Available online at www.sciencedirect.com
ScienceDirect
Energy Reports 8 (2022) 376–382
www.elsevier.com/locate/egyr

TMREES22-Fr, EURACA, 09 to 11 May 2022, Metz-Grand Est, France

Bioelectricity through microbial fuel cells using avocado waste

S. Rojas-Flores[a,*], M. De La Cruz-Noriega[a], R. Nazario-Naveda[a], Santiago M. Benites[a], D. Delfín-Narciso[b], W. Rojas-Villacorta[c], Cecilia V. Romero[d]

[a] Vicerrectorado de Investigación, Universidad Autónoma del Perú, Lima 15842, Peru
[b] Grupo de Investigación en Ciencias Aplicadas y Nuevas Tecnologías, Universidad Privada del Norte, Trujillo, 13007, Peru
[c] Escuela de Postgrado, Universidad Nacional de Trujillo, Trujillo 13001, Peru
[d] Facultad de medicina, Universidad Nacional de Trujillo, Trujillo 13001, Peru

Received 10 June 2022; accepted 25 June 2022
Available online xxxx

Abstract

The dumping of organic waste in the areas surrounding food supply centers and the excessive use of fossil fuels for energy generation have generated major pollution problems worldwide. One of the novel solutions is the use of organic waste for electricity generation through the use of microbial fuel cell technology. In this research, low-cost, laboratory-scale, double-chamber microbial fuel cells were fabricated using zinc and copper as electrodes and avocado waste as fuel. Current and voltage values of 3.7326 ± 0.05568 mA and 0.74 ± 0.02121 V were achieved on the seventh day, with an optimum operating pH of 5.98 ± 0.16 and a maximum electrical conductivity of 94.46 ± 5.12 mS/cm. The cells showed a very low operating resistance of 71.480 Ω, indicating the good electrical conductivity of the electrodes. Likewise, a power density of 566.80 ± 13.48 mW/cm^2 at a current density of 5.165 A/cm^2 was generated. This research provides an eco-friendly solution to farmers and companies dedicated to the export and import of this fruit because it shows the benefits of using their own waste for the generation of electricity, reducing costs.

Peer-review under responsibility of the scientific committee of the TMREES22-Fr, EURACA, 2022.

Keywords: Microbial fuel cells; Organic waste; Avocado; Generation; Electric current

1. Introduction

Environmental pollution due to the excessive use of fossil fuels to generate energy has become one of the main problems worldwide, due to the release of polluting gases (CO_2, CH_4, N_2O, and others). On some occasions, pollution levels can reach levels above normal causing a reduction in the quality of our environment [1]. Despite the efforts made to reduce the impact of pollution, this problem is increasing and is not adequately addressed. Moreover, it is an issue that is neglected in many agendas of international development and global health, as well as in the planning strategies of many countries [2,3]. On the other hand, organic waste produced in rural and agro-industrial

* Corresponding author.
E-mail address: segundo.rojas.89@gmail.com (S. Rojas-Flores).

https://doi.org/10.1016/j.egyr.2022.06.100

Peer-review under responsibility of the scientific committee of the TMREES22-Fr, EURACA, 2022.

areas represents a kind of contamination that is not adequately managed. In some cases, organic waste makes up half of all municipal solid waste, and most of the time it is disposed of in open dumps or "landfills", where decomposition leads to the release of some greenhouse gases [4,5]. Agro-industrial waste (pulps, stalks, seeds, peels, etc.) is generated at different stages of agricultural and industrial operations [6].

One of the tropical fruits that has become increasingly consumed in many parts of the world is the *Persea Americana* (Laureacea family) known as *aguacate* or *palta* in Latin America. Peru is the third country below Mexico and the Dominican Republic in avocado exports (with 745.7 million dollars in 2019) and mainly supplies Europe [7–9]. However, avocado cultivation leads to a consensus regarding its environmental impact, due to the large amount of water required for this crop [7]. On the other hand, due to the increase in its production, a greater amount of waste of this fruit was generated. In general, the pulp is the most consumed part and the peel, stone or seed, and leaf are discarded, which can be accumulated. This situation is a matter of concern, not only for avocado waste but for all the agro-industrial organic waste that is generated and accumulated around the world, hurting the environment [10–12].

There are two methods of organic waste treatment, anaerobic digestion and composting, which have advantages and limitations in their operational aspects [13,14]. Because of this, eco-friendly proposals that can take advantage of the energy contained in organic waste, such as emerging technologies, are being developed. In this sense, microbial fuel cells (MFCs) are a promising technology for the treatment of organic waste and have the potential to counteract the impact of the energy crisis and environmental pollution [15]. These cells consist of bioelectrochemical devices that convert the chemical energy contained in organic and inorganic matter into electric current by using microorganisms as catalysts [16]. It is generally composed of two chambers (anodic and cathodic) almost always separated by a proton exchange membrane, with electrodes inside them connected by an external circuit. The organic substrates are placed inside the chambers and can be vegetable waste or any type of organic matter. For this reason, this technology can be considered as one based on a circular economy since it uses renewable bio-waste, i.e. it is environmentally sustainable energy [17,18].

For example, Rahman et al. (2021) used mango, banana, and orange waste as substrate in their single-chamber fuel cells, achieving peak voltages of 0.350 V for the orange substrate and adding glucose at 0.5 V [19]. Likewise, Kondaveeti et al. (2019) used citrus peels as substrates in their single-chamber cells managing to generate 0.250 V and 72 mW/cm^2 voltage and power density, respectively, mentioning that the use of a proton exchange membrane would increase the power density values [20]. Prasidha and Majid (2020) used food waste leachates as substrate in their double-chamber fuel cells, managing to generate 0.410 V and 0.23 mA/cm^2 voltage and current density, concluding that aeration of the cathode chamber increases the energy values [21]. In this sense, the agro-industrial residues of *P. Americana* have already been addressed because they represent a large amount of lignocellulosic biomass, becoming a source of raw material with different technological applications in different economic and environmental sectors [22]. And, these, in turn, are candidate substrates for MFCs to generate bioelectricity, since avocado peels may contain certain amounts of polyphenolic compounds [23].

The main objective of this research is to generate bioelectricity and to produce laboratory-scale, double-chamber microbial fuel cells using zinc and copper as electrodes, monitoring their voltage, current, pH, conductivity, power density, and current density values for 35 days, giving to the waste of this fruit a second beneficial use for the exporting and importing companies dedicated to this field.

2. Materials and methods

2.1. Construction of single-chamber microbial fuel cells

Two 1-L airtight polyethylene containers were used as anodic and cathodic chambers for each cell (3 MFCs in total). In the center of each chamber, 2.5 cm diameter holes were drilled on one side of each chamber for the passage of the proton exchange membrane (10 mL of the concentration of 6 g of KCl plus 14 g of agar and 400 mL of H_2O was used), which was placed inside a 10 cm long polyvinyl chloride tube. In each chamber, a hole was drilled in the center for the passage of the conductive wire (copper of 1.5 mm diameter) that connected the electrodes inside the chambers with the external resistor of 100 Ω. The electrodes used were made of zinc and copper, 100 cm^2 and 3.5 mm thick (see Fig. 1).

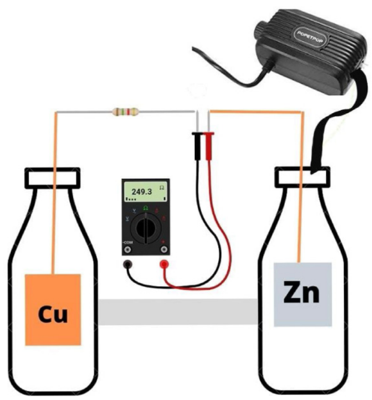

Fig. 1. Microbial fuel cell prototype.

2.2. Avocado waste collection and preparation

The organic waste of avocado (*Persea Americana*) was collected from La Hermelinda Market, Trujillo, Peru; which was washed four times with distilled water to eliminate any type of impurity (dust, insects, or other impurities), left to dry in an oven (Labtron, LDO-B10)) for 24 h at 30 ± 1 °C. With an extractor (Maqorito-400 rpm), 500 mL (150 mL for each MFC) of avocado extract was obtained.

2.3. Characterization of microbial fuel cells

Daily current and voltage monitoring was performed using a Prasek Premium PR-85 multimeter and an external resistor of 100 Ω. On the other hand, current density (CD) and power density (PD) values were measured using external resistors 10 ± 0.2, 40 ± 2.3, 50 ± 2.7, 100 ± 3.2, 300 ± 6.2, 390 ± 7.2, 560 ±10, 680± 12. 3, 820 ± 14.5, 1000 ±20.5 Ω; by the formula CD = I/A and PD=IV/A [24], where I is current with different external resistors, V is the voltage of open-circuit cells, and A the area (144 ± 5.2 cm^2). Conductivity (conductivity meter CD-4301) and pH (pH meter 110 Series Oakton) changes were also measured, and the resistance values of MFCs were measured using an energy sensor (Vernier- ± 30 V & ± 1000 mA).

3. Results and analysis

Fig. 2(a) shows the values of the voltage generated during the 35 monitoring days, which increase from the first day (0.187 ± 0.0037 V) to the seventh day (0.74 ± 0.02121 V) and then slowly decay until the last day (0.15624 ± 0.06419 V). Fig. 2(b) shows the current values generated during the monitoring period, indicating an increase from the first day with a value of 2.21307 ± 0.03512 mA to 3.7326 ± 0.05568 mA on the seventh day, and then falling until the last day (1.23939 ± 0.0932 mA). The high values generated are mainly due to the good adhesion between the anodic electrode and the microbes present on the substrate, which had a rapid adhesion because its maximum peak was on the seventh day. After that, the substrate degradation and the metallic material used could generate current losses [25–27]. The adverse effects of metal electrodes can be counteracted by coating the electrode with carbon or another material non-toxic to microorganisms [28].

Fig. 3 (a) shows the pH values of microbial fuel cells during the 35 monitoring days, showing variations from slightly acidic to slightly alkaline levels, with an optimum operating pH of 5.98 ± 0.16. The pH values influence the metabolism of the energy-generating microorganisms. Therefore, for values higher than approximately 6 for this type of cell, the voltage values generated decrease, which would suggest stabilizing by adding some chemical compound [29]. These results agree with Javed et al. (2021) showing that for low pH the power is higher and vice versa [30]. Similarly, Fig. 3 (b) shows values of the electrical conductivity of the substrate, with maximum peaks of approximately 94.46 ± 5.12 mS/cm on the ninth day and then decreasing steadily until the last day (23.24936 ± 4.5 mS/cm). Variations in the electrical conductivity values are due to the sedimentation of the substrate over time, where the substrate loses components in the process of electricity generation [31].

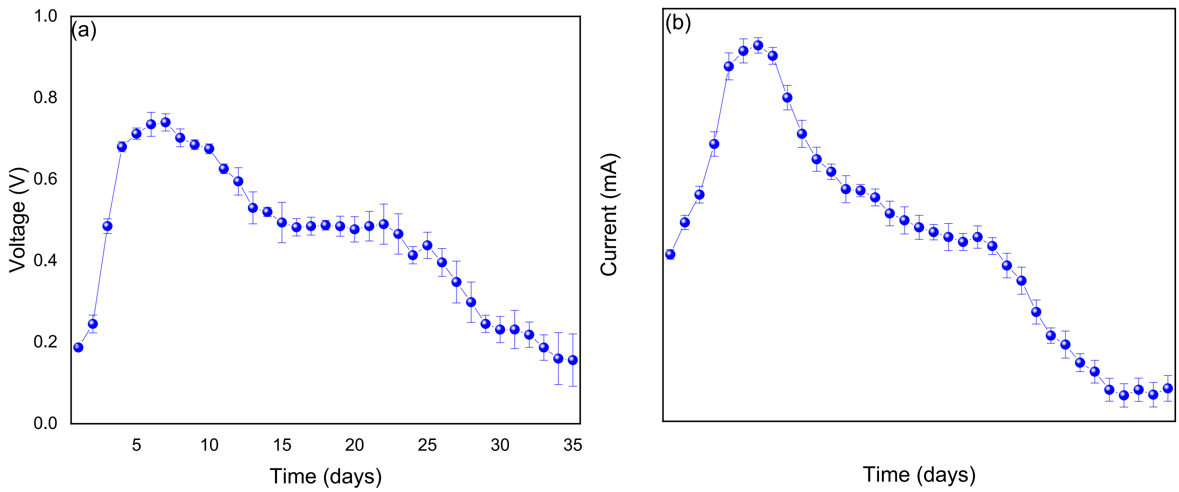

Fig. 2. Values of (a) voltage and (b) electric current of microbial fuel cells during monitoring.

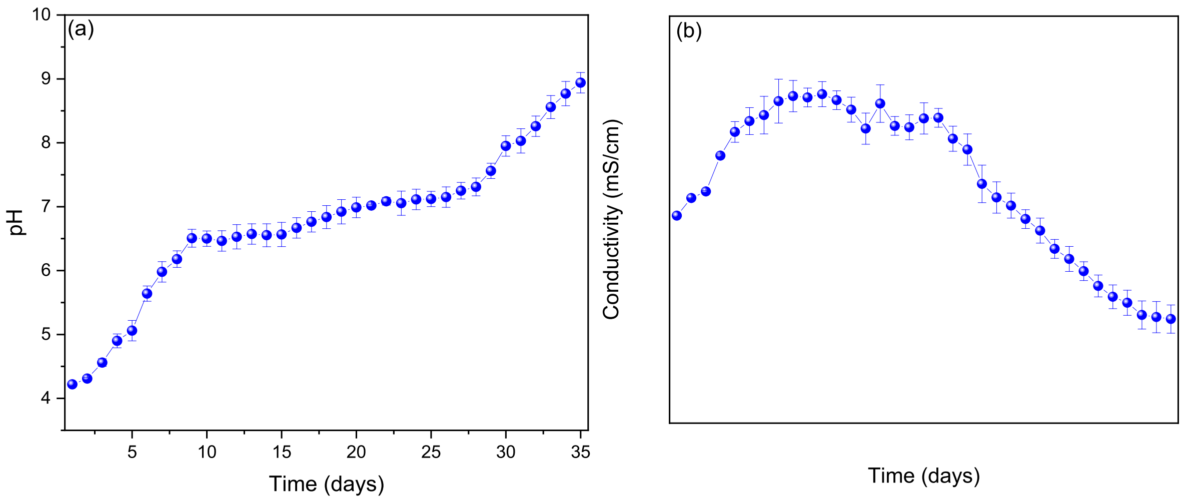

Fig. 3. Values of (a) pH and (b) electrical conductivity of microbial fuel cells during monitoring.

Fig. 4 (a) shows the modeling of Ohm's Law, which can be described by multiplying current (I) by resistance (R) to obtain the voltage (V), i.e., V = IR. In this sense, current values were assigned to the x-axis, while the potential was assigned to the y-axis. The experimental data fit the equation $y = 0.07148x + 4.1221$ with R2 = 0.028. The slope of the graph represents the average resistance of the microbial fuel cells (71.480 Ω). This low resistance shown is due to the good adhesion of microorganisms with the anode electrode and confirms the high values of current shown by the cells [32]. Likewise, metallic electrodes are characterized by their low resistance to the passage of electrons, which favored the production of energy [33]. Fig. 4 (b) shows the values of power density (PD) and voltage according to the current density (CD), achieving a $PD_{MAX.}$ of 566.80 ± 13.48 mW/cm^2 at a CD of 5.165 A/cm^2 and a peak voltage of 676.50 ± 18.1 V. The PD values shown in this work are very close to the values obtained by Mosqsud et al. (2014) who used chicken waste managing to generate a PD of 60 mW/cm^2 and 40 mW/cm^2 for bamboo waste. This high value obtained is mainly due to the high content of microorganisms found in these wastes [34]. Meanwhile, the values found by Kamau et al. (2018) are very low compared to those of our research, because it used combined melon, banana, mango, and tomato wastes, but with carbon electrodes with a high internal resistor (45 kΩ), generating a PD of 13 mW/cm^2 [35].

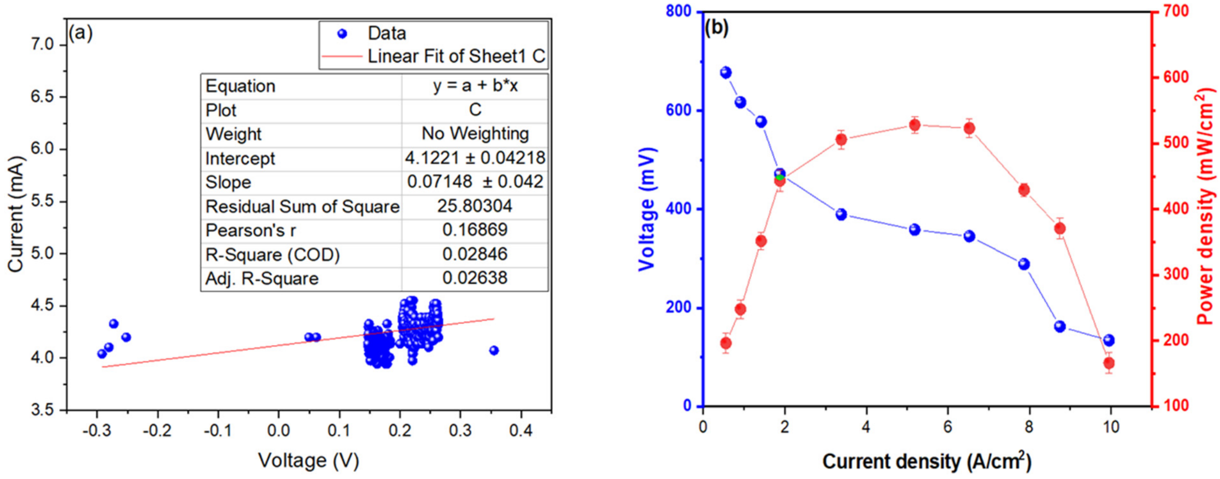

Fig. 4. Values of (a) internal resistance and (b) power density and current density of microbial fuel cells.

4. Conclusions

Bioelectricity was successfully generated through laboratory-scale, double-chamber microbial fuel cells using avocado waste as fuel (substrate). It was possible to generate 0.74 ± 0.02121 V and 3.7326 ± 0.05568 mA voltage and current, respectively, on the seventh day, with an optimum operating pH of 5.98 ± 0.16, while the electrical conductivity of the substrate increased from the first day to 94.46 ± 5.12 mS/cm on the ninth day. Resistance was calculated by using the Ohm's law, whose slope of the obtained graph was 71.480 Ω. This value was one of the main characteristics of the high electrical values. Likewise, the maximum power density was found to be 566.80 ± 13.48 mW/cm^2 at a current density of 5.165 A/cm^2 and a peak voltage of 676.50 ± 18.1 mV. This work gives an excellent beginning for future research on the use of this substrate and its capacity to improve the electrical properties, using electrodes coated with chemical compounds to increase the performance or adding to the substrate some other element to delay the degradation and stabilize the pH values. Meanwhile, in the economic-social aspect, this work shows a promising vision for agro-industrial companies in which the use of their waste may bring benefits by generating their own electricity and taking care of the environment.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Rojas-Flores S. reports article publishing charges was provided by Vicerrectorado de InvestigaciónUniversidad Autónoma del Perú, Lima 15842, Peru. Rojas Flores Segundo reports a relationship with Vicerrectorado de InvestigaciónUniversidad Autónoma del Per'u, Lima 15842, Peru that includes: non-financial support. Rojas Flores Segundo NOT has patent pending to rojas flores segundo jonathan. rojas flores segundo -autor.

Data availability

Data will be made available on request.

References

[1] Manisalidis I, Stavropoulou E, Stavropoulos A, Bezirtzoglou E. Environmental and health impacts of air pollution: A review. Front Public Health 2020;8(February):1–13. http://dx.doi.org/10.3389/fpubh.2020.00014.

[2] Landrigan PJ, Fuller R, Hu H, Caravanos J, Cropper ML, Hanrahan D, Sandilya K, Chiles TC, Kumar P, Suk WA. Pollution and global health – An agenda for prevention. Environ Health Perspect 2018;126(8):084501. http://dx.doi.org/10.1289/EHP3141.

[3] Yadav P, Singh J, Srivastava DK, Mishra V. Environmental pollution and sustainability. In: Environmental Sustainability and Economy. Elsevier; 2021, p. 111–20. http://dx.doi.org/10.1016/B978-0-12-822188-4.00015-4.

[4] Chavan D, Arya S, Kumar S. Open dumping of organic waste: Associated fire, environmental pollution, and health hazards. Adv Org Waste Manag 2022;15–31. http://dx.doi.org/10.1016/B978-0-323-85792-5.00014-9.

[5] Ferronato N, Torretta V. Waste mismanagement in developing countries: A review of global issues. Int J Environ Res Public Health 2019;16(6):1060. http://dx.doi.org/10.3390/ijerph16061060.
[6] Sadh PK, Duhan S, Duhan JS. Agro-industrial wastes and their utilization using solid-state fermentation: A review. Bioresour Bioprocess 2018;5(1):1. http://dx.doi.org/10.1186/s40643-017-0187-z.
[7] Esteve-Llorens X, Ita-Nagy D, Parodi E, González-García S, Moreira MT, Feijoo G, Vázquez-Rowe I. Environmental footprint of critical agro-export products in the peruvian hyper-arid coast: A case study for green asparagus and avocado. Sci Total Environ 2021;xxxx:151686. http://dx.doi.org/10.1016/j.scitotenv.2021.151686.
[8] Giuggioli NR, Chiaberto G, Da Silva TM. Quality evaluation of the ready-to-eat avocado cv. Hass. Int J Food Sci 2021;2021. http://dx.doi.org/10.1155/2021/6621449.
[9] Sommaruga R, Eldridge HM. Avocado production: Water footprint and socio-economic implications. EuroChoices 2021;20(2):48–53. http://dx.doi.org/10.1111/1746-692X.12289.
[10] García-Vargas MC, Contreras MDM, Castro E. Avocado-derived biomass as a source of bioenergy and bioproducts. Appl Sci 2020;10(22):8195. http://dx.doi.org/10.3390/app10228195.
[11] Marcos CN, Carro MD, Fernández-Yepes JE, Arbesu L, Molina-Alcaide E. Utilization of avocado and mango fruit wastes in multi-nutrient blocks for goats feeding: In vitro evaluation. Animals 2020;10(12):2279. http://dx.doi.org/10.3390/ani10122279.
[12] Pineda-Lozano JE, Martínez-Moreno AG, Virgen-Carrillo CA. The effects of avocado waste and its functional compounds in animal models on dyslipidemia parameters. Front Nutr 2021;8(February). http://dx.doi.org/10.3389/fnut.2021.637183.
[13] Atelge MR, Krisa D, Kumar G, Eskicioglu C, Nguyen DD, Chang SW, Atabani AE, Al-Muhtaseb AH, Unalan S. Biogas production from organic waste: Recent progress and perspectives. Waste Biomass Valorization 2020;11(3):1019–40. http://dx.doi.org/10.1007/s12649-018-00546-0.
[14] Cremonez PA, Teleken JG, Weiser Meier TR, Alves HJ. Two-stage anaerobic digestion in agroindustrial waste treatment: A review. J Environ Manag 2021;281(2020):111854. http://dx.doi.org/10.1016/j.jenvman.2020.111854.
[15] Hoang AT, Nižetić S, Ng KH, Papadopoulos AM, Le AT, Kumar S, Hadiyanto H, Pham VV. Microbial fuel cells for bioelectricity production from waste as a sustainable prospect for future energy sector. Chemosphere 2022;2872021. http://dx.doi.org/10.1016/j.chemosphere.2021.132285.
[16] Singh L, Kalia VC. Waste biomass management – A holistic approach. In: Singh L, Kalia VC, editors. Waste biomass management - A holistic approach. Springer International Publishing; 2017, http://dx.doi.org/10.1007/978-3-319-49595-8.
[17] Deng L, Ngo HH, Guo W, Chang SW, Nguyen DD, Pandey A, Varjani S, Hoang NB. Recent advances in circular bioeconomy based clean technologies for a sustainable environment. J Water Process Eng 2022;46(January):102534. http://dx.doi.org/10.1016/j.jwpe.2021.102534.
[18] Jatoi AS, Akhter F, Mazari SA, Sabzoi N, Aziz S, Soomro SA, Mubarak NM, Baloch H, Memon AQ, Ahmed S. Advanced microbial fuel cell for wastewater treatment—A review. Environ Sci Pollut Res 2021;28(5):5005–19. http://dx.doi.org/10.1007/s11356-020-11691-2.
[19] Rahman W, Yusup S, Mohammad SA. Screening of fruit waste as substrate for microbial fuel cell (MFC). In: AIP conference proceedings, Vol. 2332, (1). AIP Publishing LLC; 2021, 020003.
[20] Kondaveeti S, Mohanakrishna G, Kumar A, Lai C, Lee JK, Kalia VC. The exploitation of citrus peel extract as a feedstock for power generation in microbial fuel cell (MFC). Indian J Microbiol 2019;59(4):476–81.
[21] Prasidha W, Majid AI. Electricity production from food waste leachate using a double chamber microbial fuel cell. J Penelitian Saintek 2020;25(1):95–102.
[22] Ben-Othman S, Jõudu I, Bhat R. Bioactives from agri-food wastes: Present insights and future challenges. Molecules 2020;25(3):510. http://dx.doi.org/10.3390/molecules25030510.
[23] Hsueh C-C, Wu C-C, Chen B-Y. Polyphenolic compounds as electron shuttles for sustainable energy utilization. Biotechnol Biofuels 2019;12(1):271. http://dx.doi.org/10.1186/s13068-019-1602-9.
[24] Rojas-Flores S, Benites SM, Cruz-Noriega DLa, Cabanillas-Chirinos L, Valdiviezo-Dominguez F, Quezada Álvarez MA, Angelats-Silva L. Bioelectricity production from blueberry waste. Processes 2021;9(8):1301.
[25] Obileke K, Onyeaka H, Meyer EL, Nwokolo N. Microbial fuel cells, a renewable energy technology for bioelectricity generation: A mini-review. Electrochem Commun 2021;125:107003.
[26] Savla N, Anand R, Pandit S, Prasad R. Utilization of nanomaterials as anode modifiers for improving microbial fuel cells performance. J Renew Mater 2020;8(12):1581–605.
[27] Rusyn IB, Medvediev OV, Valko BT. Enhancement of bioelectric parameters of multi-electrode plant–microbial fuel cells by combining serial and parallel connections. Int J Environ Sci Technol 2021;18(6):1323–34.
[28] Elshobary ME, Zabed HM, Yun J, Zhang G, Qi X. Recent insights into microalgae-assisted microbial fuel cells for generating sustainable bioelectricity. Int J Hydrogen Energy 2021;46(4):3135–59.
[29] Halim MA, Rahman MO, Ibrahim M, Kundu R, Biswas B. Study of the effect of pH on the performance of microbial fuel cells for generation of bioelectricity. 2021.
[30] Javed MM, Nisar MA, Ahmad MU. Effect of NaCl and pH on bioelectricity production from vegetable waste extract supplemented with cane molasses in dual chamber microbial fuel cell. 2021.
[31] Segundo RF, La Cruz-Noriega D, Milly Otiniano N, Benites SM, Esparza M, Nazario-Naveda R. Use of onion waste as fuel for the generation of bioelectricity. Molecules 2022;27(3):625.
[32] Huang X, Duan C, Duan W, Sun F, Cui H, Zhang S, Chen X. Role of electrode materials on performance and microbial characteristics in the constructed wetland coupled microbial fuel cell (CW-MFC): A review. J Cleaner Prod 2021;301:126951.
[33] Rusyn IB, Medvediev OV, Valko BT. Enhancement of bioelectric parameters of multi-electrode plant–microbial fuel cells by combining serial and parallel connections. Int J Environ Sci Technol 2021;18(6):1323–34.

[34] Moqsud MA, Omine K, Yasufuku N, Bushra QS, Hyodo M, Nakata Y. Bioelectricity from kitchen and bamboo waste in a microbial fuel cell. Waste Manag Res 2014;32(2):124–30.
[35] Kamau JM, Mbui DN, Mwaniki JM, Mwaura FB. Utilization of rumen fluid in production of bioenergy from market waste using microbial fuel cells technology. J Appl Biotechnol Bioeng 2018;5(4):227–31.