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Biobattery Products from Kepok Banana Peel and Key Lime Extract Using $MgSO_4$ and $CaCl_2$ Electrolytes with ABC Biobattery Standards of AA Size

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Abstract: This study aims to investigate the potential of kepok banana peel (Musa paradisiaca L.) and key lime (Citrus amblycarpa) extract as raw materials for biobattery production and to evaluate the effects of KOH activation concentration and the addition of the ionic salts $CaCl_2$ and $MgSO_4$ on biobattery performance. Kepok banana peel was dried, ground into powder, and chemically activated using KOH solutions with concentrations ranging from 0.2 M to 1.0 M. The electrolyte was prepared by mixing key lime extract with 15 g of either $CaCl_2$ or $MgSO_4$, followed by the addition of activated banana peel powder. The resulting electrolyte mixture was packed into empty AA battery casings to fabricate the biobattery cells. The fabricated biobatteries were evaluated for output voltage, loaded voltage, and operating time using a 2.2 V LED load. The results showed that the biobattery activated with 0.6 M KOH and supplemented with $MgSO_4$ exhibited the best performance, producing a maximum output voltage of 3.01 V (two cells connected in series), a loaded voltage of 1.75 V, and an operating time of 10 h 31 min. In contrast, activation concentrations that were either too low (0.2 M) or too high (1.0 M) reduced biobattery performance because insufficient or excessive ions hindered the electrochemical reactions. Furthermore, $MgSO_4$ was more effective than $CaCl_2$ in improving electrolyte conductivity and ionic stability. These findings indicate that organic waste, such as kepok banana peel and key lime extract, can be effectively utilized as components in the development of preliminary biobattery prototypes.

Keywords: biobattery, kepok banana peel, key lime, $MgSO_4$, $CaCl_2$.

1. Introduction

The increasing demand for electrical energy has intensified the need to develop environmentally sustainable alternative energy sources [1], [2]. Various electrochemical systems, including microbial fuel cells and zinc-ion hybrid supercapacitors, have demonstrated the potential of utilizing organic and waste-derived materials as sustainable components for energy generation [3], [4].

Kepok banana peels and key lime peels extracts are known to contain acidic compounds, including citric acid and ascorbic acid, which have the potential to generate electrical ions through electrochemical reactions. This study aims to evaluate the effectiveness of combining these materials in generating electrical energy and to assess the effects of KOH

activator solution concentration and electrolyte type on biobattery performance.

To optimize biobattery performance, the addition of an inorganic electrolyte is required to enhance the electrical conductivity of the solution. Accordingly, this study employed two supplementary electrolytes, namely calcium chloride ($CaCl_2$) and magnesium sulfate ($MgSO_4$). Both compounds are widely used in electrochemical systems because they contain divalent metal ions (Ca^{2+} and Mg^{2+}) with high ionic mobility, thereby facilitating ion transport within the electrolyte medium. This study compares the empirical performance of biobatteries formulated with equal masses (15 g) of either $CaCl_2$ or $MgSO_4$. While this mass-based approach does not yield equimolar solutions, it provides practical baseline data regarding the electrical output of these specific formulations in this preliminary prototype system.

2. RESEARCH METHOD

The study was conducted experimentally at the Chemical Engineering Laboratory of Politeknik Negeri Sriwijaya. Banana peels were dried, ground into powder, and chemically activated using KOH solutions with concentrations ranging from 0.2 M to 1.0 M [5], [6]. The key limes were crushed and squeezed to obtain their extract. The extract was then mixed with 15 g of either $CaCl_2$ or $MgSO_4$ as the supporting electrolyte. The resulting electrolyte mixture was subsequently blended with 20 g of banana peel powder and packed into an empty battery casing to fabricate the biobattery cells [7]. The performance of the fabricated biobatteries was evaluated by measuring electrolyte pH, the output voltage of two cells connected in series, the loaded voltage, and the illumination duration of a 2.2 V LED. Voltage measurements were performed using a digital multimeter, while the LED operating time was recorded using a stopwatch.

In this preliminary study, all electrochemical evaluations were conducted on single prototype cells for each formulation without independent replication. Consequently, statistical uncertainty, standard deviations, and significance tests were not determined, and the findings represent direct empirical observations.

2.1 Biobattery Fabrication Procedure

1. Material Preparation
   At this stage, the raw materials were prepared through washing, drying, cutting, and grinding prior to further processing.
2. Activation Process
   The kepok banana peel powder was chemically treated using KOH solutions with concentrations ranging from 0.2 M to 1.0 M for 1 hour. The treated material was subsequently used in the preparation of the biobattery electrolyte.
3. Electrolyte Preparation
   A total of 15 g of the selected ionic salt (either $CaCl_2$ or $MgSO_4$) was dissolved in 100 mL of key lime extract and stirred until a homogeneous solution was obtained. Subsequently, 20 g of the activated kepok banana peel powder was added and thoroughly mixed to produce the biobattery electrolyte.
4. Battery Disassembly and Filling
   The electrochemical cell was constructed using empty commercial AA battery casings. The original internal chemical paste and separator were completely extracted and discarded. The original zinc casing was retained to function as the anode (negative terminal), while the central carbon rod was cleaned and reinserted to serve as the cathode and primary current collector (positive terminal). The prepared biobattery electrolyte mixture corresponding to each experimental variation was then packed into the casing, filling the space between the zinc wall and the carbon rod. While this configuration provided a functional prototype, the inter-electrode spacing and surface area were constrained by the fixed standard dimensions of the commercial AA casing.
5. Circuit Assembly
   A 2.2 V LED was connected to the battery holder, and two AA-size biobattery cells were installed in series to complete the electrical circuit.
6. Performance Evaluation
   The fabricated biobatteries were evaluated by measuring the output voltage, the voltage under load, and the illumination duration of the LED.

2.2 Biobattery Fabrication Procedure:

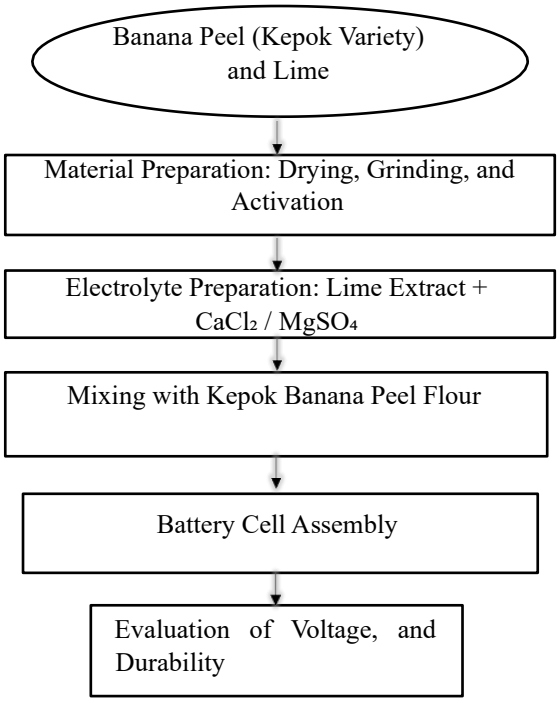

Figure 1. Flow Diagram of the Biobattery Fabrication Process

3. RESULTS AND DISCUSSION

3.1. Experimental Results

Table 3.1. Results of the Biobattery Electrical Performance Tests

Sample	Activated Banana Peel Powder	Key Lime Extract	KOH Activation Concentration	Added Ionic Salt (15 g)
1	20 g	100 mL	0.2 M	$CaCl_2$
2	20 g	100 mL	0.4 M	$CaCl_2$
3	20 g	100 mL	0.6 M	$CaCl_2$
4	20 g	100 mL	0.8 M	$CaCl_2$
5	20 g	100 mL	1.0 M	$CaCl_2$
6	20 g	100 mL	0.2 M	$MgSO_4$
7	20 g	100 mL	0.4 M	$MgSO_4$
8	20 g	100 mL	0.6 M	$MgSO_4$
9	20 g	100 mL	0.8 M	$MgSO_4$
10	20 g	100 mL	1.0 M	$MgSO_4$

3.2. Discussion

3.2.1 Two Cell Series Voltage Test

The relatively low voltage observed at the 0.2 M concentration (Samples 1 and 6) can be attributed to the limited number of free ions available in the electrolyte solution. These ions function as charge carriers between the electrodes, and when their concentration is insufficient, the rate of charge transfer decreases substantially. Consequently, the internal resistance of the cell increases, resulting in a lower output voltage [3], [8]. In contrast, although a high electrolyte concentration (1.0 M) provides a greater number of ions, it also increases the viscosity of the solution, thereby reducing ionic mobility. Furthermore, it is important to acknowledge that because the biobattery prototype utilized retained zinc casings and carbon rods from commercial batteries, the measured output voltage is a combined electrochemical product of the organic electrolyte formulation and the existing metallic electrodes. As this preliminary study did not employ blank-casing controls, the electrical output cannot be solely attributed to the biological materials, and the system is most accurately described as a hybrid biological-conventional battery prototype. Additionally, it should be noted that this preliminary study evaluated the biobattery electrolyte as an integrated mixture (KOH-activated banana peel, key lime extract, and ionic salts) without the inclusion of component-resolved control cells, such as untreated peel or lime extract alone. Therefore, while the combined formulation demonstrated functional electrical output, the individual electrochemical contribution of each specific constituent cannot yet be quantitatively isolated from the overall system performance.

The results of the two-cell series voltage test are presented in Figure 2

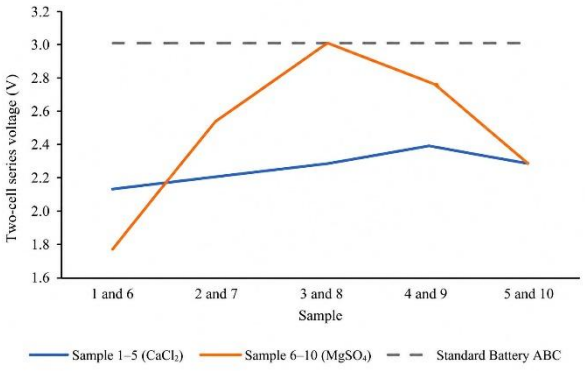

Figure 2. *Comparison of Ionic Salt Type on the Two-Cell Series Voltage*

As shown in Figure 2, Samples 1–5 containing $CaCl_2$ exhibited a gradual increase in output voltage as the KOH activation concentration increased from 0.2 M to 0.8 M. The voltage increased from 2.14 V at 0.2 M to 2.39 V at 0.8 M. However, at the highest concentration of 1.0 M (Sample 5), the voltage declined to 2.30 V. A similar trend was observed for Samples 6–10 containing $MgSO_4$. The voltage increased from 1.76 V at 0.2 M to a maximum of 3.01 V at 0.6 M, followed by a decrease at 0.8 M and 1.0 M to 2.79 V and 2.29 V, respectively. We hypothesize that the differences in KOH treatment concentration may have influenced the electrochemical response of the treated banana peel material. However, because no direct structural or surface characterization was performed in this study, the specific effects of KOH treatment on pore development or degradation cannot be confirmed experimentally [5], [7], [9].

A comparison between the two ionic salts at identical activation concentrations further revealed that $MgSO_4$ generally outperformed $CaCl_2$, particularly at concentrations ranging from 0.4 M to 0.6 M. For example, at 0.6 M, the $CaCl_2$-based electrolyte (Sample 3) produced an output voltage of 2.30 V, whereas the $MgSO_4$-based electrolyte (Sample 8) generated 3.01 V, representing an improvement of nearly 0.7 V. This superior performance is likely attributable to the greater effectiveness of Mg^{2+} ions in facilitating electrical charge transfer, owing to their favorable ionic conductivity and enhanced electrochemical stability, particularly within the acidic environment provided by the key lime extract. Furthermore, the interaction between Mg^{2+} ions and citric acid compounds may promote the redox reactions more efficiently, thereby enhancing the overall

electrochemical performance of the biobattery. This observation theoretically aligns with broader findings in biomass-based electrochemical systems, such as microbial fuel cells and supercapacitors, which demonstrate that the appropriate combination of biomaterials and organic electrolytes can substantially improve overall charge transfer and performance [10], [11], [12].

3.2.2 Voltage Under Load Test

The performance of the ten biobattery samples was evaluated under an electrical load using a 2.2 V LED. The results showed that all samples experienced a substantial reduction in voltage compared with their respective open-circuit voltages. The highest loaded voltage was recorded for Sample 8 at 1.75 V, followed by Samples 7 and 9, each producing 1.72 V. In contrast, the lowest voltage was observed for Sample 6 at 1.21 V. This voltage reduction indicates that the biobatteries still exhibit relatively high internal resistance, causing a significant decline in their ability to maintain both current and voltage when subjected to an external load [3], [13].

The results of the voltage under load test are presented in Figure 3.

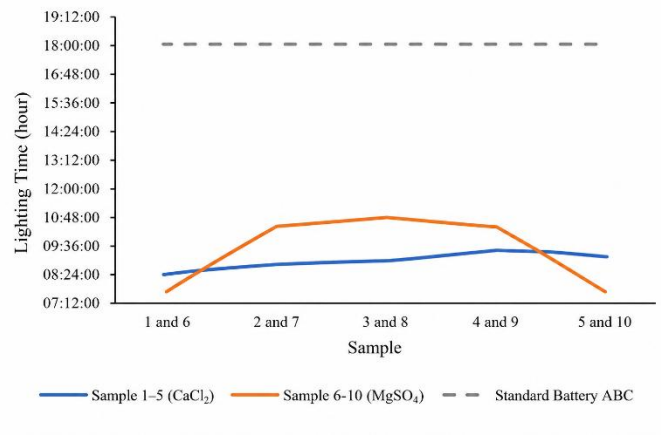

Figure 3. *Comparison of Ionic Salt Type on the Voltage Under Load*

As illustrated in Figure 3, the biobatteries employing $MgSO_4$ as the electrolyte (Samples 6–10) generally demonstrated superior performance compared with those containing $CaCl_2$ (Samples 1–5), particularly at activation concentrations of 0.6–0.8 M [14]. Sample 8, prepared with 0.6 M KOH activation and $MgSO_4$ electrolyte, produced the highest loaded voltage, indicating that this concentration represents the highest-performing condition under the tested conditions activation condition for developing the pore structure of the kepok banana peel while maintaining relatively low electrolyte resistance. Conversely, Sample 6 (0.2 M $MgSO_4$) generated the lowest voltage because the activation concentration was insufficient to adequately develop the pore structure of the banana peel [15]. These findings are consistent with electrochemical principles, which state that insufficient ionic conductivity at low electrolyte concentrations increases internal resistance and consequently reduces battery performance [8].

For the $CaCl_2$-based biobatteries (Samples 1–5), the loaded voltage ranged from 1.37 to 1.55 V, with the highest performance achieved by Sample 4 (0.8 M). Although these values remained below the operating voltage required for the 2.2 V LED, they were noticeably higher than those obtained from Samples 1 and 2 (0.2–0.4 M), indicating that increasing the activation concentration also enhanced the ability of the biobattery to sustain its output voltage under load [16]. Nevertheless, a considerable voltage drop was still observed because Ca^{2+} ions possess lower ionic conductivity than Mg^{2+} ions and are more susceptible to ion-pair formation and passive layer development on the electrode surface at elevated concentrations. Consequently, $CaCl_2$ was less effective than $MgSO_4$ in maintaining voltage stability during load operation.

A photograph of the brightest LED illumination, produced by Sample 8, is presented in **Figure 3**.

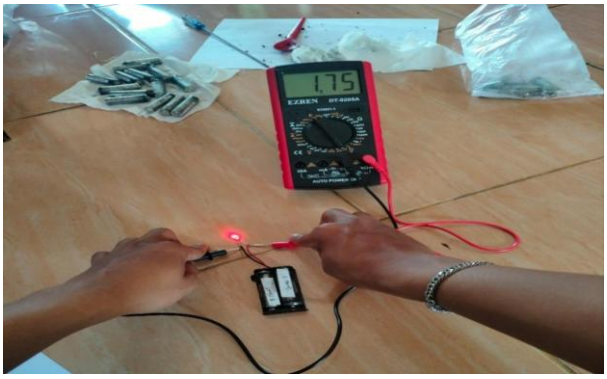

Figure 4. *Biobattery Voltage Test Under Electrical Load*

As shown in **Figure 4**, activation of the adsorbent at KOH concentrations of 0.6–0.8 M combined with the use of $MgSO_4$ as the supporting electrolyte not only increased the output voltage but also generated a higher and more stable current, thereby producing sufficient power to illuminate the LED with maximum brightness. These results demonstrate that both the type of ionic salt and the activation concentration play crucial roles in determining the ability of the biobattery to sustain electrical output under load conditions [16], [17].

3.2.3 Battery Endurance Test

The battery endurance test was conducted to determine the

duration for which each biobattery sample was capable of powering the electrical load, represented by a 2.2 V LED. The results indicated that none of the ten biobattery samples achieved the operating duration of the commercial reference battery [14]. Nevertheless, several samples approached 10 h of continuous operation, particularly Sample 8, which exhibited the longest operating time of 10 h 31 min, followed by Samples 7 and 9. In contrast, Sample 6 demonstrated the lowest performance, with an operating duration of only 7 h 38 min. The shorter operating time can be attributed to the relatively high internal resistance of the biobattery, which restricts efficient current flow under load conditions [13]. This aligns with principles observed in other biological energy systems, such as microbial fuel cells [14], where high internal resistance restricts efficient current flow and becomes a primary factor limiting operating duration.

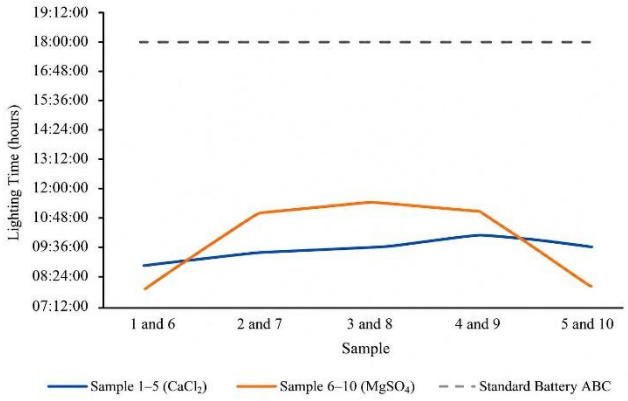

Figure 5. Comparison of Ionic Salt Type on Battery Operating Time

As shown in Figure 5, the biobatteries utilizing $MgSO_4$ as the supporting electrolyte (Samples 6–10) generally exhibited superior endurance compared with those employing $CaCl_2$ (Samples 1–5). This observation is consistent with the results obtained from the previous performance tests, indicating that Mg^{2+} ions possess higher ionic mobility and greater stability in the electrolyte solution, thereby enabling electrochemical reactions within the cell to proceed more efficiently and for a longer period. In particular, Sample 8 (0.6 M) achieved the highest performance because the combination of an highest-performing condition under the tested conditions ion concentration and enhanced electrochemical stability provided the most favorable conditions for sustained battery operation [18]. These findings are consistent with the study by Gautam et al. (2022) also reported that biomass-based electrodes, when combined with efficient ionic electrolytes such as $MgSO_4$, can significantly extend battery operating time

In contrast, the biobatteries employing $CaCl_2$ as the supporting electrolyte achieved operating times ranging from approximately 8 to 9 h. The best performance within this group was obtained by Sample 4 (0.8 M), which sustained LED illumination for 9 h 19 min. The comparatively lower endurance relative to the $MgSO_4$-based biobatteries can be attributed to the characteristics of Ca^{2+} ions, which exhibit lower ionic conductivity and are more prone to forming precipitates or ionic interactions that reduce electrochemical stability. Consequently, charge transfer within the electrolyte becomes less efficient, leading to a shorter discharge duration. These findings are consistent with the study by Singh et al. (2019) reported that the intrinsic properties of electrolyte ions play a critical role in determining the long-term efficiency of redox reactions, particularly in electrochemical systems employing natural liquid electrolytes.

4. Conclusion

Based on the empirical observations in this preliminary study, the following conclusions can be drawn. The treatment of kepok banana peel using a 0.6 M KOH solution resulted in the highest output voltage and the longest operating time of 10 h 31 min among the tested concentrations. The highest-performing condition under the tested conditions was the 0.6 M KOH treatment combined with the $MgSO_4$ equal-mass formulation. This combination produced a two-cell series voltage of 3.01 V, a loaded voltage of 1.75 V, and an operating time exceeding 10 h. Overall, these results demonstrate that the specific $MgSO_4$ formulation yielded a higher electrical output and longer LED illumination time compared to the $CaCl_2$ formulation under the evaluated experimental conditions.

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