AgroSainTa: Widyaiswara Mandiri Membangun Bangsa, Juli 2026
ISSN: 2579-7417
EISSN: 2774-4922

Vol. 10 (1): 29-36
https://epublikasi.pertanian.go.id/berkala/ags
DOI: https://doi.org/10.51589/2d5wyf57

Valorization of Persimmon Waste for Sustainable Bioelectricity Production in a Soil-Mediated Single-Chamber Microbial Fuel Cell

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INFO ARTIKEL

ABSTRACT / ABSTRAK

Sejarah Artikel

Diterima:

11 Januari 2026

Direvisi:

3 Maret 2026

Terbit:

1 Juli 2026

The global electricity shortage continues to drive the demand for sustainable and renewable energy technologies. Among emerging renewable technologies, Microbial Fuel Cells (MFCs) have attracted considerable attention because they generate electricity from organic waste through the metabolic activity of bioelectrogenic microorganisms. In this study, persimmon fruit waste was evaluated as a substrate in a soil-based, single-chamber MFC to produce clean electricity while supporting Sustainable Development Goal (SDG) 7. Japan is one of the world's leading persimmon producers and generates substantial amounts of organic waste, particularly fruit peels, during harvesting and post-harvest processing. Similar waste management challenges are encountered in many other producing regions. Rather than treating this biomass as waste, the study explores its potential as a renewable energy resource. A mixture of soil and persimmon waste was tested over 45 days under different external resistance conditions. The results showed that substrate composition strongly influenced the electrical performance of the MFC. The highest output voltage (127.2 mV) was recorded from the reactor containing a 25:75 mixture of persimmon waste and soil, whereas the reactor containing a 40:60 mixture of persimmon waste and leaf humus produced a maximum voltage of 98.3 mV. These showings indicate that persimmon waste can serve as an effective substrate for microbial fuel cells, providing a practical way to convert organic waste into clean electricity. The results highlight the potential of this system as a simple and environmentally friendly approach to sustainable waste management and renewable energy production.

Keywords: *Bioelectricity, Environmental sustainability, Microbial Fuel Cell, Persimmon wastes, Renewable energy, Soil*

1. Introduction

1.1. World energy

Have Access to reliable electricity continues to be unevenly distributed worldwide. The World Bank's *Tracking SDG* 7 report indicates that approximately 666 million people, or nearly 8% of the global population, lacked basic electricity access in 2023, and current progress suggests that universal access by 2030 will not be achieved. Adequate energy supply is essential for modern societal functions, while waste management and recycling have simultaneously emerged as significant environmental priorities due to limited disposal capacity and the need to reduce environmental impacts. In many developing regions, electricity shortages still restrict socio-economic activities. Available generation capacity often meets only part of the demand, leading to recurrent shortages and scheduled outages, particularly during nighttime (Moqsud et al., 2014).

Biomass has long been considered a readily available and renewable carbon source suitable for microbial fuel cell (MFC) systems, especially for electricity production (Moqsud et al., 2013). For this reason, MFC technology has been explored as an alternative approach for organic waste treatment, particularly in areas lacking advanced infrastructure, where waste stabilization and energy recovery can occur simultaneously (Moqsud et al., 2014). Nevertheless, practical reactor designs using inexpensive and easily obtainable materials have not been extensively investigated (Logan, 2008). Recent developments in environmentally oriented technologies have also expanded the variety of organic wastes and renewable biomass that can serve as substrates for electricity generation and for the formation of value-added products (Cristiani et al., 2013).

Microbial fuel cells convert biodegradable substrates into electrical energy through microbial metabolic processes (Kan et al., 2011; Walter et al., 2015). Numerous investigations have reported electricity production from organic wastes and wastewater using MFC systems (Moqsud et al., 2010; Lu et al., 2009; Venkata Mohan et al., 2008; Prasad et al., 2006; Feng et al., 2013; Sevda et al., 2013; Chakhtoura et al., 2014). Related bioelectrochemical systems have also been applied to hydrogen generation (Call et al., 2009). However, many conventional substrates remain economically impractical. Because of its carbon-neutral nature, biomass is increasingly considered a promising resource for sustainable electricity production in response to growing energy demand (Mao et al., 2015). In contrast, the use of persimmon waste as a biomass substrate in MFC electricity generation has received little attention so far.

1.2. Sustainable management of organic waste to reduce environmental impacts

The utilization of fruit waste has received increasing attention in the development of renewable energy systems as a means of addressing rising energy demand. According to FAOSTAT, global fruit and vegetable production reached approximately 2.1 billion tones in 2023, representing an increase of about 1% compared with 2022 (FAO, 2024). In Japan, persimmon production constitutes a significant portion of this output. Although frequently discarded, persimmon residues contain readily biodegradable organic compounds, including simple sugars such as glucose, which can function as substrates for microorganisms in microbial fuel cell (MFC) systems. Global persimmon production remains considerable, with total output reported at approximately 4.332 million tones in 2021, including about 0.1879 million tones produced in Japan. In the absence of proper management, these residues may contribute to environmental impacts. Figures 1a and 1b present the relatively high production levels of persimmons.

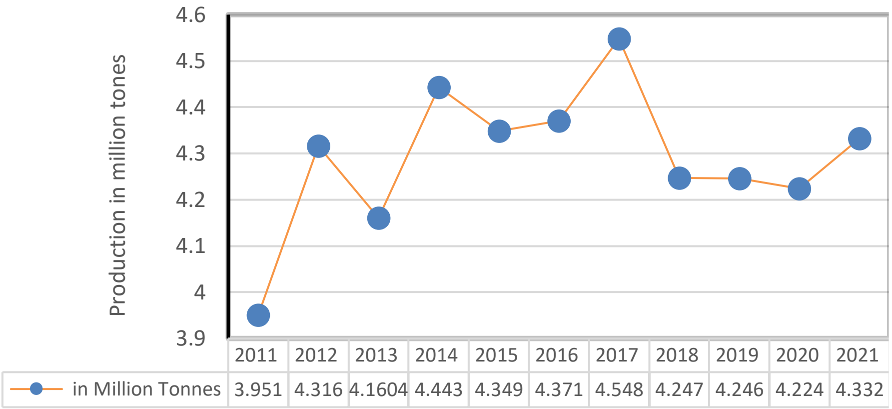

Figure 1a. Global Persimmon Production

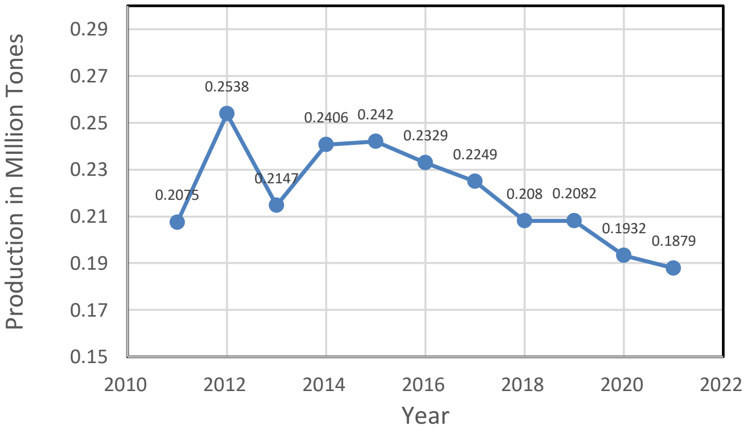

Figure 1b. Production of persimmons in Japan

Analyses of municipal solid waste composition in many developing regions indicate that organic materials constitute more than 80% of total waste; however, their potential for recycling and resource recovery remains largely underutilized. In Japan, the Ministry of the Environment (MOE) reports substantial annual generation of food waste. Recent data for FY2023 indicate approximately 4.64 million tones of Food Loss & Waste (FLW), distributed almost equally between households (2.33 million tones) and commercial activities (2.31 million tones)

(MOE Japan, 2025). A considerable portion of this waste is co-incinerated with other combustible materials, and the residual ash is subsequently disposed of in landfills. Owing to its high moisture content, the incineration process requires significant energy input. Alternative management strategies emphasizing material utilization, reuse, and recycling are therefore being investigated. Organic wastes contain abundant nutrients and minerals and can serve as suitable feedstock for resource recovery. Advances in environmentally oriented technologies have expanded the types of organic waste and renewable biomass applicable as substrates for electricity generation and the production of value-added products (Cristiani et al., 2013). In this study, a mixture of soil and persimmon fruit waste was evaluated within a microbial fuel cell (MFC) system as a waste management approach enabling simultaneous treatment and electricity generation.

1.3. Objectives

This study aims to evaluate the feasibility of using discarded persimmon fruit waste mixing with soil as a substrate in a microbial fuel cell (MFC) for concurrent organic waste treatment and electricity generation. The work investigates a soil–persimmon mixture as a naturally inoculated, low-cost medium and quantifies reactor performance through electrochemical parameters, including maximum power density and current density. By focusing on untreated persimmon waste, a fruit residue rarely examined in MFC studies, the research addresses the limited assessment of heterogeneous agricultural substrates and their applicability to localized energy recovery systems (Moqsud et al., 2014; Waheed M. et al., 2016).

2. Experimental Materials and Methods

2.1. Sample Handling

The Persimmon residues were obtained from the local Japan Agricultural Office. The collected material was mechanically crushed and stored at −15 °C prior to use as a substrate in microbial fuel cell (MFC) experiments. The persimmon (Diospyros kaki L.), commonly known as *kaki* or oriental persimmon, is widely cultivated in Japan. Non-edible portions of the fruit, including spoiled tissues and peels, were considered processing residues and used as the organic feedstock in this study.

Although persimmon is widely cultivated in Japan, its market value has declined in recent years, resulting in substantial quantities of unused fruit during harvest and postharvest handling. Processing activities generate considerable residues, particularly peels, which account for roughly 10% of the total fruit mass and may create disposal concerns if not properly managed. Similar to many fruit crops, persimmon tissues are rich in organic nutrients, including soluble carbohydrates, vitamins, and minerals. The fruit can be consumed fresh or processed into various food products; however, non-edible or surplus portions remain underutilized. The sweetness of persimmon is largely associated with soluble sugars. Sucrose present in the tissue can be hydrolyzed into glucose and fructose through enzymatic or mild acidic reactions (Mikael Sjölin et al., 2024). These readily biodegradable sugars can serve as carbon sources for microbial metabolism and are therefore suitable substrates for electricity production in microbial fuel cell systems. Table 1 shows the nutritional values of organic wastes and soil used in this research.

Table 1. Nutritional Values of Organic Waste and Soil.

Parameter	SOIL	COW DUNG	CHICKEN DROPPING	LEAF MOLD
N (mg/kg)	5.1	2.04	1.72	4.3
P (mg/kg)	10.3	0.76	1.82	3.6
K (mg/kg)	124.2	0.82	2.18	5.0
EC (mS/cm)	0.395	18.7	19.74	1.5
C/N ratio	6.72	19.9	9.65	10.2

2.2. Design of the Single-chamber Microbial Fuel Cell (MFC)

Microbial fuel cells (MFCs) typically operate with an anaerobic anode compartment and an air-exposed cathode, separated in many configurations by an ion-conducting membrane (Moqsud et al., 2013). Through the metabolic activity of electro active microorganisms, organic substrates are oxidized and the released electrons are transferred to an external circuit, allowing simultaneous waste treatment and electricity generation. Such systems have been investigated for a variety of waste streams and can supply low-power electrical output suitable for small electronic devices.

In the present work, a single-chamber MFC configuration using persimmon waste was constructed (Fig. 1). The reactor consisted of a rectangular acrylic vessel (10 × 10 × 15 cm). Crushed persimmon residues were mixed with soil, approximately 100 g of water, and 4 g of a commercial effective microorganism inoculums (EM Kenkyusho, Shizuoka, Japan) to initiate microbial activity and minimize odor formation. The homogenized mixture was introduced into the reactor, where the anode was embedded within the biomass matrix and the cathode was positioned at the surface. Both electrodes were connected to a data logger (Midi Logger GL200, Graphtec, Tokyo, Japan).

During operation, microbial oxidation of the substrate produced electrons and protons at the anode. Electrons were transferred through the external circuit to the cathode where reduction reactions occurred. The external resistance was maintained at 100 Ω, selected from polarization measurements and open-circuit voltage comparisons. Voltage and temperature were recorded at 20-min intervals throughout the experiment. To allow consistent comparison between days, one measurement taken at 13:00 each day was used for data evaluation. All experiments were conducted at a controlled laboratory temperature of 25 °C, within the mesophilic range suitable for microbial activity (approximately 0–40 °C) (Microbiology, 2012).

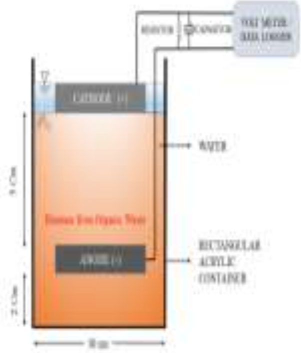

Figure 1. Microbial Fuel Cell (MFC) schematic diagram

The electrical response of the cell was measured as voltage (V) over time. Current (I, A) was calculated using Ohm's law:

$$I = V / R \qquad (1)$$

where V is the measured cell potential (V) and R is the external resistance (Ω). Electrical power (P, W) was determined by:

$$P = I \times V \qquad (2)$$

Current was obtained from the potential drop across the external resistor using a computer-assisted logging multimeter. Polarization behavior was examined by varying the external resistance from 1 Ω to 1 kΩ after the reactor reached a stable condition. Internal resistance was estimated from the slope of the linear region of the voltage–current relationship. Maximum power output and the corresponding current density were obtained from the power density profile. Power density and current density were calculated as:

$$Power\ density = V^2/R \qquad (3)$$

$$Current\ density = V/R \qquad (4)$$

where I (mA) is the generated current, V (mV) is the measured potential, R (Ω) is the applied resistance, and α represents the projected anode surface area (100 cm^2). All electrochemical parameters were normalized to the anode surface area.

For statistical evaluation, three identical reactors were operated independently. The daily values of voltage, current density, and power density were summarized using the mean (average) and standard deviation, allowing the stability of electricity production to be assessed. Changes in electrical output over operational time were examined by comparing daily averages. The relationship between temperature and voltage was examined using a simple linear correlation coefficient. A difference was considered meaningful when variation between reactors was smaller than the change observed over time.

The methodological contribution of this study is the application of a time-standardized daily measurement combined with basic statistical comparison to evaluate the stability of a soil–persimmon microbial fuel cell. Previous MFC studies have primarily focused on controlled substrates, whereas statistical characterization of heterogeneous fruit-waste systems remains limited. This approach provides a practical evaluation method for low-cost bioelectrochemical reactors using agricultural residues.

3. Observations and Analytical Discussion

Figure 2 presents the temporal profile of voltage generation in the MFC systems supplied with persimmon waste (PW) combined with different supporting media, namely soil (S), leaf mold (LM), and rice bran (RB) for all replicate sets. Overall, electrical output rose progressively as operation time advanced, with maximum values generally occurring between day 2 and day 9. For the reactors containing persimmon waste–soil (PWS) and persimmon waste–leaf mold (PWLM), a pronounced increase in voltage was observed during the early operational stage (approximately the first four days). After this initial phase, the increase became more gradual and the voltage reached its peak around the eighth day.

At the beginning of operation, the microbial community encountered a readily available substrate, which stimulated rapid metabolic activity and consequently accelerated electron production. The combined systems using persimmon waste with leaf mold (PWLM) and soil (PWS) exhibited more stable electrical output than reactors containing individual microbial sources. This improved stability is likely associated with interspecies interactions, where metabolites or redox mediators produced by one microbial group facilitate electron transfer to the electrode for another (Rakesh et al., 2014). As a result, voltage increased markedly during the early period. Over prolonged operation, however, the electrical output gradually declined, presumably due to substrate depletion as nutrients were consumed by the microorganisms. The highest recorded voltage reached approximately 127.2 mV in the reactor supplied with persimmon waste mixed with soil.

The maximum electrical output obtained in this work was approximately threefold greater than that observed in other mixed or single-substrate reactors. The elevated performance during the early phase can be attributed to intensive microbial metabolism supported by abundant biodegradable material. As the system transitioned toward anaerobic conditions, electrochemical activity became more pronounced, leading to a rapid rise in voltage. The superior performance of the persimmon waste–soil configuration is likely related to the mineral content and nutrient availability provided by the soil matrix, which enhanced microbial growth and electron transfer processes. In addition, the presence of readily fermentable carbohydrates, particularly glucose, further stimulated microbial activity and contributed to the higher electrical generation. The recorded value represents the highest voltage achieved for a single-chamber MFC employing organic substrates under comparable conditions. After approximately eight days of operation, the voltage gradually declined, most likely due to progressive depletion of utilizable substrates.

During operation, the microbial population underwent a typical growth–decay cycle. At the beginning, abundant substrate promoted rapid biomass proliferation, whereas progressive substrate depletion reduced microbial viability and consequently limited bioelectricity generation (Jessica Li, 2013). In contrast, several reactors maintained relatively stable voltage throughout the experimental period. The residual electrical output likely originated from the electrochemical potential difference between the anode and cathode, together with ongoing decomposition of organic matter within the soil matrix (Moqsud et al., 2015). In some instances, a temporary increase in voltage was still observed, suggesting renewed metabolic activity of electroactive microorganisms and enhanced electron release. This behavior indicates a partial self-recovery of electrical performance in the MFC system, highlighting its potential for sustained energy production (Siti L.A., 2012).

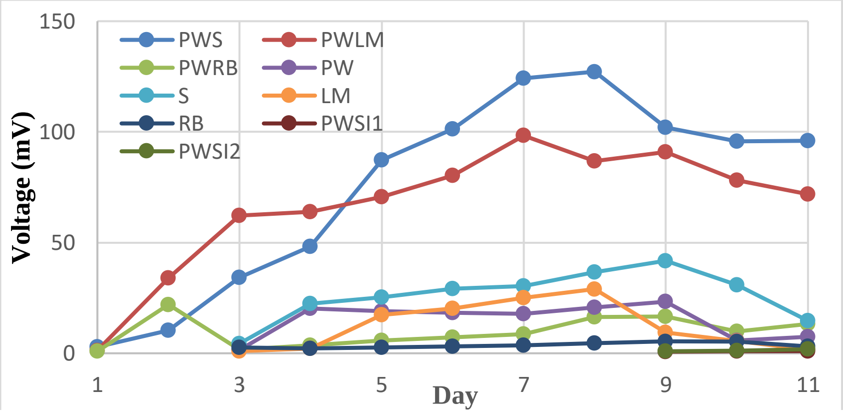

Figure 2. Performance of bioelectricity production due to time duration of MFC

Figure 3 presents the polarization response of the MFC fed with persimmon residues. Polarization analysis relates the electrical output to the applied load by examining how cell voltage varies with current (Logan, 2007). This approach provides an integrated assessment of electrochemical performance, enabling estimation of electrode over potentials and internal resistance. The internal resistance is determined from the slope of the linear (ohmic) region of the voltage–current profile, which reflects the magnitude of intrinsic voltage losses within the cell (Logan, 2008).

The power density profile was derived from the polarization data to relate electrical power generation to current output. The resulting relationship typically exhibits a bell-shaped trend with a distinct maximum power point (MPP), reached when the external load approximates the internal resistance of the cell. Polarization analysis further evaluates the ability of the MFC to sustain cell potential under increasing current demand, thereby reflecting its electrochemical performance and stability (Moqsud et al., 2015).

The electrical current was calculated from the recorded cell potential according to Ohm's law, as described in the experimental procedure. The external load resistance was sequentially adjusted, and the corresponding voltage at each setting was measured; these values were then used to determine the current and to construct the polarization curve as shows at Figure 3. Power density and current density were obtained following the approach of Logan et al. (2008). The resulting curve reflects the ability of the MFC to sustain its operating voltage as current increases. When normalized to the projected anode area, the maximum power outputs were approximately 0.0098 W/m² for the persimmon mixed with soil (PWS) and 0.162 W/m² for the persimmon mixed with leafmold (PWLM).

The obtained polarization profile followed the characteristic pattern commonly reported for microbial fuel cells (Logan and Regan, 2006; Moqsud et al., 2013). As the external resistance was reduced, the calculated power density increased and reached a maximum value. Beyond this point, further rises in current density were accompanied by a decline in power output, reflecting the conventional performance behavior of fuel cell systems (Moqsud et al., 2015).

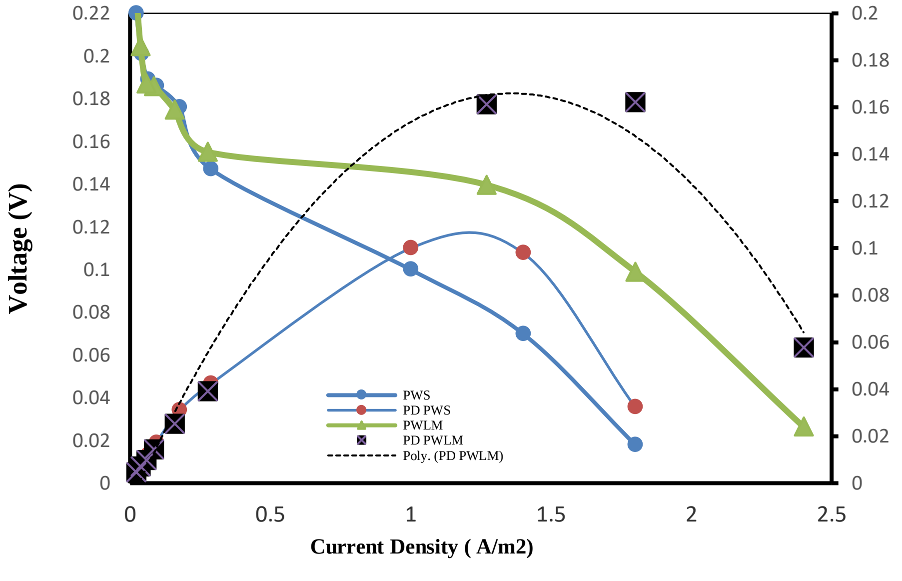

Figure 3. Electrochemical Performance

Figure 4 presents the voltage–current response of the MFC. The data followed an approximately linear trend. From this relationship, the intercept corresponds to the cell's electromotive force, while the slope reflects the internal resistance. Accordingly, better cell performance is associated with a higher open-circuit potential and lower internal resistance. The electromotive force was about 0.22 V, and the internal resistance was comparatively small.

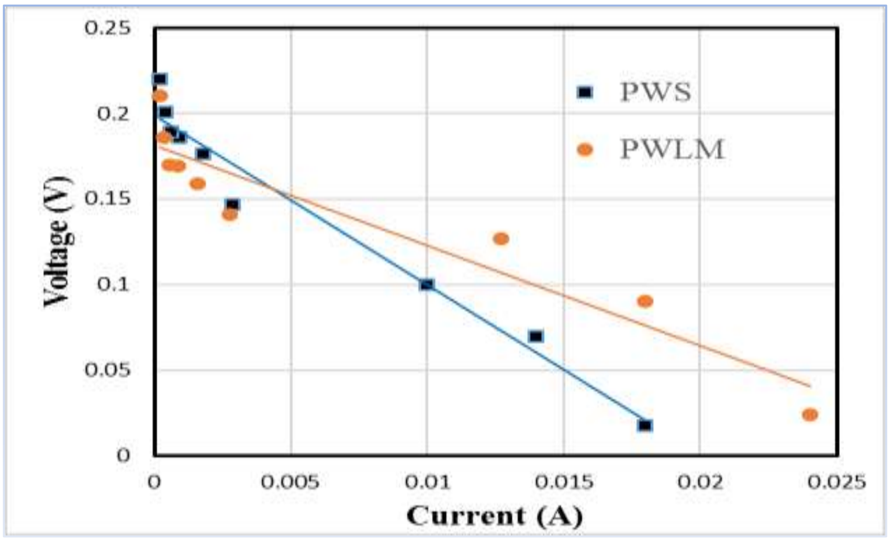

Figure 4. Voltage-Current Relationship in the MFCs

In contrast, the soil-based configuration exhibited inferior performance compared with the leaf-mold mixture, likely because ordinary soil becomes less electrochemically active under relatively dry conditions. The peak electrical output was estimated from the voltage–current relationship, yielding a maximum power density of 0.162 W/m² (normalized to anode area) for the MFC operated with persimmon waste and leaf mold.

4. Conclusions

It demonstrated that discarded persimmon residues can function as an effective substrate for electricity generation in a microbial fuel cell (MFC) system. The soil–persimmon mixture supported microbial activity and enabled simultaneous organic matter degradation and bioelectricity production. The reactor produced a maximum power density of approximately 40 mW/m², confirming the electrochemical feasibility of untreated fruit waste as a carbon source. Compared with previously studied organic substrates, persimmon residues have received limited investigation in MFC applications. The present results therefore provide experimental evidence that heterogeneous fruit-processing waste, combined with naturally available soil as a microbial medium, can sustain stable electrical output. The findings address the insufficient characterization of fruit-based substrates in bioelectrochemical systems and demonstrate a low-cost configuration that does not require refined feedstock or specialized inoculum. This work lies in the utilization of untreated persimmon waste together with soil in a single-chamber MFC and the quantitative evaluation of its electrochemical performance. This approach contributes to the development of decentralized bioelectrochemical technologies for the simultaneous treatment of agricultural residues and recovery of electrical energy.

Acknowledgements

I would like to gratefully acknowledge the guidance, constructive comments, and generous assistance extended by colleagues and collaborators throughout the course of this study.

References

Call D F., Wagner R C., Logan B E. Hydrogen Production by Geobacter Species and a Mixed Consortium in a Microbial Electrolysis Cell. Applied and Environmental Microbiology, 2009; 75: 7579–7587

Christiani, P. Cristiani, A. Franzetti, I. Gandolfi, E. Guerrini, G. Bestetti. Bacterial DGGE fingerprints of biofilms on electrodes of membraneless microbial fuel cells. Int. Biodeterior. Biodegree., 84, 2013. pp. 211–219.

El-Chakhtoura J, El-Fadel M, Rao H A, Li D, Ghanimeh S, Saikaly P E. Electricity generation and microbial community structure of air-cathode microbial fuel cells powered with the organic fraction of municipal solid waste and inoculated with different seeds. Biomass and bioenergy, 2014; 67: 24-31

FAO. Agricultural production statistics 2010–2023. FAOSTAT Analytical Briefs, No. 96. Rome. https://openknowledge.fao.org/handle/20.500.14283/cd3755en. 2024

Feng C, Hu A, Chen S, Yu C P. A decentralized wastewater treatment system using microbial fuel cell techniques and its response to a copper shock load. Bioresource Technology 2013; 143:76-82

Jessica Li. An Experimental Study of Microbial Fuel Cells for Electricity Generating: Performance Characterization and Capacity Improvement. Journal of Sustainable Bioenergy Systems, 2013, 3, 171-178

Kan, J., Hsu, L., Cheung, A., Pirbazari, M., Nealson, K. Current production by bacterial communities in microbial fuel cells enriched from wastewater sludge with different electron donors. Environment Science Technology. 45, 2011. pp 1139–1146.

Logan, B.E., Cheng, S., Watson, V., Estadt, G. Graphite fiber brush anodes for in-creased power production in air-cathode microbial fuel cells. Environ. Sci. Technol. 41, 2007. pp 3341–3346.

Logan Bruce E. Microbial Fuel Cell. New York. Wiley-interscience; 2008.

Logan B.E. B. Hamelers, R. Rozendal et al., "Microbial fuel cells: methodology and technology,"Environmental Science & Technology, vol. 40, no. 17, 2006. pp. 5181–5192.

Lu N, Zhou S.-gui, Zhuang L, Zhang J.-tao, Ni J.-ren. Electricity generation from starch processing wastewater using microbial fuel cell technology. Biochemical Engineering Journal, 2009; 43: 246-251

Mao, G., Zou, H., Chen, G., Du, H., Zuo, J. Past, current and future of biomass energy research: a bibliometric analysis. Renew. Sust. Energ. Rev. 52, 2015. pp 1823–1833

"Microbiology," 2012. http://www.ilri.org/InfoServ/Webpub/fulldocs/ilca_manu al4/Microbiology.htm.

Mikael Sjölin. Maria Djärf. Mohamed Ismail.Herje Schagerlöf. Ola Wallberg. Rajni Hatti-Kaul. Mahmoud Sayed. Investigating the Inhibitory Factors of Sucrose Hydrolysis in Sugar Beet Molasses with Yeast and Invertase. Catalysts. 14(5).330. https://doi.org/10.3390/catal14050330. 2024.

Moqsud M.A., K Omine. Bio-Electricity Generation by Using Organic Waste in Bangladesh. Proc. of International Conference on Environmental Aspects of Bangladesh (ICEAB10), 2010: 122-124, Sept., Japan

Moqsud, M.A, K. Omine, N. Yasufuku, M. Hyodo, Y. Nakata. Microbial fuel cell (MFC) for bioelectricity generation from organic wastes. Waste Management., 33, 2013, pp. 2465–2469.

Moqsud, M.A, K. Omine, N. Yasufuku, Quazi,S.Bushra, M. Hyodo, Y. Nakata. Bioelectricity from kitchen and bamboo waste in microbial fuel cell. Waste Management., 32 (2), 2014, pp. 124-130.

M.A. Moqsud, J. Yoshitake, Q.S. Bushra, M. Hyodo, K. Omine, David Strik. . Compost in plant microbial fuel cell for bioelectricity generation. Waste Management Volume 36, February 2015, Pages 63–69.

MOE Japan Discloses the Estimated Amount of Japan's Food Loss and Waste Generated in FY 2023. June 27,2025.

Prasad D, Sivaram T K, Berchmans S, Yegnaraman V. Microbial fuel cell constructed with a micro-organism isolated from sugar industry effluent. Power sources, 2006: 160: 991-996

Rakesh, Chandra, Ujwal Shreenag Meda, R. Suresh. Performance Studies of Microbial Fuell Cell. IJRET Volume: 3 Issue: 11. Nov. 2014. pp 169-173.

Sevda S, Dominguez-Benetton X, Vanbroekhoven K, Sreekrishnan T R, Pant D. Characterization and comparison of the performance of two different separator types in air–cathode microbial fuel cell treating synthetic wastewater. Chemical Engineering Journal, 2013; 228: 1-11

Siti L.A. Review: Pengaruh Jenis Mikroba terhadap Efisiensi Energi Listrik Yang Dihasilkan Pada MFC. Unesa. 2012.

Venkata Mohan S, Mohanakrishna G, Srikanth S, Sarma P N. Harnessing of bioelectricity in microbial fuel cell (MFC) employing aerated cathode through anaerobic treatment of chemical wastewater using selectively enriched hydrogen producing mixed consortia. Fuel, 2008; 87: 2667-2676

Waheed Miran, Mohsin Nawaz, Jiseon Jang, Dae Sung Lee. Sustainable electricity generation by biodegradation of low-cost lemon peel biomass in a dual chamber microbial fuel cell. International Biodeterioration & Biodegradation, Volume 106, January 2016, pp 75-79.

Walter, X.A., Greenman, J., Taylor, B., Ieropoulos, I.a.. Microbial fuel cells continuously fuelled by untreated fresh algal biomass. Algal Res. 11, 2015. pp 103–107.