anodic Chamber to the Performance of Microbial Fuel Cell (MFC)

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ABSTRACT

This paper describes a device known as a Single-chamber Microbial Fuel Cell (SMFC) that was used to generate bioelectricity from plant waste containing lignocellulosic components, such as bamboo leaves, rice husk and coconut waste, with various anodic chamber substrate compositions. The maximum power density among all assembled SMFCs was determined to be 231.18 μW/m^2, generated by coconut waste. This model's bioelectricity production was enhanced by adding organic compost to the anodic chamber, which acts as a catalyst in the system. The maximum power density of 788.58 μW/m^2 was attained using a high proportion of coconut waste (CW) and organic compost. These results show that the higher percentage of lignin in CW improved the bioelectricity of SMFC.

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INTRODUCTION

In 2050, the global population is projected to increase by 2 billion, from 7.7 billion to 9.7 billion (United Nations, 2019). Population growth will increase the energy demand, leading to the depletion of energy resources

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such as fossil fuels. Fossil fuels, made up of decomposing plants and animals buried by layers of rocks from over a million years ago, are a non-renewable energy resource consisting of coal, oil and natural gas (Energy.Gov, 2017; National Geographic Society, 2019). Eventually, these non-renewable energy sources will be depleted due to the continued use of fossil fuels to generate electricity. In addition to being non-renewable, fossil fuels contribute to global warming by emitting large amounts of CO_2 into the atmosphere due to the carbon emission's ability to retain heat (Denchak, 2022). It was estimated that over 8 million people worldwide die every year due to inhaling polluted air from burning fossil fuels containing particles such as greenhouse gases (Kottasová & Dewan, 2021). That is why finding a renewable energy source to produce electricity for all consumers is essential. Numerous renewable energy sources have been developed, including discovering Microbial Fuel Cell (MFC) to meet the ever-increasing energy demand. MFC is an environmentally friendly device with minimal carbon emissions. MFC can generate electricity from organic residues, such as food or water waste, as it converts biodegradable substances into simpler substances to generate bioelectricity (Koch et al., 2016; Ucar et al., 2017).

According to a study done in 2020, MFC, however, cannot support bioelectricity for a large population due to its low power density (Khoo et al., 2020), and a few factors influence the operation of MFC. The type of substrate and its concentration in the anodic chamber were identified as the factors that influenced the voltage production of MFC (Aghababaie et al., 2015; Kumar et al., 2017). In addition, solid organic waste has gained significant interest as MFC substrates due to its high organic matter content, a crucial component for these systems (Kumar et al., 2022). Previous research found that solid fruit waste generates more electricity than solid food waste (Moqsud, 2021). This finding suggests that plant waste has the potential to function as an MFC substrate for bioelectricity production.

Due to the higher concentration of lignocellulosic, which functions as bacteria's food source, plant wastes have the potential to be utilised as MFC substrates. Certain microorganisms, when fed lignocellulosic materials, can convert the complex polysaccharides (cellulose and hemicellulose) present in lignocellulosic materials into simpler carbohydrates that can be used for energy production (Chandra & Madakka, 2019). To the best of our knowledge, researchers are still investigating the optimal composition of plant waste for producing MFCs with a higher voltage. Therefore, this research employed lignocellulosic materials with various compositions as a substrate for a single-chamber MFC (SMFC).

METHODOLOGY

Construction of a Single-chamber Microbial Fuel Cell (SMFC) Without Adding Organic Compost

This study used a single-chamber MFC to generate electrical energy from electrons derived by bacteria in the anodic chamber.

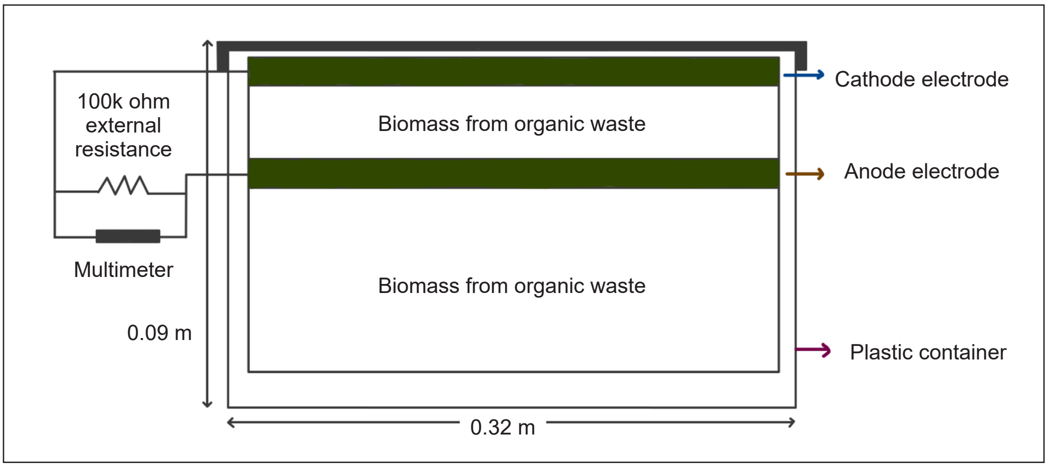

Figure 1. The schematic design of SMFC

This study uses an SMFC because of its affordability and effectiveness. Compared to a double-chamber MFC, an SMFC generates less internal resistance due to the shorter distance between its two electrodes (Flimban et al., 2019; Nawaz et al., 2022). In terms of design, it is easy to construct without any unnecessary hassle, which is excellent for research (Kumar et al., 2017).

Figure 2. Measuring voltage and current generated by the SMFC using a multimeter

The 5.03×10^{-3} m^2 of anode and cathode electrodes used in this study were constructed from granulated active carbon from coconut shells that were attached using epoxy to a circular shape stainless-steel mesh (0.24 mm stainless-steel grade 304) with a 4 cm radius. A previous study stated that an activated carbon electrode is biocompatible, less toxic and has a rough surface that can enhance the attachment of bacteria as well as generate greater bioelectricity (Sahari et al., 2022; Zhang et al., 2014).

Figure 1 shows the experimental setup of the SMFC, which is constructed by layering a mixture sample of 50 g plant waste (bamboo leaves, rice husk or coconut waste) that has been finely ground with 300 g water. The wires from both terminals of the electrodes are then connected to an external 100 kΩ resistor to ensure that the SMFC operates in a closed circuit. The details of the anodic chamber substrates are presented in Table 1. Figure 2 demonstrates the measuring of generated voltage and current by the single-chamber MFC prototype using a multimeter while connecting to an external 100 kΩ resistor, which indicates that this is conducted in a closed-circuited manner.

Construction of a Single-chamber Microbial Fuel Cell (SMFC) by Adding Organic Compost

To gain a more thorough understanding of the effect of nutrients on SMFC efficiency, plant nursery-purchased organic compost was added to the SMFC substrate containing plant waste. Organic compost and plant waste weights varied from 20 to 30 g, while the water weight was fixed at 300 g per SMFC. In total, nine distinct SMFC prototypes were assembled.

Table 1
Summary of organic substrates used for the SMFCs

SMFC No.	Organic substrates used in anodic chamber
1	50 g BL + 300 g water
2	50 g RH + 300 g water
3	50 g CW + 300 g water
4	20 g BL + 30 g OC + 300 g water
5	20 g RH + 30 g OC + 300 g water
6	20 g CW + 30 g OC + 300 g water
7	30 g BL + 20 g OC + 300 g water
8	30 g RH + 20 g OC + 300 g water
9	30 g CW + 20 g OC + 300 g water

Note. BL: bamboo leaves, RH: rice husk, CW: coconut waste, OC: organic compost

Electricity Generating Parameter

Each SMFC prototype's power density was compared to assess the SMFC's efficiency. The magnitude of the power density was determined by normalising the system's current to the electrodes' surface area. The model system's current flow was directly measured using a digital multimeter. The formula used to calculate the electrical parameters of the SMFC is depicted in Equation 1 (Ullah & Zeshan, 2020).

$$\text{Power Density } (\mu W/m^2) = V^2/(R \times A) \quad [1]$$

where, A is the surface area of the electrodes (m^2), V is the voltage generated (V), and R is the external resistance (Ω) connected to the system.

The SMFCs were observed four times per day for seven consecutive days to provide further explanation. At precisely 0600, 1200, 1800 and 2400 each day, the voltage and current produced by each SMFC were measured with a multimeter and logged. As previously mentioned, the power density of each SMFC is calculated using Equation 1.

RESULTS AND DISCUSSION

Comparison of Different Contents of Lignocellulosic Component of Plant Waste in Anodic Chamber

A study evaluated the power density generation of an SMFC from different plant wastes containing different lignocellulosic component compositions. Table 2 shows the percentage of each component of lignocellulosic, which consists of lignin, cellulose and hemicellulose, in each plant waste.

Table 2 shows that coconut waste (CW) contained the greatest percentage of lignin, whereas bamboo leaves contained the highest percentage of cellulose. These observations are related to the power density output of the SMFC with various anodic substrates, as

Table 2
Lignocellulosic component of plant waste

Plant waste	Lignocellulosic component			Reference
	% Cellulose	% Hemicellulose	% Lignin	
Rice husk	35–40	15–20	20–25	Gao et al., 2018
Coconut waste	20–30	15–30	50	Anuchi et al., 2022
Bamboo leaves	47.2	23.9	23.8	Bai et al., 2013

depicted in Figure 3. Figure 3 demonstrates that an SMFC containing coconut waste as the anodic chamber substrate produced the highest maximum power density, while an anodic chamber containing bamboo leaves produced the lowest. The power density of 50 g of coconut waste was 50% higher than that of an SMFC-containing rice husk. As discussed in a previous study, the increased power density may be attributable to lignin's ability to decrease internal resistance (Sakdaronnarong et al., 2015). This argument was founded on a previous study in which the presence of humic acid in the MFC chamber decreased internal resistance and increased power density. Due to their similar structures, it is believed that lignin has the same effect on the internal resistance of MFC as humic acid (Huang & Angelidaki, 2008). The fact that the highest power density was associated with the highest proportion of lignin proves that lignin is responsible for the highest power density. The lowest power density from an SMFC contained the highest percentage of cellulose, possibly due to its complex structure that is difficult for microorganisms to degrade, whereby special enzymes are required to convert it into simpler compounds that can be used as a fuel source (Boisset et al., 2000).

As stated previously in the methodology, SMFC data was collected four times daily at 0600, 1200, 1800 and 2400 (Figure 4). The highest power density was observed at

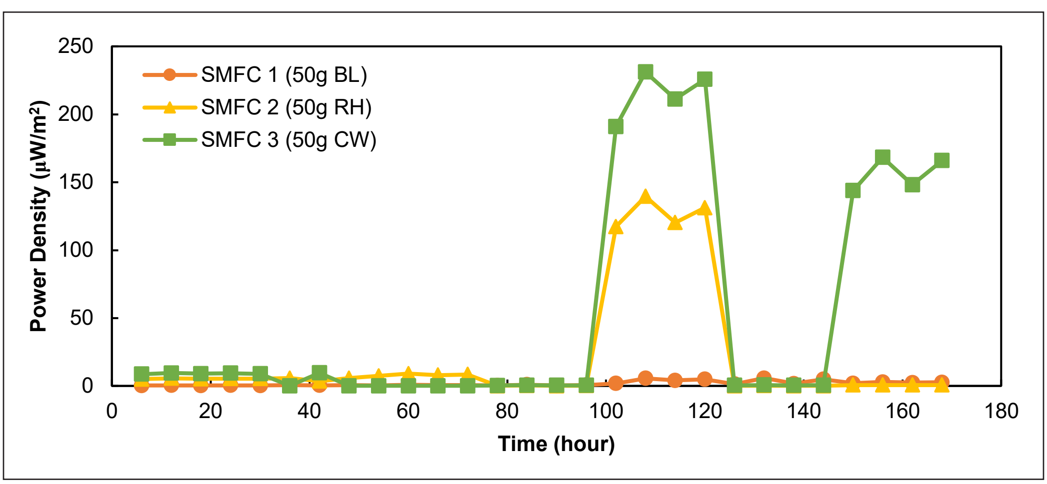

Figure 3. Power density of SMFC with different types of anodic substrate

1200 hours for SMFCs 1, 2 and 3 because the microorganisms or bacteria are actively operating currently, causing the biochemical reactions they promote to produce more electrons (Koch et al., 2016). To fully understand this phenomenon, it is necessary to investigate the effect of the surrounding temperature on the power density of SMFCs, which was not measured in this study.

Figure 5 illustrates the power density produced by various anodic substrates—clearly, all SMFCs containing CW as a substrate generated a higher power density than the others. When the volume of plant

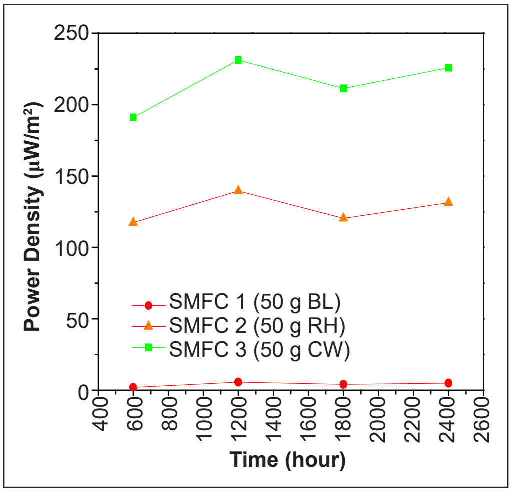

Figure 4. The generation of power density of SMFC with different time

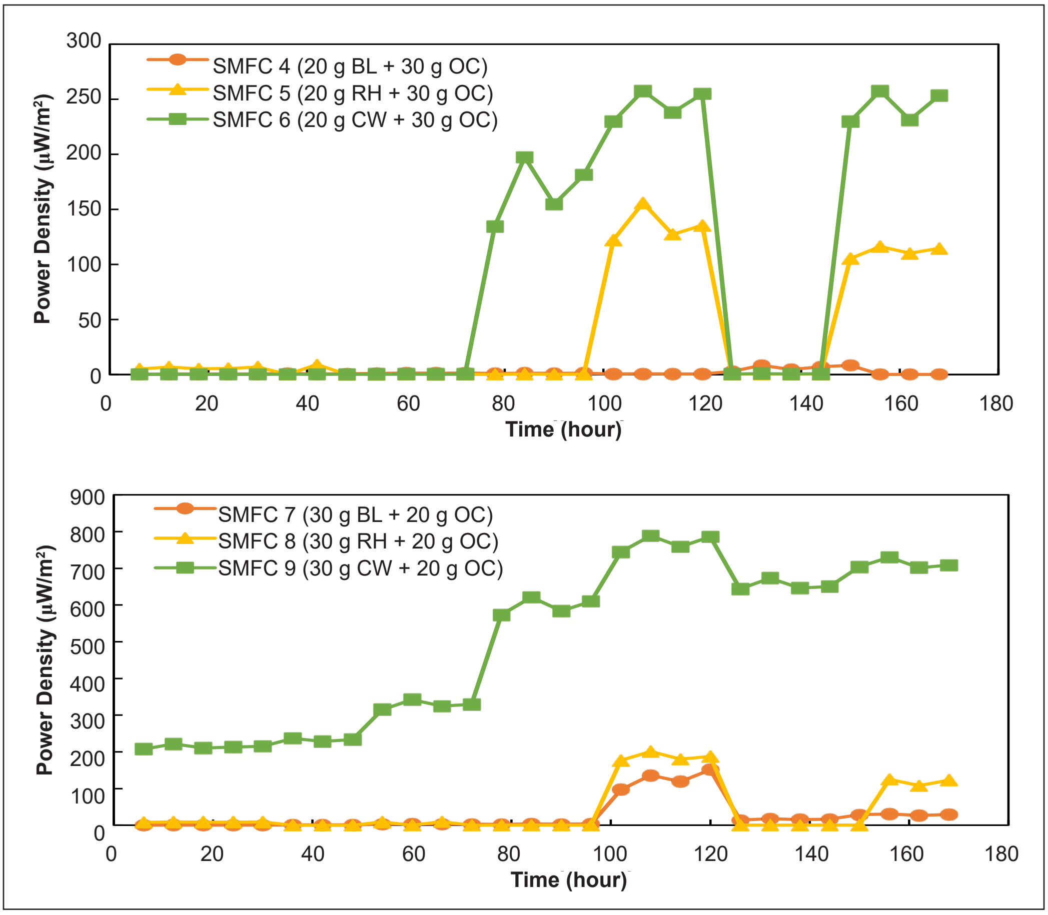

Figure 5. Different compositions of anodic substrates

waste and organic compost was increased, we discovered that the power density of all SMFCs increased by more than 100%. These results indicate that the substrate volume substantially affects the power generation of SMFCs, which is in good agreement with a previous report (Ullah & Zeshan, 2020).

We have plotted graphs summarising our findings to investigate the effect of plant waste and organic compost on the efficacy of SMFC. Figure 6 illustrates only the power generation of SMFCs containing CW, which produced the highest power density compared to the others. The SMFC with the highest power density was the one that contained more CW and less organic compost. In the SMFC, organic compost acted as a catalyst to encourage bacterial growth. The higher power density observed in the SMFC containing more CW and less organic compost may be attributable to sufficient food (CW) for the microbes in the organic compost. In contrast, the SMFC containing less CW and more organic compost revealed that the microbes had little food to sustain their lives and produce bioelectricity (Rahman et al., 2021). Table 3 summarises the findings for all SMFCs in this study.

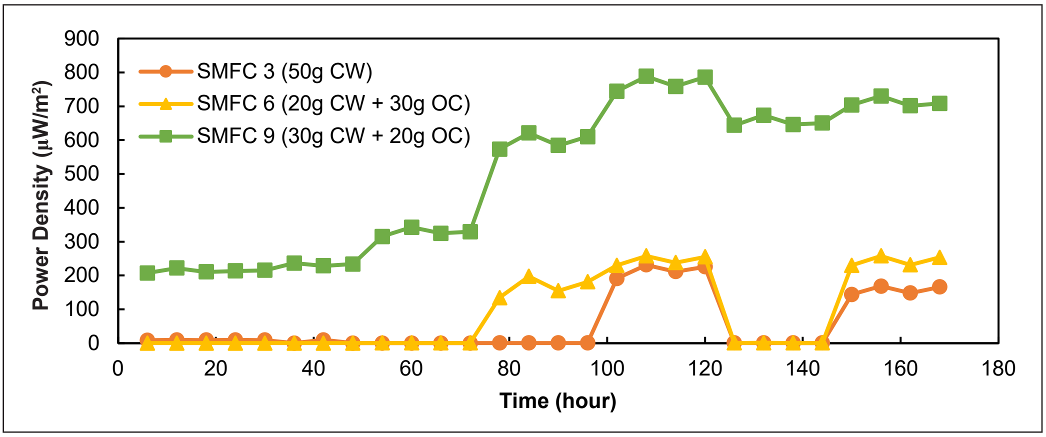

Figure 6. Different concentrations of catalyst (organic compost) to the performance of SMFC

Table 3
Summary of the power density generation for all SMFCs

SMFC No.	Types of Anodic Chamber Substrates	Maximum Power Density (µW/m²)
1	50 g BL + 300 g water	5.84
2	50 g RH + 300 g water	139.61
3	50 g CW + 300 g water	231.18
4	20 g BL + 30 g OC + 300 g water	8.45
5	20 g RH + 30 g OC + 300 g water	155.87
6	20 g CW + 30 g OC + 300 g water	257.65
7	30 g BL + 20 g OC + 300 g water	151.44
8	30 g RH + 20 g OC + 300 g water	201.04
9	30 g CW + 20 g OC + 300 g water	788.58

COMPARISON OF PREVIOUS STUDIES

Table 4 shows a summary of recent studies on MFCs with regard to anodic chamber substrates. Our findings imply that coconut waste has the potential to be used as a substrate in MFC systems that generate bioelectricity. However, the amount of power density was very small, and optimisation of parameters such as the size of electrodes, size of chamber, and configuration of chambers for the MFC system should be reconsidered.

Table 4
Recent literature on MFC with respect to various anodic chamber substrates

Types of MFC	Substrates in		Power Density (W/m^2)	Reference
	Anode Chamber	Cathode Chamber		
Single-chamber	Molasses solution	-	0.545 m	Flores et al., 2022
Dual-chamber	Wastewater with glucose	Wastewater	253.84 m	Ye et al., 2019
Dual-chamber	Rice straw with CDB	Nutrient mineral buffer	145.2 m	Hassan et al., 2014
Single-chamber	Kitchen garbage Bamboo waste	-	60 m 40 m	Moqsud et al., 2014
Terrestrial	Soil	Rocks	3 m	Zhang et al., 2013
Single-chamber	Agricultural soil Forest soil	-	42.49 m 2.44 m	Dunaj et al., 2012
Single-chamber	Coconut waste Bamboo waste Rice husk	-	788.58 μ 151.44 μ 201.04 μ	This study

CONCLUSION

We examined the impact of various plant waste types and their quantities on the efficacy of MFCs. Due to its reduced internal resistance, coconut waste that contained the highest proportion of lignin had a greater power density. In contrast, the lower power density observed in SMFCs containing bamboo waste was attributed to its higher percentage of cellulose, whose complex structure requires special enzymes for degradation, making it inappropriate for microorganism digestion. Sufficient food is essential for microorganisms to survive and produce bioelectricity. Careful selection of substrate types, catalysts, and their composition is necessary to enhance the performance of MFCs.

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