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Full Paper

Exploring Ambarella's Potential as An Eco-Friendly Zinc-Copper Biobattery Electrolyte: Preliminary Electrochemistry Study

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Abstract- Ambarella is one of the most popular tropical fruits in Southeast Asia. Since it has a high concentration of organic acids, the fruit has the potential to be employed as an electrolyte in biobatteries. In this work, Zn-Cu biobattery electrolytes are derived from the flesh and peel of ambarella fruit. The Open- and Closed-Circuit Voltage, Maximum Power Density, and Battery Capacity of Zn-Cu Biobatteries were investigated. The OCV of the fruit's flesh was 455 mV, while the OCV of its peel was 530 mV. Given the average CCV created by ambarella peel was 471.3 mV and the average CCV generated by ambarella flesh was 342.1 mV. The highest power of Zn-Cu biobatteries was 0.27 mW when fruit flesh was used as the electrolyte and 0.22 mW when fruit peel was used as the electrolyte, Indicating a difference of 18.5%. The peel of an ambarella fruit has a battery capacity of 540 mAh, while the flesh has a capacity of 328 mAh for the Zn-Cu biobattery. This indicates that Zn-Cu with an Ambarella peel has a greater capacity but less power, urging that it be investigated prior to any prospective use.

Keywords- Renewable energy; Maximum power density; Open circuit voltage; Sustainable energy; Uronic acid

1. INTRODUCTION

Ambarella is a popular tropical fruit that is native to Southeast Asia and Pacific Islands, particularly in Indonesia, Malaysia, and Thailand [1]. This fruit has a tart, fresh flavor, and several medicinal properties that are helpful to health [2]. Apart from being utilized as a culinary ingredient, Ambarella fruit has the potential to serve as an electrolyte supply in biobattery due to Its high organic acid content [3], including citric acid and malic acid. This high organic acid content in Ambarella fruit might be useful as a natural and ecologically acceptable electrolyte. In addition, ambarella fruit includes mineral salts such as sodium, potassium, and chloride [4], which serve as electrolytes in biobattery. The potential of Ambarella fruit as a biobattery electrolyte is an intriguing and environmentally friendly alternative to the use of toxic chemicals in batteries. Nevertheless, further study is needed to enhance the performance of biobattery made from ambarella electrolytes and to improve the practicality and effectiveness of this technology.

As an electrolyte for biobatteries, ambarella fruit offers both advantages and disadvantages. One of the advantages is that it is a clean and eco-friendly source of natural electrolytes without any hazardous ingredients [5]. Additionally, it is more readily available in tropical regions and can be a cost-effective substitute for traditional electrolytes. The presence of organic acids and minerals in ambarella fruit may also enhance the efficiency of energy conversion and biobattery durability. Furthermore, It is safe to utilize Ambarella fruit as an electrolyte since it is neither caustic nor toxic. However, there are some drawbacks to using ambarella fruit as an electrolyte. The organic acid content of ambarella fruit can be easily oxidized, which could negatively impact the performance of biobatteries [6]. Moreover, the mineral composition of ambarella fruit, including sodium, potassium, and chloride, is less stable, leading to a decrease in biobattery efficiency. Lastly, the highly acidic nature and water content in the ambarella fruit makes it vulnerable to contamination by microorganisms. Therefore, proper processing and treatment are necessary to prevent contamination in biobattery.

In order to solve the issues of Ambarella as a biobattery electrolyte, further study should be conducted to identify which parts of the fruit can be utilized as electrolytes to improve performance in biobattery. In addition, developing new technologies is essential to increase the performance of biobattery. Therefore, it is important to understand the electrochemical properties of the biobattery's electrolytes [7]. By carrying out these measures, it is expected that the issues associated with using ambarella fruit as a biobattery electrolyte can be resolved, and its potential as an environmentally friendly and readily accessible electrolyte source can be improved.

Previous studies have explored the use of various fruits as electrolytes for biobatteries. Togibasa et al. [8] employed tropical almond paste as a biobattery electrolyte. Rahmawati & Agnesstacia [9] fill biobatteries with star fruit and cactus. Nupearachchi et al. [10] examined the utility of banana pith as an electrolytic medium for biobatteries. The fruit-based, stretchy battery was created Using lemon juice and gelatin by Wang et al. [11] fruit-based, stretchy battery was created. Whereas Ansanay et al. [12] use betel nut (Areca catechu) from Papua as an electrolyte for a biobattery. Despite these studies, the majority of these fruits have less acidity than ambarella, making ambarella have a high potential for use as an electrolyte in biobatteries.

Zn-Cu batteries belong to a specific category of batteries that exhibit several advantages over other types, such as lower manufacturing costs, greater ecological friendliness, cost-effectiveness, and a stable, uninterrupted electric current [13]. However, Zn-Cu batteries suffer from several limitations, including a relatively low energy capacity and voltage. Therefore, a sustainable electrolyte with relatively high acidity is required for Zn-Cu battery electrolyte, and ambarella is one of the possibilities.

In this study, Fruit flesh and peel of ambarella are employed as Zn-Cu biobattery electrolytes. Electrochemical properties and Zn-Cu biobattery performance including Open and Closed-Circuit Voltage (OCV and CCV, respectively), Maximum Power Density, and battery capacity were analyzed. According to our knowledge, this study has never been conducted previously, making it an academic novelty. The objective is to explore the use of plentiful natural resources like ambarella fruit as a Zn-Cu biobattery electrolyte to generate electricity.

2. EXPERIMENTAL SECTION

2.1. Raw Material Preparation and Assembly of Cu-Zn Biobatteries

Ambarella fruit, which is purchased from a local market was separated between the flesh and the peel. The ambarella's flesh or peel is chopped into little pieces. The flesh or peel was then chopped into small pieces and mixed with water in a 1:1 mass ratio in a container. The mixture was homogenized using a blender until smooth and then poured into a beaker glass. For the Cu-Zn biobattery assembly, 10×5×0.2 cm of Zn and Cu plates, which serve as the anode and cathode, respectively, were placed in a beaker glass containing the juice of the fruit flesh or peel of the ambarella which acted as an electrolyte solution. Finally, a multimeter UNI-T UT61E was connected to each electrode for further measurements.

2.2. Electrochemical Analysis

With a homemade Arduino-based potentiostat, cyclic voltammetry (CV) experiments were conducted to assess the redox reaction. Ambarella flesh or peel juice is employed as the electrolyte in this research. In this work, typical three-electrode CV measurements were performed. As the working electrode, a disk-shaped carbon electrode with a diameter of 3.0 mm was employed. As reference and counter electrodes, respectively, a stainless-steel rod and an Ag/AgCl electrode (3 M potassium chloride) were utilized. All measurements were conducted under room conditions.

The attached multimeter to the Zn-Cu biobattery is configured to monitor DC voltage. The OCV of a Zn-Cu biobattery was measured and recorded every three hours for three days. In addition, a 1 KΩ resistor serves as the external load for CCV measurements. For the production of polarization curves and power curves, voltage measurements were conducted by altering the resistance value from 10 MΩ to 10 Ω for one hour for every resistance value change. The value of current is derived by dividing the voltage by the resistance. In the meanwhile, the voltage value is multiplied by the current value to get the power value. The battery capacity is determined by attaching an external load of 10 MΩ to the biobattery circuit. Daily current measurements are performed and documented until a result of 0 mA is attained. The capacity of the battery was then calculated by multiplying the current difference by the battery discharge time.

3. RESULTS AND DISCUSSION

3.1. The effect of ambarella fruit part as an electrolyte on the open and closed-circuit voltage of Zn-Cu biobattery

Figure 2a shows the voltage measurement of Zn-Cu biobattery cell through OCV which utilizes electrolytes produced from the ambarella fruit flesh and peel. The results indicate that incorporating the fruit flesh in the electrolyte produces slightly better outcomes compared to using only the fruit peel as the Zn-Cu biobattery's electrolyte. Although the voltage applied to the fruit peel is lower than the voltage applied to the fruit flesh, it is more stable. The average voltage across the fruit peel is 542.7 mV, which is lower than that voltage across the fruit flesh (581.6 mV). The acidity value increases in the ambarella fruit flesh due to the high organic acid content in the ambarella fruit flesh, resulting in an increase in the activity of ions in the electrolyte solution. Based on this, the voltage of Zn-Cu biobattery is higher than using electrolytes derived from fruit peel. According to Kato et al. [14], ascorbic acid (AA) is ionized into H^+ ions and ascorbate (ASC) ions, which is followed by the formation of ascorbyl radicals, and dehydroascorbic acid (DHA) through the reaction:

$$C_6H_8O_6 \overset{\rightarrow}{\Leftrightarrow} C_6H_7O_6^- + H^+ \quad (1)$$

$$C_6H_7O_6^- \overset{\rightarrow}{\Leftrightarrow} C_6H_7H_6^* + e^- \quad (2)$$

$$C_6H_7H_6^* \overset{\rightarrow}{\Leftrightarrow} C_6H_6O_6 + e^- + H^+ \quad (3)$$

Koubala et al. [15] reported that uronic acid can be found in both the flesh and peel of the ambarella, with the peel having a 10 times higher concentration than that of the flesh. When uronic acid molecules break, they produce uronate ions (-OOC-CH(OH)-CHOH-COO-) and H^+ ions. The uronate ions could help to stabilize a solution by forming hydrogen bonds with water molecules or other electrolyte ions, while H^+ can move easily between electrolytes in a solution [15]. Additionally, microbial activity in the environment enables the conversion of glucaric acid to glucarate ions. The electrolyte becomes more acidic as a result of the release of protons; hence its conductivity rises. This increase in electrolyte conductivity can also influence the anode and cathode redox reaction processes as described in equation (4) – (6):

Anode:	$Zn \rightarrow Zn^{2+} + 2e^-$	$E^0 = 0.76$ V	(4)
Cathode:	$2H^+ + 2e^- \rightarrow H_2$	$E^0 = 0$ V	(5)
Total:	$Zn + 2H^+ \rightarrow Zn^{2+} + H_2$	$E^0_{cell} = 0.76$ V	(6)

The voltage results shown in Figure 2a for the Zn-Cu biobattery derived from flesh and peel of ambarella fruit electrolyte are lower compared to the E0cell value obtained from equation (6). This difference in voltage can be attributed to various reasons, including the electrolyte concentration and pH, the type of electrolyte used, and the system temperature. These factors are connected to the Nernst equation, which determines either the anode, cathode, or total cell potential.

Figure 2b illustrates the voltage measurement of the Zn-Cu biobattery using CCV. The Zn-Cu biobattery with electrolytes derived from the ambarella fruit peel produced a higher voltage than the biobattery with electrolytes from the fruit flesh.

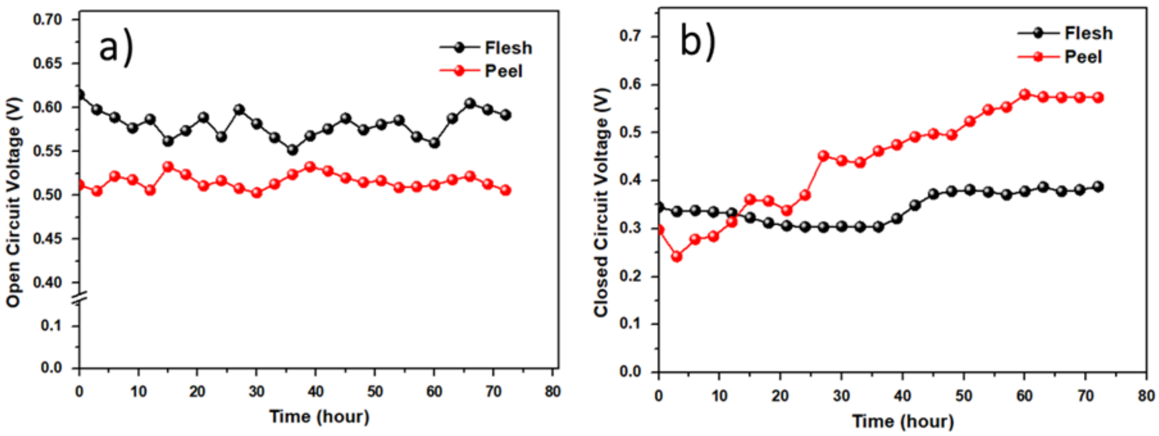

Figure 2. (a) OCV and (b) CCV of Zn-Cu biobattery containing flesh or peel of ambarella as an electrolyte solution

At first, the voltage of the Zn-Cu biobattery with fruit flesh electrolyte is higher than that of the fruit peel. However, by the third hour, the voltage of the Zn-Cu biobattery with the fruit peel electrolyte continued to rise until it surpassed the voltage of the fruit flesh, and the value was double compared to the flesh sample at the end of the measurement. The fruit peel decomposes faster than its flesh due to the high acidity of ambarella fruit, resulting in faster organic acid oxidation and ionization, as well as more rapid decomposition owing to decomposing microorganisms. The addition of a resistor as a load, seems conceivable to increase the activity of microorganisms, hence speeding the oxidation and ionization processes induced by decomposing bacteria in the electrolyte solution from the ambarella peel. As a result of this, the conductivity of the electrolyte solution increases, leading to the production of a considerable voltage. The maximum voltage value in the fruit flesh electrolyte was 400 mV at the 65th hour, whereas the highest value in the fruit peel electrolyte was 580 mV at the 60th hour. The lowest voltage measured on the fruit flesh was 301 mV at the 36th hour, while the lowest voltage measured on the fruit peel was 242 mV at the 3rd hour. Based on these results, the average voltage produced by the flesh and peel of ambarella was 342.1 mV and 471.3 mV, respectively.

3.2. The effect of ambarella fruit component as an electrolyte on the performance of Zn-Cu biobattery

The polarization of the Zn-Cu biobattery was determined using electrolytes derived from the flesh and peel of the ambarella fruit at the beginning of the CCV operation. When a 10 Ω load was used, the maximum current of the Zn-Cu biobattery with fruit flesh electrolyte is 4.1 mA and produces a voltage of 41 mV. On the other hand, the maximum current of the Zn-Cu biobattery with fruit peel electrolyte is 2.3 mA and a voltage of 23 mV. During decreasing the value of the load resistor, the current flowing through the circuit increases. However, this increase in current also leads to a decrease in voltage. This inverse relationship between current and voltage is matched with Ohm's Law. The maximum power output for the Zn-Cu biobattery of fruit peel is 18.5 % higher than the fruit flash electrolyte of about 0.27 and 0.22 mW. The electrolyte conductivity is affected by differences in the concentration of organic acids such as ascorbic acid and uronic acid in the flesh and peel of ambarella fruit [15], as well as the activity of decomposing bacteria. This variation in acidity may have an effect on the quantity of electrolyte ion activity present in the test solution. It can be concluded that the more ions present in a solution, the higher the voltage value. Abidin et al. [17] found the maximum power value of 1.56 mW for rotten tomato juice and coconut flesh in a bio-battery investigation using a weight ratio of 25% coconut flesh and 75% rotten tomato juice. Masthura and Jumiati [18] investigated the electrical properties of a Zn-Cu biobattery derived from fresh pineapple juice, where the highest power output was 83.08 mW.

The capacity of a Zn-Cu biobattery may be estimated by measuring its response to an increasing load until the current drops to a constant value. As can be seen in Figure 3b, the current in the Zn-Cu biobattery gradually diminishes over time when the peel of ambarella fruits is used as the electrolyte rather than the fruit flesh. Biobatteries constructed from both ambarella flesh and peel initially produced 1.43 mA of current and after 11 days, the average current in the ambarella flesh had settled at 0.16 mA due to the stabilization of the electrolyte. For comparison, the concentration of electrolytes in the ambarella peel was constant at 0.20 mA on day 13. The ambarella fruit peel has a 540 mAh battery capacity and a much longer lifespan than conventional batteries. However, the electrolytes produced from the ambarella fruit's flesh allow the Zn-Cu biobattery's battery to operate at a 328 mAh capacity. This is higher than the results of research from Salafa et al., [19] with a value of 4.752 mAh and Wang et al., [20] with a value of 36.16 μAh (2.9 $\mu Ah/cm^2$). The ambarella fruit peel has a greater battery capacity than the fruit flesh itself due to its more acidic pH.

The lower pH accelerates the ionization of the electrolyte, leading to a higher rate of decomposition by bacteria. This increased activity of the electrolyte leads to a longer-lasting high-capacity battery. The fruit flesh's pH increased from 0.85 to 5.03 after being subjected to various research methods. The pH of the ambarella fruit peel increased from 2.15 to 5.60 after measurement. The breakdown of organic acids such as ascorbic acid and uronic acid results in a rise in pH during the process. However, a more acidic electrolyte may affect the ionic conductivity of the battery, which in turn affects battery performance. Stable electric current and good battery performance are dependent on ionic conductivity. A battery's performance may be impacted by excessive safety levels, which can also harm the electrodes and separator. To ensure that the battery performs optimally, the pH of the electrolyte must be maintained within the specified range to maintain stability and prevent any unwanted changes in the battery's chemical composition.

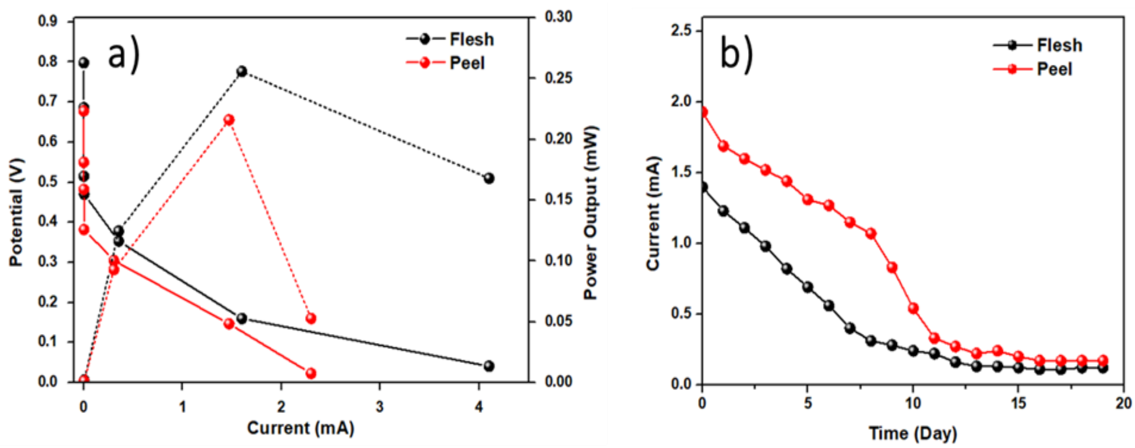

Figure 3. (a) Polarization and power curves of Zn-Cu biobattery applying flesh and peel of ambarella as electrolyte solution. While (b) is their biobattery capacity curve

3.3. Cyclic voltammetry analysis of Cu and Zn using Ambarella as an electrolyte

As a potential electrolyte option for Zn-Cu Biobatteries, the Electrochemical Properties of Ambarella flesh and peel juices, including the reversibility of redox reactions, were analyzed. Figure 4 depicts the cyclic voltammograms of the flesh and peel of Ambarella on a carbon electrode made of glassy carbon. There will be a discussion of several occurrences. Initially, the electrical double layer of Ambarella flesh is somewhat larger than Ambarella peel. This study demonstrates that the electrolytes of Ambarella flesh have a greater capacitance than the peel. Second, the oxidation peak at 0.5 V *vs.* Ag/AgCl indicates that organic acids, including ascorbic acid and uronic acid, undergo electrochemical oxidation at the working electrode. Current at the peak of oxidation is higher in Ambarella flesh than in peel, suggesting that organic acids that are oxidized and/or ionized in the electrolytes of Ambarella flesh were larger than in peel. As a result, the H^+ reduction reaction current to H_2 at peak 0 V *vs.* Ag/AgCl in Ambarella flesh electrolytes is more negative than in Ambarella peel electrolytes. This demonstrates that in the investigation of half-reaction electrochemical properties, electrolytes derived from Ambarella flesh juice are somewhat superior than those derived from Ambarella peel.

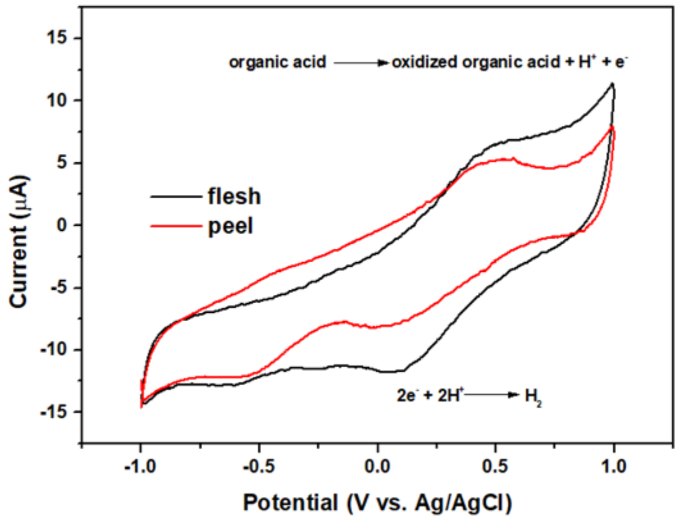

Figure 4. Cyclic Voltammogram (CV) curves of glassy carbon electrode on Ambarella flesh or peel juice as electrolyte solution at a scan rate of 100 mV/s

3.4. Kinetic study and rate-determining Step of Ambarella as Zn-Cu biobattery Electrolyte

Following the characterization mentioned above, it is essential to investigate how the two electrolytes, Ambarella flesh or peel juice, conduct the redox reaction and to determine which phase is the rate-determining step (RDS) in the mechanism. For this purpose, the electrolytes' CV profiles were measured as the scan rate increased (Figures 5a and b). Thus, the relationship between peak anodic and cathodic current densities versus scan rate was determined. The nonlinear trend of the redox peak current density of both electrolytes as a function of the scan rate (Fig. 5c and 5d) indicates that the process is governed by a diffusion regime. At 100 mV/s, the Ipa and Ipc of Ambarella flesh were 6.744 and -11.7 μA, and peel were 2.175 and -11.091 μA, means that both electrolytes are within the region of non-quasi-reversible reactions, with an I_{pa}/I_{pc} ratio far from 1. This is due to the fact that redox reactions do not originate from a single species, but rather from two distinct chemical species. Using Laviron's equation, as shown in Figures 5e and 5f, it is also possible to calculate the electron transfer rate constant (*k*s) of electrolytes, and the results are displayed as Laviron's diagram. Inferred from these Laviron plots, the *k*s values for Ambarella flesh and peel are 0.11 and 0.08 s^{-1}. These values indicated that Ambarella peel liquid will likely be more effective at facilitating electron transfer than flesh. Different chemical compositions can exist between a fruit's flesh and peel. The flesh of ambarella may contain compounds or ions that increase the electron transfer rate relative to the peel. These compounds may function as catalysts or promoters of the biobattery's redox reactions, resulting in a higher rate constant. Typically, the flesh of fruits contains enzymes that are capable of participating in biochemical reactions. It is well known that enzymes catalyse specific chemical reactions, and they can substantially affect the rate of electron transfer in biobatteries [21]. The flesh of ambarella may contain enzymes that increase the electron transfer rate relative to the peel. Ability of the electrolyte to conduct ions is a crucial factor in determining the electron transfer rate constant [22]. In terms of ionic conductivity, the flesh and peel of ambarella may differ. If the flesh possesses a greater ionic conductivity, it would facilitate the movement of ions involved in redox reactions, resulting in a higher rate constant.

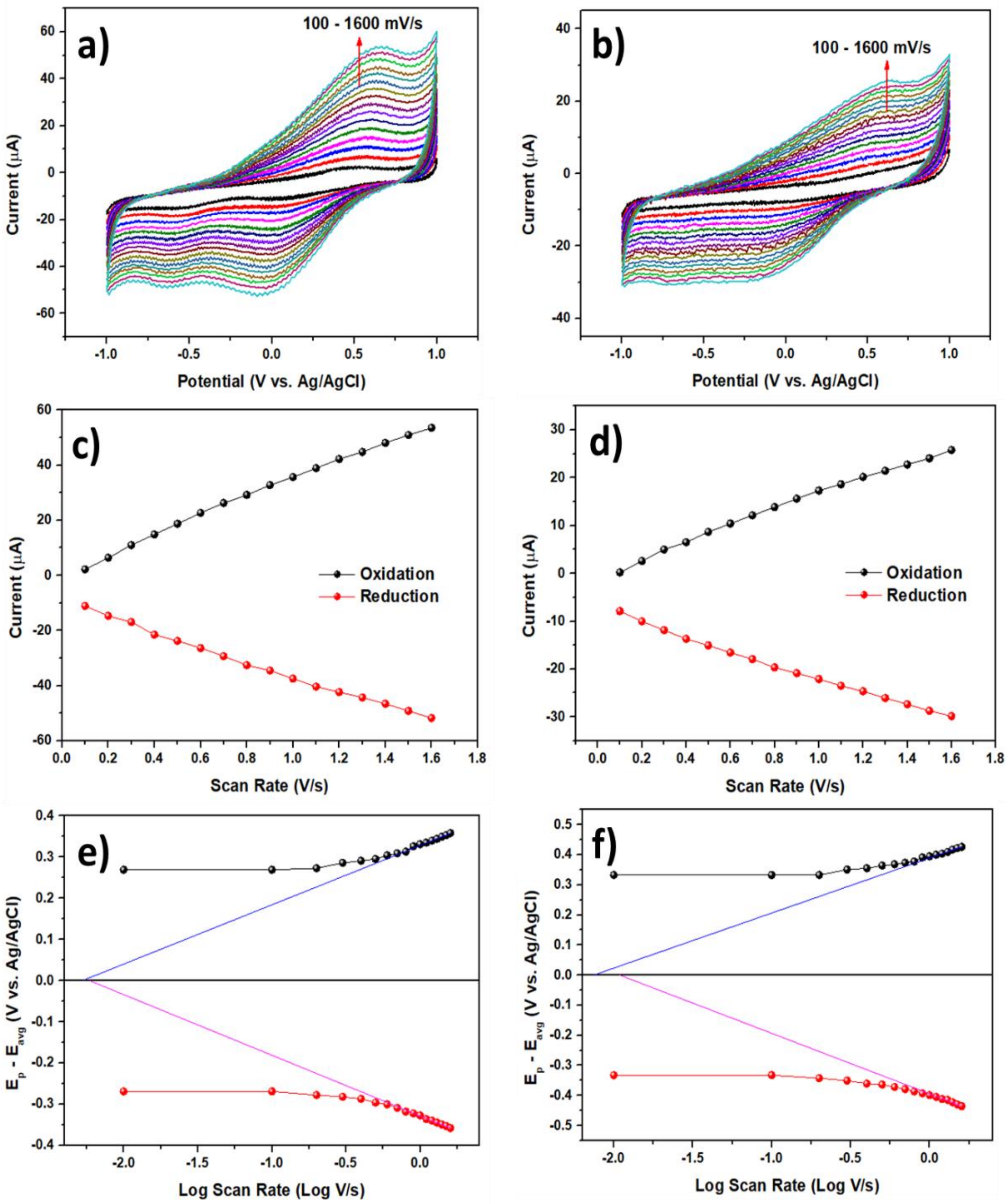

Figure 5. Cyclic voltammetry of glassy carbon electrode on Ambarella a) flesh or b) peel juice as electrolyte solution at a scan rate of 100-1600 mV/s; while c) and d) is the relationship between scan rate and current. Even though e) and f) is their Laviron plot, respectively.

3.5. Future prospect of Ambarella as Zn-Cu biobattery electrolyte

As the globe searches for renewable energy sources, the Zn-Cu biobattery electrolyte Ambarella provides a potential future. One of the major advantages of using Ambarella as a Zn-Cu biobattery electrolyte is its eco-friendliness. Unlike common electrolytes made of synthetic compounds, Ambarella is a natural and renewable source of electrolytes, which makes it an environmentally friendly and sustainable option for biobattery manufacturing. The high concentration of organic acids in Ambarella, such as citric, and malic acid, makes Ambarella fruit a potential candidate for improving the performance of Zn-Cu biobatteries by enhancing the electrolyte solution's conductivity. In addition, Ambarella is abundant in minerals such as potassium and magnesium, which may boost the conductivity of the electrolyte solution. The stability of the chemical properties of ambarella fruit is another advantage. It may retain its qualities for an extended length of time and is stable under a variety of environmental conditions. This makes it a good option for use as an electrolyte in biobatteries. However, using Ambarella as an electrolyte presents several challenges, such as the risk of microbiological contamination due to its high-water content. To maintain the quality and purity of the electrolyte, proper processing and storage methods must be adopted. Another obstacle is the manufacturing expense since Ambarella fruit is not as easily accessible or affordable as other electrolyte alternatives.

4. CONCLUSION

The use of ambarella fruit as an electrolyte in Zn-Cu biobattery technology has shown promising results. In this study, the performance of biobatteries employing ambarella fruit flesh and peel as electrolytes were compared, and it was discovered that fruit flesh produced marginally better outcomes in terms of OCV. The high ascorbic acid content in the ambarella fruit flesh increased the activity of the ions in the electrolyte solution and led to higher voltage measurement than using electrolytes derived from the fruit peel. However, when the performance of the Zn-Cu biobattery was measured using a CCV, it was found that incorporating the fruit peel produced better results. This was because the fruit's high acidity caused the peel to decompose faster than its flesh, resulting in an increase in electrolyte conductivity, and a subsequent increase in higher voltage production. The performance of the Zn-Cu biobattery was enhanced by adding a resistor as a load, which increased the activity of microorganisms, which accelerated the oxidation and ionization processes induced by decomposing bacteria in the electrolyte solution. Overall, this study demonstrates that the ambarella fruit has the potential as an electrolyte in Zn-Cu biobattery technology.

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Declarations of interest

The authors declare no conflict of interest in this reported work.

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