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Effect of Fermentation Time on Acidity, Electrical Voltage and Volume of Apple (*Malus domestica*), Mango (*Mangifera indica*), Starfruit (*Averrhoa bilimbi*) Solutions

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ABSTRACT

This study aims to analyze the effect of fermentation time on the electrical voltage, acidity (pH), and solution volume of apple, mango, and starfruit extracts as natural electrolytes in electrochemical cells. The fruit extracts were fermented using baker's yeast (Saccharomyces cerevisiae) for five days at room temperature, with measurements of electrical voltage, pH, and volume on days 1, 3, and 5. The results showed an increase in electrical voltage over fermentation time, with the highest value in starfruit (0.9 Volt, pH 2, final volume 140 mL). The decrease in pH and solution volume during fermentation indicated an increase in acidity and ion concentration which strengthened the conductivity of the solution as an electrolyte. This study proves the potential of local fruit extracts as a source of environmentally friendly electrolytes for alternative energy based on bioelectrochemistry.

Keywords: fermentation, natural electrolytes, pH, solution, bioelectrochemistry

1. INTRODUCTION

The global energy crisis and the negative impacts of fossil-based energy use have encouraged the search for more environmentally friendly, renewable, and widely applicable energy alternatives. One potential solution is the use of organic materials such as fruits as alternative energy sources in electrochemical cell systems. Fermented fruits contain organic compounds, H^+ ions, and organic acids that act as natural electrolytes, allowing redox reactions to occur that can produce electrical energy.

The core of an electrochemical cell is the redox reaction that occurs at the electrodes, which involves the flow of electrons through an external circuit and the movement of ions in an electrolyte solution to maintain charge balance[7]. The electrode potential is influenced by ion concentration, the type of redox reaction, and environmental conditions such as pH and temperature. This understanding is an important basis for optimizing the performance of fruit fermentation-based electrochemical cells.

Electrochemical techniques such as cyclic voltammetry, amperometry, and impedance spectroscopy can be used to quantitatively observe the rate and efficiency of redox reactions[2]. In fermented fruit-based research, these techniques can be used to analyze ionic dynamics and electric currents during the process. The importance of the role of biomolecules and microorganisms in accelerating bioelectrochemical reactions through bioelectrocatalysis processes that occur in systems that combine biological and electrochemical principles[11].

The selection of appropriate electrode materials, such as activated carbon and graphene, is crucial for electron transfer efficiency and cell stability[15]. The highly porous electrode structure allows for maximum contact with the fermentation solution, while increasing the reaction surface area.

The use of fruit waste and other organic materials as raw materials for electrolytes is in line with the principles of circular economy and waste reduction[9]. The development of this technology not only provides alternative energy, but also supports sustainable waste management.

Fermented Golden Berry fruit waste produces significant electrical voltage due to the high content of sugar and antioxidant compounds[12]. Meanwhile, acidic pH conditions (3–4) during fermentation produce higher electrical voltage than neutral or alkaline pH, because the dominance of H^+ ions in the solution increases the efficiency of electron transfer[4].

Optimal fermentation time (about 72 hours) increases the ion concentration in the solution, which in turn increases the electrical output of the fermented fruit cell[13]. A comparison of lemon and orange fruits found that the high citric acid content in lemons made them more conductive, and produced a higher voltage in a simple galvanic cell[6]. This suggests that the chemical composition of the fruit significantly affects the performance of the electrochemical cell.

Utilization of fruit in bio-cells from red dragon fruit extract and found that the content of active compounds such as phenol and anthocyanin can maintain the stability of electrical voltage during fermentation[8]. The importance of selecting the type of fruit, ripeness level, fermentation time, environmental temperature and solution conditions to optimize the natural electrochemical cell system. Fruit with a high level of ripeness produces a higher voltage because the high sugar and water content supports the conductivity of the solution[10].

Furthermore, the integration of electrochemical and cell biology principles is very important in the design of experiments and interpretation of data from fermentation-based bio-electrochemical research[11]. The combination of plant cell structure, microbial activity, and electrochemical parameters can form an alternative energy system that is cheap, practical, and sustainable.

Based on the background, this study aims to analyze the effect of fermentation time on acidity (pH), electrical voltage, and solution volume of apple, mango, and starfruit extracts. The results of this study are expected to strengthen the development of renewable energy technology through the use of fermented fruit as an efficient and environmentally friendly natural bio-battery.

2. EXPERIMENTAL

2.1. Materials, Equipment and Instrumentation

This study used an experimental method to determine the effect of fermentation time on electrical voltage, pH, and solution volume of apple, mango, and starfruit extracts. The materials used consisted of apples, mangoes, starfruit, boiled water, and bread yeast (Saccharomyces cerevisiae) as fermentation agents. The tools used included spoons, filters, measuring cups (250 mL), fermentation containers, paper pH meters, multimeters, copper (Cu) and zinc (Zn) electrodes, connecting cables, and alligator clips.

2.2. Fermentation Process and Sampling

Apple, mango, and starfruit were each weighed 250 grams, washed, cut into small pieces, then manually pounded until crushed and liquid was released. The pounded results were squeezed using a filter to obtain a liquid extract. Each extract was then mixed with boiled water to reach a total volume of 150 mL, then put into a closed container and added with 1.5 grams of baker's yeast (Saccharomyces cerevisiae). The mixture was fermented for 5 days at room temperature. Measurements of electrical voltage, pH, and solution volume were carried out on days 1, 3, and 5 to determine the effect of fermentation time on the electrolyte performance of each fruit extract.

2.3 Electrical Voltage Measurement

Voltage testing is done by dipping two electrodes (copper as the cathode and zinc as the anode) into the fermentation solution. Both electrodes are connected to a multimeter to determine the amount of voltage produced in Volts.

2.4 pH and Volume Analysis

The pH of the solution was measured using a paper pH meter on days 1, 3, and 5 of fermentation. The volume of the solution was measured using a measuring cup to determine changes due to fermentation, such as volume shrinkage.

3. RESULTS AND DISCUSSION

3.1 Test of Electrical Voltage, Acidity and Volume of Fermented Apple, Mango and Starfruit Solutions

The electrical voltage resistance test was conducted to determine the extent to which the fermented fruit solution could maintain its ability to produce electrical energy during the fermentation process. The test was conducted by measuring the acidity value seen from its pH, electrical voltage, and solution volume on days 1, 3, and 5. The results showed that all types of solutions from apple, mango, and starfruit extracts had an initial voltage when fermentation began (day 1) with a fixed volume of 150 mL. On day 3, the voltage increased as the volume decreased and the pH was relatively stable. While on day 5, the highest voltage was obtained from starfruit of 0.9 Volts at pH 2 and a final volume of 140 mL. Meanwhile, apples and mangoes also experienced an increase in voltage until day 5, although not as high as starfruit. This shows that the resistance of the fermentation solution in producing the most optimal electrical voltage occurs in starfruit, which has high acidity and voltage stability until the end.

Table 1. Analysis of Electrical Voltage, Acidity, and Volume of Fruit Fermentation Solution

Time (day)	Apple			Mango			Starfruit		
	Volume (mL)	pH	Voltage (Volt)	Volume (mL)	pH	Voltage (Volt)	Volume (mL)	pH	Voltage (Volt)
1	150	4	0.5	150	4	0.4	150	2	0.6
3	145	4	0.7	145	4	0.6	143	2	0.8
5	143	3	0.8	143	3	0.7	140	2	0.9

3.2 Analysis of Fermentation Time on Acidity (pH) of Solution

The pH of the solution was measured to assess changes in acidity during the fermentation process. The results showed that the pH of the apple and mango solutions decreased from pH 4 to pH 3 during five days of fermentation, while the pH of starfruit remained stable at 2. This decrease in pH is an indication of increased production of organic acids from the activity of microorganisms. Analysis of fermentation time on the acidity (pH) of the solution shown in Figure 1.

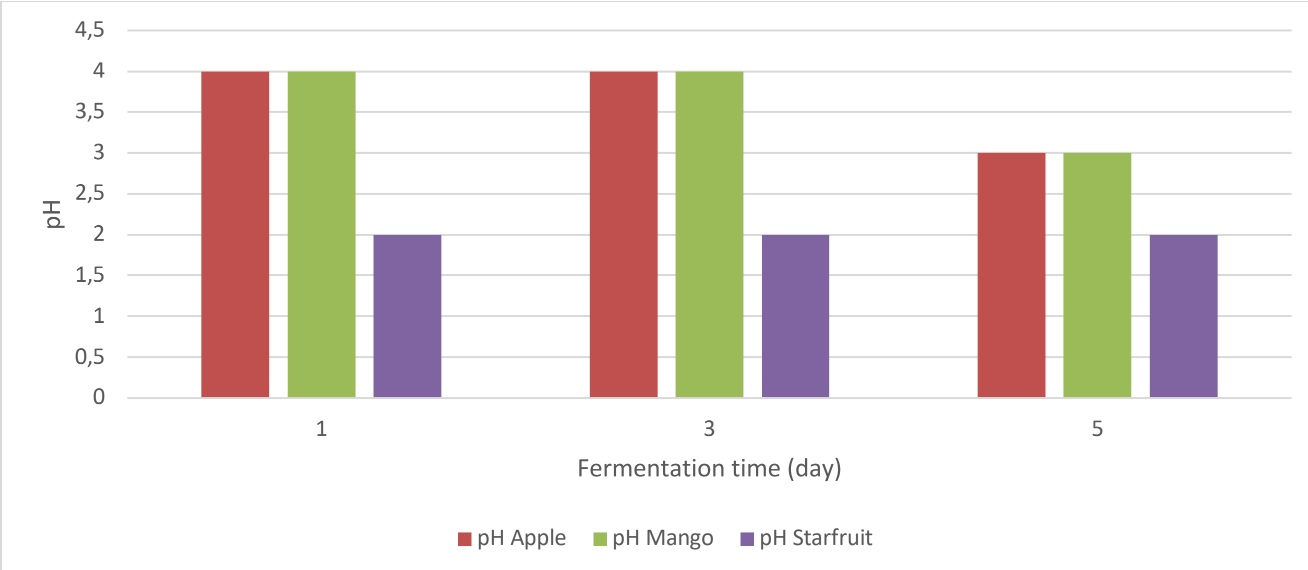

Figure 1. Fermentation Time on pH

Fermentation can produce lactic acid, acetic acid, and citric acid, which causes the pH of the solution to decrease. This is important because high acidity levels strengthen the conductivity of the solution as an electrolyte. Fermentation by lactic acid bacteria significantly reduces the pH of fruit juices, primarily due to the production of various organic acids such as lactic, acetic, and citric acids, which are key metabolites of microbial activity. During apple juice fermentation, a notable decrease in pH was observed, accompanying shifts in the microbial community structure and an increase in total titratable acidity, indicating active fermentation processes. The increase in acidity, reflected by a decrease in pH, directly correlates with an increase in the electrolytic conductivity of fermented fruit juices, attributed to the dissociation of newly formed organic acids into their respective ions.

3.3 Analysis of Fermentation Time against Electric Voltage

The electrical voltage test was conducted to determine how much electrical energy can be produced from the fruit extract solution after fermentation. The measurement results showed that the voltage increased from day 1 to day 5. Starfruit showed the highest voltage of 0.9 Volts on day 5, followed by apple at 0.8 Volts, and mango at 0.7 Volts. This increase in voltage was caused by the increasing number of ions in the solution as a result of microbial metabolism during fermentation. Organic compounds in the fruit will decompose to produce charged ions during fermentation, thereby increasing conductivity and producing higher voltage in the electrochemical cell. The highest voltage occurred in starfruit which naturally has higher acidity, thus supporting the role of H^+ ions in the redox reaction[12].

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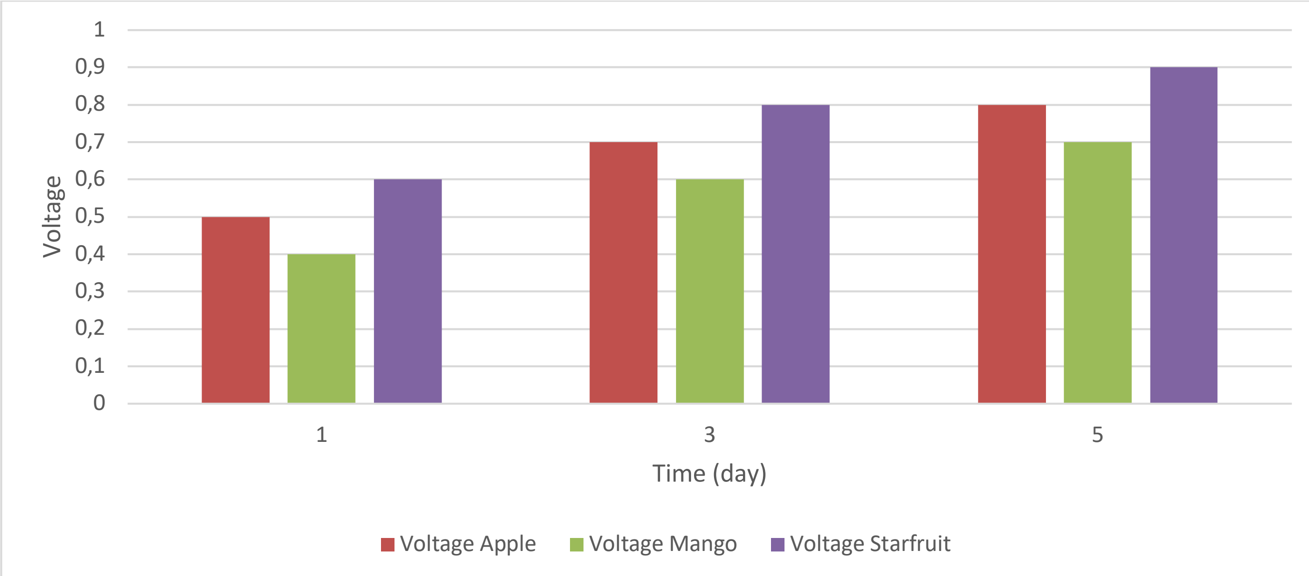

Figure 2. Fermentation Time on Voltage

The foundational principle behind enhanced bioelectricity generation lies in the microbial metabolism that degrades complex organic compounds into simpler, ion-rich byproducts, significantly improving the electrolyte's ability to conduct charge and thus elevating the overall cell voltage. Comparative analysis revealed that fruit wastes with higher initial sugar content, upon microbial degradation, resulted in a greater concentration of charged species, which was directly correlated with an increase in solution conductivity and subsequent higher voltage output. Our findings indicate that pre-fermentation significantly enhances the bioelectricity output, primarily due to the breakdown of complex organic substrates into simpler ionic forms, thereby increasing the electrical conductivity of the solution[5].

3.4 Analysis of Fermentation Time on Solution Volume

The volume of the solution decreased during fermentation, from 150 mL to 143 mL in apple and mango, and to 140 mL in starfruit. This shrinkage occurs due to evaporation and the formation of sediment from suspended compounds. During fermentation, exothermic reactions occur that can increase the local temperature of the solution, causing evaporation of the liquid. In addition, solid particles from fermentation can absorb water and precipitate, which also reduces the total volume.

Solution volume loss during fermentation, as observed in apple, mango, and starfruit juices, is a complex and multifactorial phenomenon. The main mechanisms contributing to this volume loss are evaporation and sediment formation. Exothermic reactions that are intrinsic to the metabolism of microorganisms during fermentation can significantly increase the local temperature of the solution, which in turn accelerates the rate of water evaporation from the system[14]. In addition, accumulation of microbial biomass, formation of insoluble metabolites, or physicochemical changes in suspended components of the fruit (e.g., pectin or fiber) can cause precipitation of solid particles, thereby reducing the measured free liquid volume[3]. Recent studies on fruit juice fermentation have shown that temperature management and initial suspended solids content play a crucial role in minimizing this volume loss.

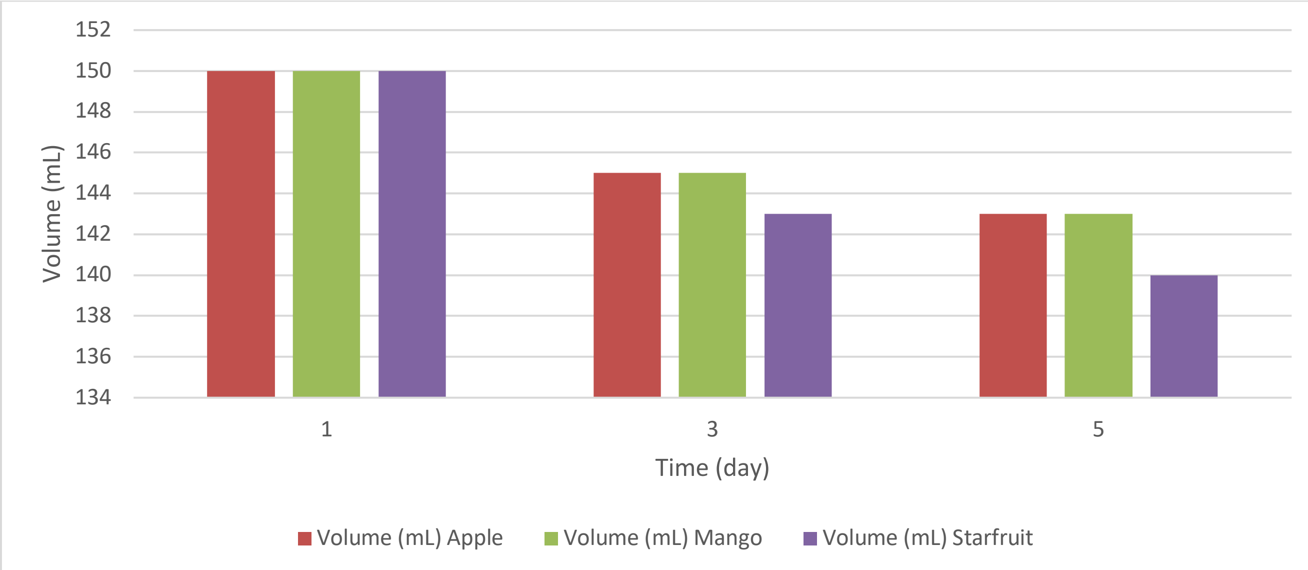

Figure 3. Fermentation Time on Volume

4. CONCLUSION

Based on the research results, it can be concluded that the fermented solution of apple, mango, and starfruit has the potential as a natural electrolyte in electrochemical cells. Fermentation for 5 days showed an increase in electrical voltage along with a decrease in pH and solution volume. Starfruit produced the highest electrical voltage of 0.9 Volts with a stable pH at 2, showing the best performance as an electrolyte compared to apples (0.8 Volts, pH 3) and mangoes (0.7 Volts, pH 3). This stated that high acidity levels (low pH) have a positive effect on increasing electrical voltage. The decrease in solution volume during fermentation is caused by evaporation and sediment formation. Overall, fermentation of fruits with high acid content can increase the conductivity and efficiency of electrochemical cells, so that it can be used as an environmentally friendly alternative in the development of renewable energy based on bio-electrochemistry.

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