

# Harvesting Bioelectricity from Aloe Vera Plants Using Copper–Zinc Electrodes: A Sustainable Energy Alternative

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**Abstract**— The growing global energy demand and environmental concerns necessitate exploration of renewable, eco-friendly energy sources. This work investigates the feasibility of generating bioelectricity directly from Aloe Vera plants through embedded copper–zinc electrodes. Acting as a galvanic cell, the plant–soil medium facilitated stable electrical outputs ranging from 0.5–0.7 V and 800–1000  $\mu$ A. These outputs were sufficient to power low-energy devices such as LEDs and digital clocks, calculators etc. Results indicate that plant-based bioelectricity, although limited in scale, represents a viable green technology for micro-power applications in off-grid environments. Future optimization of electrode materials, system scaling, and integration with energy storage could enhance its practical utility.

**Keywords**—Bioelectricity, copper–zinc electrode, off-grid environment, renewable energy, Aloe Vera plants.

## I. INTRODUCTION

The global urgency to find cleaner and more sustainable energy sources has intensified in recent decades. Rising concerns about the depletion of fossil fuels, their escalating environmental costs, and the growing demand for electricity have placed enormous pressure on scientists and engineers to explore alternatives [1,2]. While large-scale renewable technologies such as solar, wind, and hydropower continue to dominate discussions, there is also an increasing interest in small-scale, nature-inspired systems that can generate modest amounts of electricity in simple, low-cost ways. One such idea is the production of bioelectricity directly from living plants and their surrounding soil environment.

At its core, this approach makes use of naturally occurring processes in the plant–soil system. Plant roots constantly interact with the microorganisms and moisture present in the soil, creating a microenvironment rich in organic compounds and ions. These conditions foster electrochemical reactions that can be tapped into when two dissimilar electrodes are introduced into the soil. For example, placing a zinc electrode and a copper electrode into moist soil containing an actively growing plant creates a galvanic system where redox reactions can generate a small but measurable voltage and current [3–5].

Although the principle resembles that of a simple battery, the living plant contributes by maintaining soil moisture, releasing root exudates, and sustaining microbial activity, all of which enhance conductivity and prolong system stability.

Among the many plants available, Aloe Vera (*Aloe barbadensis* Miller) has proven particularly promising for such studies. Aloe is a succulent with an exceptional ability to retain water within its tissues and maintain higher moisture levels in its root zone. This feature is critical because electrical conductivity in soil is strongly dependent on hydration. Furthermore, Aloe Vera roots excrete sugars, organic acids, and electrolytes into the surrounding soil, enriching the ionic medium and making it more conducive for electron transfer [6–8]. These properties, coupled with Aloe’s relatively simple maintenance and resilience under laboratory conditions, explain why it is often chosen as a model plant in experiments exploring plant-based electricity generation [9,10]. Research so far indicates that several environmental and design-related factors strongly influence the efficiency of such bioelectric systems. Soil moisture is per-haps the most crucial factor: drier soils increase resistance and limit current flow, whereas adequate hydration improves ion mobility and facilitates charge transfer [11,12]. Light exposure is another important variable. Because photosynthesis and transpiration rates fluctuate with day–night cycles, the ionic environment around the roots also changes, which in turn affects the electrical output [13,14]. The electrode setup itself including the choice of metals, their insertion depth, and the distance between them can significantly alter the voltage and current generated [15].

Despite this growing body of knowledge, notable gaps remain. Much of the earlier work has concentrated on microbial fuel cells or electrode systems directly inserted into leaves or artificial electrolyte solutions. Soil-based copper–zinc electrode systems, which are simple and practical, have received comparatively less systematic investigation [5,7]. Additionally, there is no consensus on best practices for electrode placement, stabilization periods, or the conditions under which reliable long-term readings can be obtained [9,14].

Another limitation is that very few studies move beyond recording raw voltage and current to demonstrate whether the electricity produced can actually power real devices, even at a very small scale. As a result, the practical significance of such systems often remains unclear.

Our work has been designed to bridge some of these gaps by focusing specifically on Aloe Vera grown in soil as a living source of bioelectricity. A controlled laboratory setup was established to minimize external variation and allow systematic testing. Copper and zinc electrodes were carefully prepared and positioned near the plant's root zone, and a stabilization period was allowed to ensure consistent baseline readings. Measurements of voltage and current were then taken over an extended period, capturing both day and night cycles. Environmental factors such as soil moisture and light exposure were deliberately varied to assess their influence on the output. Finally, in order to evaluate real-world relevance, the generated electricity was tested for its ability to power a light-emitting diode (LED) and a small digital clock. By following this approach, the study aims not only to demonstrate the potential of Aloe Vera as a bioelectricity source but also to provide practical insights into how simple soil-based electrode systems can be optimized. The findings may help guide future applications of plant-driven energy, particularly for powering low-demand electronics, environmental sensors, or devices used in remote or agricultural settings where conventional power supply is limited.

## II. METHODOLOGY

This section describes the detailed experimental approach used to study the generation of bioelectricity from Aloe Vera plants using copper–zinc electrodes. The methodology was designed to maintain consistent conditions, ensure reproducibility, and allow a systematic study of factors affecting electricity generation. The experimental procedure was divided into several stages: (i) selection and preparation of biological and electrochemical components, (ii) assembly of the soil-based bio-electrochemical system, (iii) recording of baseline measurements and controlled observation under varying conditions.

### II.1 Selection of Plant System and Electrodes

#### II.1.1 Plant System:

Aloe Vera (*Aloe barbadensis* Miller) was selected as the biological component due to its ability to maintain a stable, moist, and ion-rich root environment.

Being a succulent, Aloe Vera retains soil moisture for extended periods and continuously releases root exudates (organic acids, sugars, and ions) into the rhizosphere. These factors increase soil conductivity, creating a favourable environment for galvanic reactions. A healthy Aloe Vera plant approximately 15–20 cm tall was chosen and housed in a 20 cm terracotta pot containing commercially available potting soil. The potting medium was selected for its balanced texture and good drainage, preventing waterlogging while maintaining adequate ionic mobility.



**Fig.1. Plat System**

The plant was visually inspected to ensure it was free from disease and water stress. A three-day acclimation period was allowed in the laboratory before the experiment began. This stabilization ensured that the plant's physiological activity, transpiration rate, and root-zone moisture levels were steady, providing consistent experimental conditions.

#### II.1.2 Selection of Electrodes:

Zinc (Zn) and copper (Cu) were selected as electrode materials because they create a galvanic pair with a significant potential difference in soil electrolyte. Zinc, being more electropositive, serves as the anode (electron donor), while copper acts as the cathode (electron acceptor). This choice ensures measurable open-circuit voltage and current output. Each electrode was a flat plate measuring approximately  $5 \times 1 \times 0.1$  cm. Before use, both electrodes were abraded with fine-grit sandpaper to remove oxide layers, rinsed with distilled water to eliminate residues, and allowed to air-dry. Cleaning was essential to achieve proper contact with the soil electrolyte and to minimize variability caused by surface contamination.

#### II.2 Laboratory Setup and Environmental Conditions

The experiment was performed in a controlled indoor laboratory environment with ambient temperature maintained at  $25 \pm 1$  °C.

The plant received natural, indirect sunlight for 8–10 hours daily. Soil moisture was maintained at a moderately moist condition using a calibrated watering can and spray bottle to ensure a consistent ionic pathway. Electrical measurements were taken using a digital multimeter to measure DC voltage with 0.01 V resolution and DC Current with 1  $\mu$ A resolution. Insulated copper wires with alligator clips were used to establish secure, low-resistance connections between electrodes and measurement devices.

### II.3 Assembly of the Soil-Based Bio-Electrochemical System

The bio-electrochemical system was assembled as follows:

- The zinc electrode (anode) was carefully inserted into the soil to a depth of about 6 cm, positioned close to the central root zone to maximize contact with the rhizosphere, where ion concentration is highest.
- The copper electrode (cathode) was inserted at the same depth but at a radial distance of 5–7 cm from the zinc electrode to maintain separation and avoid direct electrical shorting.
- The electrodes were then connected to the multimeter with zinc attached to the COM (negative) terminal and copper connected to the positive terminal.

Care was taken to keep the electrodes stable throughout the experiment, as any movement could disturb the soil-electrode interface and affect readings.

### II.4 Measurement Procedure

#### II.4.1 Stabilization and Baseline Recording:

Immediately after inserting the electrodes into the soil, the multimeter was connected and left undisturbed. The voltage and current readings shown on the multimeter display were recorded every 30 minutes for the first two hours. This step was done to observe whether the readings became stable over time and to ensure the system was working consistently before continuing with further measurements.



Fig.2 Voltage reading by using multimeter



Fig.3 Current reading by using multimeter

*II.4.2 Extended Monitoring:*

After the initial two-hour period, the readings were taken once every hour for the next 24 hours. This allowed observation of how the output changed naturally during the day and night cycle and how factors like light exposure and soil drying might affect the readings. All measurements were recorded in a table, and each reading was taken three times in succession to make sure the data was reliable.

*II.5 Influence of Environmental Variables*

Two key environmental factors were tested to understand their effect on electricity generation.

*II.5.1 Effect of Soil Moisture:*

After establishing baseline readings with normal soil moisture, 100 ml of distilled water was slowly added to the soil. Readings from the multimeter were taken at 30, 60, and 90 minutes after watering. This was done to see whether higher moisture would allow better flow of electric current through the soil.

*II.5.2 Effect of Light:*

Exposure Readings were also compared at two different times of day: mid-day, when the plant was in bright natural light, and late at evening, after it had been in darkness for several hours. This was done to check if the plant's day-night cycle had any noticeable effect on the electrical output.

**III. RESULTS AND DISCUSSION**

*III.1.1 Experimental Observations:*

This study evaluated bioelectricity generation from Aloe vera plants using copper-zinc electrodes under varying environmental and soil conditions. Two plants of contrasting health were selected: Aloe vera 1, which gradually showed signs of deterioration, and Aloe vera 2, which remained healthy with nutrient-rich soil. Voltage, current, and power outputs were recorded at different times and under different weather conditions.

*III.1.2 Aloe vera 1 (Declining Plant Condition):*

On first day of experiment (sunny, watered), Aloe vera 1 initially produced voltage ranging from 0.50 V at 11:30 am to 0.48 V at 8:30 pm, with corresponding currents of 372–368  $\mu$ A. This gave a maximum power output of 186  $\mu$ W. However, by 21:45 pm, the voltage fell to 0.47 V and current dropped to 315  $\mu$ A, reducing power to 148.05  $\mu$ W. On subsequent days, when no water was supplied, a steady decline was observed.

On next day (rainy, no watering), the plant registered 0.48 V, 328  $\mu$ A, and 157.44  $\mu$ W and it keep decreasing. After two days (no watering), Aloe vera 1 record-ed its lowest outputs: 0.43 V, 240  $\mu$ A, and 103.2  $\mu$ W. This downward trend clearly reflected the negative effects of stress and deteriorating plant condition on its ability to generate electricity.

*III.1.3 Aloe vera 2 (Healthy Plant, Good Soil):*

In contrast, Aloe vera 2 performed significantly better. On the same day, when Aloe vera 1 recorded its lowest outputs (no watering), the aloe vera 2 gave stable outputs like voltages stayed stable between 0.56–0.52 V, while current was much higher: 925  $\mu$ A at 16:18, peaking at 1130  $\mu$ A at 17:30, and later stabilizing around 1000–1025  $\mu$ A in the evening. This resulted in power values ranging from 518–587.6  $\mu$ W, near-ly three to four times higher than Aloe vera 1. The stronger root system and richer soil allowed for more efficient electron transfer, sustaining higher bioelectricity output.

*III.2 Voltage Trends:*

The voltage versus time plots (Fig.4 and 5) revealed clear differences between the two plants. Aloe vera 1 showed a steady decline over consecutive days, with maximum values dropping from 0.50 V to 0.48 V. By contrast, Aloe vera 2 consistently produced voltages in the 0.60–0.59 V range, even without watering. This stability suggests that both soil quality and the plant's internal ionic balance play key roles in maintaining voltage output.

Here we have observed that healthy plant-soil systems tend to exhibit more stable voltages, largely due to intact ionic gradients and robust microbial interactions. It has been showing that plant stress weakens ionic transport and disrupts the bio electrochemical system.

**Table1: Data for Aloe vera1 and Aloe vera2**

Plant Type	Date	Weather	Water condition	Voltage (V)	Current ( $\mu$ A)	Power ( $\mu$ Watt)
Aloe vera 1	15.6.25	Sunny	Given	0.50	372	186.00
	16.6.25	Rainy	Not	0.48	328	157.44
	17.6.25	Cloudy	Given	0.47	315	140.05
	20.6.25	Sunny		0.43	240	103.20
Aloe vera 2	15.6.25	Sunny	Given	0.60	1130	678.00
	16.6.25	Rainy	Not	0.56	1088	609.28
	17.6.25	cloudy	Given	0.54	1025	553.50
	20.6.25	Sunny		0.52	1015	527.80

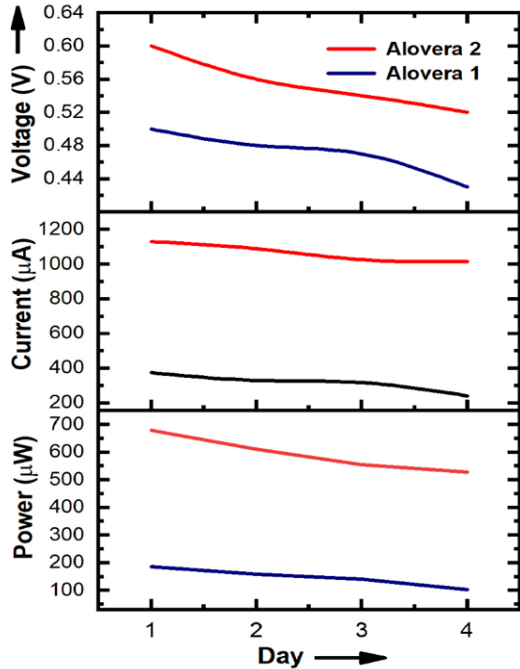


Fig. 4. Voltage, Current and Power profile over various day for Aloe vera1 and Aloe vera2

Table 2: Current and voltage of Aloe vera1 and Aloe vera2 for different time on the same day

Plant Type	Date	Time	Voltage (V)	Current (µA)
Aloe vera1	15.6.25	11.30 am	0.50	372
		2.30 pm	0.51	372
		5.30 pm	0.49	370
		8:30 pm	0.48	368
Aloe vera2	15.6.25	11.30 am	0.60	1130
		2.30 pm	0.62	1131
		5.30 pm	0.59	1129
		8:30 pm	0.59	1128

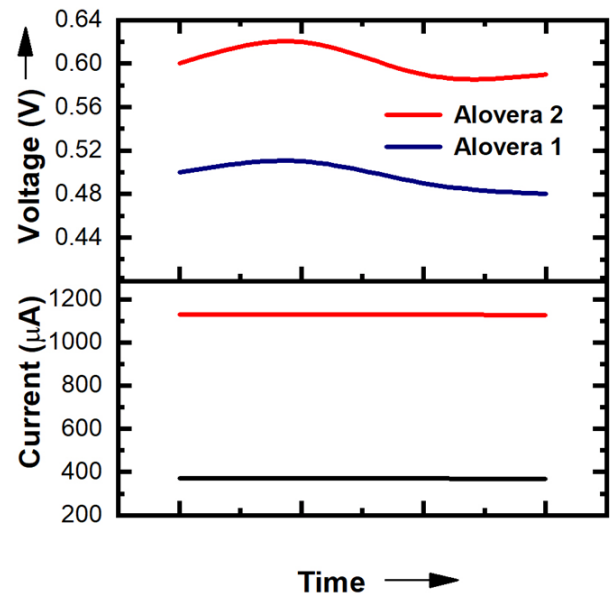


Fig. 5. Voltage, Current profile over different time on the same day for Aloe vera1 and Aloe vera2

### III.3 Current Trends:

The current versus time plots (Fig.4 and 5) showed an even sharper contrast. Aloe vera 1 had relatively low and declining values, dropping from 372 µA to 368 µA on 15.06.2025. On the other hand, Aloe vera 2 produced far stronger and more stable current outputs, always above 1100 µA, with a peak at 1130 µA.

This difference highlights the importance of soil microbial activity and organic matter. Plant roots release natural compounds into the soil, which support microbial communities. These microorganisms, in turn, release electrons through metabolic activity, increasing the flow of current. In Aloe vera 2, a healthier root system and richer soil sustained this process, while Aloe vera 1's decline reduced its capacity for current generation.

### III.4 Power Output Trends:

The most direct measure of performance, power output versus time (Fig.4 and 5), clearly demonstrated the effect of plant health.



Aloe vera 1's power declined from 186  $\mu$ W (15.06.2025) to just 103.2  $\mu$ W (20.06.2025). In contrast, Aloe vera 2 consistently produced much higher power, in the range of 678–527  $\mu$ W. These values are in line with other findings showing that Aloe vera can produce enough energy to power small devices such as LEDs and digital clocks when conditions are favorable. Our results confirm this potential but also show that efficiency is closely tied to plant vitality and soil condition.

From all the observations, we shown that Aloe vera 2 outperformed Aloe vera 1 across all parameters, proving that healthy, unstressed plants generate significantly more bioelectricity. Rich organic matter and microbial activity in Aloe vera 2's soil supported stronger electron transfer, while depleted soil in Aloe vera 1 limited performance. Aloe vera 1 deteriorated rapidly under water stress despite occasional rainfall, while Aloe vera 2 remained stable even without additional watering, likely due to better soil moisture retention and a stronger root system. Although the power levels are in the microwatt range, the system shows potential for self-sustaining micro-power generation in living plants. This could be valuable for applications in low-energy sensors and remote environments.

These results add to growing evidence that plant-based bioelectricity can serve as a sustainable, eco-friendly energy source. Unlike microbial fuel cells that rely on wastewater or engineered setups, the Aloe vera system demonstrates a simpler and more natural approach, harvesting electricity directly from a living plant without harming it.

#### IV. CONCLUSIONS

This paper presented that, the healthy plant like Aloe vera 2 generated consistently higher outputs (0.60–0.52 V, 1130–1015  $\mu$ A, 678–527  $\mu$ W), while weak plant like Aloe vera 1 showed progressive decline (0.50–0.43 V, 372–240  $\mu$ A, 186–103  $\mu$ W). The experiment highlights that plant vitality and soil health are the most important factors in bioelectricity generation.

The clear performance gap between the two plants emphasizes the potential of Aloe vera based systems for renewable micro-power applications, while also underlining the need to maintain healthy soil and plant conditions to achieve stable and efficient energy generation. As well as the selection of the best combination of electrode pairs with energy sources are also important for better output.

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