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Utilization of Rotten Tomato Juice and Starfruit Juice with the Addition of Potassium Hydroxide in Biobattery Production

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ABSTRACT

Indonesia's dependence on fossil fuels underscores the need for the development of environmentally friendly alternative energy sources. This research examines the utilization of rotten tomato waste (*Solanum lycopersicum*) and starfruit (*Averrhoa bilimbi* L.) juice as natural electrolytes in the production of bio-batteries, with the addition of potassium hydroxide (KOH) to enhance their performance. Both materials contain organic acids such as citric acid and ascorbic acid, which support electrochemical reactions. The experimental variations included electrolyte solution volumes of 200–400 mL and KOH concentrations of 0.1 M, 1.0 M, and 2.0 M. The parameters tested included pH, conductivity, voltage, current, power, capacity, and the duration of the LED light, as specified in SNI IEC 60086-1:2015. The results show that for rotten tomato extract, the optimal combination of 350 mL with 2.0 M KOH yields the highest conductivity of 15.37 mS/cm and a capacity of 2.87 mAh. For starfruit juice, the optimal combination of 200–250 mL with 1.0 M KOH provides the highest capacity. The addition of KOH generally increases conductivity and power output; however, high concentrations (2.0 M) in starfruit extract reduce efficiency due to over-ionisation. This research proves that rotten tomato waste and starfruit juice with the addition of KOH have the potential to be efficient, inexpensive, and environmentally friendly bio-battery raw materials and support the utilization of organic waste as a renewable energy source.

Contribution to Sustainable Development Goals (SDGs):

SDG 7: Affordable and Clean Energy

SDG 13: Climate Action

1. INTRODUCTION

1.1. Research Background

Energy is a fundamental human need that supports various activities, including household use, industry, and transportation. In the modern era, energy dependence continues to increase with technological advancements and population growth. Most energy still comes from fossil fuels, such as petroleum, coal, and natural gas, whose reserves are dwindling. Therefore, a shift toward renewable energy is necessary to reduce dependence on limited fossil fuel resources [1].

One innovation in renewable energy is the bio-battery, which uses organic materials as an energy source thru electrochemical reactions. Unlike conventional batteries that contain heavy metals and hazardous chemicals, bio-batteries are safer, more economical, and environmentally friendly [2]. Bio-batteries utilise natural electrolyte compounds derived from organic waste, including agricultural waste and food scraps, to generate electricity. Bio-batteries utilise natural electrolyte compounds derived from organic waste, including agricultural waste and food scraps, to generate electricity.

Rotten tomatoes (*Solanum lycopersicum*) are one of the organic wastes with high potential as a bio-battery material. Tomatoes contain citric acid and ascorbic acid compounds that



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can support electrochemical reactions. Based on data from Statistics Indonesia (BPS, 2024), tomato production in Indonesia in 2023 reached 1.14 million to; however, approximately 80% of that amount was lost due to spoilage caused by suboptimal post-harvest handling. This waste, if not utilized, can pollute the environment. Therefore, its utilization as a bio-battery material is an appropriate solution.

Besides tomatoes, bilimbi (*Averrhoa bilimbi* L.) also has great potential as a natural electrolyte. This fruit contains citric acid, formic acid, and minerals such as potassium, calcium, and magnesium, which play a crucial role in enhancing ion mobility and solution conductivity. The high acidity (pH 1.0–3.0) of starfruit extract facilitates the effective release of H^+ ions, thereby supporting electrochemical reactions. In a galvanic cell system, the electrolyte, whether in the form of an acid or base solution or a salt, plays a role in conducting electricity between the anode and cathode. Starfruit itself contains formic acid, which can function as an electrolyte [4].

In a bio-battery system, Potassium Hydroxide (KOH) plays a crucial role as a strong electrolyte, increasing the conductivity of the solution and facilitating ion movement to produce a more optimal electrical current. Previous research by Pawarangan et al. [5] showed that variations in KOH concentration affect voltage and current stability. Abidin et al. [6] also reported that the combination of coconut husk and rotten tomatoes produced power up to 1.56 mW.

This research aims to develop bio-batteries based on rotten tomato extract and starfruit juice, supplemented with KOH, and to evaluate the effect of variations in electrolyte volume and KOH concentration on the electrical characteristics of the bio-batteries. The utilization of these two types of organic waste is expected to be an alternative solution for cheap, efficient, and environmentally friendly energy, while also reducing pollution from agricultural waste.

1.2. Literature Review

The utilization of organic waste as a natural electrolyte source holds great potential for the development of bio-battery technology. Waste utilization can be transformed into high-value materials to improve energy storage performance while reducing environmental pollution. For example, fly ash, rich in silicon dioxide, can be processed into high-value materials such as silicon anodes for lithium-ion batteries, which can enhance energy storage performance while utilizing industrial waste as a valuable product for anode/electrolyte materials [7]. The utilisation of industrial waste, such as coal combustion fly ash, as a silicon source can provide dual benefits: increased anode capacity and reduced waste that could potentially pollute the environment [8]. Processing waste into battery active materials offers a dual benefit: improved system performance and a reduction in waste that could potentially pollute the environment. Upcycling waste into functional materials (such as silicon nanoparticles) can be an environmentally friendly solution while also supporting the development of energy storage technology [9].

In a bio-dispersed system, the conductivity of the electrolyte solution can be increased by selecting and adding strong electrolytes, which accelerates ion movement and lowers the cell's internal resistance [7], [9]. This increase in conductivity can also be achieved by optimizing the solution composition and modifying the morphology of the active material [8]. This finding

is consistent with the results of this study, which regulate the concentration of KOH in rotten tomato juice and starfruit juice.

The electrochemical reactions in bio-batteries involve the basic redox reaction mechanisms found in batteries, where electrons move from the anode to the cathode through the external circuit, while ions migrate through the electrolyte solution to maintain charge balance [9].

1.2.1. Electrochemistry

Electrochemistry is a branch of chemistry that studies the relationship between redox reactions and electrical energy in systems involving electrodes and electrolyte solutions. These reactions involve the transfer of electrons from the anode (where oxidation occurs) to the cathode (where reduction occurs), generating an electric current. The potential difference between the two electrodes is referred to as the cell voltage, which serves as the primary driving force for electron flow [10].

Electrochemical cells, such as Voltaic or Galvanic cells, consist of two electrodes immersed in an electrolyte solution and connected by a salt bridge to maintain ionic balance. The spontaneous redox reaction in this cell is utilized to generate electrical energy [11]. This system typically employs metal electrodes and strong electrolytes, such as KOH, which can enhance electrical conductivity in media like rotten tomato juice.

1.2.2. Electrode

An electrode is a conductor that connects an electronic system to an electrolyte medium, allowing redox reactions to occur in an electrochemical cell. There are two types of electrodes: the anode (where oxidation takes place) and the cathode (where reduction takes place), which play a role in electron exchange and the formation of electric current [2].

In a voltaic cell system, the electrodes are dipped into an electrolyte solution and connected via a salt bridge. Copper (Cu) and aluminium (Al) are commonly used as electrodes due to their excellent conductive properties. Copper has high electrical conductivity, while aluminum is lighter and more corrosion-resistant, although its conductivity is lower [12].

The standard electrode potential (E°) indicates an electrode's tendency to undergo reduction. A positive E° indicates a high tendency for reduction (oxidizer), while a negative E° indicates a tendency for oxidation (reducer). In the Al-Cu system, electrons flow from aluminum ($E^\circ = -1.66$ V) to copper ($E^\circ = +0.34$ V), resulting in a cell potential of 2.00 V, indicating a spontaneous reaction [11].

1.2.3. Bio Battery

Bio batteries are a renewable energy technology that uses natural materials, such as fruit and vegetable waste, to generate electricity. This system consists of electrodes and an electrolyte solution that works through a chemical (redox) reaction, where electrons flow from the anode to the cathode, thus forming an electric current [12].

Electrolytes are very important because they conduct ions. According to Arrhenius' theory, an electrolyte is a substance that can dissolve in a liquid and form ions, thus conducting electricity. Electrolytes are divided into two types: strong electrolytes, such as HCl, NaOH, and NaCl, which dissolve completely and conduct electricity well. And weak electrolytes, such as vinegar

(CH₃COOH) and ammonia (NH₃), which only partially dissolve into ions, resulting in low conductivity [13].

The advantages of biobatteries are that they are environmentally friendly because they do not contain toxic materials like conventional batteries. In addition, biobatteries also help reduce organic waste [14].

Although there are no specific regulations for biobatteries in Indonesia yet, general guidelines can refer to the International Standard SNI IEC 60086-1:2015, which regulates the size, voltage, performance, safety, and chemical classification of primary batteries.

1.2.4. Tomato (*Solanum lycopersicum* L.)

The tomato (*Solanum lycopersicum* L.) is a plant belonging to the Solanaceae family, originating in Central and South America. This plant grows optimally in fertile, well-drained soil and requires sufficient sunlight. Tomatoes contain active compounds such as lycopene, beta-carotene, vitamins A and C, and organic acids like citric and ascorbic acid, which play an important role in electrochemical activity [16].



Fig. 1. Rotten Tomatoes

Rotten tomato waste contains natural electrolytes and can potentially be used as a base material for biobatteries. According to Abidin et al. [6], rotten tomato extract can generate a voltage of up to 1.27 V and a current of 0.76 mA. The addition of Potassium Hydroxide (KOH) solution is known to increase electrical power, making a bio-battery from tomato waste an environmentally friendly energy alternative.

1.2.5. Belimbing Wuluh (*Averrhoa bilimbi* L.)

Fruits and vegetables contain acidic minerals, such as hydrochloric acid and citric acid, which function as strong electrolytes and can ionize when dissolved in water [17]. Starfruit (*Averrhoa bilimbi* L.) is now gaining considerable attention in various scientific studies, particularly as a highly promising natural material for use in the development of environmentally friendly and sustainable bio-batteries. This tropical plant, known for its sour taste, is surprisingly rich in organic acid compounds, especially formic acid, which is a crucial component in electrochemical systems.

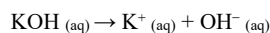


Fig. 2. Starfruit

Anjarsari et al. [15] studied the use of starfruit extract as an ion source in bio-batteries. The research results indicate that a bio-battery using pure starfruit extract can produce a maximum current of 0.84 mA and a voltage of 0.544 V at an optimal volume of 13 ml. The addition of 3 grams of NaCl increased the current to 2.17 mA, and the voltage reached 0.610 V, indicating that the addition of NaCl plays a role in increasing electrolyte conductivity.

1.2.6. Potassium Hydroxide (KOH)

Potassium hydroxide (KOH) is an inorganic compound in the form of a white solid that is strongly basic and easily soluble in water. In solution, KOH completely ionizes into K⁺ and OH⁻ ions, resulting in a solution with a high pH (≥12) [19]. Its ionization reaction is written as



KOH has hygroscopic and corrosive properties and produces an exothermic reaction when dissolved. According to the Arrhenius and Bronsted-Lowry theories, KOH is categorized as a base because it produces OH⁻ ions and can accept H⁺ from other substances.

In an electrochemical system, KOH is used as an electrolyte because it increases ionic conductivity and charge transfer efficiency. This compound is widely used in alkaline, nickel-cadmium, and bio batteries due to its chemical stability and compatibility with various types of electrodes.

1.3. Research Objective

This research aims to analyse the influence of varying volumes of rotten tomato juice and starfruit juice, as well as the concentration of Potassium Hydroxide (KOH) solution, on the pH, conductivity, and performance of the resulting bio-battery. Additionally, this research aims to evaluate the performance of bio-batteries based on the combination of these two variables in order to determine the efficiency of the electrical energy produced. Furthermore, this study assesses the potential and feasibility of bio-batteries based on rotten tomato waste and starfruit juice as environmentally friendly, economical, and sustainable alternative energy sources and examines the differences in the contribution of each material to the electrical parameters of the bio-battery.

2. MATERIALS AND METHODS

This research was conducted in April 2025 at the Chemical Engineering Laboratory, Sriwijaya State Polytechnic, Palembang. The main materials used in this study were rotten tomato juice (*Solanum lycopersicum*) and starfruit juice (*Averrhoa bilimbi* L.) that had been blended and filtered, as well as potassium hydroxide (KOH) solution with concentrations of 0.1 M, 1.0 M, and 2.0 M. The electrodes used were copper (Cu) as the cathode and aluminium (Al) as the anode. The equipment used includes a digital multimeter, conductivity meter, pH indicator paper, digital scale, measuring cylinders, stirring rods, containers (BioChamber), and LED lamps as a load.

The experimental design utilises variations in the volume of electrolyte solution for each material, specifically 200 ml, 250 ml, 300 ml, 350 ml, and 400 ml, each combined with a KOH solution at three different concentrations. Each volume and concentration

combination is tested to determine its effect on the characteristics and performance of the bio-battery.

The research procedure began with the preparation of a KOH solution at the desired concentration. Next, tomato juice and starfruit juice were mixed separately with the KOH solution according to the predetermined variations and then placed in the BioChamber. The Cu and Al electrodes were then placed in the solution and connected to the measurement circuit.

Testing was conducted to measure the pH value, conductivity, voltage, current, power, and capacity of the bio-battery. The testing also included performance tests on LED light as an indicator of the bio-battery's suitability as an energy source. All testing was conducted in accordance with SNI IEC 60086-1:2015 standards for primary batteries, specifically regarding voltage, durability, and power output performance.

3. RESULT AND DISCUSSION

3.1. *The Effect of Variations in the Volume of Rotten Tomato and Starfruit Extract with the Addition of KOH on the Characteristics of Biobatteries Before the LED Load is Applied*

Acidity (pH) and conductivity are two key parameters that influence the efficiency of electrochemical reactions in biobattery systems. The pH value varies depending on the volume of the solution and the concentration of KOH used, which determines the solution's acidity or basicity. Meanwhile, the conductivity of the solution is also influenced by both of these factors. The higher the concentration of KOH and the volume of rotten tomato and starfruit extract, the higher the conductivity generally increases because the availability of ions in the solution also increases.

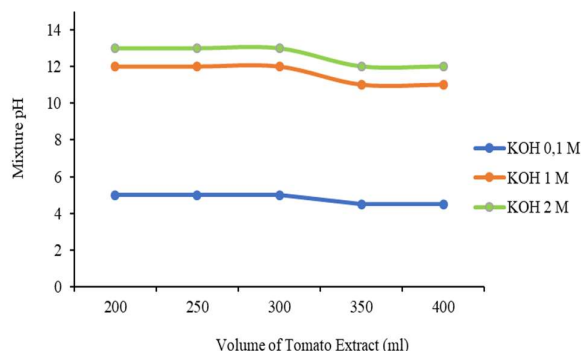


Fig. 3 The Effect of Rotten Tomato Extract Variation and KOH Concentration on the Acidity of a Biobattery Before LED Load is Applied

Figure 3 shows that at a KOH concentration of 0.1 M, the pH of the mixture ranges from 4.5 to 5, indicating a weak acid property because the neutralising ability of KOH toward tomato juice is still limited. Although the volume of tomato increases, the pH changes only slightly. Conversely, at KOH concentrations of 1 M and 2 M, the pH increases to 11–13, indicating a strongly basic solution. Adding tomato volume slightly lowers the pH, but not significantly at high KOH concentrations. This result is consistent with Welly et al. [2] who found that the higher the concentration of KOH, the more alkaline the solution. Increasing the volume of tomato tends to lower the pH to a limited extent. The interaction between the two determines the initial acidity condition of the biobattery.

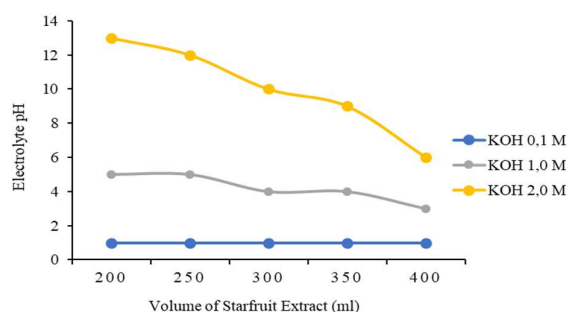


Fig. 4 The Effect of Starfruit Extract Variation and KOH Concentration on the Acidity of a Biobattery Before LED Load is Applied

Figure 4 shows that at a KOH concentration of 0.1 M, the pH of the mixture ranges from 1 to 1.5, indicating strong acidic properties derived from the starfruit extract. This low pH is caused by the dominant content of organic acids, such as citric acid and formic acid, while the amount of KOH is insufficient to neutralise the solution. At a KOH concentration of 1.0 M, the pH increases to a range of 3–5, indicating partial neutralisation by OH^- ions; however, the solution remains acidic due to the dominance of H^+ ions from organic acids. The increase in the volume of starfruit juice at this concentration tends to gradually lower the pH due to the increasing amount of reacting acid. Meanwhile, at a KOH concentration of 2.0 M, the pH range is 6–13, indicating a basic solution. The increase in the volume of starfruit juice at this high concentration causes a significant decrease in pH, from approximately 13 at 200 ml to 6 at 400 ml, due to the increasing ratio of acid to base.

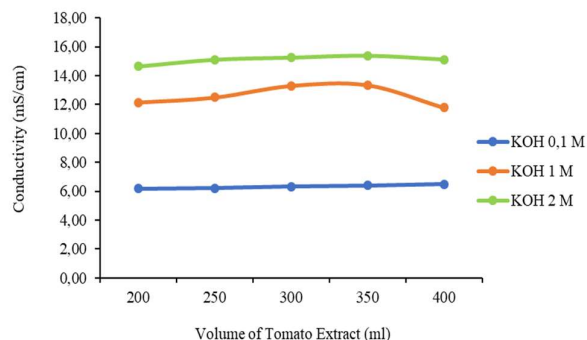


Fig. 5 The Effect of Rotten Tomato Extract Volume Variation and KOH Concentration on Biobattery Conductivity Before LED Load is Applied

Figure 5, it can be seen that increasing the concentration of KOH significantly increases the conductivity of the solution. At 0.1 M, the conductivity ranged from 6.17 to 6.49 mS/cm, while at 1 M, it increased sharply to 12.15–13.34 mS/cm. The highest concentration, 2 M, yielded the highest conductivity, ranging from 14.64 to 15.37 mS/cm. This aligns with the findings of Pawarangan et al. [5], that the higher the concentration of KOH, the more OH^- ions are available, making it easier for electricity to flow.

Besides concentration, the volume of tomato juice also affects conductivity. Generally, increasing the volume from 200 mL to 350 mL promotes an increase in conductivity due to the increased number of active ions in the solution [14]. However, at a volume of 400 mL and 1 M KOH, there was a slight decrease in conductivity due to the dilution effect of the solution. Conversely,

at 2 M KOH, the conductivity remained high and stable, indicating that the system had reached maximum efficiency in conducting electricity.

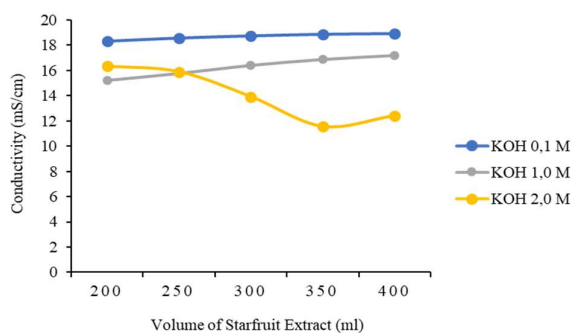


Fig. 6 The Effect of Starfruit Extract Volume Variation and KOH Concentration on Biobattery Conductivity Before LED Load is Applied

Figure 6 shows the results of conductivity measurements, indicating an increase in conductivity as the volume of starfruit extract increases at concentrations of 0.1 M and 1 M. This increase suggests that starfruit extract contains dissolved ions capable of increasing the number of charge carriers in the solution. Conversely, at a concentration of 2 M, conductivity tends to decrease with increasing extract volume, likely due to a dilution effect that reduces the number of effective OH^- ions in the solution. This indicates that although KOH increases electrical conductivity, excessive concentrations can disrupt the stability of the ionic system in bio-batteries.

3.2. The Effect of Variations in the Volume of Rotten Tomato Sap and Starfruit Extract with the Addition of KOH on Biobattery Performance Before the LED Load is Applied

Variations in the volume of tomato extract and KOH concentration significantly affect the voltage, current, and power of the biobattery before loading. Voltage and current increase as volume and concentration increase. Power, as the product of voltage and current, reflects the overall performance of the system, indicating that both parameters work synergistically to improve the efficiency of the biobattery [20].

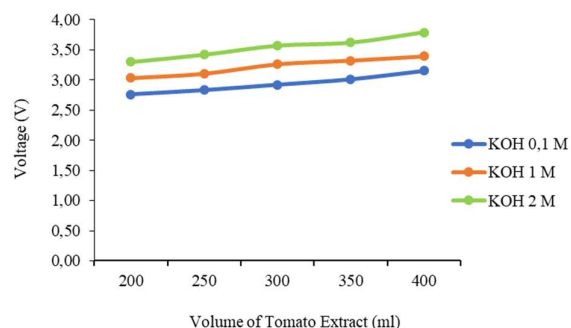


Fig. 7 The Effect of Rotten Tomato Extract Volume Variation and KOH Concentration on Biobattery Voltage Before LED Load is Applied

Figure 7, increasing the volume of tomato juice from 200 mL to 400 mL tends to increase the biobattery voltage at all KOH concentrations. This is due to the natural electrolyte content in tomatoes, such as organic acids and minerals, which supports ion movement in the solution. Additionally, as the KOH

concentration increases from 0.1 M to 2 M, the voltage also increases significantly. KOH, being a strong base, increases the concentration of OH^- ions in the solution, thereby accelerating the redox reaction at the electrodes and reducing the internal resistance of the system. The higher the concentration of a strong base, such as KOH, the higher the voltage and electrical power generated, as long as these conditions remain within the stability range of the biobattery system. This research aligns with the study conducted by Pawarangan et al. [5]. The highest voltage was achieved with a tomato volume combination of 400 ml and 2 M KOH, which was approximately 3.8 V. The results of this study are also supported by Welly et al. [2], which indicates that the use of a strong alkaline solution can effectively improve the efficiency of electrochemical reactions in biobattery systems.

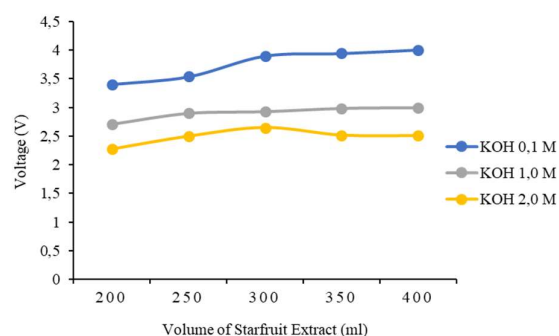


Fig. 8 The Effect of Starfruit Extract Volume Variation and KOH Concentration on Biobattery Voltage Before LED Load is Applied

Figure 8 shows that increasing the volume of starfruit juice from 200 mL to 400 mL tends to increase the bio-battery voltage at all KOH concentrations, although the increase is not very significant. The content of organic acids and minerals in starfruit, such as citric acid, formic acid, potassium, and magnesium, supports the movement of ions within the solution, thereby improving the charge transfer process [21]. At 0.1 M KOH, the highest voltage was achieved at a volume of 400 mL with a value of approximately 4.0 V, indicating that the strong acid properties of this solution are capable of producing a large potential difference between the Cu and Al electrodes. Meanwhile, at 1.0 M KOH, the voltage ranged from 2.7 to 3.0 V, and at 2.0 M KOH, it tended to be lower, around 2.3 to 2.5 V. The lower voltage at 2.0 M KOH may be due to over-ionization, which increases side reactions and reduces the potential difference between the electrodes.

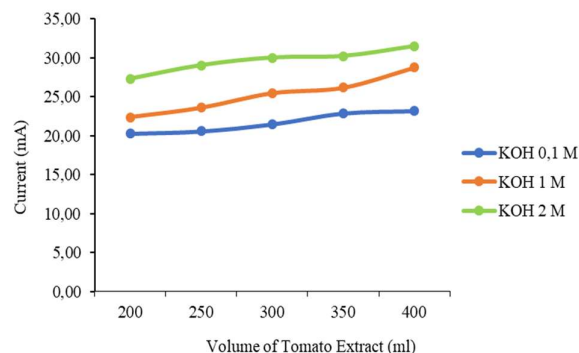


Fig. 9 The Effect of Rotten Tomato Extract Volume Variation and KOH Concentration on Biobattery Current Before LED Load is Applied

Figure 9 shows that increasing the volume of tomato juice from 200 mL to 400 mL increases the electric current at all KOH concentrations. This is because more natural electrolyte compounds, such as organic acids and mineral ions (K^+ , Mg^{2+} , Na^+), are available to conduct electricity. The larger the volume, the higher the ion mobility, and thus the current increases. However, if the volume is too large, efficiency can decrease due to increased internal resistance [18].

Increasing the KOH concentration from 0.1 M to 2 M also resulted in a higher current. A concentration of 2 M produced the highest current, reaching approximately 32 mA. KOH, being a strong electrolyte, accelerates the redox reaction and lowers the system's resistance, thus facilitating the flow of current in the biobattery.

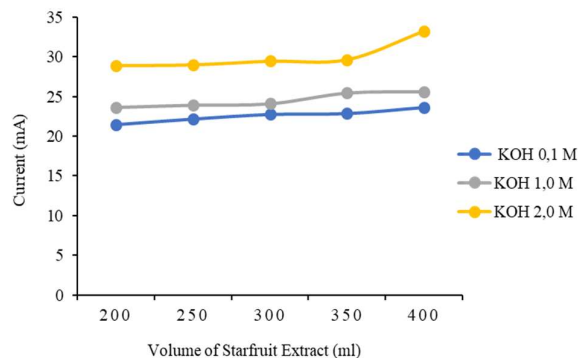


Fig. 10 The Effect of Starfruit Extract Volume Variation and KOH Concentration on Biobattery Current Before LED Load is Applied

Figure 10 shows that increasing the volume of starfruit juice from 200 mL to 400 mL generally increases the electrical current generated at all KOH concentrations. This increase is influenced by the increasing amount of natural electrolyte compounds contained in starfruit, such as citric acid, formic acid, and mineral ions (K^+ , Mg^{2+} , Na^+) that play a role in conducting electrical charge. The larger the volume of the solution, the higher the number of ions available to move toward the electrodes, thus increasing ion mobility and resulting in a greater current. This phenomenon suggests that the availability of natural electrolytes is a crucial factor in supporting electrochemical processes in biobatteries.

Beside the effect of volume, increasing the concentration of KOH from 0.1 M to 2.0 M was also shown to increase the electric current. KOH, as a strong electrolyte, plays a role in increasing the number of OH^- ions in the solution, thus accelerating the redox reaction at the electrodes and reducing the system's internal resistance. As a result, the highest current is achieved at a concentration of 2.0 M, with a value of approximately 33 mA. However, under certain conditions, excessively high KOH concentrations have the potential to trigger side reactions that can reduce system efficiency. This finding aligns with the research by Pomalingo et al. [18], which states that adding the correct amount of strong base can increase the conductivity and electrical current in bio-battery systems.

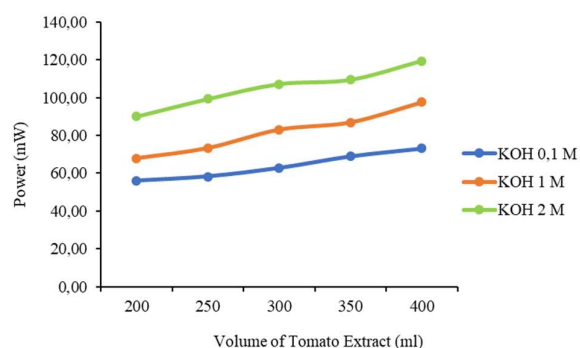


Fig. 11 The Effect of Rotten Tomato Extract Volume Variation and KOH Concentration on Biobattery Power Before LED Load is Applied

Figure 11 shows that consistently increasing the volume of tomato juice from 200 mL to 400 mL consistently improves the electrical power of the biobattery, regardless of the KOH concentration. This indicates that the more electrolyte used, the more ions are involved in the electrochemical reaction, making charge transfer more efficient and increasing the power generated [20].

Beside volume, the concentration of KOH also significantly affects the power. A concentration of 2 M produces the highest power, over 120 mW, while 0.1 M yields the lowest power. This proves that the electrolyte strength, whether from the amount of tomato extract or the concentration of KOH, is crucial for the effectiveness of the biobattery system. These results are consistent with the research by Welly et al. [2], which confirms that increasing the solution strength can improve the efficiency and energy output of biobatteries.

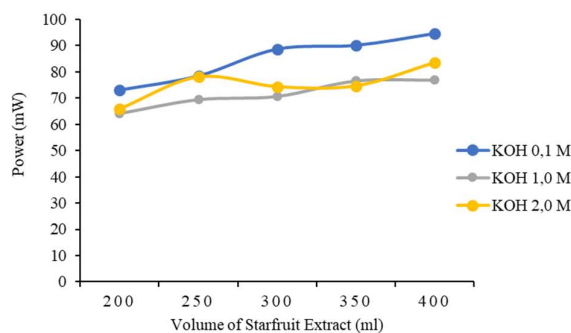


Fig. 12 The Effect of Starfruit Extract Volume Variation and KOH Concentration on Biobattery Power Before LED Load is Applied

Figure 12 shows that increasing the volume of starfruit juice from 200 mL to 400 mL generally improves the electrical power of the bio-battery at all KOH concentrations. The larger the volume of electrolyte solution, the more ions are available to participate in the electrochemical reaction, resulting in a more efficient charge transfer process and increased power output. The organic acid and mineral content in starfruit plays an important role in increasing ion mobility, so the combination of a larger volume with natural electrolyte supports the performance of the bio-battery system.

Beside volume, the concentration of KOH also affects the output power. At a KOH concentration of 0.1 M, the highest power reached approximately 95 mW at a volume of 400 mL. In contrast, at concentrations of 1.0 M and 2.0 M, the power

generated was slightly lower. This indicates that an excessively high concentration of base in starfruit can trigger side reactions that reduce system efficiency. This result is consistent with Siregar [19] research, which states that selecting the appropriate solution concentration significantly impacts the effectiveness and efficiency of bio-battery output power.

3.3. The Effect of Variations in the Volume of Rotten Tomato Extract and Starfruit Extract with the Addition of KOH on Biobattery Performance After Being Given a White LED Load

The performance of the biobattery after being loaded with an LED is measured through the main parameter, which is capacity. After loading, the voltage experienced a slight decrease compared to the unloaded condition, but remained stable at high combinations of tomato juice volume and KOH concentration. The current increases with increasing volume and concentration, indicating better charge transfer efficiency. The increase in current and voltage directly contributes to the generated power, with the highest combination of parameters providing maximum power output. Additionally, the biobattery's capacity increased, indicating its ability to supply energy for longer and more consistently when used to power loads such as LEDs.

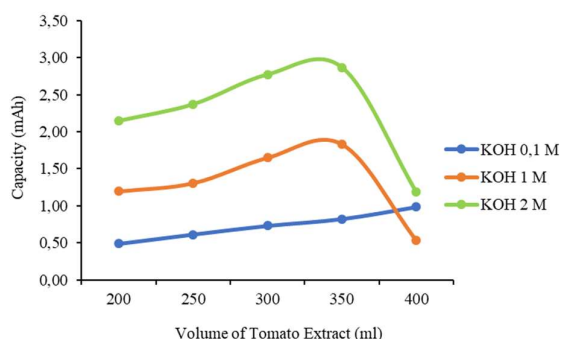


Fig. 13 The Effect of Rotten Tomato Extract Volume Variation and KOH Concentration on Biobattery Capacity After Being Loaded with a White LED

Increasing the volume of tomato juice from 200 mL to 350 mL generally increases the biobattery capacity across all KOH concentration variations. This is because more natural electrolytes in the rotten tomatoes participate in the electrochemical reaction, allowing chemical energy to be converted into electrical energy more efficiently [23]. At 0.1 M KOH, the capacity increased from 0.49 mAh to 0.98 mAh, but this is still considered low due to limited ion mobility [2].

At a concentration of 1 M, the capacity increased from 1.20 mAh to 1.85 mAh as the volume was increased to 350 mL, but then sharply decreased to 0.53 mAh at a volume of 400 mL. This decline is believed to be due to an imbalance between KOH ions and organic compounds in tomatoes, which triggers the formation of salt deposits on the electrodes [24]. A KOH concentration of 2 M yielded the highest capacity, 2.87 mAh at a volume of 350 mL, because the ions in the solution move more freely and accelerate the redox reaction. However, at a volume of 400 mL, the capacity decreased to 1.18 mAh due to the dilution of the solution and the formation of small bubbles around the electrode, which hindered the flow of electricity.

The capacity of this bio-battery is directly proportional to the duration the LED remains lit. The highest capacity (2.87 mAh) can power the LED for 8 minutes and 51 seconds, while the lowest capacity (0.49 mAh) only lasts for 2 minutes and 55 seconds. This shows that the larger the capacity, the longer energy can be supplied to the load stably [2].

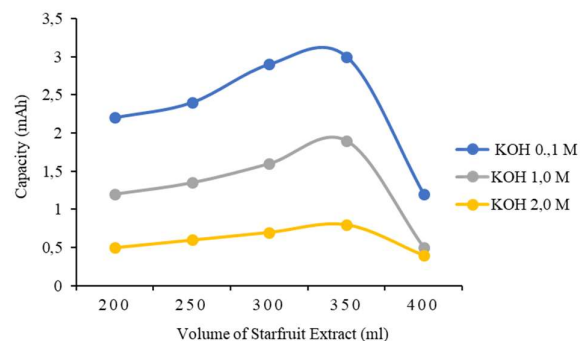


Fig. 14 The Effect of Starfruit Extract Volume Variation and KOH Concentration on Biobattery Capacity After Being Loaded with White LED

Increasing the volume of starfruit juice from 200 mL to 350 mL generally increases the capacity of the biobattery across all KOH concentration variations. This is because the increased amount of natural electrolytes in the starfruit juice participates in the electrochemical reaction, resulting in more optimal conversion of chemical energy into electrical energy. At 0.1 M KOH, the capacity significantly increased from 2.21 mAh to 3.00 mAh, indicating that at this low concentration, ion mobility is quite stable, allowing the redox reaction to occur efficiently.

A 1 M KOH concentration resulted in lower capacity compared to 0.1 M, decreasing from 1.20 mAh at a volume of 200 mL to 1.92 mAh at a volume of 350 mL, before drastically dropping to 0.53 mAh at a volume of 400 mL. This decrease is believed to be caused by an imbalance between KOH ions and organic compounds in the starfruit extract, which triggers the formation of deposits on the electrodes and inhibits ion transfer.

At 2 M KOH, the capacity is at its lowest range (0.50–0.84 mAh) and experiences a sharp decline at a volume of 400 mL. High concentrations like this tend to increase the viscosity of the solution, thereby slowing down ion diffusion and reducing the rate of electrochemical reactions [2].

The capacity of this bio-battery is directly proportional to the duration the LED stays lit. The highest capacity (3.00 mAh at 0.1 M and 350 mL) is able to keep the LED lit longer than the lowest capacity (0.37 mAh at 2 M and 400 mL). This reinforces the finding that the larger the battery capacity, the longer the energy supply can be maintained for loads such as LEDs.

4. CONCLUSION

This research shows that variations in the volume of natural electrolytes, such as rotten tomato juice and starfruit juice, as well as differences in the concentration of KOH solution, have a significant impact on the pH, conductivity, and performance of the biobattery. The combination of 350 mL of 2 M KOH with rotten tomato juice resulted in a pH change from acidic to basic, optimal conductivity of 15.37 mS/cm, and the highest voltage, current, and power before loading, with a capacity of 2.87 mAh that was able to light an LED for 8 minutes and 51 seconds.

Meanwhile, with starfruit juice, the combination of 350 mL with 0.1 M KOH provided the highest capacity of 3.00 mAh and a longer LED burn time. These results demonstrate that selecting the right electrolyte composition is crucial for maximising the efficiency of biobatteries, while also potentially serving as an environmentally friendly solution for utilising organic waste as an alternative energy source.

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