International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
IJIREV

Volume 7 Issue 23 (December 2025) PP. 16-24
DOI 10.35631/IJIREV.723002

INTERNATIONAL JOURNAL OF INNOVATION AND INDUSTRIAL REVOLUTION (IJIREV)
www.ijirev.com

GLOBAL ACADEMIC EXCELLENCE

TRANSFORMING FRUITS PEELS WASTE MANGOSTEEN *(Garcinia mangostana L.)* INTO BIO-BATTERIES

Nurulakidah Adnan[1*], Mohammad Aidil Izmer Khaled[2], Mohd Muzammir Firdaus Abu Bakar [3], Salihah Tan Shilan[4], Siti Irma Yuana Sheikh Mohd Saaid[5]

[1] Stem Foundation Center, Universiti Malaysia Terengganu
Email: akidah.adnan@umt.edu.my
[2] Stem Foundation Center, Universiti Malaysia Terengganu
Email: izdeyy06@gmail.com
[3] Stem Foundation Center, Universiti Malaysia Terengganu
Email: muzammir.firdaus@umt.edu.my
[4] Stem Foundation Center, Universiti Malaysia Terengganu
Email: salihah.shilan@umt.edu.my
[5] Pusat Asasi, Universiti Teknologi Mara, Cawangan Selangor, Kampus Dengkil
Email: sitiirma2902@uitm.edu.my
[*] Corresponding Author

Article Info:

Article history:
Received date: 30.09.2025
Revised date: 15.10.2025
Accepted date: 05.11.2025
Published date: 01.12.2025

To cite this document:

Adnan, N., Khaled, M. A. I., Abu Bakar, M. F., Shilan, S. T., & Saaid, S. I. Y. S. M. (2025). Transforming Fruits Peels Waste Mangosteen *(Garcinia mangostana L.)* Into Bio-Batteries. *International Journal of Innovation and Industrial Revolution, 7* (23), 16-24.

DOI: 10.35631/IJIREV.723002

Abstract:

This study introduces a novel bio-battery system derived from mangosteen peel waste, an underexplored agricultural by-product, as a sustainable and eco-friendly energy source. Processed peels were utilized as the electrolyte in single-, dual-, and triple-beaker configurations, with voltage and current outputs systematically evaluated. Results revealed a positive correlation between peel mass and voltage generation, increasing from 0.987 V at 10 g to 0.996 V at 30 g. The bio-battery successfully powered small electronic devices such as LED bulbs, demonstrating its functional viability. By transforming fruit waste into a renewable energy material, this work provides new insights into waste-to-energy applications and highlights the untapped potential of mangosteen peel in advancing green technology innovation.

Keywords:

Bio-Battery, Electricity Energy, Mangosteen Peel Waste

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 7 Issue 23 (December 2025) PP. 16-24
DOI 10.35631/IJIREV.723002

Introduction

Mangosteen (*Garcinia mangostana* L.) is a tropical fruit widely cultivated across Southeast Asia, known not only for its edible pulp but also for its uses in food, beverages, cosmetics, and pharmaceuticals (Aizat et al., 2019). While mangosteen fruit is valued for fresh consumption and processed products such as mangosteen water and oil, the peel constitutes a substantial portion of the fruit's biomass and is commonly discarded as agricultural waste. Recent studies have revealed that the peel waste is rich in bioactive compounds including xanthones, flavonoids, tannins, and phenolic compounds, which exhibit antioxidant, antimicrobial, and anti-inflammatory properties (Sorrenti et al., 2023; Oh Y et al., 2020).

Nowadays, the global demand for energy, driven by population growth and technological advancement, has intensified the search for sustainable alternatives to fossil fuels. Batteries, in particular, are integral to contemporary life, powering smartphones, laptops, household appliances, and renewable energy storage systems. However, conventional battery technologies rely heavily on non-renewable resources and contribute to environmental pollution through resource extraction, toxic waste generation, and disposal challenges (Kusumawati et al., 2024). These concerns have spurred interest in eco-friendly bio-batteries, which utilize biological or organic materials for energy generation.

At the same time, organic waste management remains a pressing issue. Mangosteen peel, often overlooked in waste streams, is typically left to decompose naturally, thereby underutilizing its potential value. While extracts of the peel have been used in traditional medicine and cosmetic applications, limited research has examined its electrochemical potential for renewable energy applications (Santos et al., 2015; Tahir et al., 2023). Repurposing such agricultural waste into functional energy materials aligns with circular economy principles, where waste is transformed into value-added products, reducing environmental burdens while fostering sustainable innovation (Oyedeji et al., 2024; Nurhadi et al., 2024).

Therefore, this study explores the utilization of mangosteen peel waste as an electrolyte material in bio-battery systems. By investigating single, dual, and triple-beaker configurations, this study evaluates the capacity of mangosteen peel to generate electrical energy and demonstrates its feasibility in powering small electronic devices. The novelty of this work lies in repositioning mangosteen peel traditionally viewed as waste into an active renewable energy material, thereby offering both an innovative waste-to-energy strategy and a pathway toward greener bio-electrochemical technologies.

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 7 Issue 23 (December 2025) PP. 16-24
DOI 10.35631/IJIREV.723002

Literature Review

Agricultural Waste as a Renewable Energy Resource

The increasing demand for energy and the associated environmental challenges have accelerated research into renewable and sustainable alternatives. Agricultural waste, in particular, has gained attention as a viable resource for energy generation due to its abundance, low cost, and environmentally friendly nature (Saleem M. 2022; Ali et al., 2023). Commonly discarded residues such as fruit peels, husks, and stalks contain organic acids, polysaccharides, and phenolic compounds that enhance ionic conductivity, making them suitable for use in electrochemical systems (Ramirez et al., 2024). Compared to conventional batteries, which rely on non-renewable metals like lithium and cobalt, waste-derived bio-batteries offer the dual advantage of waste management and green energy production (Dadsena et al., 2025; Kusumawati et al., 2024).

Several studies have explored fruit-based bio-batteries (Meiliyadi, et al., 2023;. Citrus peels, for example, have been reported to produce measurable voltage outputs due to their citric acid content, while banana and potato wastes provide starch-based electrolytes that facilitate ionic exchange (Ali et al., 2023). Although these systems generally yield lower voltages compared to commercial batteries, they are cost-effective, biodegradable, and scalable for educational and small-scale applications. These findings highlight the potential of agricultural waste as a renewable material in energy innovation.

Bioactive Properties of Mangosteen Peel

Mangosteen (*Garcinia mangostana* L.), often referred to as the “queen of fruits,” is native to Southeast Asia and widely cultivated for its edible arils. However, its thick pericarp accounts for nearly 60% of the fruit mass, most of which is discarded as waste. The peel contains diverse phytochemicals such as xanthones (α-, β-, and γ-mangostin), flavonoids, tannins, saponins, and phenolic acids, many of which exhibit strong antioxidant and antimicrobial activity (Nurhadi et al., 2024). These bioactive compounds, beyond their biomedical value, are also relevant for electrochemistry because they can facilitate ionic conduction and enhance electrolyte stability in aqueous systems.

While mangosteen peel has been widely studied in the pharmaceutical, nutraceutical, and cosmetic industries, its electrochemical applications remain underexplored. Extracts have been used in teas for metabolic health, in topical formulations for skincare, and in supplements for their anti-inflammatory properties. However, limited research has repositioned mangosteen peel as a material for waste-to-energy technologies. This underlines a clear gap in knowledge that this study seeks to address.

Bio-Battery Configurations and Performance Optimization

Bio-battery performance is not determined solely by the electrolyte but also by system design and configuration. Previous studies have shown that multi-cell arrangements (dual or triple beaker systems) enhance output by increasing electrode surface area and allowing voltage accumulation in series (Kusumawati et al., 2024). Parameters such as the mass of organic material, type of electrodes used, and concentration of the electrolyte solution are critical in optimizing power density and efficiency.

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
IJIREV
Volume 7 Issue 23 (December 2025) PP. 16-24
DOI 10.35631/IJIREV.723002

For example, research using citrus and potato wastes has demonstrated that increasing the amount of raw material enhances voltage and current outputs up to an optimal point, after which performance plateaus (Ali et al., 2023). This behavior is attributed to the balance between ion concentration and electrode saturation. Furthermore, the choice of electrode material, such as copper and zinc, influences the redox reaction efficiency and overall system stability. Despite these advances, no standardized methodology exists for evaluating fruit-waste bio-batteries, making comparative studies across different organic materials challenging.

Research Gap and Contribution

Although significant progress has been made in utilizing agricultural waste for bio-energy applications, mangosteen peel remains an underutilized resource despite its biochemical richness and widespread availability. Most existing research has focused on its medicinal and cosmetic applications, with minimal attention given to its electrochemical potential (Nurhadi et al., 2024). Furthermore, studies exploring waste-based bio-batteries have predominantly investigated common fruits like citrus and banana, leaving exotic yet abundant fruits like mangosteen relatively unexamined.

Conceptual Framework

This study is grounded in the concept of waste valorisation, which emphasizes converting agricultural residues into functional, value-added products. As shown in Figure 1, the framework positions mangosteen peel waste as the primary raw material for bio-battery development. The process begins with collection and preprocessing of the waste, including cleaning, drying, and grinding to prepare it as an electrolyte source. The pre-processed peel is then integrated into bio-battery systems configured in single, dual, and triple-beaker setups to evaluate energy generation.

The independent variable in this framework is the mass of mangosteen peel waste, while the dependent variable is the voltage and current output of the bio-battery. Performance assessment is conducted through voltage measurement. Finally, the framework culminates in application testing, where the generated energy is used to power small devices such as LED bulbs.

By linking waste management with renewable energy production, the framework highlights the dual benefits of environmental sustainability and green energy innovation, positioning mangosteen peel waste as a novel contributor to eco-friendly energy solutions.

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 7 Issue 23 (December 2025) PP. 16-24
DOI 10.35631/IJIREV.723002

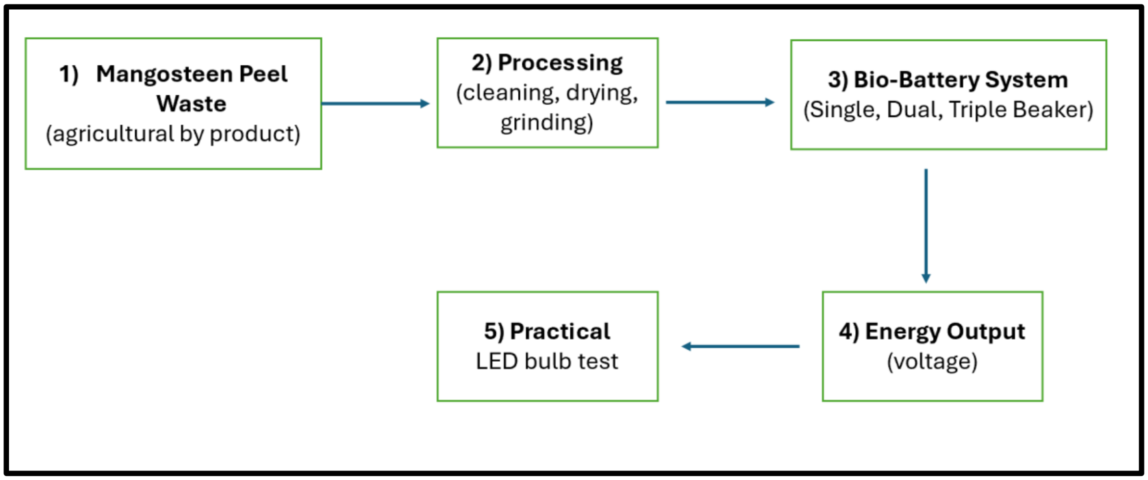

Figure 1: Conceptual Framework of Mangosteen Peel Waste as a Bio-Battery Material.

Methodology

This study aims to evaluate the effectiveness of mangosteen peel paste as a substrate for bio-battery applications. Initially, 10 g of mangosteen peel powder was weighed and combined with 10 mL of distilled water. The mixture was stirred thoroughly until a homogeneous paste was obtained and subsequently allowed to stand for 15 minutes to facilitate interaction between the mangosteen waste material and water, thereby producing the required acidic medium. The pH of the mixture was then measured to determine its acidity level, and the results were recorded.

Figure 2: Bio-Battery System with a) single beaker b) Dual Beaker and c) Triple Beaker

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
IJIREV
Volume 7 Issue 23 (December 2025) PP. 16-24
DOI 10.35631/IJIREV.723002

The bio-battery was assembled using copper (Cu) and zinc (Zn) electrodes, with an electrolyte prepared from mangosteen peel powder and distilled water. The electrolyte solution was placed in a beaker, after which the zinc electrode was inserted as the anode and the copper electrode as the cathode, ensuring that the electrodes did not make direct contact. Electrical connections were established using cables with alligator clips, connecting the anode (Zn) to the negative terminal and the cathode (Cu) to the positive terminal of the circuit. To enhance voltage output, multiple cells were connected in series (anode to cathode of the subsequent cell). The current and voltage were monitored using a digital multimeter, and when sufficient energy was produced, the system was capable of powering a light-emitting diode (LED).

All of this was carried out in three times to ensure data consistency. The electrolyte was prepared by mixing 10 g, 20 g, and 30 g of mangosteen peel paste with distilled water at a fixed mass ratio of 1:1.5. Three system configurations were evaluated: a single-beaker setup, in which both electrodes were placed within the same electrolyte solution; a dual-beaker setup, in which two electrolyte cells were connected to allow improved ion exchange; and a triple-beaker setup, in which three electrolyte cells were arranged in series to increase the potential difference as shown in Figure 2. The electrical output from each system was recorded using a digital multimeter.

Result and Discussion

The performance of the mangosteen peel bio-battery was evaluated under different system configurations and electrolyte concentrations with 10 g, 20 g, and 30 g of mangosteen peel powder mixed with distilled water at a 1:1.5 ratio. The results are presented in terms of pH characterization, voltage output, and the ability of the system to power a light-emitting diode (LED). This section discusses the influence of electrolyte concentration and cell configuration on the electrochemical performance of the bio-battery, highlighting the relationship between acidity and overall system efficiency.

Table 1: Mangosteen Powder and Voltage with Single Beaker

Mass of Mangosteen powder(g)	Test 1	Test 2	Test 3	Average (Voltage)
10	0.987	0.988	0.987	0.987
20	0.991	0.992	0.994	0.992
30	0.997	0.996	0.995	0.996

In the single-beaker configuration, the voltage produced was insufficient to power the LED at all electrolyte concentrations tested. Using 10 g of mangosteen waste yielded voltages of 0.987 V, 0.988 V, and 0.987 V, with an average of 0.987 V, which was well below the 5 V requirement. Increasing the electrolyte concentration to 20 g resulted in voltages of 0.991 V, 0.992 V, and 0.994 V, with an average of 0.992 V. The highest output was obtained with 30 g of mangosteen waste, producing 0.997 V, 0.996 V, and 0.995 V, for an average of 0.996 V. Although a slight

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
IJIREV
Volume 7 Issue 23 (December 2025) PP. 16-24
DOI 10.35631/IJIREV.723002

improvement in voltage was observed with increasing electrolyte concentration, the single beaker system remained incapable of powering the LED bulb.

Table 2: Mangosteen Powder and Voltage with Dual Beaker

Mass of Mangosteen powder(g)	Test 1	Test 2	Test 3	Average (Voltage)
10	2.887	2.885	2.883	2.887
20	2.913	2.920	2.915	2.916
30	2.933	2.935	2.936	2.935

In the dual-beaker configuration, the voltage output increased with higher electrolyte concentrations. At 10 g of mangosteen powder, the voltages recorded were 2.887 V, 2.885 V, and 2.883 V, with an average of 2.887 V. When the electrolyte concentration was increased to 20 g, the voltages obtained were 2.913 V, 2.920 V, and 2.915 V, yielding an average of 2.916 V. The highest voltage was observed at 30 g, with values of 2.933 V, 2.935 V, and 2.936 V, resulting in an average of 2.935 V. These results confirm that the dual-beaker setup improves voltage generation compared to the single-beaker configuration, but still does not reach the 5 V threshold required to operate an LED bulb.

Table 3: Mangosteen Powder and Voltage with Three Beaker

Mass of Mangosteen powder(g)	Test 1	Test 2	Test 3	Average (Voltage)
10	4.573	4.575	4.579	4.576
20	4.691	4.693	4.693	4.693
30	4.721	4.727	4.729	4.726

In the three-beaker configuration, the voltage output increased with higher electrolyte concentrations of mangosteen powder. At 10 g, the voltages recorded were 4.573 V, 4.575 V, and 4.579 V, with an average of 4.576 V. Increasing the electrolyte concentration to 20 g produced voltages of 4.691 V, 4.693 V, and 4.693 V, averaging 4.693 V. The highest output was obtained with 30 g of mangosteen powder, yielding 4.721 V, 4.727 V, and 4.729 V, with an average of 4.726 V. These results demonstrate that the three-beaker system generated a voltage approaching the 5 V threshold, indicating its capability to power low-voltage devices such as LEDs.

Volume 7 Issue 23 (December 2025) PP. 16-24
DOI 10.35631/IJIREV.723002

pH Test of The Solution

The electrolyte solution exhibited a pH of 3, as determined using pH indicator strips, indicating a moderately acidic medium. This acidity is likely due to organic acids present in mangosteen waste, which facilitate the ionization process required for electrochemical reactions (Han, Yan, & Zhu, 2024). Acidic media may enhance ion mobility and promote improved charge transfer within the bio-battery system (Yang et al., 2024). However, a pH as low as 3 can accelerate electrode corrosion, particularly in zinc and similar metallic anodes, undermining performance and longevity (Li, Xuejin et al., 2025). These findings underscore the importance of controlling electrolyte pH in order to optimize conductivity while maintaining electrode stability and sustaining overall system efficiency.

Conclusion

This study investigated the performance of a mangosteen peel bio-battery under varying system configurations. The results demonstrated that increasing the mass of mangosteen powder improved voltage output across all configurations. However, the single- and dual-beaker systems produced voltages below the 5 V threshold required to power an LED, whereas the three-beaker configuration generated up to 4.726 V, approaching the operational requirement for low-power devices.

The electrolyte solution exhibited a pH of 3, confirming its moderately acidic nature due to organic acids present in the mangosteen peel. These findings highlight the dual role of electrolyte acidity in improving conductivity while compromising durability.

Overall, the mangosteen peel bio-battery demonstrates significant potential as a sustainable energy source for low-power applications, while simultaneously promoting agricultural waste valorisation. Future research should focus on optimizing electrolyte composition and exploring advanced multi-cell configurations to further enhance efficiency, stability, and durability for practical applications.

Acknowledgements

The authors would like to acknowledge and extend special gratitude to the STEM Foundation Centre, Universiti Malaysia Terengganu, for providing institutional support throughout this research. Sincere appreciation is also extended to the laboratory assistants for their technical assistance and to the authors' colleagues for their cooperation and encouragement during the course of this study.

References

Aizat WM, Ahmad-Hashim FH, Syed Jaafar SN (2019) Valorization of mangosteen, "The Queen of Fruits", and new advances in post-harvest and in food and engineering applications: a review. J Adv Res 20:61–70.

Ali, M., Prasetyo, H., & Rahman, A. (2023). Agricultural waste-based bio-batteries: Potential and challenges. *Journal of Renewable Materials, 11*(5), 823–835.

Dadsena, L., Valde, D., Maharana, T., & Jujjavarapu, S. E. (2025). Comprehensive review of biobattery types, optimization techniques, and their potential for real-world applications. *Biofuels*, 1-23.

Volume 7 Issue 23 (December 2025) PP. 16-24
DOI 10.35631/IJIREV.723002

Han, Y., Yan, Z., Zhu, Z., et al. (2024). Recent Progress in Aqueous Zinc-ion Batteries at High Zinc Utilization. *ChemSusChem*.

Kusumawati, D. Y., Setyowati, H., & Suryani, T. (2024). Development of eco-friendly bio-battery from fruit waste materials. *Indonesian Journal of Chemical Science, 13*(2), 115–124**.**

Li, X., Liu, P., Han, C., Cai, T., Cui, Y., & Zhi, C. (2025). Corrosion of metallic anodes in aqueous batteries. *Energy & Environmental Science*, 18, 2050-2094.

Mao, Y., Zhao, B., Bai, J., Wang, P., Zhu, X., & Sun, Y. (2024). Recent progress in critical electrode and electrolyte materials for flexible zinc-ion batteries. *Nanoscale*, 16, 5042-5059.

Meiliyadi, L. A. D., Damayanti, I., & Syuzita, A. (2023). Characteristic of ceremai fruit electrical properties as electrolyte solution in galvanic cells. *Jurnal Penelitian Pendidikan IPA*, *9*(2), 478-484.

Nurhadi, R., Wibowo, A., & Santoso, F. (2024). Valorization of mangosteen peel waste for sustainable applications: From bioactive compounds to waste-to-energy strategies. *Sustainability, 17*(14), 6423.

Oh Y, Do HTT, Kim S, Kim YM, Chin YW, Cho J (2020) Memory-enhancing effects of mangosteen pericarp water extract through antioxidative neuroprotection and anti-apoptotic action. Antioxidants 10(1):1–23.

Oyedeji, S., Patel, N., Krishnamurthy, R., & Fatoba, P. O. (2024). Agricultural wastes to value-added products: economic and environmental perspectives for waste conversion. *Biowaste to Value-added Products: Economics and Technologies*, 215-248.

Ramirez, A., Munoz-Morales, M., Lopez-Fernandez, E., & Llanos, J. (2024). Harnessing Lignocellulosic Waste-Derived Carbon Materials for Green Electrochemical Applications. *ChemElectroChem*, *11*(15), e202400190.

Saleem, M. (2022). Possibility of utilizing agriculture biomass as a renewable and sustainable future energy source. *Heliyon*, *8*(2).

Sorrenti, V., Burò, I., Consoli, V., & Vanella, L. (2023). Recent advances in health benefits of bioactive compounds from food wastes and by-products: Biochemical aspects. *International Journal of Molecular Sciences*, *24*(3), 2019.

Santos, C. M., Dweck, J., Viotto, R. S., Rosa, A. H., & de Morais, L. C. (2015). Application of orange peel waste in the production of solid biofuels and biosorbents. *Bioresource Technology*, *196*, 469-479.

Tahir, Z., Khan, M. I., Ashraf, U., Adan, I. R. D. N., & Mubarik, U. (2023). Industrial application of orange peel waste; a review.

Yang, J. H., et al. (2024). Stable Zinc Metal Battery Development: Using Fibrous Zirconia for Rapid Surface Conduction of Zinc Ions With Modified Water Solvation Structure. *Small*.