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Harnessing Plant Bioelectricity through Prickly Pear as Botanical Batteries

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***Abstract:** Plants which are essential for life, have the potential to become a renewable energy source in the Future. They can generate electricity, reducing greenhouse gas emissions and being environmentally friendly. This study aims to explore the untapped potential of botanical batteries and contribute to green energy technology. Plants' capacity to convert sunlight into chemical energy could be a viable and environmentally friendly source for electrical power generation, offering a sustainable solution to the world's growing energy demands while mitigating climate change impacts.*

To achieve the goal of the study, pure experimental research was applied. And the researchers used cactus (prickly pear), copper nails, zinc nails, copper wire, alligator clips, and disposable plastic containers. The study was conducted at Bayugan National Comprehensive High School, Bayugan City.

Throughout the analysis of the data obtained after the three tests conducted, it has been found that like an electrochemical cell, copper and zinc electrodes inserted into prickly pear leaves can generate energy. With the highest current magnitude and maximum value at the highest contact area, the prickly pear plant has the highest potential for energy harvesting. Cut-off or partially leaved leaves can be harvested for their energy, which can then be utilized to charge batteries or power low-power devices.

***Keywords:** Renewable Energy, Botanical Batteries, Green Energy, Greenhouse Gas Emissions.*

1. INTRODUCTION

Background of the Study

Plants have been an important source of life to people. Plant has been used as a natural source

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of food, oxygen, medicine and to prevent air pollution. But we had no idea that plants have a potential to be a new renewable energy source, as plant can produce electricity that can empower electrical device. According to Raut and Thurat (2019), plants not only give us food and oxygen, but it can also be one of the sources of electricity. This concept is the best way to

Have a Sustainable and Renewable Electricity Source.

For more than a century, reports of electrical potential variations along plant apoplast have been made. The power recorded in earlier studies on plant harvesting was in the nW (Nano watt) range with a few hundred mV (Medium Voltage) of open circuit voltage and close to uA (Microampere) of short circuit current, (Chao et al. 2017). Due to the unique composition that most plant leaves naturally have; certain leaf structures can transform mechanical forces applied at the leaf surface into electrical energy. In more detail, a process known as contact electrification enables the leaf to accumulate electric charges on its surface. Then, these charges are rapidly exposed to the internal plant tissue. The plant tissue functions as a sort of "cable" that carries the power produced to various areas of the plant. It is therefore possible to harvest the electricity produced by plants and utilize it to power electrical gadgets by simply attaching a "plug" to the plant stem (Meder ET al.2018). According to Arifin et al. (2021), the amount of electricity that a plant can produce will vary depending on the plants that are used or combined.

The study of Bhadra et al. (2022) stated that by using plant dead biomass and Rhizodeposits secreted from plant roots as a substrate for electroactive bacteria (EAB), the plant microbial fuel cells (pMFC) can generate energy. Since plants can be found almost everywhere on Earth, they are a readily available source of energy. The pMFC is a novel setup that extracts energy from underutilized plant carbon sources, or rhizo- deposits, without competing with food biomass. The first tests investigate the potential of plant rhizo-deposits as a substrate for electroactive microbes in a microbial fuel cell (MFC) application.

Although numerous plant species have been studied for their electrical production, there is still much to learn about the scalability and feasibility of using plant-generated electricity in actual uses. Further investigation is needed to assess the feasibility of integrating botanical batteries into renewable energy systems and to determine which plants have the greatest potential for reliable and efficient power generation. Other bio-electrochemical processes that generate electricity through biological interactions between plants and microbes under the influence of sunlight have recently been developed. PMFCs can be installed on agricultural land without interfering with food production or other production processes, unlike photovoltaic systems, and even in fields that are not suitable for food production. The most important fundamental factors unique to PMFCs have been thoroughly investigated to investigate and optimize the use of living plants for the purpose of sustainable power generation (Ding et al. 2019).

In our daily lives, plants have been a common source of life, providing us with food, medicine, shelter, and oxygen. Even though plants are necessary for all life, few people are aware that they can generate electricity. Because of this, they have the potential to become a renewable energy source in the future that can power electrical devices while reducing greenhouse gas emissions and being environmentally beneficial. The aim of this study is to experiment with the idea that botanical energies can empower electrical devices and determine their potential as a new renewable energy source that can help in the future. With the world's focus shifting to renewable energy sources, solar panels and wind turbines are becoming more widespread.

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Scientists have successfully used a succulent plant to create a living "bio-solar cell" that relies on photosynthesis, even though it may seem like science fiction. Researchers believe that this renewable energy could facilitate the creation of cutting-edge sustainable technologies (Elton, 2022). According to a Singer (2018) article, ITT biologists and roboticists have found that green plants are a "green" source of electrical power. Future electricity generators that blend seamlessly with the environment could be made of green plants. Globally accessible sources of energy include green plants. An additional article by Ong (2023) discusses the project by Green
Display's botanical light the future of plant-powered energy, which aims to sustainably produce light from plants. Renewable energy that also safeguards the environment is desperately needed on a global scale.

Through the utilization of light energy, which is often added together, plants employ the process of photosynthesis to create molecules of carbohydrates from carbon dioxide and water. Due to the movement of electrons caused by this mechanism, there will be a potential difference between the leaves and roots when exposed to light. With such conditions, a plant may produce a potential difference of up to 50mv. This phenomenon is caused by the frequent changes in light and darkness from the light source (Chong et al. 2019). The primary process by which biological systems transform light energy into chemical energy. To harness photosynthesis for the production of green energy, the original photosynthetic system is interfaced with electrodes and electron mediators to construct bio- photoelectrochemical cells (BPECs), which convert light energy into electrical power. This started gaining attention and interest due to the potential for developing lab-scale BPECs into practical and functional green energy production equipment in the future. The thylakoids, cyanobacteria, other algae, or plants can all provide the photosynthetic electrons. The design of the BPEC architecture,
The light source, and the electrodes are the other crucial factors to consider and plan for in order to construct an effective, long-lasting system that generates a sizable current density on the anodes (Adir et al. 2022).

Through this study, we expect to not shed light on the untapped potential of botanical batteries but also contribute valuable insights to the field of green energy technology and to posits that plants, with their inherent capacity to convert sunlight into chemical energy, may serve as a viable and environmentally friendly source for electrical power generation, presenting a sustainable solution to the world’s growing energy demands while mitigating the impacts of climate change.

Objectives of the Study

This study aims to investigate the attainability of utilizing cactus plants as an alternative source of electricity to generate electricity and to empower light bulbs. The primary objective is to explore how cactus-based bioelectricity can be harnessed and applied effectively to provide sustainable illumination using light bulbs as the target devices. This study sought to determine the:

1. Influence from the electrodes' distance from the energy gathered.
2. Using the bioelectricity that cacti create and transforming it into useful electrical energy in the following ways:

A. thickness
B. thinness

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3. The bioelectricity produced by cacti differs from traditional battery technologies in the following ways:
a. Sustainability
b. Effect on Environment.

Significance of the Study

The result of this study will provide knowledge on how to produce electricity using plants as a source. It will allow us to provide renewable energy sources and decrease the use of coal as a source of electricity, which poses a concern about pollution.
The study benefits the following:
RESEARCHER. This study helps expand our understanding of plants, opening doors to the creation of sustainable and renewable energy sources.
COMMUNITY. Using renewable energy can enhance resilience and lower the vulnerability to power disruptions during severe weather conditions.
ENVIRONMENT. It has the potential to enhance the environment, fostering cleaner air and purer water, ultimately creating a healthier planet for future generations.
FUTURE RESEARCHERS. The conducted studies will create numerous research opportunities in various fields that will make a meaningful contribution to the progression of clean energy solutions and the cultivation of sustainable energy sources.

Scope and Delimitation

This study focused on utilization of photosynthesis in cacti to generate electricity, with the primary objective of powering small electrical devices such as light bulbs. Through careful examination, the research will ascertain the capability and factors of cacti to supply bioelectricity to light bulbs. Furthermore, the research will explore the far-reaching potential of plants as a viable renewable energy alternative, comparable to other conventional sources.
This research does not aim to empower any large electric appliances. It will not extensively investigate the other factors that are not related to bioelectricity from plants. The study will primarily focus on powering light bulbs.

Conceptual Framework

Shows the output in conducting the experiment of Microbial Fuel Cell. The diagram depicts the entire process of this study. The materials used in conducting the study to the process and result of this study. Finally, data from the conducted study will be collected.

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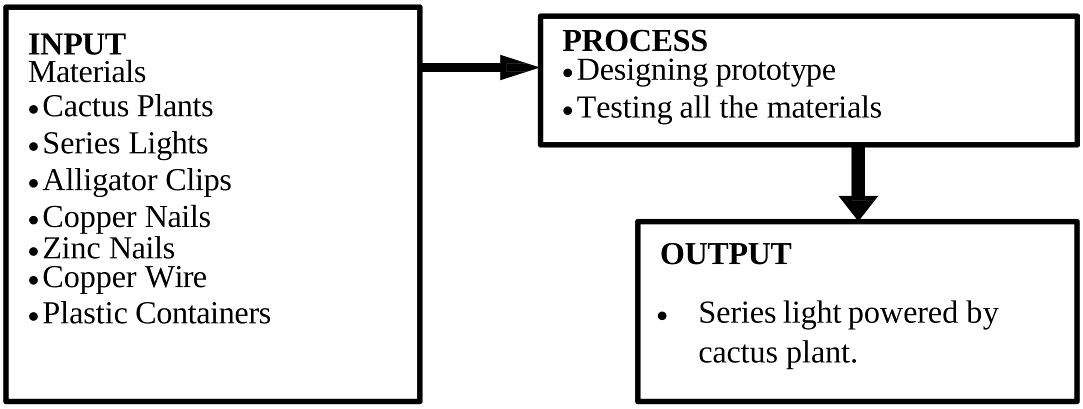
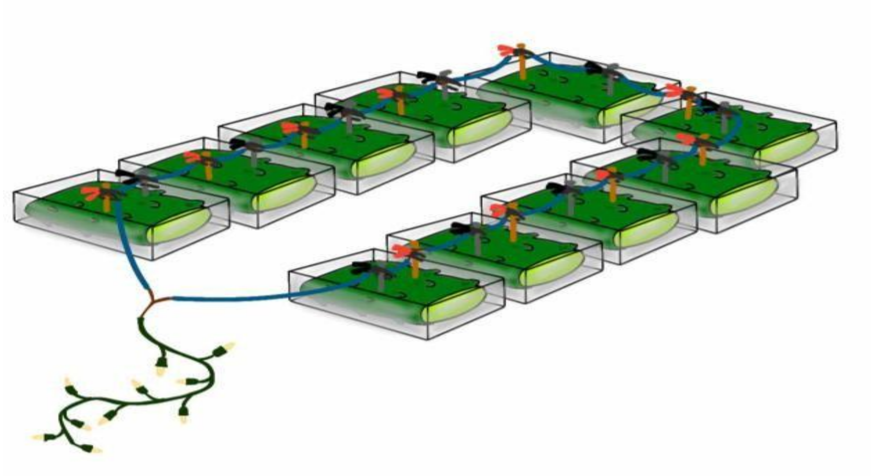
Research Paradigm



Prototype



2. RELATED WORK

Energy Harvesting and Plant Microbial Fuel Cells (PMFCs) for Sustainable Power
With billions of batteries disposed of annually, current technologies like Wireless Sensor Networks (WSNs), the Internet of Things (IoT), and Machine-to-Machine (M2M) communications are dependent on the use of batteries, which presents a significant environmental danger. The combination of wireless communication devices and sensors, however, consumes a lot of electricity. The utilization of low-power electronic devices that obtain their energy from external sources, like solar power, thermal and kinetic energy, Microbial Fuel Cells (MFC), and other sources, is made possible by Energy Harvesting (EH).
A well- known sustainable energy source, the Plant Microbial Fuel Cell (PMFC) represents a significant advancement in the creation of self- sufficient systems for both indoor and outdoor use. A primary obstacle associated with PMFCs is their dynamic power supply, dynamic charging rates, and low energy supply. In this paper, an energy harvester system based on PMFCs is proposed for the implementation of self-powered, autonomous sensor nodes with IoT and cloud-based service communication protocols.
With the suggested EH circuit, the PMFC design is specifically modified for the execution of

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IoT-WSN-based applications. The PMFC-EH system has a maximum power point of 0.71 V, a current density of 5 mA cm−2, and a power density of 3.5 mW cm−2 with a single plant. Considering a sensor node with a current consumption of 0.35 mA, the PMFC-EH green energy system allows a power autonomy for real-time data processing of IoT-based low-power WSN systems (Aguilar, et al. 2019).

Electrode Configuration and Distance Impact on Energy Extraction

The study of Algarni ET, al (2022), the setting of the experiment investigates how the distance between the two electrodes affects the amount of energy that is extracted from the prickly pear plant. To discover the ideal distance for extracting the most energy from the plant, the same copper and zinc electrodes are submerged in the leaf at a fixed depth of 1 cm. However, the spacing between them can be adjusted between 0.5 and 15 cm. Two different leaf types—thin and thick are used in this experiment.

A leaf is considered thin if its thickness is less than or equal to one centimeter, whereas a leaf is considered thick if its thickness is more than one centimeter. The study demonstrates that a thin leaf's current value is higher than a thick leaf's current value. The voltage is roughly equal to 0.975 V, according to the measurement results presented in. However for thick leaves, the current magnitude drops from 8.5 mA to 0.4 mA and for thin leaves, from 2.9 mA to 0.2 mA, when the distance between inserted electrodes grows from 0.5 cm to 15 cm.. Because of this, when the zinc and copper electrodes are closer together and covered in thick leaves, the amount of energy that is captured from the prickly pear plant is greater. As a result, a lower distance also means a decreased resistance, which facilitates simpler electron transport and raises the current magnitude. To capture optimum quantity of energy, electrodes should be embedded in a thick leaf at close distance.

Foreign Works

Electrode Material Innovation and Stability

Another experimental study of Amayreh, Mohammad (2021). The experiment demonstrated that the generated potential difference was increased by 50% when Mg/Cu electrodes were used in place of Zn/Cu electrodes. Additionally, employing these electrodes resulted in a 40% reduction in the quantity of cactus pieces required to produce the same potential difference. In terms of the potential variation over time, the outcomes demonstrated the capacity to generate a high voltage that was semi-stable for over 4 days, during which the LED lamp's brightness remained exceptionally high. Because of the low cost of the raw materials, the ease of application, the long glow up period, and the high current values of the cactus battery extract (1mA), the cut cactus pieces, and cactus plate extract may become viable soon.

Agriculture, Renewable Energy, and Bioelectricity Generation in Vietnam

Vietnam's economy is rapidly growing, with a focus on modernizing and expanding its agriculture sector. The Mekong River Delta, one of Vietnam's major agricultural regions, is a significant contributor to GDP, exports, and employment. The country's 2018 report on renewable energy highlights the country's future goals, with electricity demand growing at a rate of 9% annually and renewable energy demand growing at a rate of 10% annually. The rate of increase for renewable energy is expected to surpass that of hydropower and coal gas fire.

However, the Mekong River Delta's intensive paddy farming causes significant rice husk

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discharge, posing environmental risks. To mitigate these issues and prevent regular rice husk disposal into rivers, a study investigates the use of rice husk for bioelectricity. The development of 11 MW rice husk power plants aligns with the Clean Development Mechanism (CDM) for sustainable and ecologically friendly activities in the Mekong River Delta.The transition from a command to a market economy in agriculture is crucial for Vietnam's economic growth, as it impacts exports, employment, and GDP.
The Mekong River Delta's ambitious goal of incorporating 10% renewable energy in electricity consumption is a key focus. However, the extensive rice husk discharge from paddy farming poses environmental risks (Hanh, et. al 2021).

Plant-Based Bio Electrochemical Systems (P- BES) and Prickly Pear Cactus
According to (Abdelkareem et al., 2021). In recent years, the exploration of plant- based bio electrochemical systems (P- BES) has emerged as a promising avenue for sustainable energy generation and environmental remediation. The utilization of botanical organisms, such as the Prickly Pear cactus, as bio-batteries represents an innovative approach to harnessing bioelectricity. P-BES leverage the plant- microbial interactions within the rhizosphere to generate electrical energy while simultaneously offering a green solution for pollutant removal from water and soil. The development of Prickly Pear-based bio-batteries demonstrates the potential for integrating natural plant systems into renewable energy technologies, paving the way for eco-friendly and efficient energy production methods.

Comprehensive Understanding and Future Directions
Previous studies have mostly focused on extracting practical insights from the usage of solar cells, microbial fuel cells, plant-based triboelectric generators, and prickly pears in the production of bioelectricity. Despite these advancements, there are still several important research gaps that need to be filled. A significant problem in the field of sustainable energy research could be resolved by looking into potential synergies and merging different energy sources to increase the overall efficiency and reliability of bioelectricity generation. This tactic opens the door to more innovative solutions to the growing demands of sustainable energy by facilitating a deeper understanding of the relationships between different energy sources.

3. MATERIALS AND METHODS

This chapter contains the study's methodology.
3.1 Materials:
Alligator Clips (50 pairs)
Cactus (Prickly Pear) (150 pcs.)
Copper Nails (½ kg)
Copper Wire (10m)
Disposable Plastic Containers (150 pcs.)

3.2 Process
1. Cactus Selection
Begin by selecting suitable prickly pear cacti for the experiment. Choose healthy cacti with well- developed stems and pads.

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2. Container Preparation
Prepare individual plastic containers for each cactus. Ensure the containers have enough space to accommodate the cactus and the electrical components.
3. Electrode Connection
Cut wires into suitable lengths and connect them to copper and zinc nails. These nails will serve as the electrodes for collecting the bioelectricity. To secure the connection and prevent them from easily loosening up, add alligator clips to each wire after connecting them to the copper and zinc nails.
4. Placement of Cactus
Place each prickly pear cactus in its respective plastic container, ensuring it is securely positioned.
5. Inserting of Electrodes
While inserting the copper and zinc nails, make sure to place them near each other, approximately 2 inches apart. This proximity will help facilitate the flow of electricity between the electrodes and maximize the electricity generated by the prickly pear cactus.
6. Wiring Configuration
Arrange the wires connected to the copper and zinc nails in a way that allows for easy connection to the LED lights.
7. Connecting the LED Lights
At the end of the wire, connect the positive and negative charges of the electricity to the LED lights. This will enable the generated bioelectricity to power the LED lights.
8.Observing the LED Lights
Observe the LED lights to see if they light up when the bioelectricity is generated by the prickly pear cacti. Note any variations in brightness or patterns

4. RESULTS AND DISCUSSIONS

The findings and analysis of the study are displayed in the data below. The findings are evident in the related literature's conclusions and will be very beneficial for further research.

4.1 Influence between the Distances of the Electrodes to the Harvested Energy

The purpose of the experiment investigates how the distance between the two electrodes affects the amount of energy that is extracted from the prickly pear plant. To discover the ideal distance for extracting the most energy from the plant, the same copper and zinc electrodes are submerged in the leaf at a fixed depth of 1 cm. However, the spacing between them can be adjusted between 0.5 and 15 cm. Two different leaf types thin and thick are used in this experiment. A leaf is considered thin if its thickness is less than or equal to one centimeter, whereas a leaf is considered thick if its thickness is more than one centimeter. The current value obtained from a thin leaf is higher than the current value obtained from a thick leaf.

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		Distance	
		1cm	15cm
Thickness of Cactus	1cm	2.2mA	0.2mA
	3cm	8.5mA	0.4mA

4.2 Conversion of Plant's Bioelectricity to Usable Electricity
With the use of two electrodes—copper and zinc—the 150 cacti palms can generate series light. The energy required to generate the lights will be obtained by these electrodes through the absorption of energy from the cactus plant and converting it into electrical energy.

4.3 The Bioelectricity Generated by Cactus Plants Demonstrates Promising Sustainability.
In the second trial of a new pair of electrodes Cacti are hardy plants, requiring minimal water and resources, making them resilient in various ecosystems unlike conventional batteries, which often involve resource-intensive manufacturing processes, cactus plants offer a more sustainable option for electricity generation. Cactus bioelectricity generally has a lower environmental impact compared to conventional batteries. The latter involves the extraction and processing of metals, contributing to environmental degradation. Cactus plants, being part of natural ecosystems, have a smaller ecological footprint and can be integrated into existing environments without causing significant harm. Cactus bioelectricity generally has a lower environmental impact compared to conventional batteries. The latter involves the extraction and processing of metals, contributing to environmental degradation. Cactus plants, being part of natural ecosystems, have a smaller ecological footprint and can be integrated into existing environments without causing significant harm.

5. SUMMARY, CONCLUSION AND RECOMMENDATION

This chapter consists of three sections deals with a summary of all the previous chapters, the conclusions are also given and the recommendations.

Summary of Findings
Based on the analysis of the data, these are the following findings of the study:
1. The voltage is about equal to 0.975 V. The current magnitude falls from 8.5 mA to 0.4 mA for a thick leaf and from 2.9 mA to 0.2 mA for a thin leaf as the distance between inserted electrodes rises from 0.5 cm to 15 cm. As a result, more energy is extracted from the prickly pear plant when the copper and zinc electrodes are next to one another and have dense leaves covering them.
2. Series light can be generated by the 150 cacti palms using two electrodes, copper and zinc.

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These electrodes will absorb energy from the cactus plant and transform it into electrical energy to produce the energy needed to power the lights.

3. Cactus plants, part of natural ecosystems, have a smaller ecological footprint and can be integrated into existing environments without significant harm. Cactus bioelectricity has a lower environmental impact compared to conventional batteries, which involve metal extraction and processing, contributing to environmental degradation.

Conclusions

Based on the data analysis and the results of the study, the following conclusions were drawn:

1. The study explores the efficient use of renewable, sustainable, and green energy resources, particularly in living plant power generation. It was found that copper and zinc electrodes embedded in prickly pear leaves can produce energy, like an electrochemical cell.
2. The prickly pear plant has the highest potential for energy harvesting, with the highest current magnitude and maximum current value at the highest contact area.
3. The study also found that a combination of series and parallel connections of electrode pairs at the leaves of the prickly pear plant can generate the optimum amount of energy.
4. The study also found that the same amount of energy can be harvested using cut-off leaves of the prickly pear plant, with the highest energy produced at the cut-off leaves or half-leaves. The harvested energy can be used to power low-power consumption devices or charge batteries.

Recommendations

We proposed that our research could aid in the creation of sustainable green energy sources derived from prickly pears. However, the quantity of energy that is captured can be used to power portable, low-power gadgets that are connected and used everywhere. Our future research aims to increase the harvest energy that can be retained in a rechargeable battery. Additionally, we suggest using both live and dead plants to power an Internet of Things smart farm monitoring system.

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