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Citrus Peel Waste as an Electrolyte Solution for Energy Storage in Bio-Batteries

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Abstract

This study explores the potential of citrus peel waste as an electrolyte solution for energy storage in bio-batteries. This research offers an environmentally friendly solution to obtain clean and sustainable energy by utilizing abundant organic waste as raw material. An experimental method was conducted to analyze the ability of electrolyte solutions from citrus fruit peel waste to support bio-battery performance. The results showed that citrus peel waste has significant potential as an electrolyte solution with competitive capabilities in energy storage. The implications of this research include the development of more sustainable alternative energy technologies and the effective use of unused resources, which could be an essential step in achieving global sustainability goals.

Keywords: Electrolyte solution, Orange peel, Performance, Energy storage, Bio-battery

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1. Introduction

To face global challenges in the energy sector, technological innovations are needed that can support sustainable development in the future (Jaya & Muhammad Nawawi, 2025; Maradin, 2021). In recent years, various research and development have been carried out to create sustainable power sources through various methods. Especially in sustainable energy-based electricity production, optimal technology is needed for energy production and storage using batteries (Zhang et al., 2024).

However, there are a number of challenges in battery development, especially in overcoming environmental impacts and maintaining stability and efficiency in long life cycles to meet current energy needs. It is worth noting that battery technology has undergone significant developments over the years (Anggara Trisna Nugraha et al., 2024; Nupearachchi et al., n.d.). The battery itself is an electronic device that converts chemical energy into electrical energy through an electrochemical process known as redox reaction (Anggara Trisna Nugraha et al., 2024; Cho et al., 2015). One promising innovation is the development of bio-batteries, which have great benefits given our dependence on batteries in our daily lives (A., Urba Ziyauddin Siddiqui, 2013).

Bio-batteries' role in the future will become increasingly vital in meeting energy needs (Babaei et al., 2022; Biswas et al., 2022; Buaki-Sogó et al., 2020; Guerra et al., 2024; Manogaran et al., 2022; Nuryanti et al., 2022; Zaidi et al., 2021). Renewable energy is the hope to meet energy needs, with the advantages of abundant availability, sustainability, and environmental friendliness (Maradin, 2021; Nunes, 2020; Uddin et al., 2021; Ullah et al., 2020). Bio-batteries are a solution to replace conventional batteries that are environmentally friendly (Biobaterai & Lingkungan, 2021; Fitrya et al., 2021; Oumarou Amadou et al., 2023; Uddin et al., 2021).

Bio-batteries are considered more environmentally friendly than commercial batteries (Cattaneo et al., 2023; Fitrya et al., 2021). Commercial batteries can pollute the environment if thrown into landfills, causing harmful impacts such as fires and explosions (Fitrya et al., 2021; Kim et al., 2023; Maradin, 2021). Fruits and vegetables are used because

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they contain electrolyte ions that produce electrical energy, making them bio-batteries that meet electricity needs (Fauzia et al., 2019; Fitrya et al., 2021).

Bio-battery research uses oranges, mangoes, banana peels, and plant waste (Nathawibawa et al., 2016; Nelson, 2018; Ristiono & Pd, 2021). Batteries need a solution that can conduct electricity well. This is influenced by several factors, such as the number of ions in the solution, how fast the ions move (ion mobility), and temperature. In addition, the oxidation number also plays a role in this process. (Kang et al., 2024; Liu et al., 2024; Mirshafiee et al., 2024; Riaz et al., 2024). Fruits and vegetables contain mineral acids such as hydrochloric acid and citric acid, which are strong electrolytes that completely decompose into ions in aqueous solution. The acid and water content of fruits and vegetables creates a potential difference between metal and water, generating electrode potential that can generate an electric current. On this basis, fruits and vegetables can serve as replacement electrolytes in bio-batteries (Fitrya et al., 2021; Hussain et al., 2021; Wikaningrum et al., 2022).

As a device that converts chemical energy into electrical energy through electrochemical reactions of reduction and oxidation, batteries require a solution with conductivity influenced by the number of ions, ion mobility, oxidation number, and temperature (Pangestu & Supardi, 2020; Prasetyo & Saputro, 2015). Fruits and vegetables contain mineral acids such as hydrochloric and citric acid, vital electrolytes that decompose entirely into ions in aqueous solution. The acid and water content of fruits and vegetables creates a potential difference between metal and water, generating electrode potential that can generate an electric current. On this basis, fruits and vegetables can serve as replacement electrolytes in bio-batteries (Han et al., 2024; Hussain et al., 2021; Ma et al., 2024).

Based on the type of electrolyte, batteries are divided into wet cells, such as accumulators, and dry cells, such as batteries (Fauzia et al., 2019; Mu et al., 2024; Pratama, 2019). Wet cells based on the H2SO4 solution, widely used in automotive batteries, are at high risk because the H2SO4 solution is environmentally unfriendly and harmful to human health. The use of H2SO4 also requires special handling due to potential hazards to the skin and inhalation. Therefore, further research is needed to replace H2SO4 electrolytes with natural materials that are more environmentally friendly to produce environmentally friendly batteries (Kim et al., 2023; Prasetyo & Saputro, 2015), (Touileb & Abbou, 2023).

This battery has the advantage of using lead (Pb) on both electrodes as the active material. Both electrodes are solids dipped in sulfuric acid solution (H2SO4) with a diaphragm as a separator. When fully charged, this battery has an acid density of about 1.24 kg/liter at a temperature of 25oC (Babaei et al., 2022; Hussain et al., 2021; Pangestu & Supardi, 2020; Xia et al., 2024). In batteries, there are two types of electrodes, the cathode (negative) and the anode (positive), with Pb acting as the cathode and PbO2 as the anode.

In the context of alternative energy research, attention is increasing, especially on renewable energy sources from nature. Bio-batteries, devices that generate electrical energy from living organisms, are coming into focus. Fruit was identified as a material with a high potential for bio-batteries because some fruits contain acidity levels that can produce electrical energy. The hydrochloric acid and citric acid in the fruit become electrolytes that can completely decompose into ions, creating a solid electrolyte (Arizona et al., 2021; Riaz et al., 2024), (De Angelis et al., 2024).

The theory of generating electrical energy from fruits and vegetables follows the principle of voltaic cells. Redox reactions (oxidation-reduction) can occur in voltaic cells if two metals are immersed in an electrolyte solution, producing an electric current. This principle suggests that fruits and vegetables, with substances that can form electrolyte solutions, have potential as renewable energy sources or even as alternative sources of electrical energy.

Several previous studies, such as those conducted by Fahmi Salafa, Latiful Hayat, and Anwar Ma'ruf, successfully used orange peels instead of battery electrolytes. Research shows that orange peels with a pH of 3.8 and acidic properties can be used as battery electrolytes. Orange peel produces a potential difference of 0.81 Volt and a current of 0.049 mA with a load resistance of about 4.7 KΩ (Salafa et al., 2020)(Mu et al., 2024) Another study by Sri Wahyu Suciyati, Suci Asmarani, and Amir Supriyanto used citrus waste as an alternative energy source for bio-batteries, using copper (Cu) and zinc (Zn) as electrode materials(Häupler et al., 2015; Mah Bengi et al., 2018; Riaz et al., 2024; Zhang et al., 2024).

Citrus, known for its acidity and citric acid content, is considered an ideal candidate for bio-batteries. Another advantage of oranges is the abundant availability and waste of orange peels that can be used as bio-battery materials. Therefore, further research needs to be done to evaluate the most suitable types of oranges as electrolyte solutions in bio-batteries as a step to support environmentally friendly renewable electrical energy sources (Fahmi Salafa et al., 2020; Hussain et al., 2021; Nelson, 2018) In this context, the solution to reduce the negative impact of batteries is to replace their electrolyte solution with a more environmentally friendly fruit peel solution. This study aims to optimize electrolytes by using fruit peels as a substitute, hoping they can be more economical, efficient, and easy to maintain.

Previously, research on the content of citric acid ($C_6H_8O_7$) in citrus fruit peels has been conducted by Moranain May Tulus Ikhsan (2018). The study results showed that pure lime juice has a pH of 1.55 with a voltage of 6.00 Volts. With the addition of NaCl and Na-EDTA additives, the pH becomes 0.51 with a voltage of 7.40 Volts, while the H_2SO_4 solution has a pH of -0.08 with a voltage of 11.97 Volts. The content of citric acid ($C_6H_8O_7$) can be an alternative to the electrolyte solution in the battery (Sitanggang et al., 2021), (Martins & Torresi, 2020).

This research aims to optimize the use of electrolytes by utilizing fruit peels as an alternative, so that it is expected to be more economical, efficient, and easy to maintain. The main innovation in this study is the addition of gel, which plays a role in improving voltage stability and extending battery life. Compared with conventional liquid electrolytes, gels have the advantage of reducing evaporation and electrolyte loss, thereby improving the efficiency of bio-batteries. In addition, the gel also serves to control the rate of electrochemical reactions, which contributes to increased battery life compared to traditional liquid electrolyte systems. This approach offers a new concept in the development of bio-batteries by utilizing a combination of orange peel waste and jelly, which has been rarely explored in previous research. These findings have the potential to be the basis for further research in the use of biomaterials as an alternative energy source, especially in the development of flexible and portable batteries.

2. Methods

This study is an experimental study that aims to evaluate the effectiveness of orange peel solution as an electrolyte in bio-batteries, with the addition of gel as a voltage stabilizer. The experimental method was chosen because it allows the design of a system that can optimize the use of renewable energy. In this study, orange peel was used as an electrolyte with the addition of a gel to increase the energy storage capacity in the battery.

This research also focuses on the utilization of unused orange peel waste by testing it as an electrolyte solution. Electrolytes are obtained from Kintamani orange peel extract, which is known to be abundant and environmentally friendly. Voltage and current measurements are carried out in the electrolyte cell after the electrolyte derived from fresh and fermented orange peels is changed. In battery configurations, copper (Cu) is used as the anode (+), while zinc (Zn) acts as the cathode (-).

To support this experiment, several main instruments were used, including: Digital multimeter, which serves to measure the voltage (Volts) and electric current (Ampere) generated by bio-batteries. pH meter, which is used to determine the acidity level of an orange peel solution, because that acidity level affects the conductivity of the electrolyte. Conductivity meter, which serves to measure the level of electrical conductivity of an electrolyte solution. In addition, this study uses several main ingredients, namely: Orange peel, as a natural source of electrolytes containing citric acid, flavonoids, and polyphenols, which play a role in increasing electrical conductivity. Gel, which acts as a voltage stabilizer and helps slow down the evaporation of the electrolyte. Aquades, which is used as a solvent in the process of extracting orange peels.

The following is an explanation of the composition and stages of making gel from Kintamani orange peel solution as a means of bio-batteries, which focuses on the formation of electrolyte gels.

a. Composition of Kintamani Orange Peel Solution Electrolyte Gel

   The electrolyte gel derived from the Kintamani orange peel solution is prepared using 100 mL of Kintamani orange peel extract. This extract is produced by blending 10–15 grams of orange peel together with distilled water to obtain natural electrolyte compounds such as citric acid, flavonoids, and polyphenols. To create a semi-solid gel structure, a thickening agent such as natural pectin or carboxymethyl cellulose (CMC) of about 1.5–2.5 grams is added, which functions to build a polymer matrix while still allowing the movement of ions. In order to increase the electrical conductivity capacity, the solution is given an additional 0.1–0.3 grams of citric acid and 0.2–0.5 grams of salts such as NaCl or KCl as an ion source. The design of this composition is directed to produce a gel that is stable, has good conductivity, and is environmentally friendly so that it can function efficiently as an electrolyte medium in bio-battery cells.

b. Kintamani Orange Peel Solution Electrolyte Gel Making Process

   The process of making electrolyte gels from Kintamani orange peels begins with cleaning 10–15 grams of orange peels. After that, the orange peel is blended with 100 mL of distilled water until it is mixed into a solution to take up natural electrolyte compounds such as citric acid and flavonoids. After extraction, the solution is filtered to separate the pulp, then heated to 60–70°C. Next, 1.5–2.5 grams of gelling ingredients such as natural pectin or carboxymethyl cellulose (CMC) are added while stirring until dissolved and mixed evenly. To improve conductivity, the solution can be added citric acid (0.1–0.3 grams) as well as NaCl or KCl salts (0.2–0.5 grams). The prepared mixture is then poured into a mold and cooled at room temperature, then stored in the refrigerator (±4°C) for 2–3 hours until a stable electrolyte gel is formed and ready to be used as an ion-conducting medium in a bio-battery cell.

At the electrode selection stage, a copper electrode (Cu) is used as an anode, while a zinc (Zn) electrode acts as a cathode. These two electrodes are placed in a container containing an orange peel-based electrolyte solution with the addition of gel, then connected to a digital multimeter to measure the initial voltage. Voltage and current measurements are carried out every 60 minutes for 12 hours using a digital multimeter. Voltage stability was analyzed by comparing bio-batteries that used gels with those that did not. In addition, pH testing is carried out on a filtered orange peel solution to determine the acidity level, with the pH value measured using a pH meter.

This research consists of several main stages, including a literature review, collection of supporting data, and application of electrolysis methods using orange peel-based electrolyte solutions for environmentally friendly energy storage. The variables in this study include: Independent variables, namely the type of solvent derived from orange peel waste used as electrolyte, the concentration of the gel in the electrolyte solution, and the acidity level (pH) of the electrolyte solution. Bound variables, including *short circuit current* (Isc) and open circuit voltage (V_{OC}), are measured using appropriate instruments. In addition, voltage stability is also observed over a period of time to assess the performance of the system.

3. Results and Discussion

Bio-batteries' role in the future will become increasingly vital in meeting energy needs. Today, commonly used batteries are made of heavy chemicals such as mercury, lead, cadmium, and nickel, which can pollute the environment if not managed properly. Therefore, innovation is needed to overcome this problem so that the battery does not harm the environment. One solution is to replace the battery contents with more environmentally friendly materials than those used today. Overall, the steps in this study design involve:

- Citrus Peel Selection: Select orange peels, which are then filtered and mashed for liquid ion extraction, separating electron-containing water from other materials such as carbohydrates.
- Electrode types commonly found in the battery market include copper (Cu) electrodes as anodes and zinc (Zn) electrodes as cathodes. These electrodes are also considered more effective than carbon electrodes in generating voltage.

Based on the literature review and test results presented previously, the research hypothesis is that filtering citrus fruit peels with the addition of NaCl+Na-EDTA can be used for energy storage in batteries. Using citrus peels enriched with NaCl+Na-EDTA as the electrolyte, this study aimed to assess their potential and impact on battery performance.

pH testing; Perform tests to determine the acidity level of the filtered orange peel. Extraction uses water (H_2O) and steeping time at one-hour intervals. The pH value is measured on a sample taken using a pH meter. The process of making an electrolyte solution from the skin of the Kintamani citrus fruit is shown in figure 1. The analysis of the citric acid content in the orange peel solution was carried out using the UV-Vis spectrophotometer shown in Figure 2.

The UV-Vis graph shown in Figure 3 shows the absorption spectrum of several different types of electrolyte samples, namely Air AC, ACCU hydrobate, ACCU star, and orange peel water in the wavelength range of 200 to 800 nm. It appears that orange peel water has the highest absorption value with an absorbance of about ~0.085 at a wavelength of about 323 nm, which indicates that this sample contains the highest amount of active compounds (possibly flavonoids or conjugated organic compounds). This peak indicates the presence of $\pi \rightarrow \pi^*$ electron transitions that often occur in conjugated aromatic or carbonyl compounds. ACCU star also shows a clear peak of absorbance in the range of 240–260 nm, indicating the presence of active compounds although not as large as in orange peel water.

Meanwhile, Air AC and ACCU hydrobat showed a lower absorbance value overall, below 0.02, with a flatter spectrum and no significant peaks, indicating a low content of chromophore compounds or active ingredients that can absorb UV light. This low absorption pattern also suggests that both samples have less electrochemical activity or organic ion content compared to the other two samples. Based on this graph, it can be concluded that orange peel water is the most optically active electrolyte and has the potential to be further developed as an electrolyte medium in bio-battery systems.

Figure 1. Electrolyte Solution Manufacturing Process

Figure 2. Spektrofotometer UV-Vis (UV-1800 Shimadzu)

The results of UV-Visible analysis of Kintamani orange peel solution produced a graph showing the relationship between absorbance and wavelength. If the solution absorbs light in the range of 200–300 nm, this indicates the presence of flavonoids and organic acids. Based on the test results that compare Kintamani orange peel solution with Star and Hydrobat brand battery water, as shown in Figure 3, orange peel solution has similar characteristics to battery water. This is indicated by a significant peak of absorption in the range of 250–350 nm, which confirms the presence of flavonoids and organic acids, such as citric acid, which play a role in the ion transport process in bio-batteries.

The results of this study produced voltage measurement data on bio-batteries using lime peel solution, either without or with the addition of gel, over a period of 12 hours. The data is presented in Tables 1 and 2. The following is a table showing the results of electrical voltage measurements from lime peel solution-based bio-battery samples with and without the addition of gel.

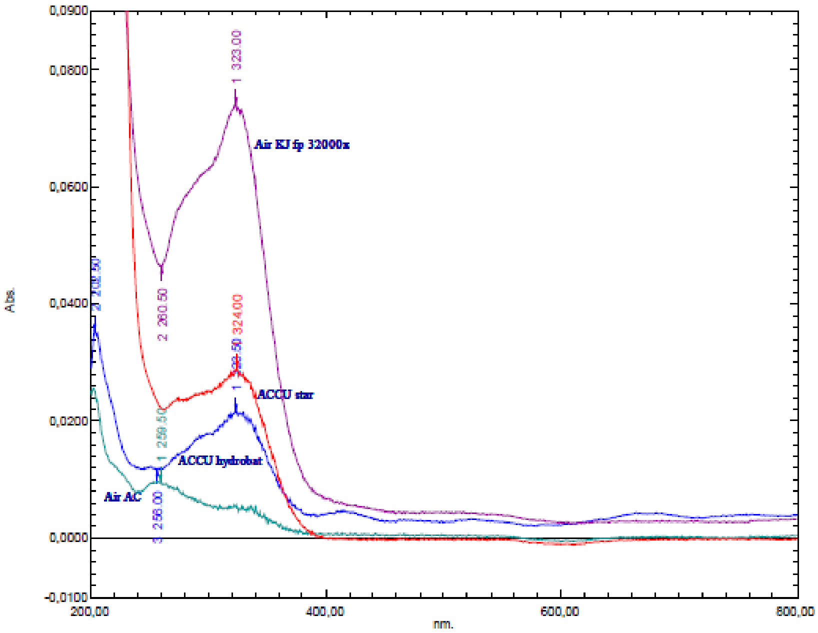

Figure 3. Orange Peel Solution Test Results

Table 1. Data from electrical voltage measurement results Citrus Pruit Peel Solution

Solution Volume (ml)	Electrode	Electrical Voltage (Volts)			
		Time (0 Hours)	Time (4 Hours)	Time (8 Hours)	Time (12 Hours)
15	Cu-Zn	1	1	1	1
15	Cu-Fe	0,6	0,6	0,59	0,59
15	Cu-Pb	0,4	0,4	0,4	0,39

Table 2. Data from electrical voltage measurement results Citrus peel solution with the addition of Jel

Solution Volume (ml)	Electrode	Electrical Voltage (Volts)			
		Time (0 Jam)	Time (4 Hours)	Time (8 Hours)	Time (12 Hours)
15	Cu-Zn	0,8	0,8	0,8	0,8
15	Cu-Fe	0,4	0,4	0,4	0,4
15	Cu-Pb	0,4	0,4	0,4	0,4

Tables 1 and 2 present data from the results of the measurement of the electrical voltage of the orange peel solution, either without or with the addition of gel, using various combinations of electrodes, namely Cu-Zn, Cu-Fe, and Cu-Pb. Based on these data, the results of the voltage measurements seen in the image show that the gel medium provides a relatively more stable voltage compared to the solution medium. For the Cu-Zn electrode configuration, the voltage generated by the gel is in the range of 1.00–1.05 V, while the solution shows greater variation in the range of 0.90–1.00 V. In addition, for the Cu-Fe and Cu-Pb electrodes, the voltage value in the gel medium is not only slightly higher but also more stable compared to the solution medium. This suggests that the gel can maintain the stability of ions within the electrolyte medium and slow down the evaporation process or damage of active compounds, thus supporting more efficient and sustainable electron transfer in bio-battery systems.

Judging from the aspect of economic feasibility, the use of gel from orange peel solution as a medium for bio-batteries shows bright prospects, especially related to the availability of raw materials and their production costs. Orange peel is an abundant organic waste that is often unused, so it can be obtained at a very affordable price or even at no cost. The process of extracting electrolytes and making gels from orange peels does not require expensive equipment, it is enough to use a blender to obtain the solution and add thickening agents such as gelatin or carbopol which are also quite affordable. This makes the cost of producing electrolyte gels much lower compared to commercial electrolytes based on heavy metals or synthetic chemicals. In addition, the use of these natural materials supports the principles of a circular and sustainable economy, which is in line with the global trend towards more environmentally friendly technologies.

From the perspective of long-term economic benefits, the use of gels from orange peel solutions as a medium for bio-batteries has the potential to reduce reliance on conventional batteries, especially for small-scale applications such as sensors, IoT devices, or distributed energy systems. Although its capacity and energy stability still need to be improved, its low operating costs and potential for mass production from agricultural waste make it an attractive economic alternative for further development. If this technology is developed domestically, it will not only reduce the need to import chemicals but also open up new business opportunities in processing waste into renewable energy, thus having a positive impact on society socially and economically.

4. Conclusion

Research on the use of orange peel waste as an electrolyte solution for energy storage in bio-batteries shows very promising potential in dealing with energy and organic waste problems. Bio batteries that utilize citrus waste as an electrolyte provide an environmentally friendly and sustainable solution, as well as utilize unused resources and reduce negative impacts on the environment. The orange peel-based bio-battery system performs best when using Cu-Zn electrode pairs, as it produces the highest voltage compared to other metal pairs. In addition, the use of gel media as an electrolyte has been shown to be more stable and consistent in maintaining voltage when compared to solutions, thanks to its ability to maintain ion stability and slow down the degradation of active compounds. Therefore, the combination of Cu-Zn electrodes and gel media from orange peel is the most promising configuration to be developed into an alternative energy source that is environmentally friendly in bio-battery systems. However, the electrolyte derived from orange peel still needs further development before it can be fully applied. Thus, this research shows an encouraging potential to develop more sustainable alternative energy technologies

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