Proceedings of the 10th World Congress on Civil, Structural, and Environmental Engineering (CSEE 2025)
Barcelona, Spain - April, 2025
Paper No. ICEPTP 142
DOI: 10.11159/iceptp25.142

Microbial Fuel Cells from Artichoke Waste: Preliminary Results

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***Abstract* -** Agricultural waste has increased rapidly in recent years due to increased food production, which has risen due to the increase in the world population. On the other hand, the high cost of energy consumption and scarcity of this sound in remote communities has caused the scientific community to look for new ways to sustain electricity. For this reason, the main objective of this research is to observe the potential of artichoke waste as fuel in single-chamber microbial fuel cells using carbon and zinc electrodes. An average maximum power density of 220.271 ± 11.174 mW/cm^2 was achieved in an average current density of 5.841 ± 0.285 A/cm^2 on the tenth day, with an average maximum voltage of 0.795 ± 0.025 V and an average maximum electric current of 1.980 ± 0.0.072 mA. These electric flies were obtained on the tenth day, where the microbial fuel cells operated at a pH of 4.351 ± 0.161 with an electrical conductivity of 127.844 ± 8.512 mS/cm and an electrical resistance of 40.314 ± 6.813 Ω. The single-chamber microbial fuel cells with artichoke waste were connected in series, producing a 2.35 V voltage necessary to light an LED light.

***Keywords*:** Microbial fuel cells, agricultural waste, artichoke waste, bioelectricity, sustainability.

1. Introduction

The human population has increased from approximately 3.7 billion to 8 billion from 1970 to 2021 and is estimated to reach 9 billion people by 2050 [1]. This vast increase has brought significant challenges, one of the most important being the agro-industrial area due to the food supply and the energy area, which is vitally essential for human activities [2,3]. Countries such as China, India, and Africa have rapidly increased their food production capacity to meet food demand, achieving great economic benefits. On the other hand, the production of large amounts of agricultural waste has also increased. India alone is estimated to produce between 350-990 Mt/year annually [4,5]. In addition, it is estimated that of all the waste generated, 2 million tons are not used, and this figure will be 3.4 million tons by 2050 [6]. Peru has become an agro-exporting country, with the artichoke (Cynara scolymus L.) being the second most in-demand product for export, wherein 2023, 7,817 tons were registered for 2.8 dollars per kilogram, and the demand for 2024 is growing [7,8]. This vegetable is in great demand worldwide because it contains minerals, vitamins, bioactive phenolic compounds (caffeoylquinic, apigenin, and luteolin), and prebiotics, from which many dietary and pharmaceutical agents have been obtained in recent years [9,10]. In Peru, the waste from this fruit that may be discarded or by-products of these are not being used for a purpose [11].

On the other hand, microbial fuel cells (MFCs) have emerged as an innovative system capable of generating electrical energy through different types of organic waste [12]. An MFC generally comprises an anodic chamber containing the waste used as fuel and a cathodic chamber containing the reducing agent; the energy generation processes occur through various processes [13,14]. Both chambers are linked by an external circuit, where electrons are transported, and electrical energy is created [15]. Microbial fuel cells have been used in various ways; for example, Kalagbor et al. (2020) used pineapple, tomato, and banana waste mixed in 20 kg microbial fuel cells, managing to generate voltage peaks of 4.2 V and 3.2 A of electric current, the cells were composed of carbon electrodes [16]. Likewise, Verma et al. (2023) used banana waste as fuel in their dual-chamber MFCs, generating 2.2 ± 0.1 mW/m2 of power density and an 80% reduction in chemical oxygen demand [17]. Ahmad et al. (2024) used a mixture of different types of vegetable waste in their microbial fuel cells, managing to generate voltage peaks of 0.154 V on the fifteenth day, whose power density value was 1.450 mW/m2, whose internal resistance of the MFC was 724 Ω [18]. Artichoke waste has no use in the literature as a substrate in single-chamber microbial fuel cells.

Due to all this, the objective of the research is to examine the potential of using artichoke waste as a fuel source in single-chamber fuel cells for electricity generation, using carbon and zinc electrodes. For this purpose, the internal resistance values, voltage, electrical conductivity, electric current, pH, current density, and power density will be monitored. This proposal promises an innovative solution to generate sustainable and environmentally friendly energy since it uses its waste as a fuel source and will significantly help agro-exporting companies of this product.

2. Materials and method

Three single-chamber microbial fuel cells with a capacity of 1000 ml were obtained from Xin Tester (Shanghai, China). The electrodes were made of carbon (anode) and zinc (cathode), and a proton exchange membrane/Nafion 117 (Wilmington, DE, USA) was used. The area of the anode electrode was 40 cm^2, and the cathode electrode was 20.25 cm^2; an external circuit connected both electrodes with a resistance of 50Ω (see Figure 1).

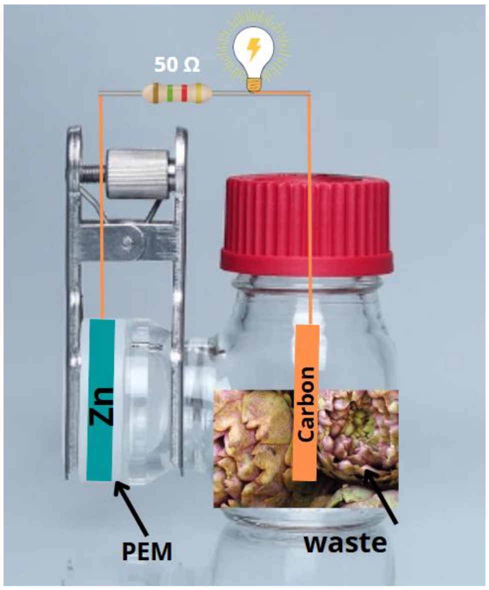

Figure 1. Design and schematization of the MFC used.

The substrate (artichoke waste) was collected from the Santo Dominguito market, Trujillo, La Libertad, Peru; the waste was taken to the laboratory and washed several times to remove impurities. 4.5 kg were collected, which, once washed, were left to dry at 30 °C for one day so that finally, with an extractor (extractor, Labtron, LDO-B10-USA), a liquid solution of 2200 ml was obtained, this solution was used as the substrate used in the MFCs. The voltage and electric current values were monitored for 21 days using a digital multimeter (Truper MUT-830 Digital Multimeter) and an external resistor of 100 Ω. The closed reflux colorimetric method measured the COD (chemical oxygen demand) values according to the NTP 360.502:2016 standard. In contrast, the electrical conductivity, pH, dissolved solids, and oxidation-reduction potential (ORP) values were measured by a multiparameter (HI98194 Multiparameter Meter). The internal resistance values of the MFC were performed by an energy sensor (Vernier- ± 30 V and ±1000 mA). The PD (power density) and CD (current density) values were performed using the method of Segundo et al. (2023) [19].

3. Results and Discussion

The initial voltage values were 0.028 ± 0.001 V, which increased until the tenth day (0.795 ± 0.025 V) and then showed a loss of voltage until the twenty-first day (0.489 ± 0.032 V); see Figure 2 (a). The literature has reported that the voltage values commonly tend to increase due to the redox reactions within the microbial fuel cells, which generate a potential differential between the cathodic and anodic electrodes. As the compounds responsible for the redox reactions decrease, the voltage values also tend to decrease [20,21]. In addition, it has also been observed that when a new one replaces replaces the substrate used as fuel, the values do not reach their maximum value again, as shown at the first time of recharging recharging [22,23]. The current values showed an increase from the first day (0.093 ± 0.004 mA) to the tenth day (1.980 ± ± 0.072 mA) and then successively decreased until the twenty-first day (1.375 ± 0.087 mA). During the process of generating generating electrical energy, the metabolism of electron-generating microbes plays a fundamental role; these types of microbes, when carrying out their metabolism, release electrons in this process that are captured by the anodic electrode and are transferred through the external circuit to the cathodic electrode, producing the electric current as the carbon sources decrease the microbes slow down their metabolism reflected in the loss of electric current values [24-26]. For example, lettuce waste has been used as fuel in microbial fuel cells, generating voltage and electric current peaks of 0.959 ± 0.026 V and 5.697 ± 0.065 mA, mentioning that using metallic nature electrodes helps to increase the electric current values [27]. In the research by Zhao et al. (2023), a low microbial load capacity and poor compatibility between microbes and the anodic electrode directly affect the production and uptake of electrons [28].

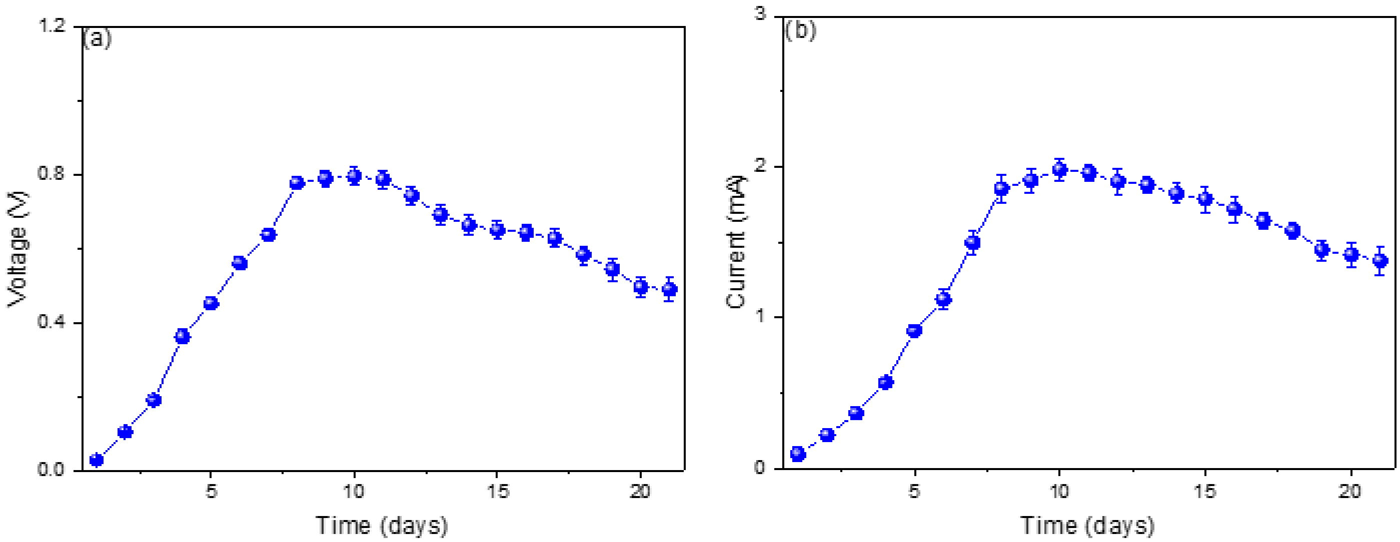

Figure 2. Monitoring of (a) voltage and (b) electric current values of microbial fuel cells.

Microbial fuel cells with artichoke waste gradually increased pH values, from moderately acidic to slightly acidic, from the first (3.651) to the twenty-first day (4.931 ± 0.167). Still, the optimal operation value of the MFCs was on the tenth day with a value of 4.351 ± 0.161, see Figure 3 (a). For example, Din et al. (2024) used potato waste as a substrate in their microbial fuel cells, managing to generate maximum values of 12.45 mA and 1.120 V of voltage and current, respectively; the microbial fuel cells operated with a pH of 7 mentioning that any variation of this parameter influences the development of microbes [29]. In their research, Haruna et al. (2024) varied different pH values , observing that pH values of 9 obtained higher power density values, increasing the population of microbes present in the waste used as substrates [30]. While in Figure 3 (b), the values obtained from the microbial fuel cells with artichoke waste can be observed, it can be observed that the electrical conductivity values showed similar behavior to the values shown for voltage and electric current because the first day of the value was 27.968 ± 1.332 mS/cm and then showed an increase until the tenth day (127.844 ± 8.512 mS/cm) the following days the electrical conductivity values successively decreased until the twenty-first day (78.083 ± 4.163 mS/cm). In the literature, it has been observed that the increase in values of electrical conductivity increases in the first days when the organic load is high, but as a sedimentation of the compounds in the microbial fuel cells is observed, a decrease in these values is also observed [31].

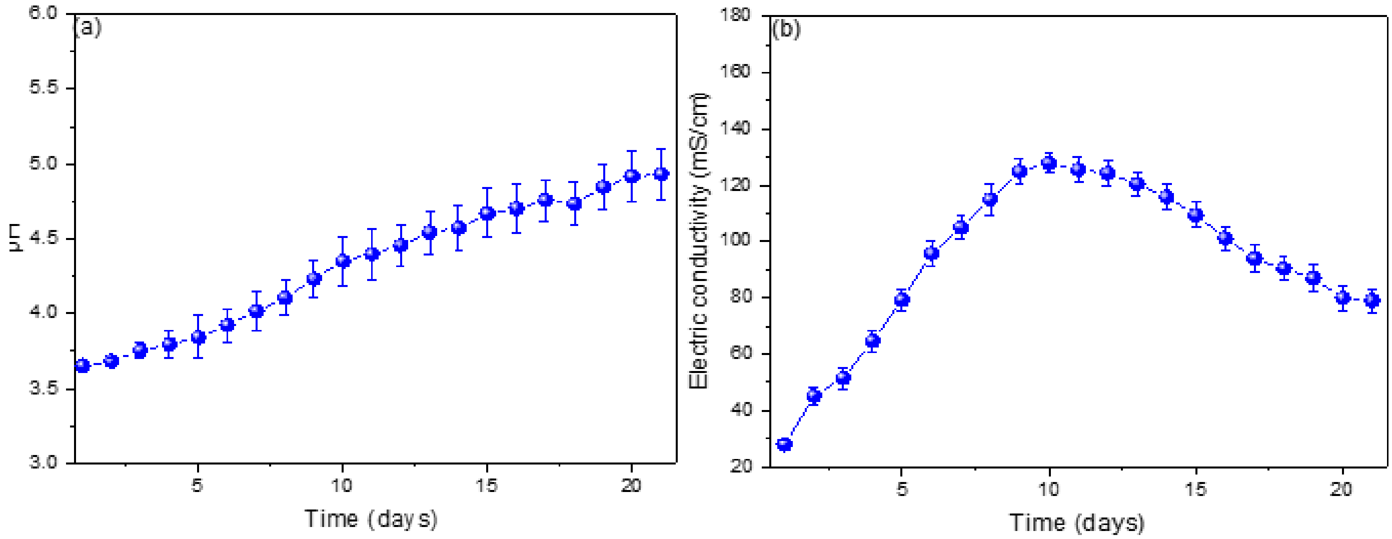

Figure 3. Monitoring of (a) pH values and (b) conductivity of microbial fuel.

The internal resistance values of the used microbial fuel cells are shown in Figure 4 (a), which were obtained using Ohm's law, where the slope represents the resistance value. Therefore, the average value of the internal resistance of the MFCs was 40.314 ± 6.813 Ω. The literature has shown that the internal resistance values tend to decrease due to the nature of the electrodes used; there is a record that by increasing the proportion of metallic materials, the resistance tends to decrease up to a specific limit because the internal resistance values also depend on the substrate used [32,33]. Yaakop et al. (2023) used household waste as substrates in their microbial fuel cells, generating peaks of 0.110 V with an internal resistance of 117 □, showing the importance of the ionic charge of the substrate in the internal resistance values [34]. Yu et al. (2021) mention in their research on the influence of anode electrodes on the internal resistance values of MFCs that a high electrical conductivity of the substrate helps the movement of electrons in the medium, which would reduce the internal resistance values [35]. The power density (PD) and current density (CD) values of microbial fuel cells with artichoke waste can be observed in Figure 4 (b), observing a maximum PD value of 220.271 ± 11.174 mW/cm2 at a CD of 5.841 ± 0.285 A/cm2 and a peak voltage of 556.686 ± 23.411 mV. The literature has reported that power density values vary depending on the electrode sizes and electrode distance used in microbial fuel cells [36,37]. Sonu et al. (2024) used jasmine flower waste in their microbial fuel cells, managing to generate a maximum power density of 2 mW/cm2, mentioning that the biocompatibility of the biofilm formed on the anodic electrode influences the power density values [38]. In the process of making the use of artichoke waste as a fuel source viable, the generation of bioelectricity is a crucial point, which is why Figure 5 shows the schematic of the light generation process, for which the three single-chamber fuel cells were connected, managing to generate 2.35 V, which was enough to light an LED light during the 21-day operation of the microbial fuel cells.

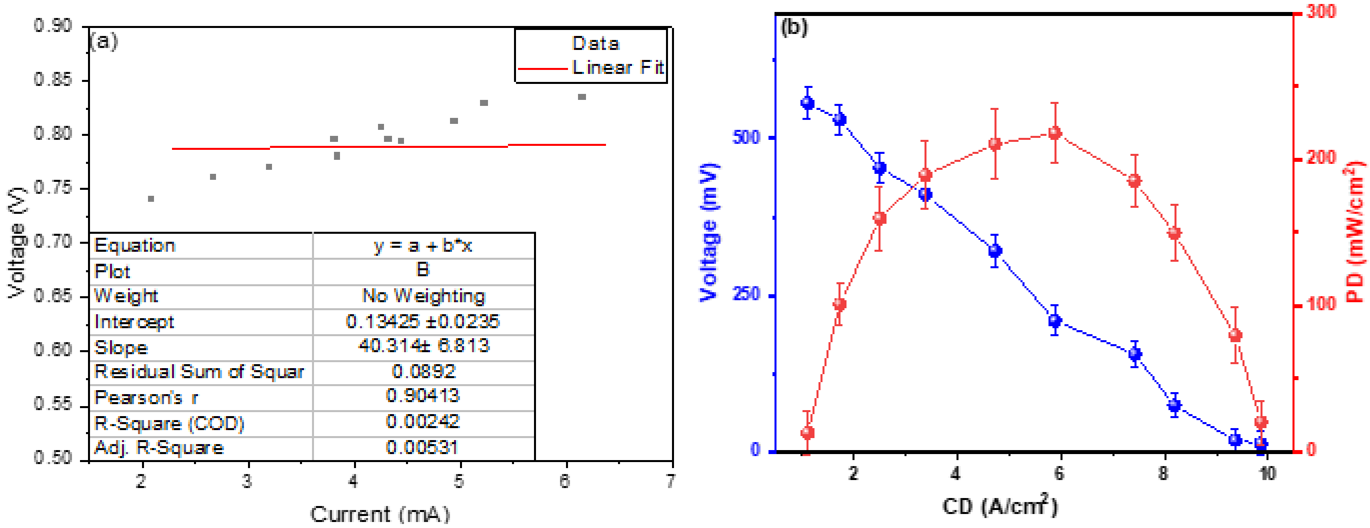

Figure 4. Values of (a) internal resistance and (b) power density as a function of current density.

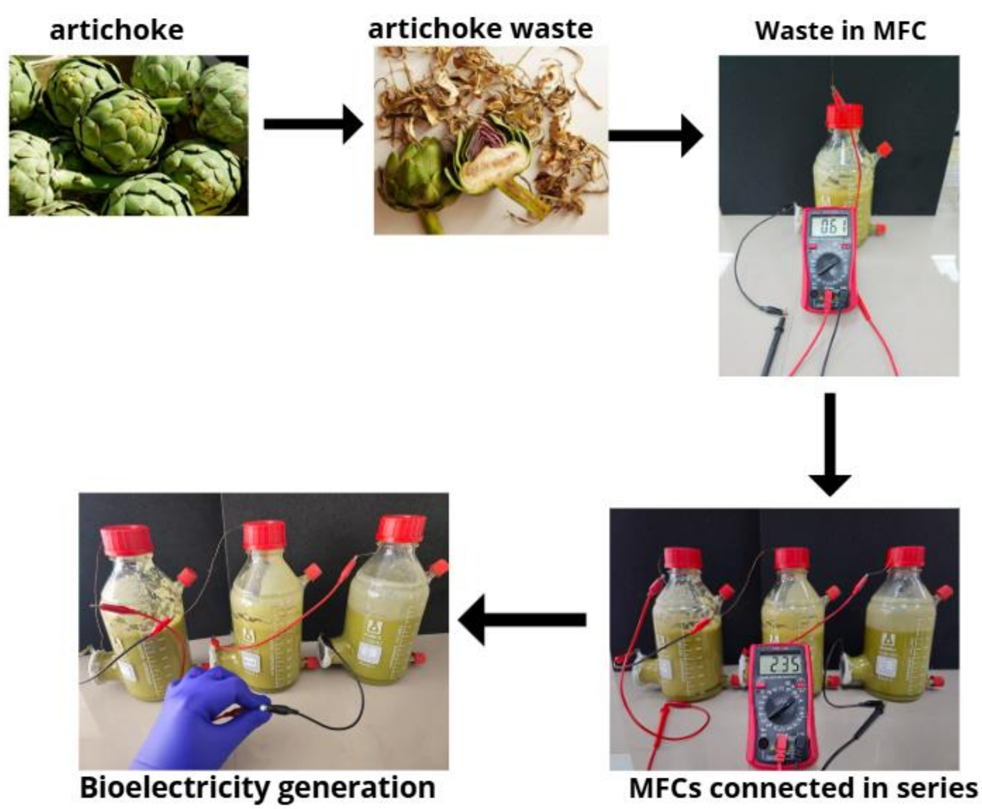

Figure 5. Schematic of the bioelectricity generation process.

4. Conclusion

The experimental results obtained from using artichoke waste as fuel in single-chamber microbial fuel cells are promising because high electrical values were obtained with a small amount of waste. The highest values were obtained on the tenth day; for example, the maximum average voltage values were 0.795 ± 0.025 V and 1.980 ± 0.072 mA of electric current; the microbial fuel cells operated on the tenth day with an electrical conductivity of 127.844 ± 8.512 mS/cm and a pH of 4.351 ± 0.161. At the same time, the internal resistance of the microbial fuel cells found on the tenth day was 40.314 ± 6.813 Ω, whose average maximum power density was 220.271 ± 11.174 mW/cm2 for an average current density of 5.841 ± 0.285 A/cm2. Finally, the microbial fuel cells with artichoke waste were connected in series, generating a voltage of 2.35 V, which is necessary to turn on an LED light, thus demonstrating the functionality of this prototype for the generation of bioelectricity. The results shown in this research are the pioneers with this waste; for future work, the use and standardization of pH values are recommended to obtain maximum efficiency throughout the operationalization period of the microbial fuel cells.

Acknowledgements

The research was funded by Universidad Cesar Vallejo.

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