fermentation

MDPI

Communication

Increase in Electrical Parameters Using Sucrose in Tomato Waste

Rojas-Flores Segundo [1,*], De La Cruz-Noriega Magaly [1], Santiago M. Benites [1], Delfín-Narciso Daniel [2], Luis Angelats-Silva [3], Felix Díaz [4], Cabanillas-Chirinos Luis [5] and Silva-Palacios Fernanda [6]

[1] Vicerrectorado de Investigación, Universidad Autónoma del Perú, Lima 15842, Peru; mdelacruzn@autonoma.edu.pe (D.L.C.-N.M.); santiago.benites@autonoma.pe (S.M.B.)
[2] Grupo de Investigación en Ciencias Aplicadas y Nuevas Tecnologías, Universidad Privada del Norte, Trujillo 13007, Peru; daniel.delfin@upn.edu.pe
[3] Laboratorio de Investigación Multidisciplinario, Universidad Privada Antenor Orrego (UPAO), Trujillo 13008, Peru; langelatss@upao.edu.pe
[4] Escuela Académica Profesional de Medicina Humana, Universidad Norbert Wiener, Lima 15046, Peru; felix.diaz@uwiener.edu.pe
[5] Instituto de Investigación en Ciencias y Tecnología de la Universidad Cesar Vallejo, Trujillo 13001, Peru; lcabanillas@ucv.edu.pe
[6] Escuela de Ingeniería Ambiental, Facultad de Ingeniería, Universidad Cesar Vallejo, Trujillo 13001, Peru; fasilvas@ucvvirtual.edu.pe
* Correspondence: segundo.rojas.89@gmail.com

Abstract: The use of organic waste as fuel for energy generation will reduce the great environmental problems currently caused by the consumption of fossil sources, giving agribusiness companies a profitable way to use their waste. In this research, tomato waste with different percentages of sucrose (0-target, 5, 10, and 20%) was used in microbial fuel cells manufactured on a laboratory scale with zinc and copper electrodes, managing to generate maximum peaks of voltage and a current of 1.08 V and 6.67 mA in the cell with 20% sucrose, in which it was observed that the optimum operating pH was 5.29, while the MFC with 0% (target) sucrose generated 0.91 V and 3.12 A on day 13 with a similar pH, even though all the cells worked in an acidic pH. Likewise, the cell with 20% sucrose had the lowest internal resistance (0.148541 ± 0.012361 KΩ) and the highest power density (224.77 mW/cm^2) at a current density of 4.43 mA/cm^2, while the MFC with 0% sucrose generated 160.52 mW/cm^2 and 4.38 mA/cm^2 of power density and current density, respectively, with an internal resistance of 0.34116 ± 0.2914 KΩ. In this sense, the FTIR (Fourier-transform infrared spectroscopy) of all the substrates used showed a high content of phenolic compounds and carboxylate acids. Finally, the MFCs were connected in a series and managed to generate a voltage of 3.43 V, enough to light an LED (green). These results give great hope to companies and society that, in the near future, this technology can be taken to a larger scale.

Keywords: waste; tomatoes; saccharose; microbial fuel cells; bioelectricity

check for updates

Citation: Segundo, R.-F.; Magaly, D.L.C.-N.; Benites, S.M.; Daniel, D.-N.; Angelats-Silva, L.; Díaz, F.; Luis, C.-C.; Fernanda, S.-P. Increase in Electrical Parameters Using Sucrose in Tomato Waste. *Fermentation* **2022**, *8*, 335. https://doi.org/10.3390/fermentation8070335

Academic Editor: Alessia Tropea

Received: 16 June 2022
Accepted: 15 July 2022
Published: 16 July 2022

1. Introduction

Industrialization and urbanization have led to a series of environmental problems, among which the increase in energy demand stands out, which has brought with it the emission of greenhouse gases (carbon dioxide, methane, nitrous oxide, and fluorinated gases are mixed with water vapor in the atmosphere) due to the exponential increase in the use of fossil fuels, these currently being the main source of electricity generation [1–4]. The problem lies in the environmental impact that is generated when using them, which intensifies global warming, as well as their limited availability and depletion because they are an unsustainable energy source [5,6]. On the other hand, another latent problem is the increase in the generation of waste, especially of organic origin, such as fruits and vegetables which, due to their demand in the market and their inadequate management during their production, storage, and marketing, they generate large amounts of waste [7]. All this has led to the advancement of new green energy technologies which have attracted great interest from the scientific community, so various alternatives have been developed to solve these environmental problems, with one of these technologies being microbial fuel cells (MFCs), which are bioelectrochemical systems based on the conversion of biodegradable substrates due to the metabolic activity of electricity-generating micro-organisms, taking advantage of the transformation between the electric current and the chemical products through the capacity of the electroactive microbial communities [8,9]. MFCs have a series of essential components for their correct operation, such as the anode where, from the metabolic action of microorganisms, electrons are generated through oxidation, which are transported to the cathode through an external cable where reduction occurs. In this context, microorganisms are essential in MFCs due to their role in the decomposition of fuels to generate protons and electrons used in the production of electricity [10]. MFCs have various types of configurations, and it has been reported that single-chamber MFCs require fewer materials due to their design, that their electrical values are high, and that they have advantages in terms of cost; these cells are designed to have a single cylindrical compartment, where the anode is in contact with the substrate and the cathode is exposed to air (O_2) [11]. The performance of MFCs is influenced by several factors, one of them being the substrates, which are essential in these systems since they are the source of the electron donors; in this regard, the use of various substrates has been reported, including wastewater, activated sludge, decomposed lignocellulosic waste, and organic waste [12,13], the latter being a substrate found in large quantities, in addition to its compounds. Bioactive materials have great potential in various industries, as these residues are mostly the product of fruits and vegetables [6]. Research has been reported in which the use of various substrates in MFCs has been studied, such as tomato waste, which possess carotenoids, flavonoids, and lycopene [14,15]; in the investigation carried out by Kalagbor et al. (2020), tomato, banana, and pineapple residues were used for the generation of electricity using a single-chamber MFC where the voltage was monitored, managing to generate a maximum voltage of 4.2 V for the tomato residue, 3.1 V for the residue of the banana, and 3.0 V for the pineapple residue [16].

Likewise, the generation of electricity from agricultural residues (tomatoes, onions, and potatoes) has been investigated in a single-chamber MFC where the cells were monitored for a period of 21 days, and the results showed an upward trend in the voltage produced by the onion substrate while the tomato generated a maximum voltage of 0.974 volts and a current of 32.7 mA, the latter being a good substrate for electricity generation [17]. Similarly, Kamau et al. (2020) studied the influence of the properties of tomatoes, avocados, and other substrates on the voltage and current generated in a double-chamber MFC; the monitoring period was 30 days, from which it was determined that the tomato generated a higher voltage (0.702 V) compared to the rest of the residues. These results indicated that properties such as the level of carbohydrates and humidity were factors that influenced the performance of the MFCs [18]. It has been observed that other substrates conventionally used in MFCs are sugars such as glucose [19]. Rahman et al. (2021) reported the generation of 483.5 mV from the use of this substrate in an MFC, and this result was associated with the high availability of glucose as an energy source for microorganisms so that sugars such as glucose are easily metabolized by a wide range of microbes, for which it has been shown that this substrate is a beneficial fuel for bioelectricity generation in an MFC [20–22]. In this sense, sugars such as glucose and sucrose have several advantages because they are low cost, easy to obtain, and sustainable since they can be easily produced in a natural environment, so a source that provides large amounts of sugars as organic waste from food industries is fruit processing plants [23,24].

Due to this, the main objective of this research was to generate bioelectricity using tomato residue as a substrate by adding different concentrations of sucrose (0, 5, 10, and 20%) in a single-chamber microbial fuel cell manufactured at low temperatures with a laboratory scale cost and zinc and copper electrodes. The cells were monitored for thirty days for the voltage, current, and pH values, as well as for the values of current density, power density, internal resistance, and transmittance spectrum by FTIR, thus giving a sustainable way to generate electricity at a low cost.

2. Materials and Methods

2.1. Fabrication of Microbial Fuel Cells

The single-chamber microbial fuel cells were manufactured using 15 × 15 × 10 cm^3 polyethylene terephthalate, to which a 10 cm^2 hole was made on one of their faces to place the cathodic electrode (copper-Cu), while the electrode anodic (Zinc-Zn) was placed in the center of the container; both electrodes were connected through an external circuit whose resistance was 100 Ω. From a 50% sucrose stock solution, solutions at 5, 10, and 20% were prepared, and each one was incorporated into a tomato extract to complete a final volume of 200 mL, while the proton exchange membrane (PEM) was in contact with the cathodic electrode and the substrate—whose membrane contained 10 mL of the concentration of 6 g of KCl plus 14 g of agar and 400 mL of H_2O—as shown in Figure 1.

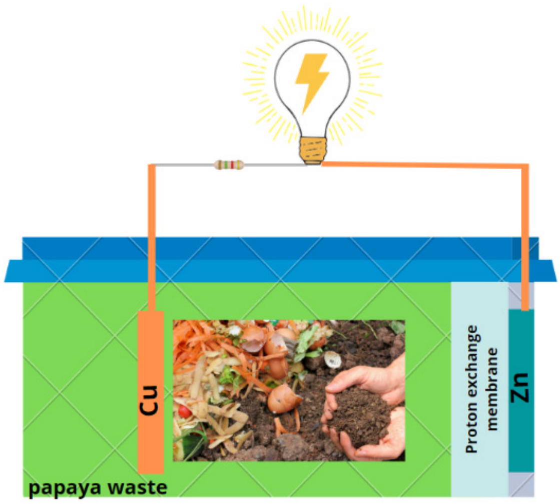

Figure 1. Schematization of microbial fuel cells.

2.2. Collection of Tomato Waste

Tomato waste (3 kg) was collected from Mercado La Hermelinda, Trujillo, Peru, which was selected by the commercials of the market. The waste was collected in hermetic bags and was taken to the laboratory to be washed several times to eliminate any type of impurities; finally, the waste was dried in an oven at 23 ± 2 °C for 24 h and then crushed by an extractor whose juice was stored in closed containers until it was used in the microbial fuel cells, where 180 mL of tomato waste was used on each MFC.

2.3. Characterization of Microbial Fuel Cells

The generated voltage and current values were monitored using a multimeter (Prasek Premium PR-85) for 30 days with an external resistance of 100 Ω, while the current density (CD) and the power density (PD) were calculated using the method of Segundo et al. (2022), where the A (area) of the cathode had an approximate value of 78.54 cm^2 and external resistances ($R_{ext.}$) of 0.3 ± 0.1, 0.6 ± 0.18, 1 ± 0.3, 1.5 ± 0.31, 3 ± 0.6, 10 ± 1.3, 20 ± 6.5, 50 ± 8.7, 60 ± 8.2, 100 ± 9.3, 120 ± 9.8, 220 ± 13, 240 ± 15.6, 330 ± 20.3, 390 ± 24.5, 460 ± 23.1, 531 ± 26.8, 700 ± 40.5, and 1000 ± 50.6 Ω [25]. The changes in conductivity (CD-4301 conductivity meter) and pH (Oakton Series 110 pH-meter) were also measured. The transmittance values were measured by FTIR (Thermo Scientific IS50) and the resistance values of the MFCs were measured using an energy sensor (Vernier-±30 V and ±1000 mA).

3. Results and Discussion

Figure 2a shows the voltage values generated by the microbial fuel cells during the 30 days of monitoring, demonstrating that the values increased from the first day and that the MFC at 20% sucrose was the one that generated higher values during the entire monitoring period, achieving a generation peak of 1.08 V on the tenth day. Figure 2b shows the values of the electrical current during the monitoring period, with the MFC at 20% sucrose being the one that generated the highest current values, with maximum peaks of 6.67 mA on the thirteenth day and slowly dropping until the last day (4.02 mA) of monitoring. The MFC used as a blank (0% sucrose) was the one that generated the least amount of current, with 48.5% less electric current than the MFC at 20% on day 13. According to Stein and Granot (2019), sucrose is a raw material for many metabolic pathways providing energy, as well as carbon skeletons for the production of organic matter such as amino acids and structural carbohydrates [26]. Many microorganisms that generate electricity use carbohydrates and different types of compounds for their proliferation, which is why there would be a direct relationship where, when increasing the values of the voltage and electric current, it would be due to the increase in the percentage of sucrose [27,28]. It has been observed in some works of the literature that the use of metallic materials produces high values of currents and voltage, but it is also counterproductive for the proliferation of microorganisms and therefore for the generation of electric currents [25,29]. Figure 2c shows the monitored pH values of the microbial fuel cells for thirty days, demonstrating that the values increased from the first day to the last, although these increases were slight in all the MFCs that were kept in the acidic region naturally, without adding chemical compounds. The pH parameter is an important factor in MFCs, mainly for power generation, because the microorganisms that form biofilms on the anodic electrode grow at certain environmental pH values, although this variable varies for each type of cell design and substrate used according to the literature [30,31]; e.g., it has been found that the optimum operating pH for MFCs with banana waste is 4.023 + 0.064, with a peak voltage and current of 1.01 V and 3.71667 [32]. Similarly, Schievano et al. (2018) used organic waste, achieving stable pH values of approximately seven at voltage values of 0.08 V on the sixth day of operation [33].

In Figure 3, the power density (DP) values are observed as a function of the current density (DC) of all the microbial fuel cells at different percentages of sucrose (0, 5, 10, and 20%). The DP_{max} values found were 160.52, 173.73, 197.55, and 224.77 mW/cm^2 in a CD of 4.38, 4.34, 5.46, and 4.43 mA/cm^2, with peak voltages of 896.95, 932.18, 983.68, and 1021.13 V for the MFCs with 0. 5, 10, and 20% sucrose, respectively. The values obtained were high compared to those in the literature; for example, Xin et al. (2018) used an air-assisted cylindrical-type single-chamber MFC using carbon electrodes and food scraps as the substrate and managed to generate 0.20 W/m^2 of PD at a CD of 0.27 A/m^2 and a peak voltage of 0.58 V [34]. Similarly, Choudhury et al. (2021) used single-chamber MFCs with carbon electrodes in the absence of a proton exchange membrane and managed to generate 0.71 W/m^2 of PD in a CD of 0.149 A/m^2 with a peak voltage of 0.63V [35]. The high values obtained in our work, according to Huang et al. (2021), would be due to the use of metallic electrodes, due to their high properties for electron transport [36], while the increase in the PD values in relation to the percentage of sucrose was mainly due to the increase in the carbon sources in the substrate for the metabolism of microorganisms [37].

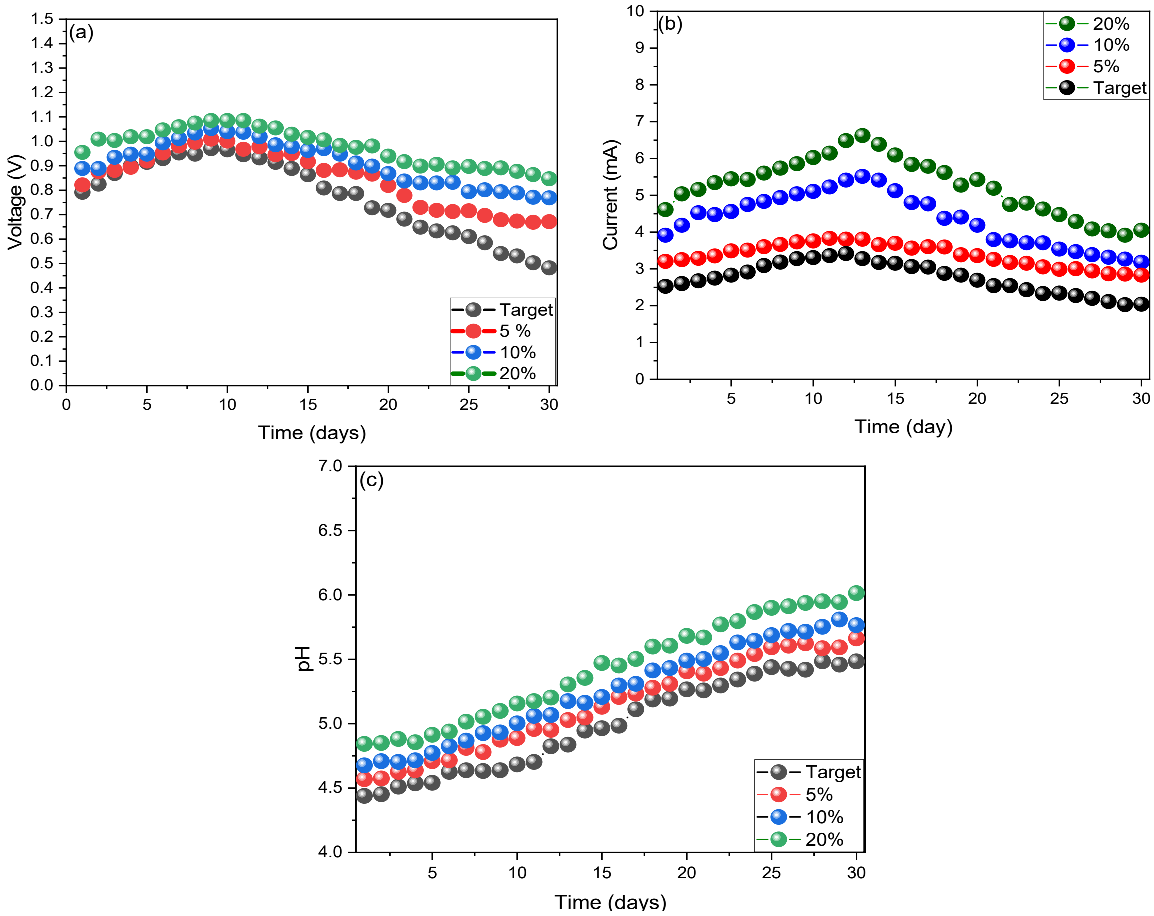

Figure 2. Values of (**a**) voltage, (**b**) electric current, and (**c**) pH obtained from the monitoring of the microbial fuel cells during 30 days.

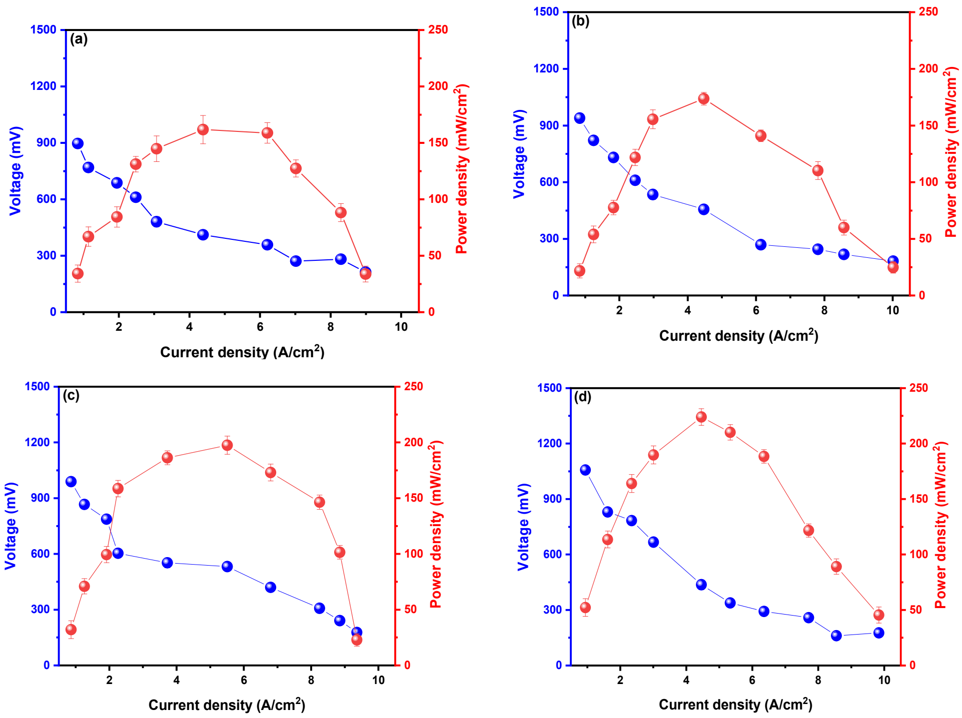

Figure 3. Values of the power densities as a function of the current density of the microbial fuel cells at (**a**) 0-target, (**b**) 5, (**c**) 10, and (**d**) 20% sucrose.

Figure 4 shows the absorbance spectrum of the compounds present in the different substrates (0, 5, 10, and 20% sucrose), showing the most intense peak at 3286 cm^{-1} belonging to the N-H stretch, O-H groups, phenols, and carboxylate acids, while the peaks 2933 and 2854 are associated with the C-H stretching of alkane, aldehyde, and ketones; in the same way, the 1627 cm^{-1} peak is associated with C=C stretching, N-H primary amine, C==N stretching, and amide stretch. The one 1441 cm peak indicates the presence of alkane C-H stretching, alkene C=C stretching, C==N stretching, primary and secondary amine C-N stretching, and amide stretching, and the last one indicates the presence of 1040 cm^{-1} alkane C-H stretching, alkene C=C stretching, C==N stretching, primary and secondary amine C-N stretching, and amide stretching [38–40]. It has been shown that the high content of phenols releases large amounts of electrons, which travel through the external circuit to the cathodic electrode, thus generating a higher electrical current output [41,42]. Ferreira-Santos et al. (2020) used extruded pine phenolic extracts to check bioactivity in different applications due to the compounds they contain (Quercetin, Procyanidin A2, Procyanidin B1, and Procyanidin B2) in a large percentage of carbon, which is the main food source for microorganisms [43].

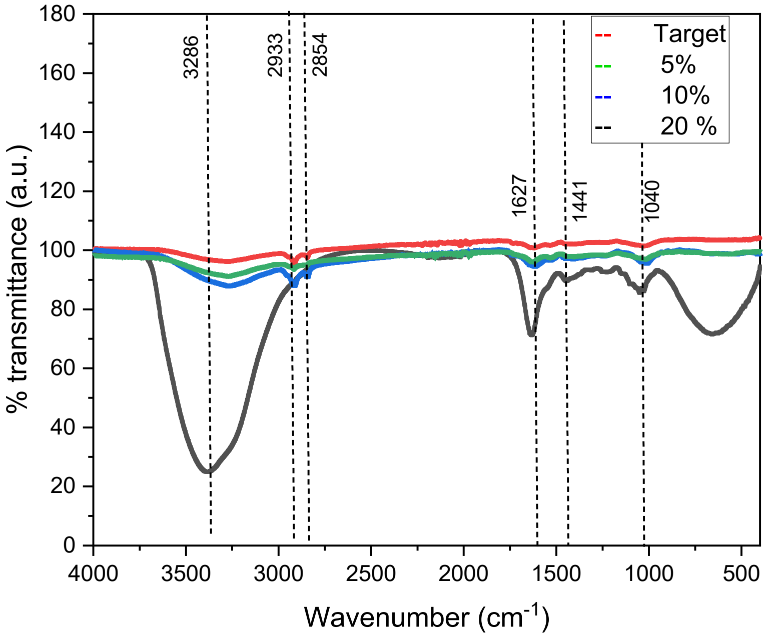

Figure 4. FTIR spectrophotometry of the tomato residues with saccharose.

Figure 5 shows the values of the internal resistance of the microbial fuel cells at different percentages of sucrose (0, 5, 10, and 20%); the experimental data was adjusted to the formula V=RI of Ohm's law, where the x-axis represents the values of the electric current (I) and the y-axis represents the values of the voltage (V), for which the slope of the linear fit is the internal resistance ($R_{int.}$) of the MFCs. The R_{int} values found were 0.34116 ± 0.2914, 0.301241 ± 0.01754, 0.26841 ± 0.012134, and 0.148541 ± 0.012361 KΩ for the MFCs with 0, 5, 10, and 20% sucrose, as shown in Figure 5. The values of the internal resistances of the MFCs decreased with an increasing sucrose concentration, and according to Potrykus et al. (2021), the internal resistance of the MFCs is dependent on the decomposition of the substrates used for power generation because the electrons that are released in the oxidation process in the anode chamber flow more freely throughout the system when the internal resistance is low, which also influences the anodic biofilm formation of the MFCs [44,45]. Figure 6 shows the bioelectricity generation process of the microbial fuel cells connected in a series, which managed to generate a voltage of 3.43 V, enough to light a green LED bulb.

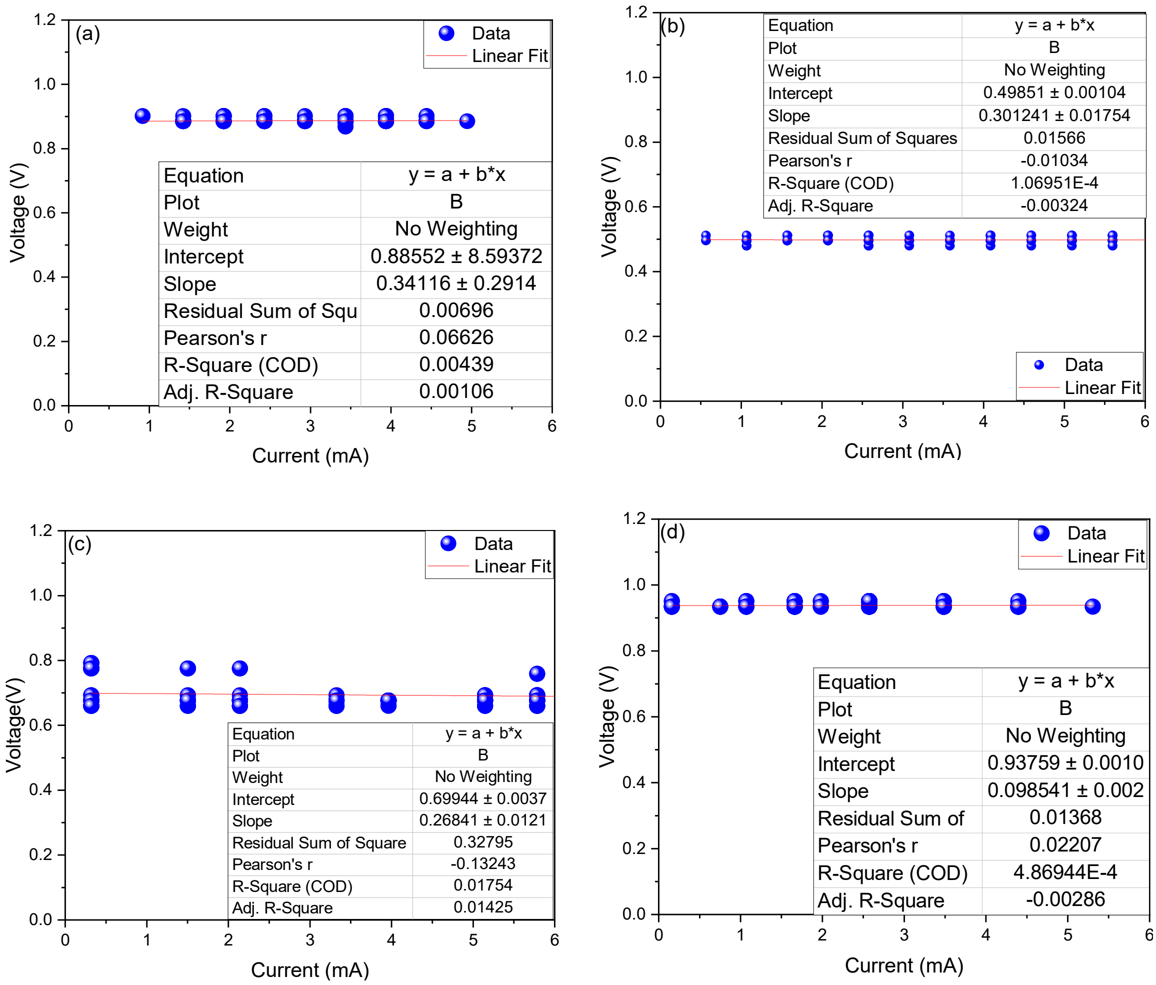

Figure 5. Internal resistance values of microbial fuel cells with tomato waste with (**a**) 0-target, (**b**) 5, (**c**) 10, and (**d**) 20% sucrose.

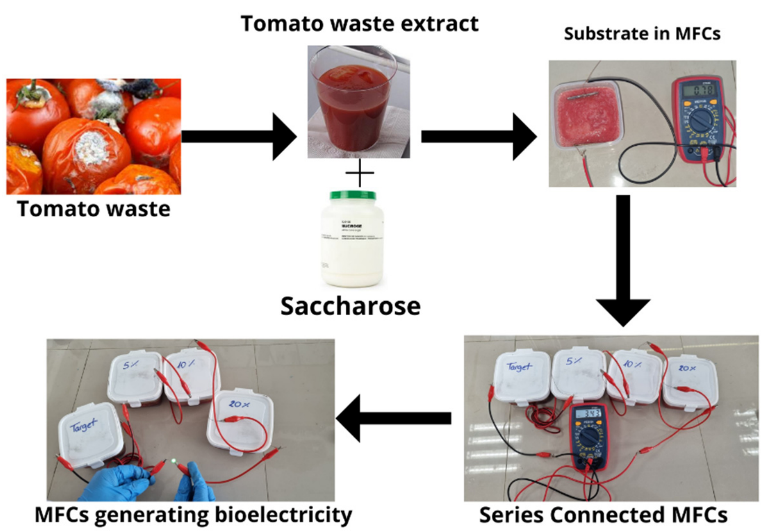

Figure 6. Generation of bioelectricity by MFCs.

4. Conclusions

Bioelectricity was successfully generated through low-cost, laboratory-scale microbial fuel cells using tomato waste with different percentages of sucrose (0, 5, 10, and 20%) as substrates and using zinc and copper electrodes. The cell with 20% sucrose was the one that generated the maximum current and voltage values of 6.67 mA and 1.08 V, respectively; on the other hand, the cell with 0% sucrose (used as a blank) was the one that generated the lowest values, with the optimum operating pH for the cell with 20% sucrose being 5.29, although all the MFCs remained in the acidic region. The maximum power density found was 224.77 mW/cm^2 at a current density of 4.43 mA/cm^2 for the cell with 20% sucrose, whose internal resistance was the minimum found, also being 0.148541 ± 0.012361 KΩ. In all the substrates used, a high content of phenolic compounds and carboxylate acids was found by FTIR transmittance. Finally, it was possible to generate 3.43 V by connecting the MFCs in a series, turning on a LED bulb (green) and thus demonstrating that the energy obtained from the waste can be converted into light. This research offers great advances for the optimization of tomato waste in energy generation because it was observed that the increase in sucrose could increase the electrical values in an eco-friendly way with the environment. For future work, it is recommended to use metal electrodes coated with some type of material that is biocompatible with the microorganisms present, so that they affect their performance; likewise, it is recommended to work with the optimal pH of operation that was found in this investigation.

Author Contributions: Conceptualization, R.-F.S.; methodology, S.M.B.; validation, L.A.-S. and F.D.; formal analysis, R.-F.S. and D.L.C.-N.M.; investigation, R.-F.S. and S.-P.F.; data curation, D.L.C.-N.M.; writing—original draft preparation, D.-N.D.; writing—review and editing, R.-F.S.; project administration, R.-F.S. and C.-C.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Liu, X.; Bae, J. Urbanization and industrialization impact of CO_2 emissions in China. *J. Clean. Prod.* **2018**, *172*, 178–186. [CrossRef]
2. Miller, L.; Carriveau, R. Energy demand curve variables—An overview of individual and systemic effects. *Sustain. Energy Technol. Assess.* **2019**, *35*, 172–179. [CrossRef]
3. Yoro, K.O.; Daramola, M.O. CO_2 emission sources, greenhouse gases, and the global warming effect. In *Advances in Carbon Capture*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 3–28. [CrossRef]
4. Sharma, K.; Park, Y.K.; Nadda, A.K.; Banerjee, P.; Singh, P.; Raizada, P.; Banat, F.; Bharath, G.; Jeong, S.M.; Lam, S.S. Emerging chemo-biocatalytic routes for val-orization of major greenhouse gases (GHG) into industrial products: A comprehensive review. *J. Ind. Eng. Chem.* **2022**, *109*, 1–20. [CrossRef]
5. Soeder, D.J. Fossil Fuels and Climate Change. In *Fracking and the Environment*; Springer: Cham, Switzerland, 2020; pp. 155–185. [CrossRef]
6. Wang, H.; Wang, G.; Qi, J.; Schandl, H.; Li, Y.; Feng, C.; Yang, X.; Wang, Y.; Wang, X.; Liang, S. Scarcity-weighted fossil fuel footprint of China at the provincial level. *Appl. Energy* **2020**, *258*, 114081. [CrossRef]
7. Sagar, N.A.; Pareek, S.; Sharma, S.; Yahia, E.M.; Lobo, M.G. Fruit and Vegetable Waste: Bioactive Compounds, Their Extraction, and Possible Utilization. *Compr. Rev. Food Sci. Food Saf.* **2018**, *17*, 512–531. [CrossRef] [PubMed]
8. Yaqoob, A.A.; Ibrahim, M.N.M.; Rodríguez-Couto, S. Development and modification of materials to build cost-effective anodes for microbial fuel cells (MFCs): An overview. *Biochem. Eng. J.* **2020**, *164*, 107779. [CrossRef]
9. Tran, H.V.H.; Kim, E.; Jung, S.P. Anode biofilm maturation time, stable cell performance time, and time-course electrochemistry in a single-chamber microbial fuel cell with a brush-anode. *J. Ind. Eng. Chem.* **2022**, *106*, 269–278. [CrossRef]
10. Dutta, K.; Kundu, P.P. Introduction to Microbial Fuel Cells. In *Progress and Recent Trends in Microbial Fuel Cells*; Elsevier: Amsterdam, The Netherlands, 2018; pp. 1–6. [CrossRef]
11. Nandy, A.; Kundu, P.P. Configurations of Microbial Fuel Cells. In *Progress and Recent Trends in Microbial Fuel Cells*; Elsevier: Amsterdam, The Netherlands, 2018; pp. 25–45. [CrossRef]
12. Prathiba, S.; Kumar, P.S.; Vo, D.-V.N. Recent advancements in microbial fuel cells: A review on its electron transfer mechanisms, microbial community, types of substrates and design for bio-electrochemical treatment. *Chemosphere* **2022**, *286*, 131856. [CrossRef] [PubMed]

13. Sarma, R.; Tamuly, A.; Kakati, B.K. Recent developments in electricity generation by Microbial Fuel Cell using different substrates. *Mater. Today Proc.* **2022**, *49*, 457–463. [CrossRef]
14. Ali, M.Y.; Ibn Sina, A.A.; Khandker, S.S.; Neesa, L.; Tanvir, E.M.; Kabir, A.; Khalil, M.I.; Gan, S.H. Nutritional Composition and Bioactive Compounds in Tomatoes and Their Impact on Human Health and Disease: A Review. *Foods* **2020**, *10*, 45. [CrossRef]
15. Li, D.; Zheng, T.; Yu, J.; He, H.; Shi, W.; Ma, J. Enhancement of the electro-Fenton degradation of organic contaminant by accelerat-ing Fe^{3+}/Fe^{2+} cycle using hydroxylamine. *J. Ind. Eng. Chem.* **2022**, *105*, 405–413. [CrossRef]
16. Kalagbor, A.; Azunda, B.; Igwe, C.; Akpan, J. Electricity Generation from Waste Tomatoes, Banana, Pineapple Fruits and Peels Using Single Chamber Microbial Fuel Cells (SMFC). *Open Access J. Waste Manag. Xenobiotics* **2020**, *3*, 141. [CrossRef]
17. Flores, R.; Naveda, R.N.; Paredes, E.A.; Orbegoso, J.A.; Céspedes, T.C.; Salvatierra, A.R.; Rodríguez, M.S. Agricultural Wastes for Electricity Generation Using Microbial Fuel Cells. *Open Biotechnol. J.* **2020**, *14*, 52–58. [CrossRef]
18. Kamau, J. Influence of Substrate Proximate Properties on Voltage Production in Microbial Fuel Cells. *J. Sustain. Bioenergy Syst.* **2020**, *10*, 43–51. [CrossRef]
19. Fadzli, F.S.; Bhawani, S.A.; Mohammad, R.E.A. Microbial Fuel Cell: Recent Developments in Organic Substrate Use and Bacterial Electrode Interaction. *J. Chem.* **2021**, *2021*, 4570388. [CrossRef]
20. Rahman, W.; Yusup, S.; Mohammad, S.N.A.A. Screening of fruit waste as substrate for microbial fuel cell (MFC). *AIP Conf. Proc.* **2021**, *2332*, 020003. [CrossRef]
21. Zhao, N.; Jiang, Y.; Alvarado-Morales, M.; Treu, L.; Angelidaki, I.; Zhang, Y. Electricity generation and microbial communities in microbial fuel cell powered by macroalgal biomass. *Bioelectrochemistry* **2018**, *123*, 145–149. [CrossRef] [PubMed]
22. Sreelekshmy, B.R.; Basheer, R.; Sivaraman, S.; Vasudevan, V.; Elias, L.; Shibli, S.M.A. Sustainable electric power generation from live anaerobic digestion of sugar industry effluents using microbial fuel cells. *J. Mater. Chem. A* **2020**, *8*, 6041–6056. [CrossRef]
23. Wang, J.; Zhang, X.; Li, Y.; Liu, P.; Chen, X.; Zhang, P.; Wang, Z.; Liu, X. Sweet Drinks as Fuels for an Alkaline Fuel Cell with Nonprecious Catalysts. *Energies* **2021**, *14*, 206. [CrossRef]
24. Andayani, D.G.S.; Andini, D.G.T. Utilization of tofu wastewater and sugar industry by-products as a medium for the production of antifungal metabolites by Paecylomyces Marquand StrainTP4. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *623*, 012069. [CrossRef]
25. Segundo, R.-F.; De La Cruz-Noriega, M.; Nazario-Naveda, R.; Benites, S.M.; Delfín-Narciso, D.; Angelats-Silva, L.; Díaz, F. Golden Berry Waste for Electricity Generation. *Fermentation* **2022**, *8*, 256. [CrossRef]
26. Stein, O.; Granot, D. An Overview of Sucrose Synthases in Plants. *Front. Plant Sci.* **2019**, *10*, 95. [CrossRef] [PubMed]
27. Hou, B.; Liu, X.; Zhang, R.; Li, Y.; Liu, P.; Lu, J. Investigation and evaluation of membrane fouling in a microbial fuel cell-membrane bioreactor systems (MFC-MBR). *Sci. Total Environ.* **2022**, *814*, 152569. [CrossRef] [PubMed]
28. Rojas-Flores, S.; Benites, S.M.; De La Cruz-Noriega, M.; Cabanillas-Chirinos, L.; Valdiviezo-Dominguez, F.; Quezada Álvarez, M.A.; Vega-Ybañez, V.; Angelats-Silva, L. Bioelectricity production from blueberry waste. *Processes* **2021**, *9*, 1301. [CrossRef]
29. Naveenkumar, M.; Senthilkumar, K. Microbial fuel cell for harvesting bio-energy from tannery effluent using metal mixed biochar electrodes. *Biomass Bioenergy* **2021**, *149*, 106082. [CrossRef]
30. Liu, L.; Zeng, G.; Chen, J.; Bi, L.; Dai, L.; Wen, Z. N-doped porous carbon nanosheets as pH-universal ORR electrocatalyst in vari-ous fuel cell devices. *Nano Energy* **2018**, *49*, 393–402. [CrossRef]
31. Jadhav, D.A.; Carmona-Martínez, A.A.; Chendake, A.D.; Pandit, S.; Pant, D. Modeling and optimization strategies towards per-formance enhancement of microbial fuel cells. *Bioresour. Technol.* **2021**, *320*, 124256. [CrossRef] [PubMed]
32. Rojas-Flores, S.; De La Cruz-Noriega, M.; Nazario-Naveda, R.; Benites, S.M.; Delfín-Narciso, D.; Angelats-Silva, L.; Murga-Torres, E. Use of Banana Waste as a Source for Bioelectricity Generation. *Processes* **2022**, *10*, 942. [CrossRef]
33. Schievano, A.; Colombo, A.; Cossettini, A.; Goglio, A.; D'Ardes, V.; Trasatti, S.; Cristiani, P. Single-chamber microbial fuel cells as on-line shock-sensors for volatile fatty acids in anaerobic digesters. *Waste Manag.* **2018**, *71*, 785–791. [CrossRef] [PubMed]
34. Xin, X.; Ma, Y.; Liu, Y. Electric energy production from food waste: Microbial fuel cells versus anaerobic digestion. *Bioresour. Technol.* **2018**, *255*, 281–287. [CrossRef] [PubMed]
35. Choudhury, P.; Ray, R.N.; Bandyopadhyay, T.K.; Basak, B.; Muthuraj, M.; Bhunia, B. Process engineering for stable power recovery from dairy wastewater using microbial fuel cell. *Int. J. Hydrog. Energy* **2020**, *46*, 3171–3182. [CrossRef]
36. 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. Clean. Prod.* **2021**, *301*, 126951. [CrossRef]
37. Córdova-Bautista, Y.; Ramírez-Morales, E.; Pérez-Hernández, B.; Ojeda-Morales, M.E.; López-Lázaro, J.S.; Martínez-Pereyra, G. Electricity Production and Bioremediation from Synthetic Sugar Industry Wastewater by Using Microbial Isolate in Microbial Fuel Cell. *Sugar Tech* **2020**, *22*, 820–829. [CrossRef]
38. Sharma, N.; Khajuria, Y.; Singh, V.K.; Kumar, S.; Lee, Y.; Rai, P.K.; Singh, V.K. Study of molecular and elemental changes in nem-atode-infested roots in papaya plant using FTIR, LIBS and WDXRF spectroscopy. *At. Spectrosc.* **2020**, *41*, 110–118. [CrossRef]
39. Ahlawat, J.; Kumar, V.; Gopinath, P. Carica papaya loaded poly (vinyl alcohol)-gelatin nanofibrous scaffold for potential applica-tion in wound dressing. *Mater. Sci. Eng. C* **2019**, *103*, 109834. [CrossRef]
40. Kale, R.; Barwar, S.; Kane, P.; More, S. Green synthesis of silver nanoparticles using papaya seed and its characterization. *Int. J. Res. Appl. Sci. Eng. Technol.* **2018**, *6*, 168–174. [CrossRef]
41. Hedbavna, P.; Rolfe, S.A.; Huang, W.E.; Thornton, S.F. Biodegradation of phenolic compounds and their metabolites in contaminated groundwater using microbial fuel cells. *Bioresour. Technol.* **2016**, *200*, 426–434. [CrossRef]

42. Shen, J.; Du, Z.; Li, J.; Cheng, F. Co-metabolism for enhanced phenol degradation and bioelectricity generation in microbial fuel cell. *Bioelectrochemistry* **2020**, *134*, 107527. [CrossRef]
43. Ferreira-Santos, P.; Zanuso, E.; Genisheva, Z.; Rocha, C.M.R.; Teixeira, J.A. Green and Sustainable Valorization of Bioactive Phenolic Compounds from *Pinus* By-Products. *Molecules* **2020**, *25*, 2931. [CrossRef]
44. Potrykus, S.; León-Fernández, L.F.; Nieznański, J.; Karkosiński, D.; Fernandez-Morales, F.J. The influence of external load on the performance of microbial fuel cells. *Energies* **2021**, *14*, 612. [CrossRef]
45. Abbas, S.Z.; Yong, Y.C.; Chang, F.X. Anode materials for soil microbial fuel cells: Recent advances and future perspectives. *Int. J. Energy Res.* **2022**, *46*, 712–725. [CrossRef]