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The new report of domestic wastewater treatment and bioelectricity generation using *Dieffenbachia seguine* constructed wetland coupling microbial fuel cell (CW-MFC)

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Abstract: The constructed wetland integrated with microbial fuel cell (CW-MFC) has gained attention in wastewater treatment and electricity generation owing to its electricity generation and xenobiotic removal efficiencies. This study aims to use the CW-MFC with different macrophytes for domestic wastewater treatment and simultaneously electricity generation without chemical addition. The various macrophytes such as *Crinum asiaticum*, *Canna indica, Hanguana malayana*, *Philodendron erubescens*, and *Dieffenbachia seguine* were used as a cathodic biocatalyst. The electrochemical properties such as half-cell potential and power density were determined. For wastewater treatment, the chemical oxygen demand (COD) and other chemical compositions were measured. The results of electrochemical properties showed that the maximal half-cell potential was achieved from the macrophyte *D. seguine*. While the maximal power output of 5.42±0.17 mW/m^2 (7.75±0.24 mW/m^3) was gained from the CW-MFC with *D. seguine* cathode. Moreover, this CW-MFC was able to remove COD, ammonia, nitrate, nitrite, and phosphate of 94.00±0.05%, 64.31±0.20%, 50.02±0.10%, 48.00±0.30%, and 42.05±0.10% respectively. This study gained new knowledge about using CW-MFC planted with the macrophyte *D. seguine* for domestic wastewater treatment and generation of electrical power as a by-product without xenobiotic discharge.

Introduction

Domestic wastewater is the man-made liquid waste that harms human health and affects groundwater quality and the ecosystem because it contains a high concentration of organic matter, as well as microbial and other pollutants (Pasquini et al. 2014). For wastewater treatment, various processes such as carbon adsorption, chemical precipitation, biological degradation, evaporation, and membrane filtering have been successfully used. However, biological treatments such as activated sludge (Klimsa et al. 2020), microbial fuel cells (Ni et al. 2021), and constructed wetland (Ho et al. 2020) have become considered to remove contaminants among treatment processes (Rajasulochana et al. 2016).

Constructed wetland (CW) is a fascinating alternative to domestic wastewater treatment owing to its low operating cost, noncomplicated operation, and low energy consumption. The CW system has been used for green treatment systems in various areas, especially in developing countries (Zhang et al. 2015). In Vega de Lille et al. (2021), the CW system has been used for domestic wastewater treatment under high-temperature conditions. The maximum organics and solids of 88%, phosphate removal of 90%, and nitrogen removal of 70% were gained. Moreover, the CW system can be used as a pathogen removal from contaminated wastewater. On the other hand, the maximal chemical oxygen demand (COD) removing performance of 77% and fecal coliform removal of 64% was reached (Shukla et al. 2021).

Microbial fuel cells (MFC) are an electrochemical technology that uses microbial metabolism to convert chemical energy in organic matter to electrical energy. It has been interested in a variety of objectives for lowering operating costs, such as the design of electrodes, microbial inoculum, and feed materials (Das et al. 2021). In Ni et al. (2021), the MFC has been used for domestic wastewater treatment and electricity generation. The maximal power output of 0.95 W/m^3 was reached with a maximal voltage density of 0.92 V/L. On the other hand, the MFC coupled with a biofilter has been applied for real domestic wastewater treatment. The COD removal of 80% has been detected where the voltage of 0.10 V is generated (Karla et al. 2022).

Currently, the constructed wetland coupling microbial fuel cell (CW-MFC) has been interested due to its potential for improving wastewater treatment efficiency and generating electricity. It has been used in a variety of wastewater applications, including domestic wastewater (Corbella & Puigagut 2018). Furthermore, the CW-MFC can be used to remove ammonium contaminants from domestic wastewater (Vo et al. 2021). For these reasons, the goals of this study were to: (A) select appropriate macrophytes for electricity generation from domestic waste, (B) design the CW-MFC model, and (C) investigate the potential of CW-MFC in domestic wastewater treatment and electricity generation.

Materials and Methods

Domestic wastewater

The synthetic domestic wastewater (COD of 600 mg/L, total nitrogen (TN) of 40 mg/L, and total phosphorous (TP) of 8 mg/L) was prepared according to Almeida-Naranjo et al. (2020). The synthetic wastewater was sterilized under 121°C for 15 mins before being used.

The raw domestic wastewater was collected from the collecting tube of a domestic wastewater treatment plant. It was kept in a sterilized plastic container and stored at -20ºC to prevent biodegradation by normal flora. The physiochemical characteristics of synthetic domestic wastewater and real domestic wastewater are summarized in Table 1.

Macrophyte selection

The various macrophytes such as *Crinum asiaticum* (P1), *Canna indica* (P2), *Hanguana malayana* (P3), *Philodendron erubescens* (P4), and *Dieffenbachia seguine* (P5) were collected from the local market. They were soaked with 1 M NaOH for 10 min and washed with sterile deionized water to remove the contaminated microbes. All macrophytes were planted into the cathode chamber of a dual-chamber MFC (modified from Chaijak et al. 2018) to determine the half-cell potential compared with the $Ag/AgCl_2$ reference electrode for selecting the suitable macrophyte in electricity generation. The macrophyte was individually placed onto the 10 cm^2 moisture carbon cloth cathode electrode and connected to the reference electrode. The half-cell potential was monitored, and the maximal voltage-producing macrophyte was selected.

CW-MFC design and operation

The CW-MFC was made from a 1,000 mL plastic box. (Figure 1). The 10 cm^2 of microwave-expanded graphite plates were used as electrodes (Kim et al. 2021). The copper wire was used to connect between electrodes. A sterile volcanic rock of 5 cm depth was inserted between a cathodic electrode and an anodic electrode. The selected macrophyte was planted on the cathodic electrode. 10% (v/v) of *Acinetobacter* sp. rich consortium (1×10^8 cells/mL) was described in Chaijak et al. (2022), and was

Table 1. Physiochemical characteristics of synthetic and real domestic wastewater

Characteristic	Synthetic	Real	Unit
COD	500.00±4.00	500.00±10.00	mg/L
NH_4^+	23.00±0.10	25.13±0.10	mg/L
NO_2^-	0.02±0.00	0.00±0.00	mg/L
NO_3^-	3.40±0.24	3.00±0.00	mg/L
PO_4^{3-}	9.20±0.10	8.10±0.00	mg/L
pH	7.50±0.10	7.30±0.10	–

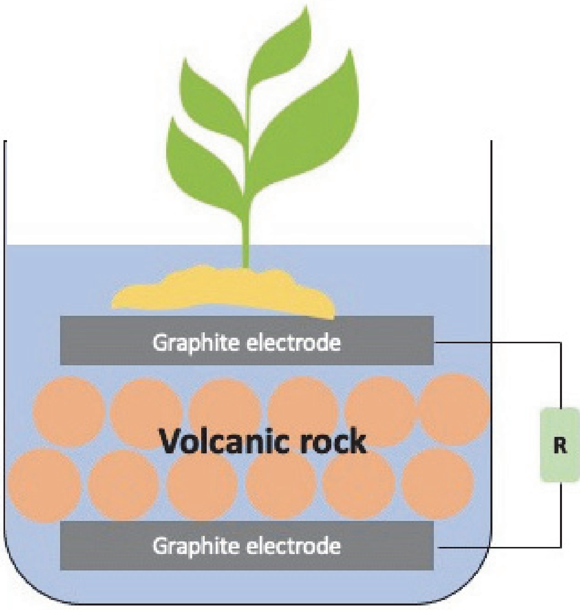

Fig. 1. The diagram of CW-MFC with macrophyte on a cathodic electrode

cultured in nutrient broth and added to the CW-MFC chamber. The 700 mL of synthetic and real domestic wastewater (sterile and non-sterile) were used as an anolyte.

Electrochemical properties

The open-circuit voltage (OCV) was collected every 12 h for 5 days. The closed-circuit voltage (CCV) at 5 KΩ external resistance was collected. The electrochemical properties such as current (mA), power (mW), current density (mA/m^3), and power density (mA/m^3) were calculated as follows:

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

$$P = IV \quad (2)$$

$$CD = I/A \quad (3)$$

$$PD = P/A \quad (4)$$

where: I is the current, V is the closed-circuit voltage at 5 KΩ, R is the external resistance, P is the power, CD is the current density, PD is the power density, and A is the working volume.

Wastewater treatment

After the CW-MFC operation, the influent and effluent were measured for COD, ammonia, nitrate, nitrites, and phosphate removal according to APHA-AWWA-WEF (2005).

Results and Discussion

Half-cell potential

The electrochemical ability to accept an electron and complete an electric circuit on a cathodic electrode has been demonstrated in terms of cathodic half-cell potential (Dincer & Siddiqui 2020). In this study, the half-cell potential of all macrophytes was measured every 30 minutes for 300 mins. The *D. seguine* (P5) had the highest half-cell potential, followed by *C. asiaticum* (P1), as shown in Figure 2. The results revealed that *D. seguine* had the highest half-cell potential of 44.07±2.12 mV.

Araneda et al. (2018) evaluated the potential of the synthetic greywater treatment system and energy recovery by planting *Phragmites australis* in the CW-MFC system. The maximum COD removal rate of 91.70±5.10% was achieved. The maximum power density (PD) of electrical generation was 33.52±7.27 mW/m^3.

On the other hand, the shade macrophyte *Philodendron cordatum* has been used in the coupling of CW-MFC for electricity generation. The results showed that *P. cordatum* produced a maximum voltage of 103 mV (Guadarrama-Perez et al. 2020). Furthermore, water hyacinth has been planted on the CW-MFC electrode to improve nitrobenzene removal and electricity generation. The maximum nitrobenzene removal rate of 92.89% was achieved (Xie et al. 2018).

Electrochemical properties

Figure 3 shows the OCV of CW-MFC with *D. seguine*. A maximum power voltage of 467.00±2.00 mV was obtained. The CCV was measured at 5 KΩ during the stationary phase. Table 2 shows the electrochemical properties of CW-MFC with *D. seguine* in synthetic, sterile, and non-sterile domestic wastewaters. The maximum current density was 21.11±1.07 mA/m^2 and the maximum power density was 2.23±0.23 mW/m^2 for synthetic domestic wastewater. The sterile wastewater generated a maximum current density of 22.59±0.59 mA/m^2 and a maximum power density of 2.55±0.13 mW/m^2 for raw domestic wastewater, where the maximum current density was 32.93±0.50 mA/m^2 and the maximum power density was 5.42±0.17 mW/m^2.

According to Vo et al. (2021), a maximum power output of 1.59 mW/m^2 was generated by vertical up-flow-CW integrated with MFC with a cathode of wild ornamental grass (*Cenchrus setaceus*) and domestic wastewater as an anolyte. On the other hand, the CW-MFC system with the macrophyte *Typha orientalis* has been used for domestic wastewater treatment. The maximum power output was 21.53 mW/m^2 (Wang et al. 2017). In addition, the CW-MFC was used in conjunction with hydrolytic sludge acidification for domestic wastewater treatment and power generation. A maximum power output of 430 mW/m^2 was achieved (Han et al. 2021).

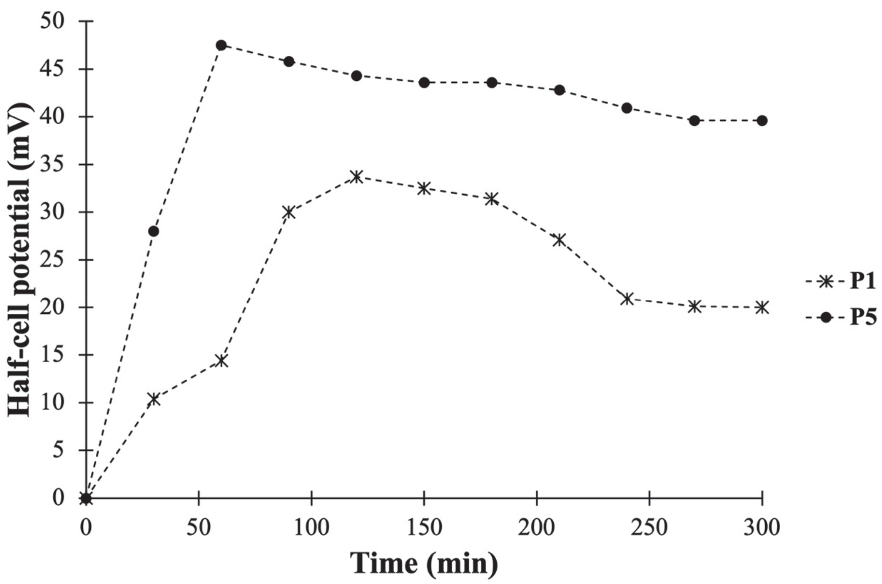

Fig. 2. The half-cell potential of a cathodic electrode with different macrophytes

The *P. australis* was planted in the CW-MFC by Xu et al. (2018) for pollutant removal and electricity generation. A maximum voltage of 256.77 mV was produced. Furthermore, the macrophyte *Canna indica* has demonstrated a high potential for electricity generation. A maximum power density of 2.67 mW/m^2 was achieved (Ge et al., 2020). However, no previous research has reported the use of the CW-MFC in conjunction with *D. seguine* for domestic wastewater treatment.

Wastewater treatment

Following the CW-MFC operation, the effluents (synthetic, sterile, and non-sterile) were collected. The pollutant removals have been determined, and the results are shown in Figure 4.

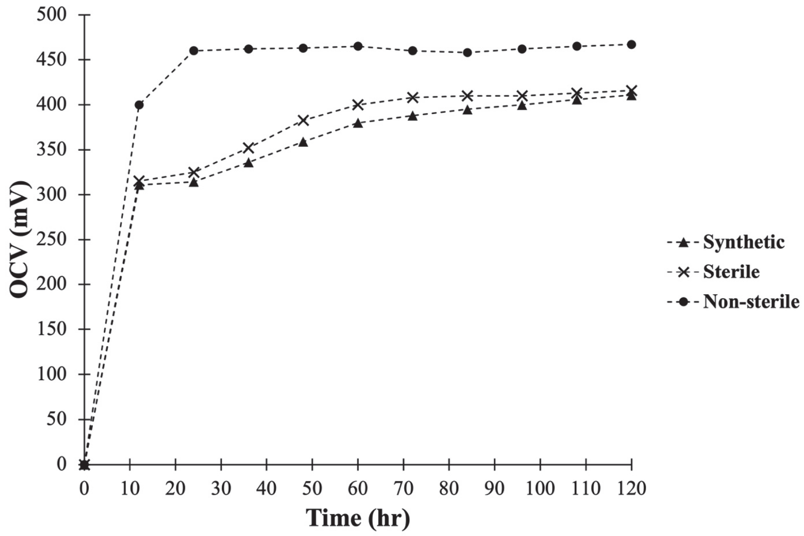

Fig. 3. The OCV of the CW-MFC system with *D. seguine*

Table 2. The electrochemical properties of CW-MFC with the *D. seguine*

Electrochemical properties	Synthetic	Sterile	Non-sterile
CCV at 5 KΩ (mV)	105.57±5.36	112.97±2.95	164.67±2.52
I (mA)	0.021±0.001	0.023±0.001	0.033±0.001
CD* (mA/m^2)	21.11±1.07	22.59±0.59	32.93±0.50
CD** (mA/m^3)	30.16±1.53	32.28±0.84	47.05±0.72
P (mW)	0.002±0.000	0.003±0.000	0.005±0.000
PD* (mW/m^2)	2.23±0.23	2.55±0.13	5.42±0.17
PD** (mW/m^3)	3.19±0.32	3.65±0.19	7.75±0.24

* based on electrode area
** based on working volume

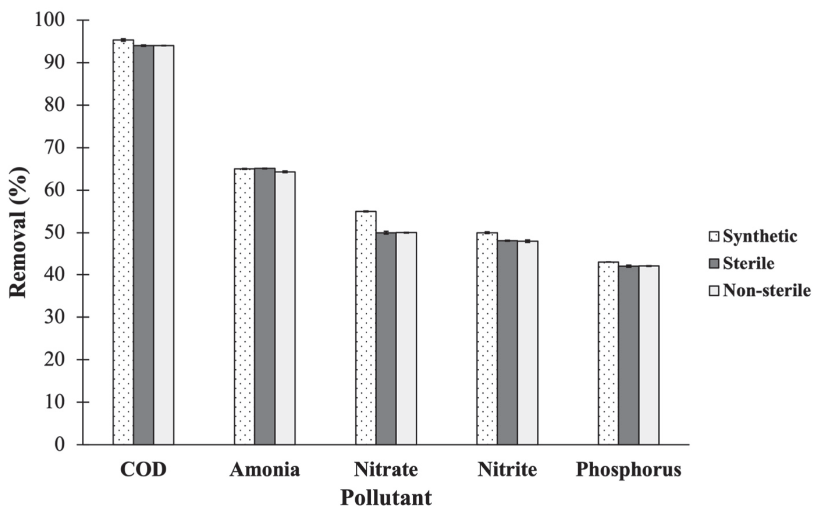

Fig. 4. The potential of domestic wastewater treatment using the CW-MFC with *D. seguine*

In this study, the COD removal rate was 94.00±0.05%, the ammonia removal rate was 64.31±0.20%, the nitrate removal rate was 50.02±0.10%, the nitrite removal rate was 48.00±0.30%, and the phosphate removal rate was 42.05±0.10% using non-sterile domestic wastewater as an anolyte.

Moondra et al. (2020) used microalgae to remove nutrients from domestic wastewater. The maximum removal efficiency of phosphate, ammonia, and COD was 87.67%, 96.88%, and 80.39%, respectively. In contrast, no power was generated during the operation. Furthermore, the electrocoagulation--flotation system was used in the treatment of domestic wastewater. This process achieved a turbidity removal potential greater than 98.00%. However, it must continue to use electrical current for process operation (Bracher et al. 2020).

The subsurface wastewater infiltration system was used for decentralized domestic wastewater treatment by Yang et al. (2021). The performance of COD removal and total phosphorus removal was 94.81% and 97.25%, respectively. The sponge-based moving bed biofilm reactor has been used for nutrient and organic pollutant removal from domestic wastewater. The results showed that on day 80, the maximum COD, total nitrogen, and total phosphorus removal rates were 85.00%, 68.90%, and 40.30%, respectively (Nhut et al. 2020). Phosphorus was removed by Libecki and Mikolajczyk (2021) using micro-electrolysis and sedimentation. The results showed that approximately 84% of phosphorus was removed.

Conclusion

The macrophyte *D. seguine* showed the high efficiency as a plant biocatalyst on the cathode of the CW-MFC system as it revealed the highest half-cell potential. The CW-MFC can act as a combination of constructed wetland and MFC for high efficiency of domestic wastewater treatment and electricity generation. The maximal power output of 7.75±0.24 mW/m^3 was achieved where the COD removal of 94.00±0.05% was gained. This study provided novel information about using the CW-MFC with macrophyte *D. seguine* for domestic wastewater treatment that gained the best qualities of both the CW and the MFC in wastewater treatment and electrical energy production. However, the high-toxic xenobiotic tolerance ability of this system can be determined in further study.

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