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Original Article

# Carbon capture – microbial fuel cell for energy, bacterial nanocellulose and nutraceuticals production from coconut processing waste

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## Abstract

Microbial fuel cells (MFCs) represent a promising biotechnological approach for sustainable electricity generation from waste substrates without combustion or secondary pollutant formation. In this study, a kombucha starter culture was employed to convert organic compounds in coconut processing waste into electricity within a carbon-capture MFC integrated with the green microalga *Chlorella* sp. BF03. The electrochemical performance of the MFC was evaluated according to Ohm's law. By-products, carbon fixation rates, and degraded metabolites of the waste were also analyzed. The maximum current density and power density of the system were $6.40 \pm 0.01$ A/m$^2$ and $0.77 \pm 0.02$ W/m$^2$ respectively, with *Komagataeibacter saccharivorans* and *Acetobacter tropicalis* as the main bacterial cultures. No harmful compounds were detected among the degraded metabolites. The system achieved a maximum carbon fixation rate of $0.13 \pm 0.00$ g/L/day and a bacterial nanocellulose production rate of $0.54 \pm 0.04$ g/L/day accompanied by total chlorophyll a and b contents of $0.31 \pm 0.01$ µg/L and $0.32 \pm 0.02$ µg/L, respectively. Biomass extracts contained various nutraceuticals, including limonene, n-hexadecanoic acid, octadecanoic acid and vitamin E. These results demonstrate the potential of kombucha-based carbon-capture MFCs for integrated energy generation, waste valorization, and production of high-value bioproducts.

**Keywords**: Agricultural waste, By-product, Electricity generation, Fatty acid, SCOBY, Upcycling

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## Introduction

Mature coconut water is a by-product released during coconut milk or coconut oil production. Due to its poor sensory properties, it is often discharged as waste leading to environmental pollution (Aba et al., 2024; Yodrach et al., 2025). In Thailand, coconut cultivation is predominantly concentrated in the Southern region. In 2020, the total plantation area was reported at 137,510.24 hectares (Sivakorn et al., 2023) with an average yield of approximately 6,250 coconuts per hectare and national production was estimated at about 859.44 million coconuts (Junmee et al., 2021). Considering that each mature coconut contains between 50 and 250 mL of mature coconut water, the annual volume of mature coconut water generated as a by-product is estimated to range from 42.97 to 214.86 million cubic meter (Yodrach et al., 2025). Therefore, discharging mature coconut water without an efficient treatment system can cause serious environmental problems.

Microbial fuel cell (MFC) is a promising technology that can convert organic matter into electrical energy through microbial metabolism without combustion (Ojha and Pradhan, 2025). Various types of agricultural waste have been used for electricity generation, including grape waste (Korojdeh et al., 2024), jackfruit waste (Chandra et al., 2025), chestnut waste (Chandra et al., 2024), food waste (Yadav et al., 2024), oil waste (Yin et al., 2024), dairy waste (Singh et al., 2025), potato waste (Din et al., 2024) and vegetable waste (Idris et al., 2025).

Kombucha starter culture is a symbiotic consortium of microorganisms, primarily comprising acetic acid bacteria such as *Acetobacter* sp. and *Komagataeibacter* sp. along with various yeast strains (Lima et al., 2025). Previous studies have reported that *Acetobacter aceti* is capable of generating electricity in MFC (Karthikeyan et al., 2016). The symbiotic culture of bacteria and yeast (SCOBY) in kombucha is a by-product nanocellulose biofilm embedded with microorganisms derived from kombucha fermentation (Venegas et al., 2023; Chausse et al., 2024). Bacterial nanocellulose (BNC) is a biopolymer composed of glucose molecules linked by β-1,4-glycosidic bonds. It is produced through the fermentation of a bacterial consortium, mainly from the genus *Acetobacter* (Claro et al., 2024). BNC has been utilized for various applications, such as wound dressings (Amorim et al., 2022), food packaging films (Jang et al., 2023), leather-like materials (Ayyappan et al., 2022), supercapacitors (Li et al., 2023) and tissue engineering (Phatchayawat et al., 2022). Therefore, SCOBY represents an alternative by-product generated from the kombucha starter that could be widely utilized in future studies.

Microalgae are promising microorganisms for renewable energy production and the generation of nutrient-rich biomass (Sato et al., 2025). They have been widely applied in wastewater treatment and for enhancing electricity generation in photosynthetic MFC. Moreover, microalgae-assisted MFC can generate value-added products from microalgal biomass through carbon capture processes (Ahirwar et al., 2025; Yolanda et al., 2025). No previous study has reported the use of carbon-capture MFCs for mature coconut water treatment, electricity generation, and carbon capture.

This study aims to utilize a kombucha starter to convert the organic matter in coconut processing waste into a source of electricity generation in a carbon-capture MFC. The electrochemical properties, degraded metabolites, microalgae-carbon capture rate and by-products were analyzed.

## Material and Methods

### Coconut processing waste

The coconut processing waste was collected from a local market in southern Thailand. It was stored in an icebox and promptly transported to the laboratory at the Faculty of Science and Digital Innovation, Thaksin University, Phatthalung Campus, Thailand.

The sample was filtered through sterile medical gauze (Ambulance, Thailand) to remove fruit sediment, and then filtered again using sterile Whatman nylon filter discs with a 0.45 μm pore size (Whatman, United Kingdom) to eliminate microbial contaminants. The clarified coconut water was preserved at -25 °C in a freezer (Hitachi, Japan) until it was used in subsequent experiments. The components of coconut processing waste are shown in Table 1.

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**Table-1.** The components of coconut processing waste used in this study.

| Components | Value (g/100g coconut water) |
|---|---|
| Water | 94.40±0.10 |
| Protein | 0.50±0.02 |
| Total lipid | 0.14±0.01 |
| Total carbohydrate | 4.30±0.10 |
| Total sugar | 3.35±0.02 |
| Fiber | 0.00±0.00 |
| Ash | 0.37±0.10 |

## Kombucha starter

The kombucha pellicles (RY_01) used in this experiment were obtained from a local kombucha producer in southern Thailand. The pellicles were fermented three times prior to use in order to stabilize the microbial consortium. They were then stored in a solution containing 70 g/L sucrose (Mitr Phol, Thailand) and 10 g/L black tea (ChaTraMue, Thailand) (Villarreal-Soto et al., 2020). The liquid was fermented for 15 days at room temperature for use as a stock culture.

## Microbial community analysis

The microbial cell was collected from the stock culture and transferred into 1.5 mL sterile microcentrifuge tubes (SPL, South Korea). The samples were centrifuged at 12,000 rpm for 10 mins using a Micro-12 high-speed mini centrifuge (Biosan, United States). The supernatant was discarded, and the cell pellet was washed 2–3 times with sterile reverse osmosis water.

The genomic DNA of the kombucha microbial community was extracted using a gDNA Isolation Kit (Qiagen, Netherlands). The extracted DNA was used to identify the bacterial and fungal communities present in the coconut kombucha.

The bacterial microbiome was sent for identification to Macrogen (South Korea). Identification was performed by targeting the V3–V4 region of the 16S rRNA gene using universal primers 341F (CCTACGGGNGGCWGCAG) and 805R (GACTACHVGGGTATCTAATCC) (Wasimuddin et al., 2020).

The fungal microbiome was sent for analysis to Macrogen (South Korea). Identification was performed by targeting the ITS region using universal primers ITS1F (CTTGGTCATTTAGAGGAAGTAA) and ITS2R (GCTGCGTTCTTCATCGATGC) (Zhang et al., 2021).

## Microalgae

The microalgae *Chlorella* sp. BF03 was obtained from the Biotechnology Program, Department of Science and Digital Innovation, Thaksin University (Kongthong et al., 2025). The growth performance of *Chlorella* sp. BF03 under autotrophic conditions was evaluated to ensure its ability to grow via carbon dioxide fixation (Bonett et al., 2020). A 10% (w/v) inoculum of microalgal cells was introduced into BG11 medium (Himedia, India) and incubated at room temperature for 7 days under a light intensity of 4,400 lux. Growth performance was assessed using a microplate reader (Thermo Fisher Scientific, United States) by measuring absorbance at a wavelength of 680 nm. The dry cell weight (DCW) of the microalgae was calculated based on a previous study, where an optical density (OD) at 680 nm of 1.0 is equivalent to 0.19 g/L DCW (Cheah et al., 2018).

## MFC construction

The dual-chamber MFC was constructed using an acrylic cube with a working volume of 10 mL (Figure 1). Parafilm (Bemis, United States) was used as a low-cost proton exchange membrane (PEM) (Selaman et al., 2025). A plain carbon cloth electrode (Fuel cell store, United States) with a thickness of 15 mm and effective surface area of 2 $cm^2$ was used as the electrode. A 4 mm diameter PVC oxygen tube (U Smiles, Thailand) was used to transfer carbon dioxide from the anodic chamber to the cathodic chamber.

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In the cathodic chamber, 9 mL of BG11 medium was mixed with 1 mL of 7-day-old microalgae culture ($OD_{680}$ = 1.0). In the anodic chamber, 9 mL of coconut processing waste was mixed with 1 mL of kombucha starter culture ($OD_{600}$ = 1.0). The MFC system was operated under static conditions at room temperature for 7 days. The sterile coconut processing waste was used as a negative control for electricity generation. The open circuit voltage (OCV) was measured every 6 hr. The closed circuit voltage (CCV) was measured under static conditions using an external resistance at 300-5,000 Ω. The polarization curve was constructed based on the CCV, power density and current density.

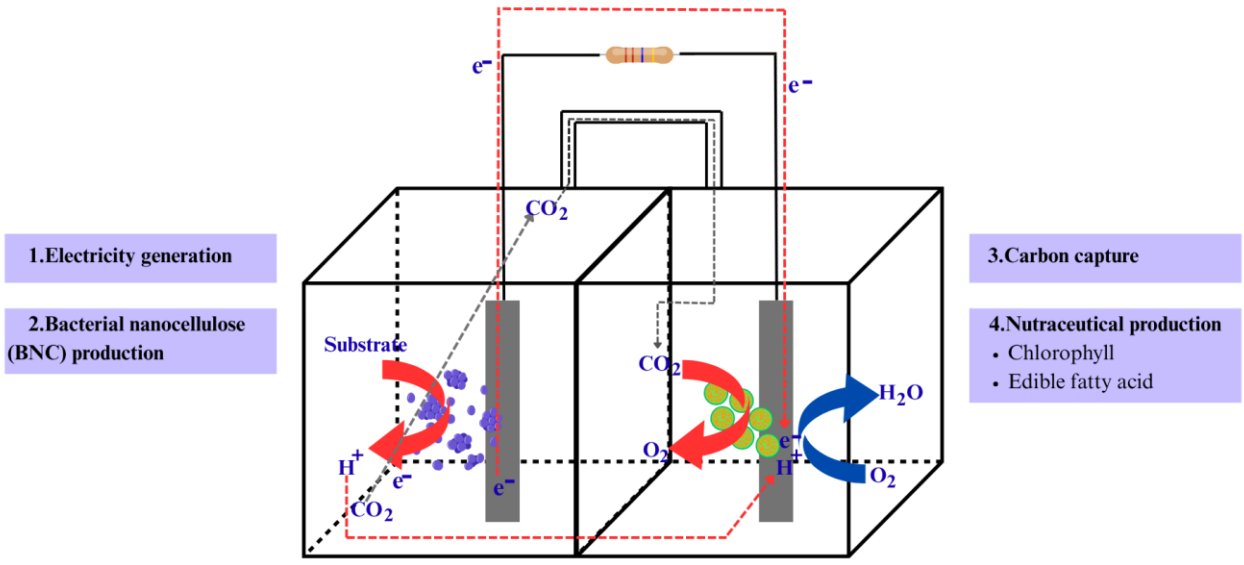


**Figure-1.** Schematic diagram of carbon capture – microbial fuel cell (MFC) used in this experiment.

## MFC performance

The electrochemical properties were calculated based on Ohm's law.

$$I = V / R \quad (1)$$
$$P = I \times V \quad (2)$$
$$CD = I / A \quad (3)$$
$$PD = P / A \quad (4)$$

Where I is the current (A), V is the CCV (V), R is the external resistance (Ω), P is the power (W), A is the electrode area ($m^2$) or working volume ($m^3$), CD is the current density ($A/m^2$ or $A/m^3$), and PD is the power density ($W/m^2$ or $W/m^3$).

The microalgae cell yield was calculated according to Equation (5) (Yang et al., 2024).

$$P_m = (C_{mt} - C_{m0}) / t \quad (5)$$

Where $P_m$ is the microalgae cell yield (g/L/day), $C_{mt}$ is the initial microbial cell biomass (g/L), $C_{m0}$ is the biomass yield at day $t$ (g/L).

The carbon fixation rate (g/L/day) was calculated using Equation (6) (Lim et al., 2021).

$$\text{Carbon fixation rate} = W_{dry} \times C \times (m_{CO2} / m_C) \quad (6)$$

Where $W_{dry}$ is the dried biomass concentration (g/L/day), C is the carbon content (0.5), $m_{CO2}$ is the molecular mass of $CO_2$ (g/mol), and $m_C$ is the molecular mass of C (g/mol).

The energy production by the MFC was described using normalized energy recovery (NER) based on the conversion of organic compounds into energy (Equations 7–8).

$$NER_v = (P \times t) / V \quad (7)$$
$$NER_{COD} = (P \times t) / V \times \Delta COD \quad (8)$$

Where $NER_v$ is the normalized energy recovery per working volume ($KWh/m^3$), $NER_{COD}$ is the normalized energy recovery per chemical oxygen demand (KWh/KgCOD), P is the power (W), $t$ is the operating time (h), V is the working volume ($m^3$) and

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ΔCOD is the change in the chemical oxygen demand (KgCOD).

## Degraded metabolites

The degraded metabolites of coconut processing waste were analyzed using gas chromatography–mass spectrometry (GC-MS) (Yao et al., 2023).

## BNC production

The BNC was harvested from the anodic chamber and purified using 1 M NaOH at 80 °C for 60 min in a water bath (Memmert, Germany) to remove cellular and medium components. It was then washed with distilled water 2–3 times until the pH reached 7. The BNC was dried at 60 °C in a hot air oven (Memmert, Germany) until a constant weight was achieved using a 4-digit analytical balance (Shimadzu, Japan) (Akintunde et al., 2022). The BNC yield was calculated according to Equation (9).

$$\text{BNC yield (g/L)} = \text{Dried weight} / V_{working} \quad (9)$$

Where $V_{working}$ is the working volume of culture medium (mL).

## Microalgae biomass analysis

The microalgae cells in BG11 medium were collected from the cathodic chamber and centrifuged at 5,000 rpm for 10 min using a Microspin 12 high-speed mini centrifuge (Biosan Laboratories Inc., United States). The pellet was washed 2–3 times with distilled water (Gerin and Remacle, 2024). Then, 1 mL of n-hexane was added to 1 g of wet cells, followed by vortexing and incubation at room temperature for 30 min (Amin et al., 2018).

Pigment concentration was determined using UV-Vis spectrophotometer (Shimadzu, Japan) at 663, 645 and 630 nm. The concentrations of chlorophyll a and chlorophyll b were subsequently calculated follows Equation (10) -(11) (Oo et al., 2017).

$$\text{Chlo-A} = (11.64A_{663} - 2.16A_{645} + 0.10A_{630}) \times v / (l \times V) \quad (10)$$

$$\text{Chlo-B} = (-3.94A_{663} + 20.97A_{645} + 3.66A_{630}) \times v / (l \times V) \quad (11)$$

Where Chlo-A is the chlorophyll a concentration (μg/mL), Chlo-B is the chlorophyll b concentration (μg/mL), v is the ethanol volume (mL), l is the spectrophotometric length (cm), and V is the sample volume (mL).

The fatty acid profile was analyzed using GC-MS (Kongthong et al., 2025).

## Statistical analysis

All experiments were performed in triplicate. Data are presented as mean ± SD from three independent experiments (n = 3). Statistical significance was evaluated using a t-test in SPSS software (SPSS Inc., United States).

# Results

## Microbial community

Figure 2 shows the Krona chart of bacterial taxonomy in kombucha starter. At the phylum level, the bacterial microbiome is composed of 99.96% *Pseudomonadota* and 0.04% *Bacillota*.

At the class level, the bacterial microbiome is composed of 99.87% *Alphaproteobacteria*, 0.09% *Gammaproteobacteria*, and 0.04% *Bacilli*.

At the order level, the bacterial microbiome is composed of 99.87% of *Rhodospirillales*, 0.09% of *Moraxellales*, 0.03% of *Lactobacillales* and 0.01% of *Bacillales*.

At the family level, the bacterial microbiome is composed of 99.87% of *Acetobacteraceae*, 0.09% of *Moraxellaceae*, 0.02% of *Lactobacillaceae*, 0.01% of *Carnobacteriaceae* and 0.01% of *Staphylococcaceae*.

At the genus level, the bacterial microbiome is composed of 93.45% of *Komagataeibacter*, 6.42% of *Acetobacter*, 0.08% of *Acinetobacter*, 0.02% of *Leuconostoc*, 0.01% of *Dolosigranulum* and 0.01% of *Staphylococcus*.

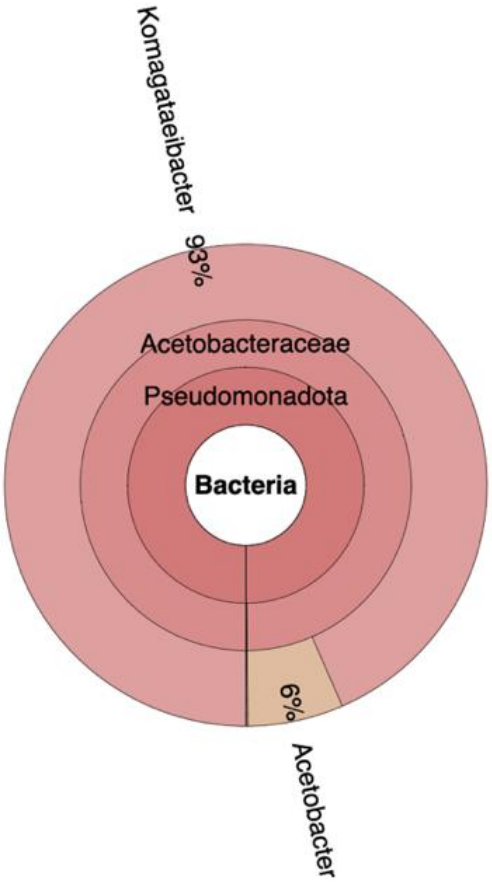


**Figure-2.** Taxonomic Krona chart of the bacterial microbiome in kombucha starter.

Figure 3 presents the bacterial taxonomic composition of kombucha starter in the species level. At the species level, the bacterial microbiome is composed of 92.77% of *Komagataeibacter saccharivorans*, 6.42% of *Acetobacter tropicalis*, 0.38% of *Komagataeibacter sucrofermentans*, 0.30% of *Komagataeibacter rhaeticus*, 0.07% of *Acinetobacter septicus*, 0.02% of *Leuconostoc mesenteroides*, 0.01% of *Dolosigranulum pigrum* and 0.01% of *Staphylococcus capitis*. A heatmap plot of the bacterial microbiome in kombucha starter is shown in Figure 4. The diversity analysis of bacterial microbiome is shown in Table 2.

**Table-2.** The diversity index (Alpha diversity) of bacterial microbiome in kombucha starter.

| ASVs | Shannon | Gini-Simpson | PD_whole tree |
|---|---|---|---|
| 16 | 0.477 | 0.144 | 1.234 |

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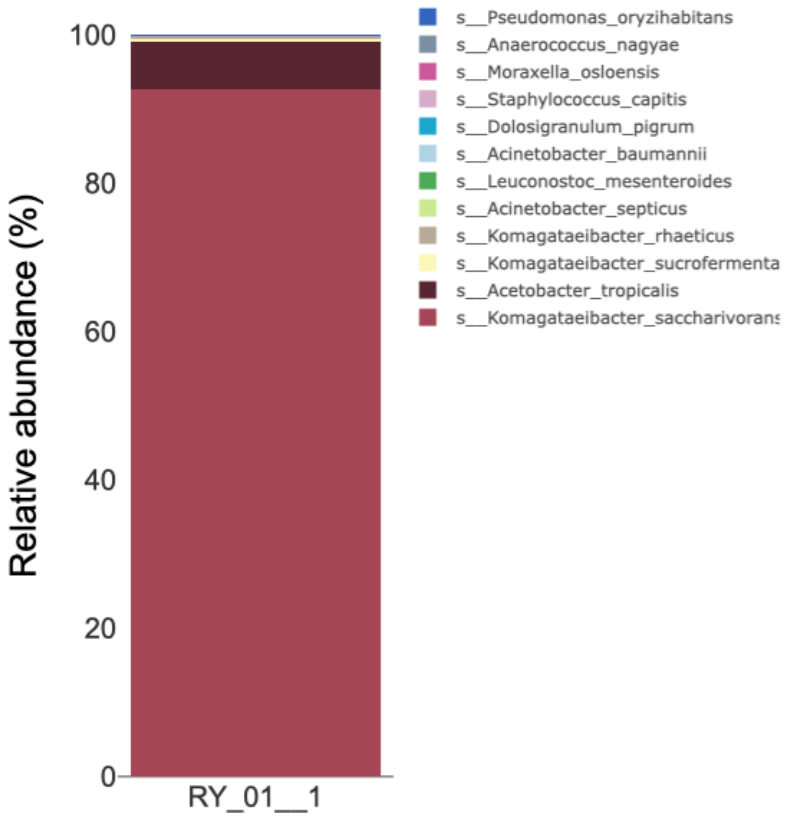


**Figure-3.** The bacterial taxonomic composition in the species level in kombucha starter.

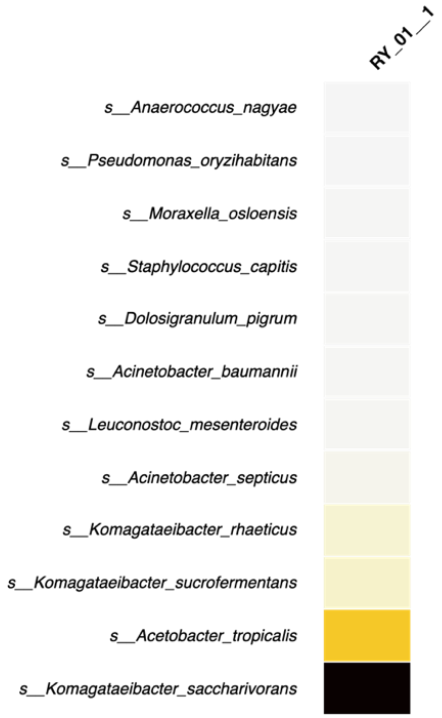


**Figure-4.** The heatmap plot of the bacterial microbiome in kombucha starter.

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Figure 5 shows the Krona chart of fungal taxonomy in kombucha starter. The taxonomic analysis indicated that the only fungal species present belonged to the phylum *Ascomycota*, class *Saccharomycetes*, order *Saccharomycetale*s, family *Pichiaceae*, genus *Dekkera* and species *Dekkera bruxellensis* (Figure 6). A heatmap plot of the fungal microbiome in kombucha starter is shown in Figure 7. The diversity analysis of fungal microbiome is shown in Table 3.

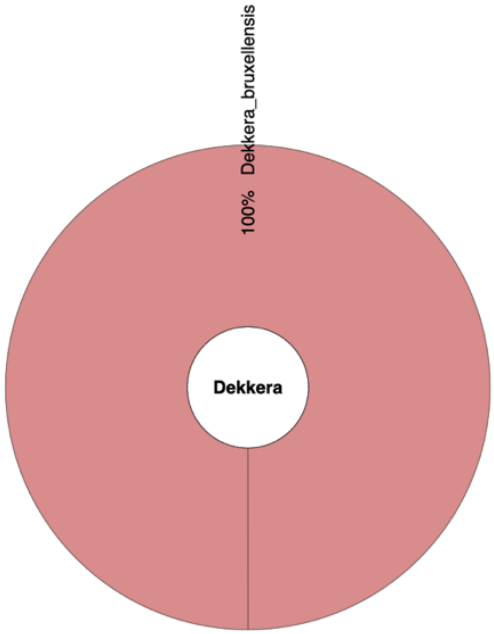


**Figure-5.** Taxonomic Krona chart of the fungal microbiome in kombucha starter.

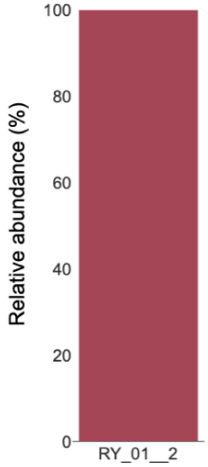


**Figure-6.** The fungal taxonomic composition in the species level in kombucha starter.

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**Figure-7.** The heatmap plot of the fungal microbiome in kombucha starter.

**Table-3.** The diversity index (Alpha diversity) of fungal microbiome in kombucha starter.

| ASVs | Shannon | Gini-Simpson | PD_whole tree |
|---|---|---|---|
| 8 | 2.191 | 0.758 | 0.099 |

On the other hand, the kombucha starter consisted of the bacterial genus *Komagataeibacter* and the fungal genera *Zygosaccharomyces*, *Lachancea* and *Starmerella* (Harrison and Curtin, 2021). In Wang et al. (2023), the cellulosic pellicles consisted of *Komagataeibacter rhaeticus*. The yeast isolates belonged to *Debaryomyces prosopidis* and *Zygosaccharomyces lentus*. Moreover, DNA metabarcoding analysis of the probiotic microbial consortium showed that the kombucha starter was composed of acetic acid bacteria from 2 genera *Komagataeibacter* and *Gluconobacter*, as well as several yeast genera including *Brettanomyces, Dekkera* and *Pichia* (Reva et al., 2015).

In Qin et al. (2024), the bacterium *Komagataeibacter nataicola* was used for organic-matter fermentation in a coconut-water substrate. This bacterium can be used to convert organic matter into BNC. This synthesis process is mediated by glycolysis, which can improve the performance of the microbial fuel cell with respect to electricity generation (Rezazadeh et al., 2020; Christwardana et al., 2025)

## Microalgae growth performance

The growth performance of microalgae *Chlorella* sp. BF03 under autotrophic conditions using carbon dioxide as the sole carbon source, was evaluated using UV-Vis spectrophotometry. The results showed that microalgal growth was slow from day 1 to day 3, followed by a rapid increase on day 4. A maximum dry cell weight of 0.37±0.00 g/L or 370.64±3.36 mg/L was obtained (Figure 8).

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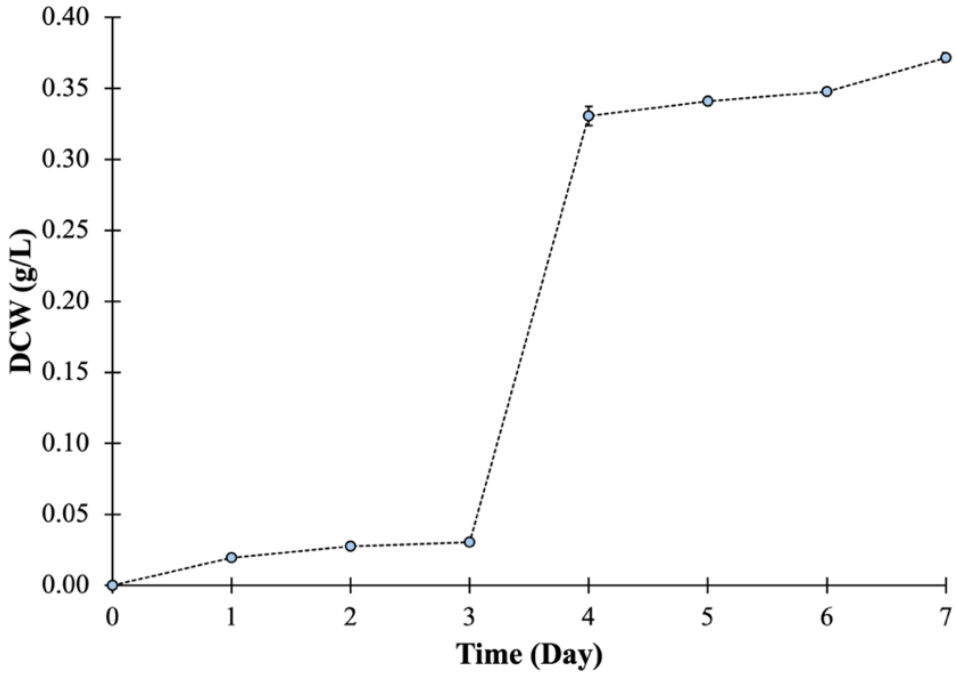


**Figure-8.** The growth performance of microalgae *Chlorella* sp. BF03 under autotrophy condition.

On the other hand, the microalga *Chlorella vulgaris* grew under autotrophic conditions. The maximum microalgal biomass concentration of 1.494 g/L was observed (Dasan et al., 2022). In Bonett et al. (2020), the green microalga *Chlorella sorokiniana* L1A was grown in BG11 medium under autotrophic conditions. The results showed that the maximum microalgal biomass concentration achieved was 0.09 g/L. Moreover, the mixed fresh microalgal culture was grown under autotrophic conditions in a 4 L stirred-tank reactor for 10 days. A biomass concentration of 0.26 g/L was obtained (Tsai et al., 2023).

## Electrochemical properties

The electrochemical properties of the carbon capture-microbial fuel cell were studied using Ohm's law. The open-circuit voltage (OCV) was monitored every 6 hr for 7 days. At the stationary phase, the closed-circuit voltage (CCV) was determined using various external resistances. A maximum OCV of 697.50 ± 6.22 mV was obtained from the carbon capture-microbial fuel cell integrated with the kombucha starter, whereas the control produced only 45.83 ± 4.71 mV (Figure 9). The maximum current density (CD) and power density (PD) were calculated from the polarization curve, yielding values of 6.40 ± 0.01 $A/m^2$ and 0.77 ± 0.02 $W/m^2$, respectively (Figure 10). The electrochemical properties of carbon capture-microbial fuel cell integrated with kombucha starter using coconut processing waste as a substrate was shown in Table 4. Despite these promising results several limitations remain. The system was tested in a relatively small reactor volume, which may restrict scalability and does not fully represent performance under practical operating conditions. The study also lacked a long-term stability or durability assessment, leaving uncertainties about sustained performance, biofilm robustness, and electrode degradation.

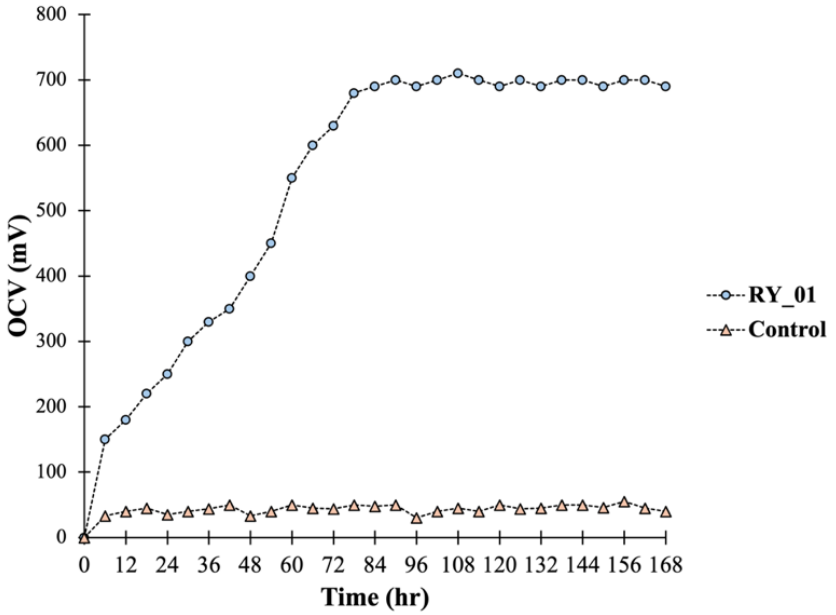


**Figure-9.** The open-circuit voltage of a carbon-capture microbial fuel cell using coconut processing waste as a substrate.

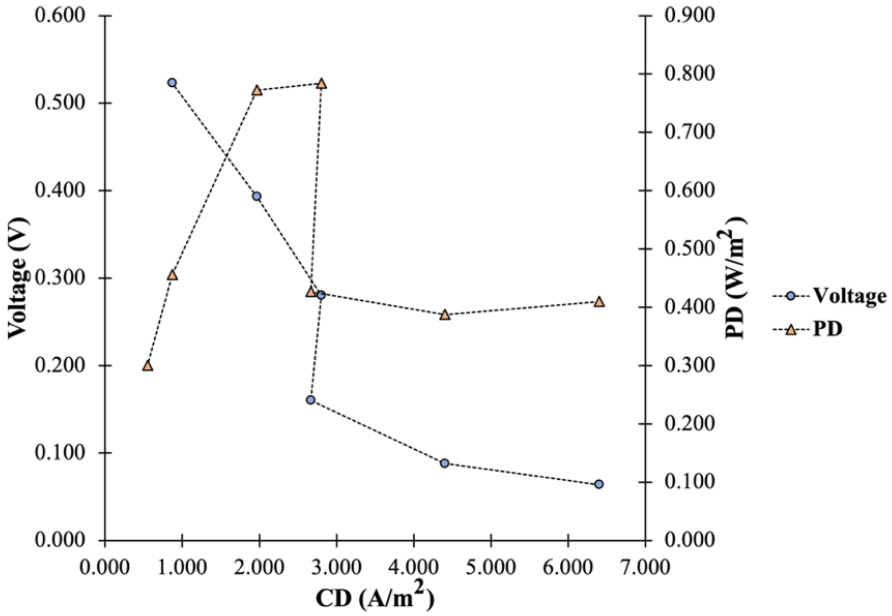


**Figure-10.** The polarization curve of a carbon-capture microbial fuel cell using coconut processing waste as a substrate.

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**Table-4.** Electrochemical properties of carbon capture-microbial fuel cell (p-value = 0.012).

| Electrochemical properties | Value |
|---|---|
| OCV | 697.50±6.22 |
| I (mA) | 1.28±0.02 |
| P (mW) | 0.15±0.01 |
| CD* ($A/m^2$) | 6.40±0.01 |
| CD** ($A/m^3$) | 128.10±0.05 |
| PD* ($W/m^2$) | 0.77±0.02 |
| PD** ($W/m^3$) | 0.78±0.05 |
| $NER_v$ ($KWh/m^3$) | 0.75±0.15 |
| $NER_{COD}$ (KWh/KgCOD) | 37.63±3.00 |

* Based on electrode surface area
** Based on working volume

On the other hand, bacterium *Acetobacter aceti* has been used as a biocatalyst in microbial fuel cells. The winery waste was used as the substrate. A maximum power density of 18.8 $W/m^3$ was achieved when a phosphate buffer was used in the anodic chamber. Potassium ferricyanide was used as the catholyte (Karthikeyan et al., 2016). In Pham et al. (2022), it was reported that the bacterium *Leuconostoc* sp. could utilize glucose to produce electrical energy. Moreover, the bacterium *Leuconostoc* sp. was also found in the microbial consortium, which could convert azo dye into electrical energy using a microbial fuel cell (Tizazu et al., 2023). In Ahirwar et al. (2025), microalgae were used to enhance electricity generation in a microbial fuel cell by supplying electron acceptors at the surface of the cathodic electrode.

## Degraded metabolites

The degraded metabolite from the carbon capture-microbial fuel cell integrated with kombucha starter using the coconut processing waste is shown in the chromatogram (Figure 11). The results showed that the metabolites comprised 2,4,5-trihydroxypyrimidine; cyclotrisiloxane, hexamethyl; cyclopentasiloxane, decamethyl; cyclotetrasiloxane, octamethyl; cyclohexasiloxane, dodecamethyl and n-hexadecanoic acid.

The identification of 2,4,5-trihydroxypyrimidine that is a pyrimidine derivative. It is notable due to the limited literature on its bioactivity in food or fermentation contexts. Pyrimidine-based molecules are known to possess antioxidant and antitumor potential and derivatives have been studied for their antimicrobial and enzyme-inhibitory properties (Fekri et al., 2022). Moreover, cyclotrisiloxane, hexamethyl has been reported to be found in coconut waste. It has potential as a medicinal compound with antioxidant, antitumor, antiseptic and antimicrobial properties (Ismail et al., 2024). Whereas the volatile organic compound cyclotetrasiloxane, octamethyl has been found to be produced by fungal cells and can be used as a plant growth-promoting agent (Joo and Hussein, 2022). In Supriya and Haritha (2022), dodecamethyl cyclohexasiloxane was found in sea lettuce extract and exhibited antifungal activity. Moreover, n-hexadecanoic acid has been found to have high anti-inflammatory potential (Purushothaman et al., 2025). Moreover, n-hexadecenoic acid has been detected in coconut-processing waste, including the tender and mature coconut water by-products of coconut milk production (Jiang et al., 2025).

The 2,4,5-Trihydroxypyrimidine (5-hydroxyuracil) can arise from oxidative degradation of pyrimidine bases. Its presence would suggest nucleic-acid oxidation of microbial DNA damage (Lirussi and Nilsen, 2023).

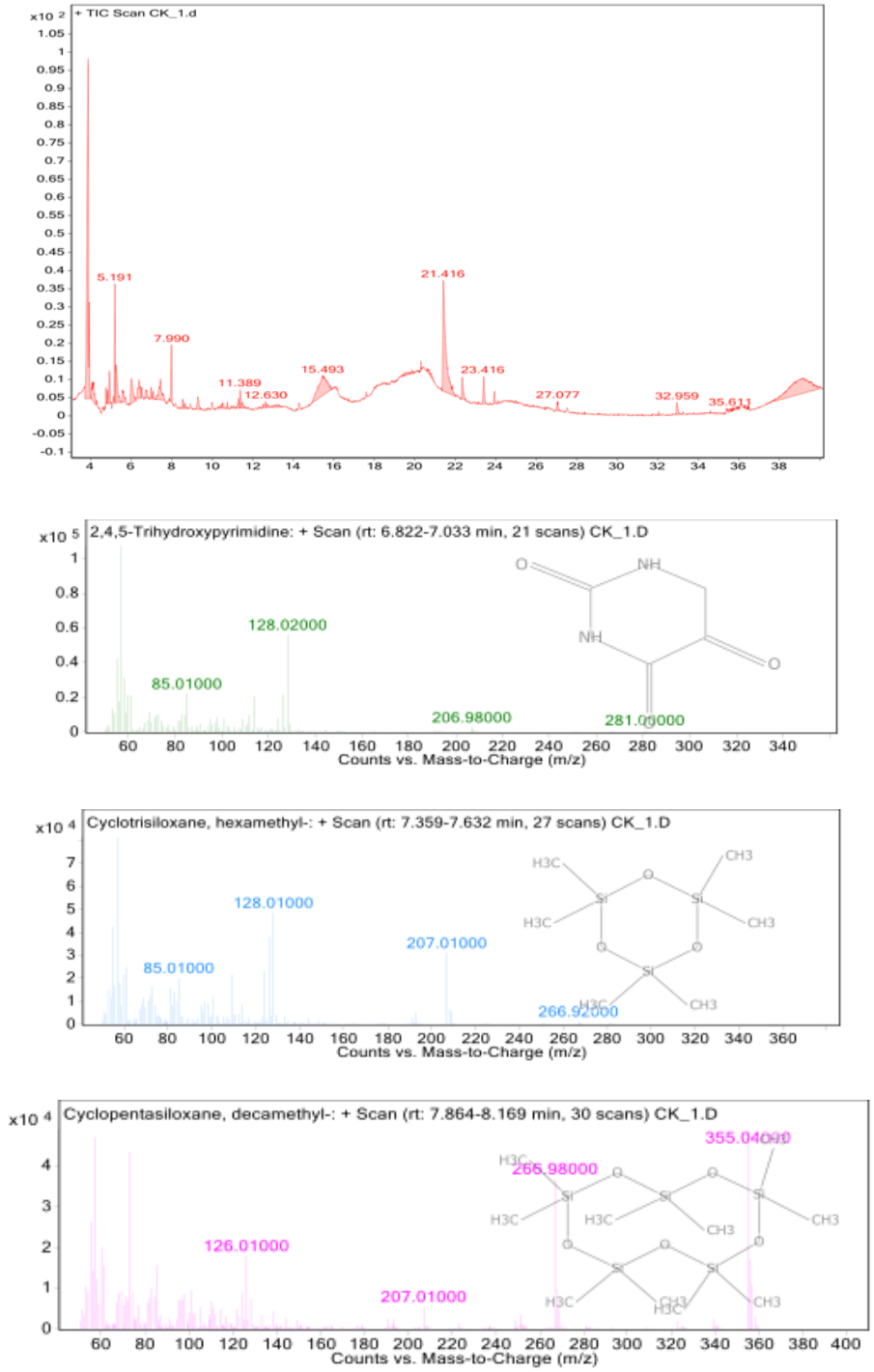


**Figure-11.** The chromatogram of degraded metabolites of carbon capture-microbial fuel cell.

*https://doi.org/10.35495/ajab.2025.258*

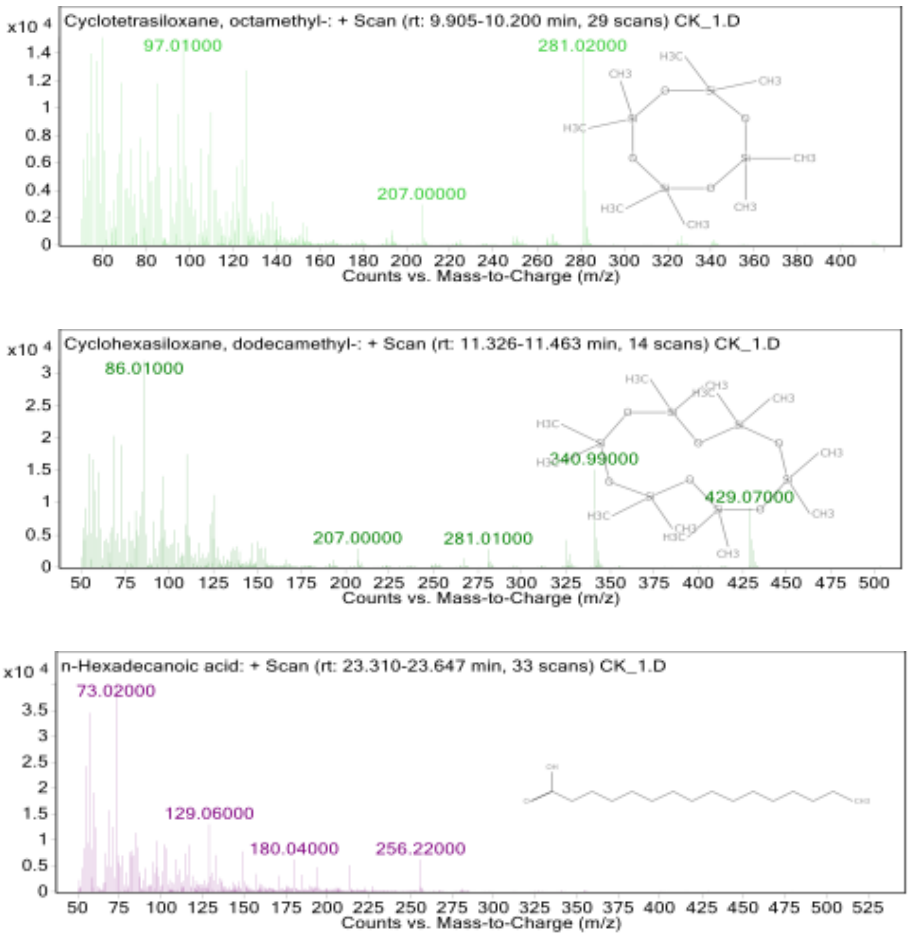


**Figure-11.** The chromatogram of degraded metabolites of carbon capture-microbial fuel cell (Continue).

## By-product yield

The by-products from the carbon capture-microbial fuel cell integrated with a kombucha starter and utilizing coconut processing waste were analyzed. As shown in Figure 12, the microalgae cell yield reached its maximum on day 4 with a value of 0.07 ± 0.00 g/L/day. The carbon capture rate of the microalgae in the cathodic chamber of the carbon capture-microbial fuel cell using carbon dioxide as the sole carbon source for biomass production, is presented in Figure 13. A maximum carbon fixation rate of 0.13 ± 0.00 g/L/day was achieved. The other by-products of the microalgae biomass are shown in Table 5. On the other hand, a carbon fixation rate of 0.03 g/L/day was achieved when the microalgae were cultured in synthetic medium at pH 8 (Yolanda et al., 2025). In Yao et al. (2026), microalgae were synergistically co-cultured with bacteria. The results showed that the maximum carbon fixation rate of 0.6 g/L/day was achieved.

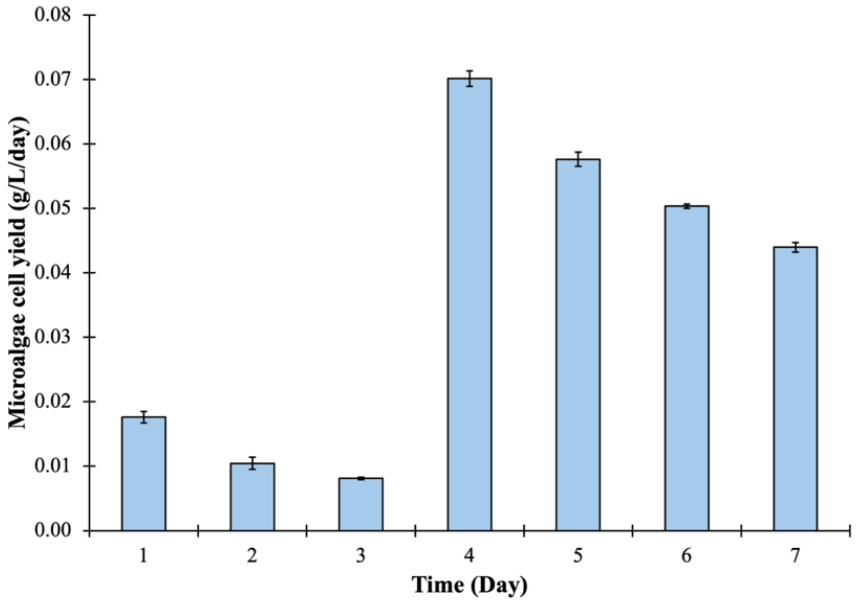


**Figure-12.** The microalgae cell yield produced of carbon capture-microbial fuel cell.

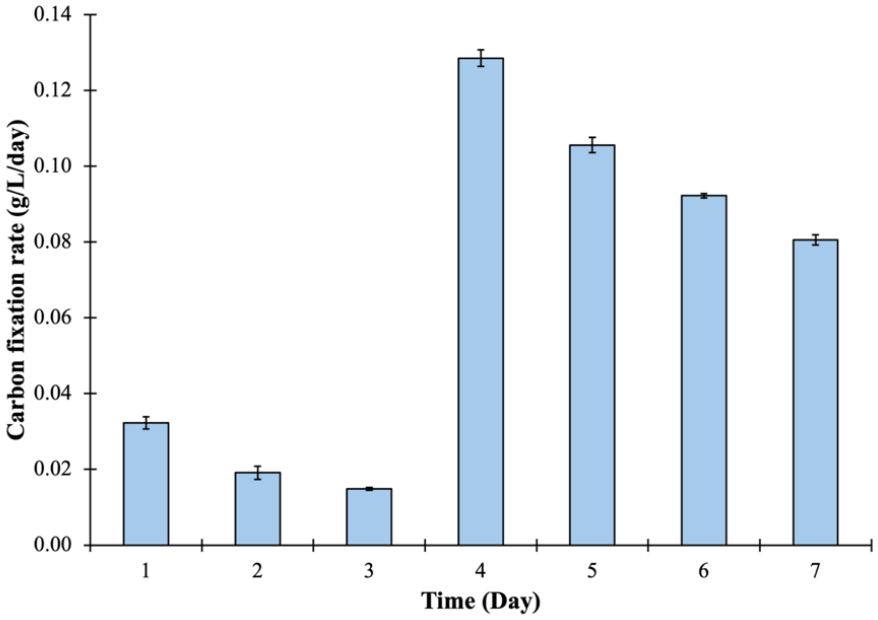


**Figure-13.** The carbon fixation rate of carbon capture-microbial fuel cell (p-value = 0.02).

**Table-5.** The other by-products of the microalgae biomass.

| By-product | Value |
|---|---|
| BNC (g/L) | 3.80±0.26 |
| Chlorophyll A (µg/mL) | 0.31±0.01 |
| Chlorophyll B (µg/mL) | 0.32±0.02 |

https://doi.org/10.35495/ajab.2025.258

After the electricity generation, the BNC was collected from the anodic chamber (Table 4). The BNC productivity rate was evaluated in relation to the incubation time. The maximum BNC productivity rate was 0.54 ± 0.04 g/L/day. On the other hand, the BNC polymer was synthesized from molasses waste utilizing *Komagataeibacter saccharivorans* MD1 as the producing strain and cultured for 7 days. A maximum BNC yield of 3.90 g/L was achieved. However, the corresponding electricity generation performance was not reported (Abol-Fotouh et al., 2020). In Jafari et al. (2024), the BNC polymer was produced from a molasses and cheese whey medium using *Gluconacetobacter hansenii* with ethanol and acetic acid added as supplements. A maximum productivity rate of 0.53 g/L/day was achieved.

Moreover, the biomass extracted from the microalgae cells was analyzed using GC-MS. The chromatogram of the microalgae extract is shown in Figure 14. The results showed that the microalgae extract comprised limonene; Undecane,4,8-dimethyl; n-hexadecanoic acid; octadecanoic acid; tricyclo[(8.6.0.0(2,9)]hexadeca-3,15-diene, trans-2,9-anti-9, 10-trans-1,10; squalene; cholest-5-en-3-ol(3.beta),-carbonochloridate; glycerol tricaprylate; cholesterol; vitamin E; 2-(decanoyloxy)propane-1,3-diyl dioctanoate and alpha-tocopherol acetate.

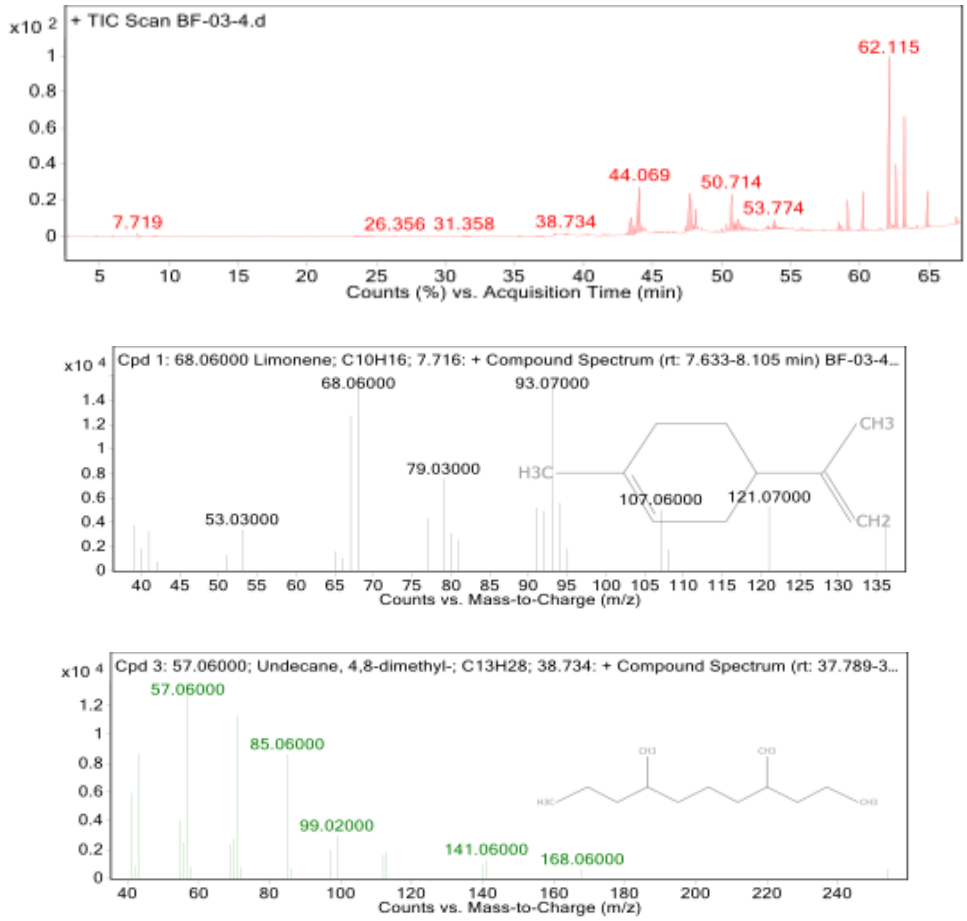


**Figure-14.** The chromatogram of biomass extracted from the microalgae cells.

*https://doi.org/10.35495/ajab.2025.258*

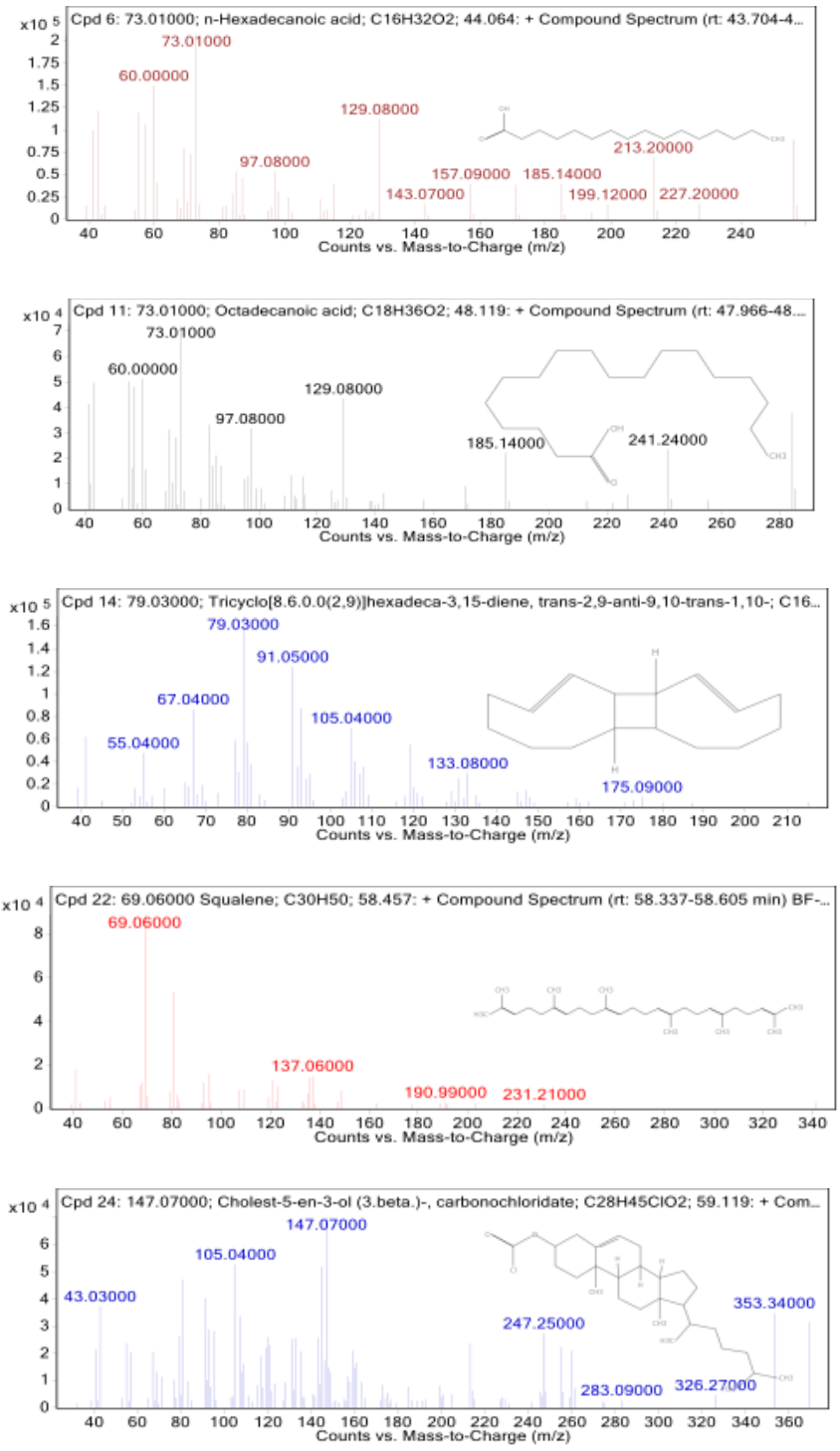


**Figure-14.** The chromatogram of biomass extracted from the microalgae cells (Continue).

*https://doi.org/10.35495/ajab.2025.258*

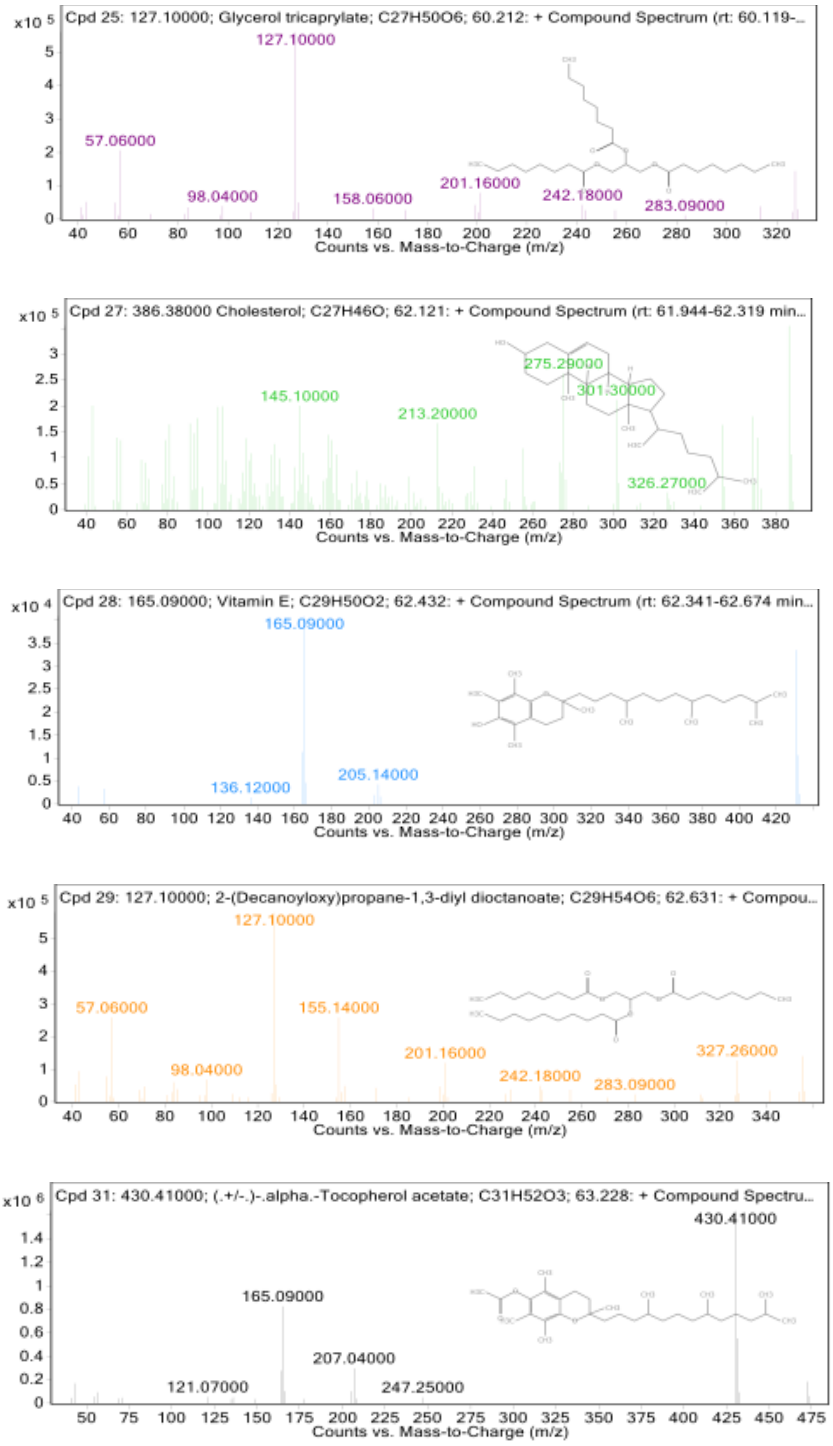


**Figure-14.** The chromatogram of biomass extracted from the microalgae cells (Continue).

On the other hand, limonene was produced by cyanobacteria *Synechocystis* sp. PCC 6803 through the conversion of carbon dioxide (Kiyota et al., 2014). In Songserm et al. (2022), the n-hexadecanoic acid was produced from the microalgae *Scenedesmus falcatus* (KU.B1) and *Chlorella sorokiniana* (KU.B2). Moreover, lipids from the microalga *Chlorella* sp. were extracted and analyzed using GC–MS. Octadecanoic acid was identified as one of the major components (Kaeoboon et al., 2025). In Potijun et al.

(2021), squalene was produced by the green microalga *Chlamydomonas* sp. under outdoor conditions. Furthermore, the vitamin E or tocopherol was identified in the extracted product from the microalgae *Porphyridium* sp. and *Chlorella* sp. (Fithriani and Melanie, 2022).

## Conclusions

This study demonstrates that a kombucha microbial consortium can generate electricity in a carbon-capture microbial fuel cell using coconut processing waste as a substrate. The system supported microalgal metabolic activity that contributed to carbon uptake, and it produced measurable amounts of bacterial nanocellulose and selected bioactive metabolites. These results indicate that the carbon-capture microbial fuel cell can integrate energy generation with biomass and metabolite production under the tested laboratory conditions, providing a foundation for further investigation into its performance and scalability.

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## Contribution of Authors

Thammasorn W & Chaijak P: Conceptualization and methodology.

Rothjanawan K, Siriwong P, Kongthong A & Chaijak P: Data curation and writing - original draft preparation.

Chaijak P: Visualization, investigation writing - reviewing and editing.

Rothjanawan K: Software analysis and validation.

All authors read and approved the final draft of the article.

## References

Aba RPM, Luna MBZ, Villasis JC and Ching AAA, 2024. Characterization of mature coconut water (*Cocos nucifera* L.) water from different varieties. Food & Humanity. 2(1): 100248. doi:https://doi.org/10.1016/j.foohum.2024.100248

Abol-Fotouh D, Hassan MA, Shokry H, Roig A, Azab MS and Kasyout EHB, 2020. Bacterial nanocellulose from agro-industrial wastes: low-cost and enhanced production by *Komataeibacter saccharivorans* MD1. Sci. Rep. 10(1): 3491. doi:https://doi.org/10.1038/s41598-020-60315-9

Ahirwar A, Khan MJ, Khandelwal P, Singh G, Harish H, Vinayak V and Ghangrekar MM, 2025. Bioelectromics of a photosynthetic microalgae assisted microbial fuel cell for wastewater treatment and value added production. Sci. Rep. 15(1): 30196. doi:https://doi.org/10.1038/s41598-025-13271-1

Akintunde MO, Adebayo-Tayo B, Ishola MM, Zamani A and Horvath S, 2022. Bacterial cellulose production from agricultural residues by two *Komagataeibacter* sp. strains. Bioengineered. 13(4): 10010-10025. doi:https://doi.org/10.1080/21655979.2022.2062970

Amin M, Chetpattananondh C, Khan MN, Mushtaq F and Sami SK, 2018. Extraction and quantification of chlorophyll from microalgae *Chlorella* sp. IOP Conf. Ser.: Mater. Sci. Eng. 414(1): 012025. doi:doi:https://doi.org/10.1088/1757-899X/414/1/012025

Amorim JDPD, Junior CJGDS, Medeiros ADMD, Nascimento HAD, Sarubbo M, Medeiros TPMD, Costa AFDS and Sarubbo LA, 2022. Bacterial cellulose as a versatile biomaterial for wound dressing application. Molecules. 27(17): 5580. doi:https://doi.org/10.3390/molecules27175580

Ayyappan VG, Vhatkar SS, Bose S, Sampath S, Das SK, Samanta D and Mandal AB, 2022. Incorporations of gold, silver and carbon nanomaterials to kombucha-derived bacterial cellulose: Development of antibacterial leather-like materials. J. Indian Chem. Soc. 99(1): 100278. doi:https://doi.org/10.1016/j.jics.2021.100278

Bonett JEA, Geraldino PDS, Cardoso PG, Coelho FDF and Duarte WF, 2020. Isolation of freshwater microalgae and outdoor cultivation using cheese whey as substrate. Biocatal. Agric. Biotechnol. 29(1): 101799. doi:https://doi.org/10.1016/j.bcab.2020.101799

Chandra S, Pandit S, Roy A, Rab SO, Roy AK, Saeed M, Kumar A, Sharma K, Ranjan N and Raj S, 2025. Bioenergy recovery from jackfruit waste via biohydrogen production through dark fermentation and power generation through stacked microbial fuel cells. Int. J. Hydrogen Ener. 102(1): 845-855. doi:https://doi.org/10.1016/j.ijhydene.2025.01.044

Chandra S, Pandit S, Deb S, Mohan C, Rajeev M, Ranjan N, Kumar A and Dikshit PK, 2024. Utilization of water chestnut waste for biohydrogen production and enhanced power generation by stacked microbial fuel cell. Biocatal. Agric. Biotechnol. 62(1): 103425. doi:https://doi.org/10.1016/j.bcab.2024.103425

Chausse J, Girard VD, Perron T, Challut T and Vermette P, 2024. Characterization of bacterial cellulose produced by the KomEt strain isolated from a Kombucha SCOBY. Biocatal. Agric. Biotechnol. 58(1): 103172. doi:https://doi.org/10.1016/j.bcab.2024.103172

Cheah WY, Show PL, Juan JC, Chang JS and Ling TC, 2018. Microalgae cultivation in palm oil mill effluent (POME) for lipid production and pollutants removal. Ener. Conv. Manage. 174(1): 430-438. doi:https://doi.org/10.1016/j.enconman.2018.08.057

Christwardana M, Fauziah Z and Sarjono PR, 2025. Investigating the influence of Saccharomyces cerevisiae on microbial fuel cell performance through bioelectrochemical and biochemical approaches under varied operating conditions. Biomass Conv. Bioref. 15(1): 8189-8202. doi:https://doi.org/10.1007/s13399-024-05734-8

Claro AM, Dias IKR, Fontes MDL, Colturata VMM, Lima LR, Savio LB, Berto GL, Arantes V and Barud HDS, 2024. Bacterial cellulose nanocryltals obtained through enzymatic and acidic routes: A comparative study of their main properties and in vitro biological responses. Carbohydr. Res. 539(1): 109104. doi:https://doi.org/10.1016/j.carres.2024.109104

Dasan YK, Lam MK, Lim JW, Tan IS, Foo HCY, Kiew PL, Show PL and Lee KT, 2022. The impact of using recycled culture medium to grow *Chlorella vulgaris* in a sequential flow system: Evaluation on growth, carbon removal, and biochemical compositions. Biomass Bioener. 159(1): 106412. doi:https://doi.org/10.1016/j.biombioe.2022.106412

Din MI, Iqbal M, Hussain Z and Khalid R, 2024. Bioelectricity generation from waste potatoes using single chambered microbial fuel cell. Energy Sources A: Recovery Util. Environ. Eff. 46(1): 12596-12606. doi:https://doi.org/10.1080/15567036.2020.1797944

Fekri A, Keshk EM, Khalil AGM and Taha I, 2022. Synthesis of novel antioxidant and antitumor 5-aminopyrazole derivatives, 2D/3D QSAR, and molecular docking. Mol. Divers. 26(2): 781-800. doi:https://doi.org/10.1007/s11030-021-10184-9

Fithriani D and Melanie S, 2022. Vitamin and mineral content of microalgae *Phorpyridium* and *Chlorella* and development prospects for food raw materials in Indonesia. IOP Conf. Ser.: Earth Environ. Sci. 1034(1): 012043. doi:https://doi.org/10.1088/1755-1315/1034/1/012043

Gerin S and Remacle C, 2024. Efficient secretion of true laccase by the acidophilic green microalgae *Chlamydomonas pitschmannii* switched to alkaline pH. J. Appl. Phycol. 36(1): 2545-2557. doi:https://doi.org/10.1007/s10811-024-03299-7

Harrison K and Curtin C, 2021. Microbial composition of SCOBY starter cultures used by commercial kombucha brewers in North America. Microorganisms. 9(5): 1060. doi:https://doi.org/10.3390/microorganisms9051060

Idris MO, Noh NAM, Ibrahim MNM, Yaqoob AA, Almeer R, Umar K and Guerrero-Barajas C, 2025. Oxidation of vegetable waste and organic pollutant degradation to generate energy through microbial fuel cell. Biomass Conv. Bioref. 15(1): 14159-14177. doi:https://doi.org/10.1007/s13399-024-06125-9

Ismail HF, Akhir FNM, Othman NA and Hara H, 2024. Bioresources of anticancer and potential medicinal compound from coconut waste. J.

Adv. Res. Des. 119(1): 16-26. doi:https://doi.org/10.37934/ard.119.1.1626

Jafari MS, Khan T, Mantripragada S and Lajeunesse DR, 2024. Bacterial nanocellulose production: Improvement in productivity and properties via a sustainable medium. Int. J. Biol. Macro. 283(2): 137607. doi:https://doi.org/10.1016/j.ijbiomac.2024.137607

Jang EJ, Padhan B, Patel M, Pandey JK, Xu B and Patel R, 2023. Antibacterial and biodegradable food packing film from bacterial cellulose. Food Control. 153(1): 109902. doi:https://doi.org/10.1016/j.foodcont.2023.109902

Jiang R, Xue D, Chen Y, Lv X, Ni L and Liu Z, 2025. Comparative study of the fatty acid and phenolic profiles of tender and mature coconut for coconut milk production. Foods. 14(23): 4023. doi:https://doi.org/10.3390/foods14234023

Joo JH and Hussein KA, 2022. Biological control and plant growth promotion properties of volatile organic compound-producing antagonistic *Trichoderma* spp. Front. Plant Sci. 13(1): 897668. doi:https://doi.org/10.3389/fpls.2022.897668

Junmee S, Sittha H, Chusinuan N and Twishsri W, 2021. The study of supply chain model of coconut production in Prachuap Khiri kan, Chumphon and Surat Thani provinces. Thai Agric. Res. J. 39(2): 202-214. doi:https://doi.org/10.14456/thaidoa-agres.2021.17.

Kaeoboon S, Songserm R, Suksungworn R, Duangsrisai S and Sanevas N, 2025. In vitro antioxidant potential, antidiabetic activities, and GC-MS analysis of lipid extracts of *Chlorella* microalgae. Biotech (Basel).14(2): 46. doi:https://doi.org/10.3390/biotech14020046

Karthikeyan R, Krishnaraj N, Selvam A, Wong JWC, Lee PKH, Leung MKH and Berchmans S, 2016. Effect of composites based nickel foam anode in microbial fuel cell using *Acetobacetr aceti* and *Gluconobacter roseus* as a biocatalyst. Bioresour. Technol. 217(1): 113-120. doi:https://doi.org/10.1016/j.biortech.2016.02.114

Kiyota H, Okuda Y, Ito M, Hirai MY and Ikeuchi M, 2014. Engineering of cyanobacteria for the photosynthetic production of limonene from $CO_2$. J. Biotechnol. 185(1): 1-7. doi:https://doi.org/10.1016/j.jbiotec.2014.05.025

Kongthong A, Sola P and Chaijak P, 2025. Polyunsaturated fatty acid (PUFA) production by microalgae using palm oil mill effluent as a substrate under dark stress. Pol. J. Environ. Stud. 34(4): 4481-4487. doi:https://doi.org/10.15244/pjoes/186876

Korojdeh MS, Hadavifar M, Birjandi N, Mehrkhan R and Li Q, 2024. Enhanced bioenergy production through dual-chamber microbial fuel cells: Utilizing citric acid factory wastewater and grape waste as substrates. J. Environ. Manage. 370(1): 122739. doi:https://doi.org/10.1016/j.jenvman.2024.122739

Li Q, Tang R, Zhou H, Hu X and Zhang S, 2023. A high-performance and flexible electrode film based on bacterial cellulose/polypyrrole/nitrogen-doped graphene for supercapacitors. Carbohydr. Polym. 311(1): 120754. doi:https://doi.org/10.1016/j.carbpol.2023.120754

Lim YA, Chong MN, Foo SC and Ilankoon IMSK, 2021. Analysis of direct and indirect quantification methods of $CO_2$ fixation via microalgae cultivation in photobioreactors: A critical review. Renew. Sust. Ener. Rev. 137(1): 110579. doi:https://doi.org/10.1016/j.rser.2020.110579

Lima ASLD, Felipe ATDM, Cruz MEDSD, Junior LSFJ, Junior FCDS, Medeiros FGMD and Pedrini MRDS, 2025. Kombucha fermentation with dried strater cultures: A strategy for microbial stabilization via spray and freeze drying. J. Food Sci. 90(8): e70474. doi:https://doi.org/10.1111/1750-3841.70474

Lirussi L and Nilsen HL, 2023. DNA glycosylases define the outcome of endogenous base mofications. IJMS. 24(12): 10307. doi:https://doi.org/10.3390/ijms241210307

Ojha R and Pradhan D, 2025. The potential of microbial fuel cell for converting waste to energy: An overview. Sustain. Chem. Environ. 9(1): 100196. doi:https://doi.org/10.1016/j.scenv.2024.100196

Oo YY, Su MC and Kyaw KT, 2017. Extraction and determination of chlorophyll content from microalgae. Int. J. Adv. Res. Pub. 1(5): 298-301.

Qin X, Yuan Y, Fei S, Lin X, Shi S, Wang X, Pang Q, Kang J, Li C and Liu S, 2024. Exploring the biotic and abiotic drivers influencing *nata de coco* production by *Komagataeibacter nataicola* in pre-fermented coconut water. Int. J. Food

Microbiol. 414(1): 110620. doi: https://doi.org/10.1016/j.ijfoodmicro.2024.110620

Reva ON, Zaets IE, Ovcharenko LP, Kukharenko OE, Switlana P, Shpylova S, Podolich OV, Vera JPD and Kozyrovska NO, 2015. Metabarcoding of the kombucha microbial community grown in different microenvironments. AMB Express. 5(1): 1-8. doi:https://doi.org/10.1186/s13568-015-0124-5

Rezazadeh M, Babaeipour V and Motamedian E, 2020. Reconstruction, verification and in-silico analysis of a genome-scale metabolic model of bacterial cellulose producing *Komagataeibacter xylinus*. Bioproc. Biosyst. Eng. 43(1): 1017-1026. doi:https://doi.org/10.1007/s00449-020-02299-4

Sato C, Alikaram G, Kolajo OO, Dudgeon J, Hazard R, Apollon W and Kamaraj SK, 2025. An algae cultivator coupled with a hybrid photosynthetic-air-cathode microbial fuel cell with ceramic membrane interface. Membranes. 15(1): 295. doi:https://doi.org/10.3390/membranes15100295

Selaman R, Achoi MF, Nurdik MR and Lepit A, 2025. Effect of different membrane use in micro-bacterical voltaic cell for electrical energy generation from wastewater. Malaysian J. Sustain. Environ. 2025(1): 185-198. doi:https://doi.org/10.24191/myse.v12i2.7077

Singh S, Kirrolia AS, Pannu D and Bishnoi NR, 2025. Exploring the synergy between microbial fuel cells and constructed wetlands in dairy waste water treatment: A comprehensive review. J. Water Proc. Eng. 71(1): 107211. doi:https://doi.org/10.1016/j.jwpe.2025.107211

Sivakorn P, Raumjit N and Sumonrat J, 2023. Farmer satisfaction with coconut cultivation: A case study in the upper southern region of Thailand. Int. J. Agric. Technol. 19(3): 1327.

Songserm R, Kaeoboon S, Suksungworn R, Duangsrisai S and Sanevas N, 2022. GC-MS profiling, anti-oxidant and anti-diabetic assessments of extracts from *microalgae Scenedesmus falcatus* (KU.B1) and *Chlorella sorokiniana* (KU.B2). Plant Sci Today. 9(3): 632-641. doi: https://doi.org/10.14719/pst.1560

Supriya P and Haritha N, 2022. Bioactive compound produced by *Ulva lactuca* and antifunal activity against pathogenic fungi. Int. J. Emerg. Technol. Innov. Res. 2(2): 15-22.

Tizazu S, Tesfaye G, Wang A, Guadie A and Andualem B, 2023. Microbial diversity, transformation and toxicity of azo dye biodegradation using thermos-alkaliphilic microbial consortia. Heliyon. 9(1): e16857. doi:https://doi.org/10.1016/j.heliyon.2023.e16857

Tsai DDW, Ramaraj R, Unpaprom Y, Bhuyar P, Ramaraj R and Chen PH, 2023. Autotrophic production of bio-functional protein from freshwater microalgae using natural water medium for an economical and ecofriendly approach. Maejo Int. J. Energ. Environ. Comm. 5(2): 29-34. doi:https://doi.org/10.54279/mijeec.v5i2.250835

Pham MT, Tran TD and Zayabaatar E, 2022. Leuconostoc mesenteroides utilizes glucose fermentation to produce electricity and ameliorates high-fat diet-induced abdominal fat mass. Arch. Microbiol. 204(1): 670. doi:https://doi.org/10.1007/s00203-022-03281-2

Phatchayawat P, Khamkeaw A, Yodmuang S and Phisalaphong P, 2022. 3D bacterial cellulose-chitosan-alginate-gelatin hydrogel scafford for cartilage tissue engineering. Biochem. Eng. J. 184(1): 108476. doi:https://doi.org/10.1016/j.bej.2022.108476

Potijun S, Jaingam S, Sanevas N, Vajrodaya S and Sirikhachonkit A, 2021. Green microalgae strain improvement for the production of sterols and squalene. Plant. 10(8): 1673. doi:https://doi.org/10.3390/plants10081673

Purushothaman R, Vishnuram G and Ramanathan T, 2025. Antiinflammatory efficacy of n-hexadecanoic acid from a mangrove plant *Excoecaria agallocha* L. through in silico, in vitro and in vivo. Pharmacol. Res. 7(1): 100203. doi:https://doi.org/10.1016/j.prenap.2025.100203

Venegas CA, Saona LA, Urbina K, Quintrel P, Pena TA, Mardones W and Cubillos FA, 2023. Addition of *Saccharomyces eubayanus* to SCOBY fermentations modulates the chemical and volatile compound profiles in kombucha. Food Microbiol. 116(1): 104357. doi:https://doi.org/10.1016/j.fm.2023.104357

Villarreal-Soto S, Bouajila J, Pace M, Leech J, Cotter PD, Souchard JP, Taillandier P and Beaufort S, 2020. Metabolome-microbiome signatures in the fermented beverage, Kombucha. Int. J. Food Microbiol. 333(1): 108778. doi:https://doi.org/10.1016/j.ijfoodmicro.2020.108778

Wang B, Rutherfurd-Markwick K, Naren N, Zhang XX and Mutukumira AN, 2023. Microbiological and physico-chemical characteristics of black tea kombucha fermented with a New Zealand starter culture. Foods. 12(12): 2314. doi:https://doi.org/10.3390/foods12122314

Wasimuddin W, Schlaeppi K, Ronchi F, Leib S, Erb M and Ramette A, 2020. Evaluation of primer pairs for microbiome profiling from soils to humans within the one health framework. Mol. Ecol. Resour. 20(6):1558-1572. doi:https://doi.org/10.1111/1755-0998.13215

Yadav S, Doki MM, Ghangrekar M and Dubey BK, 2024. Postliminary treatment of food-waste digestate via combined hydrothermal carbonization and microbial fuel cell for bio-energy recovery: a comparative life cycle impact assessment. Green Chem. 26(1): 11673-11685. doi:https://doi.org/10.1039/D4GC04081C

Yao D, Li Y, Han Z, Tan D, Wang M, Deng H, Wang H and Liu Y, 2026. Enhancement of microalgal carbon fixation via synergistic interactions with a facultative autotrophic bacterium *Cytobacillus* KQ-2. Bioresour. Technol. 439(1): 133310. doi:https://doi.org/10.1016/j.biortech.2025.133310

Yao L, Zhang J, Lu J, Chen D, Song S, Wang H, Sun M and Feng T, 2023. Revealing the influence of microbiota on the flavor of kombucha during natural fermentation process by metagenomic and GC-MS analysis. Food Res. Int. 169(1): 112909. doi: https://doi.org/10.1016/j.foodres.2023.112909

Yang YW, Li MJ and Hung TC, 2024. The study on coupled $CO_2$ fixation and power generation in microalgae-microbial fuel cells embedded with oxygen-consuming biofilms. Fuel. 367(1): 131410. doi: https://doi.org/10.1016/j.fuel.2024.131410

Yolanda YD, Kim S, Sohn W, Shon HK, Yang E and Lee S, 2025. Simultaneous nutrient-abundant hydroponic wastewater treatment, direct carbon capture, and bioenergy harvesting using microalgae-microbial fuel cells. Desalin. Water Treat. 321(1): 100941. doi:https://doi.org/10.1016/j.dwt.2024.100941

Yin X, Liu L, Shao W, Ai M and Liang G, 2024. High-performance bacterium-enhanced dual-compartment microbial fuel cells for simultaneous treatment of food waste oil and copper-containing wastewater. Sci. Rep. 14(1): 23244. doi:https://doi.org/10.1038/s41598-024-74856-w

Yodrach R, Rattanabundan P and Chaijak P, 2025. Simultaneous electricity generation and bacterial nanocellulose (BNC) production from mature coconut water (MCW) waste. J. Degrad. Min. Lands Manag. 12(4): 8015-8021. doi:https://doi.org/10.15243/jdmlm.2025.124.8015

Zhang X, Zhang J, Jiang L, Yu X, Zhu H, Zhang J, Feng Z, Zhang X, Chen G and Zhang Z, 2021. Black soldier fly (*Hermetia illucens*) larvae significantly change the microbial community in chicken manure. Curr. Microbiol. 78(1): 303-315. doi:https://doi.org/10.1007/s00284-020-02276-w