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Comparison of Electrical Properties and Endurance of Papaya Peel and Cassava Peel-Based Bio-Batteries as Potential Alternative Energy Sources

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Abstract

Background of study: Bio-batteries represent an attractive energy solution utilizing organic substances to generate electrical energy. Organic waste materials, such as fruit peels, contain electrolytic compounds harnessed for bioelectricity generation. Cassava and papaya peels, rich in natural acids and carbohydrates, offer potential as low-cost, eco-friendly materials for bio-battery development.
Aims and scope of paper: This study investigates the electrical performance and endurance of biobatteries made from cassava peel and papaya peel subjected to varying fermentation durations (0, 2, and 4 days).
Methods: The study employed an experimental comparative approach using 1.5 V battery casings filled with fermented cassava and papaya peel pastes. Electrical parameters (voltage, current, and power) were measured using a digital multimeter. Additionally, endurance was tested by using the biobatteries to power a 1.2 W LED until discharge.
Result: Cassava peel-based biobatteries showed higher electrical output than those based on papaya peel, especially after 4 days of fermentation. The cassava battery reached a peak voltage of 1.6 V and power of 0.107 mW, while papaya reached 1.57 V and 0.105 mW. Cassava peel biobatteries also demonstrated longer endurance, operating up to 27 hours compared to 21 hours for papaya.
Conclusion: Fermentation enhances the electrical properties of fruit peel biobatteries, with 4 days as the optimal duration. Cassava peel is more effective than papaya peel due to its higher content of fermentable substrates and organic acids. This study supports the feasibility of using fermented fruit waste as sustainable bio-battery material and suggests further optimization for practical applications.

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INTRODUCTION

Indonesia remains heavily dependent on primary energy sources such as petroleum and coal to meet its electricity demands. As of 2022, approximately 67.5% of the country's power plants still relied on coal, while the contribution of renewable energy sources stagnated at below 14% (Bagaskara et al., 2022) .The increasing energy consumption driven by human activities underscores the urgent need to explore more environmentally friendly and sustainable alternative energy sources. Alternative energy refers to renewable and environmentally friendly sources that serve as substitutes for fossil fuels and have the potential to mitigate climate change and environmental degradation. Organic waste, such as fruit and vegetable peels, can be used as a promising raw material for bio-batteries(Sigalingging & Sitorus, 2024).

Fruits contain chemical compounds such as ascorbic acid, citric acid, and NADH (Nicotinamide Adenine Dinucleotide Hydrogen), which can act as electrolytes. Fruits and vegetables contain organic acids and mineral compounds such as sodium, potassium, and magnesium, whose inherent electrolytic properties can be enhanced through fermentation that produces additional organic acids, such as acetic acid, thereby improving ionic conductivity (Fatimah et al., 2023; Mauliza & Afrida, 2024). These electrolytic compounds are capable of conducting electricity, enabling organic waste to serve as an eco-friendly alternative material for bio-batteries (Atina, 2015)

Bio-batteries represent an attractive energy solution by utilizing organic substances such as carbohydrates, enzymes, and amino acids to generate electrical energy. In addition to being environmentally friendly, bio-batteries are considered safer and more sustainable compared to conventional batteries that rely on hazardous chemicals like mercury and cadmium, which can lead to environmental contamination (Setiawan et al., 2023). The development of bio-batteries not only reduces dependence on conventional batteries but also offers a viable approach for organic waste management.

Previous research has demonstrated that various types of organic waste have potential as bio-battery materials. For instance, cassava peel waste has been shown to produce a maximum voltage of 10.9 V when arranged in a 20-cell series circuit (Susanto et al., 2018). Furthermore, cassava peel charcoal placed in a 1.5 V battery cell casing yielded a voltage output of 0.563 V and a current of 0,014 mA (Nuryanti et al., 2022). A study utilizing a mixture of cassava and pineapple peel waste as bio-battery material reported relatively insignificant variation in electrical output, with a maximum voltage of 0.79 V and peak current of 0.79 mA (Sitanggang et al., 2021). Papaya peel has also been reported to produce a bio-battery voltage of 1,205 V and and a current of 2,0175 mA(Sasongko et al., 2024). Additionally, papaya at pH 7 managed to generate voltage of 1,03 V and a current of 17,97 mA using the microbial fuel cell method(Segundo et al., 2022). Although studies have explored the separate use of cassava and papaya peels as bio-battery materials, no research has directly compared the two with respect to fermentation time variations and the resulting battery endurance. These findings indicate that fruit and vegetable waste, including cassava, papaya, banana, and potato peels, holds considerable promise for sustainable bioelectricity generation.

Although previous research has explored the use of various fruit and vegetable wastes such as cassava, papaya, banana, and potato peels, as bio-battery materials, most studies focused on individual materials without direct comparative analysis. Moreover, the role of fermentation time as a factor influencing electrical output and endurance has not been thoroughly investigated. Few studies have systematically examined how variations in fermentation duration affect the electrochemical performance and discharge longevity of different organic waste-based biobatteries under identical conditions.

This study was conducted to address the limited comparative data between cassava and papaya peels as bio-battery materials, particularly under varying fermentation durations. Given the distinct biochemical compositions of each peel type, a controlled comparison is needed to understand their electrical behavior and endurance capabilities. The research aims to provide insights into optimizing fermentation as a method to enhance bio-battery performance, thereby supporting both renewable energy development and organic waste valorization.

The purpose of this study is to compare the electrical output and endurance of cassava and papaya peel-based biobatteries across different fermentation durations (0, 2, and 4 days). It is hypothesized that (1) fermentation duration significantly affects the electrical performance of fruit peel-based biobatteries, and (2) cassava peel will demonstrate superior electrical characteristics and endurance compared to papaya peel.

METHOD

A comparative experimental design was employed to examine the electrical properties (voltage, current, and power) and durability of bio-batteries made from cassava and papaya peels. The bio-batteries were constructed using cassava and papaya peel materials, which were subjected to fermentation for 0, 2, and 4 days. Each bio-battery was assembled in a 1.5 V battery casing by replacing the carbon paste with fermented cassava or papaya peel paste.

Electrical characterization was conducted by measuring the voltage (V) and current (mA) of the bio-battery using a digital multimeter. To evaluate power endurance, a 1.2 W LED lamp was employed as the load, and the illumination duration was recorded until the lamp turned off completely. The electrical power was calculated using the power equation (Eq. 1), which served as a parameter for assessing the degradation of the bio-battery's endurance. The measurement data were analyzed to determine the effect of fermentation time variation on the resulting voltage, current, and electrical power.

$$P = V.I \quad (1)$$

The preparation of cassava and papaya peel paste was carried out by blending the materials into a fine consistency. The resulting paste was then divided into three groups: unfermented (0 days), fermented for 2 days, and fermented for 4 days. Fermentation was conducted at room temperature (approximately 27 ± 2 °C) in a closed environment with controlled ambient conditions to minimize humidity fluctuations and ensure consistency. Sealing was performed by applying adhesive around the outer edge of the battery casing, specifically at the interface where the electrode terminals exited the container. This method ensured that the internal fermented paste remained isolated from ambient air, thereby minimizing the risk of oxidation or moisture interference that could affect the electrochemical stability during measurement. Electrical measurements were conducted using two batteries connected in series to power a 1.2 W LED lamp, which served as both the load and an indicator of battery endurance.

(a)

(b)

Figure 1. Paste of (a) papaya peel and (b) cassava peel

(a)

(b)

Figure 2. Bio-battery preparation: (a) Papaya peel and (b) Cassava peel

Descriptive statistics were used to present the values of voltage, current, and electrical power. The performance between materials (cassava vs. papaya) and fermentation durations (0, 2, 4 days) was compared using direct value comparison without inferential statistics. Due to the nature of the physical experiment, no advanced statistical analysis (e.g., ANOVA or regression) was applied. Graphical comparisons supported data interpretation.

This Study focused only on two types of organic waste (cassava and papaya peels) with three fermentation durations. The performance between materials (cassava vs. papaya) and fermentation durations (0, 2, 4 days) was compared using direct value comparison without inferential statistics. Limitations this study was no microbiological analysis of fermentation processes, small-scale implementation, Lack of control over environmental fermentation factors such as temperature and microbial strains. No repeatability or variability testing reported

RESULTS AND DISCUSSION

Obtained for each bio-battery paste. Table 1 presents the measurement results of voltage, current, and electrical power for each paste with fermentation durations of 0, 2, and 4 days. As shown in Table 1, the voltage, current, and electrical power generated by cassava peel and papaya peel bio-batteries increased with longer fermentation periods. This trend is consistent with the rise in organic acid content (ascorbic acid and citric acid), which enhances the electrolyte properties of the bio-battery paste. In this study, a fermentation period of four days provided optimal electrical characteristics for both cassava peel and papaya peel bio-batteries.

Table 1. Measurement of Voltage, Current, and Electrical Power in Cassava Peel and Papaya Peel Bio-Batteries

No	Bio-battery Type	Fermentation Time	Voltage (V)	Current (mA)	Electrical Power (mW)
1.	Cassava Peel	0 Days	1.47	0.052	0.076
		2 Days	1.57	0.057	0.090
		4 Days	1.6	0.067	0.107
2.	Papaya Peel	0 Days	1.27	0.033	0.042
		2 Days	1.47	0.04	0.059
		4 Days	1.57	0.067	0.105

As shown in Figure 1, the power endurance test revealed a general decline in the electrical endurance of both cassava and papaya peel bio-batteries over an 8-hour period. The cassava peel bio-batteries fermented for four days exhibited the most optimal endurance performance. Moreover, cassava peel bio-batteries fermented for two and zero days also outperformed their papaya peel counterparts at equivalent fermentation durations. The observed decrease in endurance reflects a decline in voltage and current during operation. Specifically, cassava peel bio-batteries fermented for 0, 2, and 4 days lost power after 18, 23, and 27 hours, respectively, while papaya peel bio-batteries exhausted their energy at 17, 17, and 21 hours, respectively. These findings indicate that cassava peel bio-batteries retain energy longer under fermentation conditions compared to papaya peel bio-batteries. Nevertheless, the difference in endurance between non-fermented cassava and papaya peel bio-batteries was relatively minor, with only a one-hour advantage for cassava.

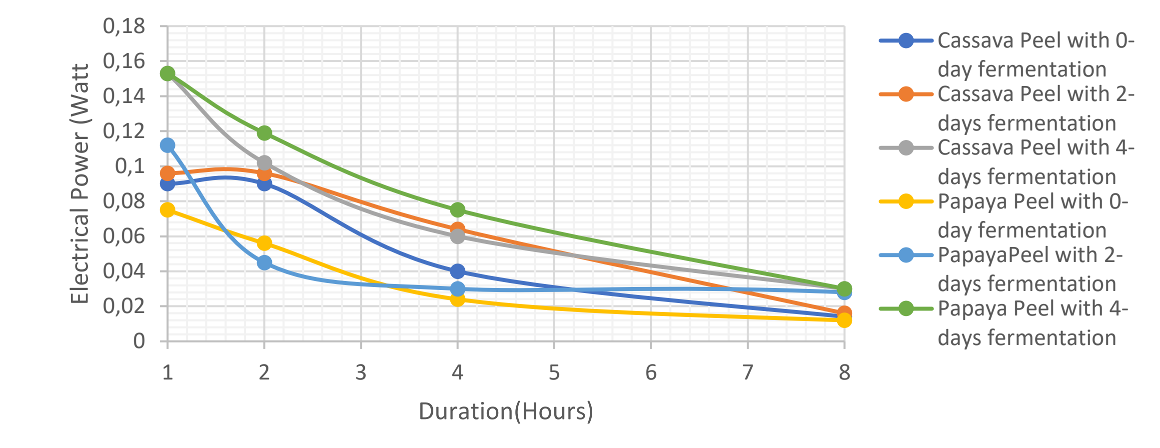

Figure 3. Battery endurance of cassava and papaya peel biobatteries under three fermentation time variations

The cassava peel bio-battery demonstrated superior performance compared to the papaya peel bio-battery. This outcome is attributed to the higher content of starch and ascorbic acid in cassava peel, which promotes the release of more free ions, thereby enhancing the conductivity of the bio-battery paste. During fermentation, microbial activity produces acids (e.g., lactic, acetic, citric) that increase ion availability and improve redox reaction efficiency. This is consistent with electrochemical theory (Nernst equation), where ion concentration influences cell potential. The concentration of ions within fruit- and vegetable-based electrolytes plays a critical role in determining the electrical output of bio-batteries, as it directly influences the conductivity of the medium and facilitates the movement of electrons between electrodes. This effect is closely linked to pH, where a lower pH reflects a higher concentration of hydrogen ions (H^+), enhancing ionic mobility and thus increasing the voltage and current produced. Fermentation period affects pH and Material Content (Jankowska et al., 2017). Fauzia et al. (2019) that various fruit and vegetable wastes exhibit different pH levels, and their study demonstrates a clear inverse correlation between pH and both voltage and current output. This relationship is further supported by data from citrus and mango fruit waste, where lower pH values resulted in stronger electric currents and higher voltages. An increase in pH can enhance the reactivity of ions in the solution, thereby accelerating the reduction process (Govindarajan et al., 2022; Liu et al., 2024).

Based on the review conducted by Ramadana et al. (2022) on the study by Sitanggang et al. (2021), the combination of cassava peel with pineapple peel did not yield favorable results, as both voltage and current decreased with the increasing proportion of pineapple peel in the mixture. This indicates that cassava peel possesses superior electrochemical properties compared to pineapple peel. This was also observed in the mixture of cassava peel and papaya peel conducted in the present study. In contrast, the papaya peel bio-battery, which contains a higher proportion of amino acids, such as aspartic acid and glutamic acid, exhibited lower electrical performance due to the limited presence of organic acids compared to cassava. Although amino acids can facilitate ionization and contribute to current generation, their effect is not as significant as that of organic acids in enhancing bio-battery conductivity. The role of amino acids in conductivity lies in their function as electrolyte additives to improve the stability and reversibility of zinc anodes in aqueous Zn-ion batteries. They modulate the interfacial microenvironment and promote orientational zinc deposition, which helps reduce side reactions and dendrite formation, thereby enhancing the cycling stability of the cells (Li et al., 2024). This is different from organic acids, which can form stable complexes with metal ions, facilitating more efficient ion transport and contributing to higher conductivity in battery systems (Zhang et al., 2023). In addition, organic acids provide effective proton transport pathways that further support ionic conductivity (Yardeni et al., 2016).

The magnitude of current and voltage generated by bio-batteries is highly dependent on the type of organic waste used, as different materials possess varying acidity levels and fermentation byproducts. In addition to the fermentation process itself, the duration of fermentation plays a critical role in influencing the electrical properties. The results of this study support the notion that a four-day fermentation period (96 hours) leads to saturation in the fermentation reaction, resulting in optimal voltage output. Fermentation duration significantly influences the electrical output of fruit waste-based biobatteries (Mauliza & Afrida, 2024). This trend aligns with findings by Fatimah et al. (2023), who observed that extended fermentation beyond four days can lead to a decline in electrical output due to fermentation saturation.

The paste form of the bio-battery also potentially affects its electrical performance. Both excessive and insufficient moisture content in the bio-battery paste can negatively influence its electrical output. The moisture content influences the oxidized decomposition of electrolyte, The battery impedance increased rapidly when the moisture content in the negative electrode was high (Yang et al., 2016). However, water content is not entirely limiting, as water also contains ions that facilitate electron transfer during the electrochemical process. The non-linear increase in current and voltage across samples may be attributed to differences in the mass of cassava and papaya peels placed into the battery containers. As reported by Arizona et al. (2021), the mass of organic electrolyte material can significantly influence the electrical output of bio-batteries.

The study demonstrates that fruit peel waste, especially cassava peel, can be effectively transformed into sustainable biobatteries using simple fermentation techniques. This opens up low-cost alternatives to toxic chemical batteries, especially in rural or off-grid areas, and supports organic waste valorization

This research contributes to the growing field of bioenergy by providing; a direct comparison between cassava and papaya peels for bio-battery use, empirical evidence on the role of fermentation time in enhancing electrical output, and a simple model of bio-battery construction using locally available materials.

The study was conducted at small scale under controlled laboratory conditions. Environmental factors such as temperature and pH during fermentation were not varied or controlled. No replication or statistical analysis was performed to assess significance or variability. Microbial characterization and electrochemical impedance analysis were not included.

Include control of fermentation parameters (e.g., temperature, pH, microbial inoculum), explore longer fermentation durations to understand the performance saturation curve, apply statistical analysis to support the consistency and reproducibility of findings, and investigate the scalability and long-term stability of such biobatteries for real applications.

CONCLUSION

Based on this study, it can be concluded that a fermentation period of 4 days provides the highest electrical performance for both types of biobatteries. The cassava peel-based bio-battery exhibits higher voltage, current, and electrical power compared to the papaya peel bio-battery. The cassava peel bio-battery also demonstrates a longer LED light duration. These results confirm that the type of organic waste and fermentation duration significantly affect the performance of biobatteries, with cassava peel fermented for four days representing the optimal condition compared to papaya peel. As a recommendation for future development, it is necessary to control fermentation conditions (such as temperature, pH, and microbial starter concentration) to explore fermentation durations beyond four days and the performance saturation point. This approach is expected to not only improve the efficiency and endurance of biobatteries but also open opportunities for larger-scale applications as a renewable energy source based on organic waste.

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AUTHOR CONTRIBUTION STATEMENT

NGR served as the primary researcher, responsible for data collection, data analysis, and the initial drafting of the manuscript. H provided supervisory guidance, contributed to the interpretation of data, and was involved in refining the manuscript, particularly in the English-language editing and academic framing. RR contributed to research supervision and provided input on data analysis and the manuscript draft. All authors reviewed and approved the final version of the manuscript. AAR served as the proofreader, ensuring clarity, consistency, and linguistic accuracy throughout the final manuscript.

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