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Effect of Fermentation Time Variation on Electrical Energy Generation in Batteries Using Electrolyte Solutions from Orange (*Citrus*), Pineapple (*Ananas comosus* (L.) Merr), Watermelon (*Citrullus lanatus*), and Mixed Fruit Peels

Adryansyah Anugrah Pratama [1*], Ali Hamzah Lubis [1], Yoel Ezra Micael Ginting [1], Giovani Mei Anggasta Telaumbanua [1], Muhammad Farhan [1], Adhitya Shahrian Putra [1], Zuhairiah Nasution [1]

[1] *Department of Chemistry, Faculty of Mathematics and Natural Sciences, State University of Medan, Jl. Willem Iskandar Pasar V Medan Estate, Medan 20221, Indonesia*

**Corresponding author : adryansyah1673@gmail.com*

ABSTRACT

This study aims to determine the effect of fermentation time variation of orange, pineapple, watermelon, and mixed fruit peels on electrical energy production in a battery system. The research was conducted experimentally using fermentation durations of 96, 120, and 144 hours. Based on the results and discussion, it was found that differences in fermentation time significantly influenced the electrical performance of the bio-battery for all types of fruit peel electrolytes tested. The variation in fermentation duration affected the electrochemical characteristics of the voltaic cell, where longer fermentation increased acidity and enhanced ion formation, resulting in higher pH reduction, current, voltage, and yield values. The best performance was obtained from the orange peel electrolyte fermented for 144 hours, producing a pH of 2.31, current of 18.88 A, voltage of 7.86 V, and yield of 85.24%. These results indicate that fermentation duration plays an important role in optimizing the electrochemical properties of natural electrolytes derived from fruit peels for sustainable energy applications.

Keywords: fermentation, electrolyte solution, electrical current, bio-battery

1. INTRODUCTION

Energy has become one of the most essential resources sustaining modern human activities in all sectors industry, transportation, business, and household. Most of the world’s energy consumption still relies on fossil-based sources, which are non-renewable and increasingly limited. In Indonesia, dependence on petroleum-based fuels continues to rise, leading to economic vulnerability and environmental degradation due to

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greenhouse gas emissions and global warming. The decline in Indonesia's energy resilience index over the past decade highlights the urgent need to optimize the use of renewable energy resources such as solar, hydro, geothermal, wind, and biomass. Among these, biomass-based energy offers a unique advantage because it utilizes abundant organic waste materials, aligning with sustainable development goals and the circular economy concept.[1,2]

Electrical energy, in particular, plays a vital role in daily life. Traditional batteries and accumulators commonly employ mineral-based or synthetic electrolytes such as sulfuric acid (H_2SO_4), which, despite their efficiency, contribute to environmental pollution and generate toxic waste.[3] To address these issues, recent studies have explored the use of bio-based electrolytes derived from natural or organic materials. Several investigations demonstrated that organic acids and sugars in fruits such as citric acid, malic acid, and ascorbic acid can facilitate ionic conduction comparable to conventional electrolytes.[4] Organic waste, especially fruit peels, is rich in these compounds and can thus be converted into an eco-friendly electrolyte solution through biochemical processes such as fermentation. This approach not only reduces environmental pollution but also transforms waste into a renewable energy source.[5]

Previous studies have shown the potential of fermented fruit peels to produce electricity in bio-battery systems. Marianti et al.[6] reported that variations in fermentation duration affected the electrical output generated by different fruit peels, including lime, banana, and avocado peels. However, most prior works focused on single types of fruit peel and applied limited fermentation time ranges. The synergistic potential of combining different fruit peels each with distinct organic acid, sugar, and mineral compositions—has rarely been explored. In addition, the correlation between fermentation time and electrochemical performance remains insufficiently characterized. Therefore, this study aims to investigate the effect of fermentation duration (96, 120, and 144 hours) on the production of electrical energy using electrolyte solutions derived from orange (Citrus), pineapple (Ananas comosus (L.) Merr), watermelon (Citrullus lanatus), and their mixture. The novelty of this work lies in optimizing fermentation time and employing mixed fruit peels to enhance ion generation and electrical conductivity in a bio-battery system. The outcomes are expected to contribute to the development of low-cost, renewable, and environmentally friendly electrolytes for sustainable energy applications.

2. EXPERIMENTAL

2.1. Chemicals, Equipment and Instrumentation

The materials used in this research consisted of orange peels (Citrus), pineapple peels (Ananas comosus (L.) Merr), watermelon peels (Citrullus lanatus), and their mixture in equal portions (1:1:1 by weight). Young coconut water was used as a natural fermentation medium, while a used 12 V lead-acid battery served as the container for the bio-electrolyte solution. All chemicals were of analytical grade and used without further purification. The main equipment employed included a blender (Philips HR2115), analytical balance (Ohaus PA213), pH meter (Hanna HI 2211), multimeter (Sanwa CD800A), and amperemeter. Supporting tools such as 1500 mL plastic bottles (for fermentation), beakers, sieves, knives, glass rods, and filter cloths were also utilized. A 7-watt LED lamp was used as a visual indicator of the generated electrical current. All experiments were conducted at room temperature (27 ± 2 °C) in the Physical Chemistry Laboratory, Universitas Negeri Medan.

2.2. Research Procedure

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Each type of fruit peel was first washed thoroughly to remove impurities, then cut into small pieces and weighed at 500 g per sample. For the mixed sample, 166 g of each peel type (orange, pineapple, and watermelon) were combined to reach 500 g total. The fruit peels were blended with 500 mL of young coconut water to produce a homogeneous slurry, which was subsequently transferred into labeled fermentation bottles.

The fermentation was carried out under anaerobic conditions by sealing each bottle tightly and storing them at ambient temperature. The fermentation durations were varied at 96, 120, and 144 hours. The pH of each sample was measured before and after fermentation to monitor acidification and ion formation. Observable physical changes such as color, aroma, and gas release were also noted qualitatively to indicate microbial activity during fermentation.

After fermentation, each solution was filtered through a fine cloth to separate the liquid phase from solid residues. The filtrates served as electrolyte solutions. A used 12 V accumulator battery was cleaned, and its internal acid solution was carefully removed. The fermented electrolyte solution was then poured into the battery compartment until it filled approximately three-quarters of the total volume. The battery was resealed and connected to a simple galvanic circuit consisting of copper and zinc electrodes.

The generated electrical energy was characterized by measuring voltage (V) and current (A) using a multimeter and amperemeter. The pH values were measured with a digital pH meter, and the yield percentage was calculated by comparing the volume of the filtrate obtained to the initial fermentation volume. The performance of each electrolyte was evaluated based on the relationship between fermentation time, pH, voltage, and current output.

3. RESULTS AND DISCUSSION

3.1. Analysis of Characterization Results

The fermentation process significantly affected the acidity of the electrolyte solutions. As the fermentation duration increased, the pH values decreased, indicating the accumulation of organic acids such as citric, malic, and ascorbic acids. These compounds are produced through microbial metabolism, mainly by lactic acid bacteria and yeasts that convert carbohydrates into organic acids under anaerobic conditions. Figure 1 shows that the lowest pH value (2.31) was obtained from the orange peel electrolyte after 144 hours of fermentation, followed by the pineapple, watermelon, and mixed samples with pH values ranging from 2.4 to 3.8. The reduction in pH enhances the concentration of hydrogen ions (H^+) in the solution, thereby improving ionic mobility and conductivity. This finding is consistent with previous research reporting that acidity plays a crucial role in determining the efficiency of bio-electrolytes in generating electrical energy.[4,5]

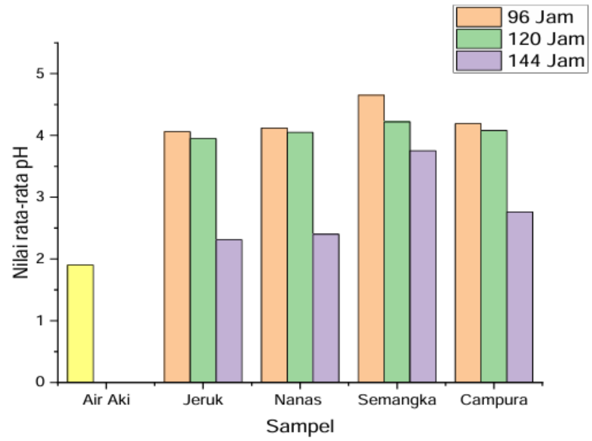

Figure 1. Variation of pH values of fermented electrolyte solutions from orange, pineapple, watermelon, and mixed peels at different fermentation durations (96, 120, and 144 hours)

3.2. Electrical Current (Ampere) Output

The current generated from each fermented electrolyte solution increased with fermentation duration, as shown in Figure 2. The orange peel electrolyte produced the highest current value of 18.88 A at 144 hours, while the other samples showed lower values due to their relatively weaker acidity and lower ion concentrations. The increase in current corresponds to the rise in ion mobility within the electrolyte, which facilitates electron flow between the electrodes. The inverse correlation between pH and current demonstrates that stronger acidity promotes better charge transfer. This trend aligns with observations by Marianti et al. (2021), who reported that extended fermentation enhances the electrochemical performance of bio-batteries through continuous ion generation.[6]

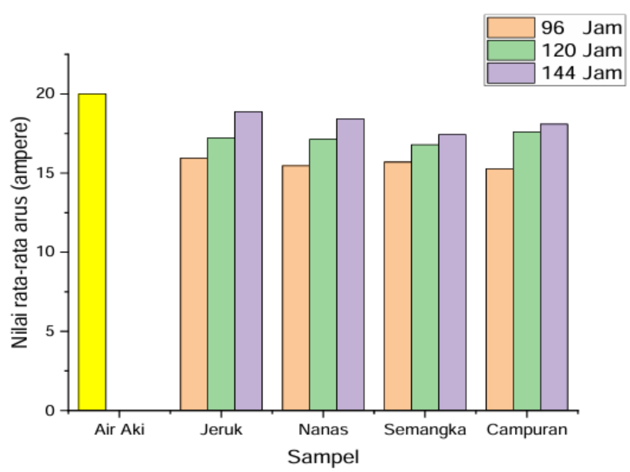

Figure 2. Current output of fermented electrolyte solutions from different fruit peels at varying fermentation durations

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3.3. Voltage (Volt) Generation

Similar to the current output, the voltage generated by the bio-battery system also increased with fermentation time (*Figure 3*). The maximum voltage of 7.86 V was recorded for the orange peel electrolyte after 144 hours, indicating that this condition provided optimal ionic conductivity. The voltage rise results from the enhanced concentration of dissociated ions in the electrolyte, which improves the redox reactions at the copper and zinc electrodes. The relationship between pH and voltage was inversely proportional, confirming that higher acidity correlates with greater electron mobility. The increased voltage is attributed to both the dissociation of ionic species and the redox processes occurring at the electrode interfaces. According to Faraday's laws, the total electrical potential is directly proportional to the number of ions participating in the electrochemical reaction, explaining why prolonged fermentation produced higher voltage values.

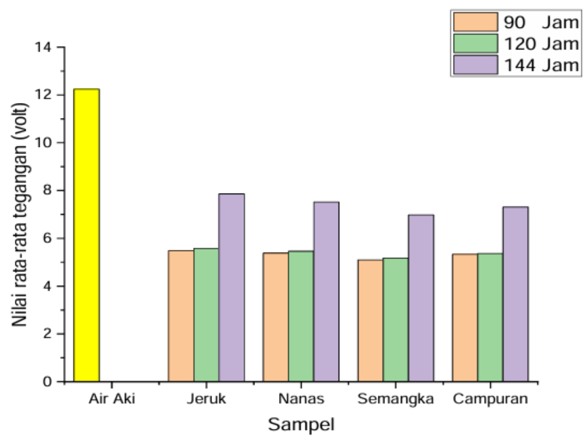

Figure 3. Voltage output generated by fermented electrolyte solutions from orange, pineapple, watermelon, and mixed peels

3.4. Yield Analysis

The yield of the fermented electrolyte solutions was calculated based on the ratio of recovered liquid volume to the initial fermentation volume. As depicted in *Figure 4*, the highest yield (85.24%) was obtained from the orange peel electrolyte after 144 hours of fermentation, followed by pineapple, mixed, and watermelon samples. A higher yield indicates a more efficient fermentation process that generates a greater number of ions and soluble compounds. The yellowish color and slightly alcoholic aroma of the orange peel electrolyte also confirmed the presence of ethanol and organic acids, both of which contribute to increased ionic concentration. These results suggest that the orange peel electrolyte not only produced the most favorable acidity but also the highest liquid recovery, both of which enhance bio-battery performance.

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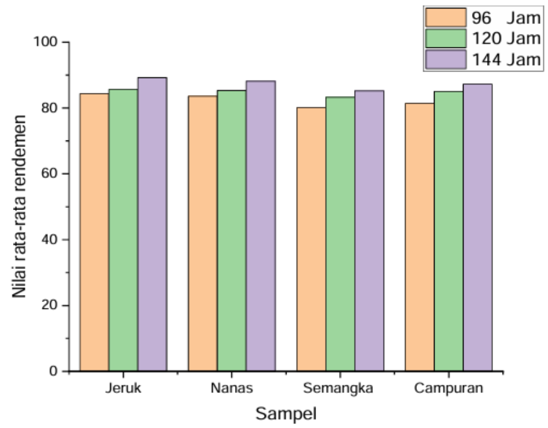

Figure 4. Yield percentage of fermented electrolyte solutions after 96, 120, and 144 hours of fermentation

4. CONCLUSION

The results of this study demonstrate that fermented fruit peel solutions can function effectively as natural electrolyte media for bio-battery systems. The fermentation duration strongly influences the acidity, ion concentration, and electrochemical performance of the electrolyte. Among all tested samples, the orange peel electrolyte fermented for 144 hours produced the optimal results with a pH of 2.31, current of 18.88 A, voltage of 7.86 V, and yield of 85.24%. The enhanced electrical performance is attributed to the high concentration of organic acids and ions generated during fermentation. These findings confirm the potential of fruit peel waste as an environmentally friendly and renewable alternative to conventional acid-based electrolytes in sustainable energy applications.

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