



# An Analysis of The Bio-Battery Efficiency from Fruits and Vegetables' Waste as An Alternative to Energy Sources

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## Abstract:

Global warming and increasing air pollution have encouraged humans to continue to develop various environmentally friendly energies. One solution that was taken was the development of bio-batteries, an energy storage system using microorganisms as an energy source. Bio-batteries promised environmentally friendly energy because they utilized organic waste. In this research, a bio-battery was designed using electrolyte paste from several fruit and vegetable wastes, including oranges, mangoes, bananas, papaya, tomatoes, and star fruit. These fruits and vegetables were previously mashed and added with electrolyte liquid and then put into used batteries that had been cleaned from the manganese oxide, which was the content of the battery. A comparison was also carried out with conventional batteries to determine the efficiency level of these bio-batteries for fruit and vegetable waste. This research shows that fruit and vegetable waste was less efficient when used as a substitute for manganese oxide or electrolyte in unused batteries. Compared to conventional batteries, the highest efficiency value for bio-batteries only reached 32.47% for tomato waste bio-batteries, and the lowest efficiency value was 4.77% for banana waste bio-batteries.

## Keywords:

Bio-Batteries, Eco-Friendly Energy, Current, Voltage, Organic Waste

## 1. Introduction

Increasing air pollution has encouraged humans to continue to develop various environmentally friendly energies. One environmentally friendly energy source that can be used is bio-batteries, an energy storage system that uses microorganisms. Bio-batteries promise energy that is friendly to the environment because it uses organic waste as a manufacturing material which can minimize humanity's dependence on fossil fuels. Organic waste that can be used for bio-batteries can include rotting fruit or vegetables. This waste can usually be found easily in vegetable and fruit markets. Waste results from human activities and natural processes that are no longer usable, so the material is wasted or deliberately thrown away. Waste is material that has no economic value and waste can have negative impacts if it cannot be handled properly.

Fruits contain various substances such as ascorbic acid, citric acid, and NADH (a chemical that can create cell energy), which will act as an electrolyte. Likewise, vegetables have acids, bases, and water.

When fruit or vegetables rot, a chemical process is created which is usually called fermentation. When the fermentation process occurs, the levels of acid contained in fruit and vegetables will increase, causing the electrolytes contained in fruit and vegetables to also increase. Thus, paste made from ripe or rotten fruit and vegetables will be more reactive to the electrode, resulting in a higher voltage compared to fresh fruit and vegetable paste. Based on these electrical properties, fruit, and vegetable waste can be used to create a renewable energy source called bio-battery. This bio-battery is very useful for human life because the use of batteries is very important for humans [1].

The basic principle of a bio-battery was the transfer of electrons between two electrodes separated by an electrolyte, which could also create an electrical force called voltage and current [2]. An electrolyte was a substance that could conduct electricity in solution. There were two substances produced in an electrolyte solution, namely ionic compound solutes and non-ionic compounds. This substance would produce ions when dissolved in water. In electrolyte conductors, electrons would move and also produce ions such as acids, bases, or salts [3][4]. Based on the way batteries work and the substances contained in fruit and vegetables, this organic waste could be used to replace the electrolyte solution in batteries. Therefore, research was carried out titled "Analysis of Bio-Battery Efficiency from Fruit and Vegetable Waste as an Alternative Energy Source." In this research, bio-batteries were filled using electrolyte paste made from various types of fruit and vegetable waste, including oranges, mangoes, bananas, papaya, tomatoes, and star fruit. These fruits and vegetables were mashed and added with electrolyte liquid, then placed into used batteries that had been cleaned of the manganese oxide, which was the content of the battery.

## **2. Materials and Methods**

### **2.1 Efficiency**

Efficiency refers to how well or how effectively a system, process, or device uses resources to achieve goals or produce desired output [5]. Efficiency is a very important concept in many fields, including technology, economics, and environmental science.

### **2.2 Electrochemistry**

The science that studies the relationship between chemical processes and electric currents is known as electrochemistry. When electrons are released at one electrode (oxidation) and received at another electrode (reduction), the electrochemical cell produces electrical energy. Anode refers to the electrode that releases electrons, and cathode refers to the electrode that receives electrons. Therefore, an electrochemical cell always has two electrodes: an anode and a cathode, where each half of the oxidation reaction occurs. These half-reactions are separated to allow utilization of the electric current (electrons) produced [6].

### **2.3 Battery**

Batteries are electrochemical devices that store chemical energy and convert it into electrical energy as needed. A battery consists of one or more cells, each of which has an anode (negative electrode) and cathode (positive electrode) immersed in electrolyte. The chemical reactions that occur in a battery during operation produce a flow of electrons known as an electric current [7].

### **2.4 Electricity of Fruit and Vegetables**

A battery is an electrochemical cell that converts the chemical energy stored in it into electrical energy. Fruit that contains large amounts of citric acid can produce electrical energy. Because a solution containing acid is a good conductor of electrons, this will create an electric current that can

be used as a bio-battery. The principle of a bio-battery is a transportation process carried out by electrons between two electrodes and separated by an electrolyte so that it will produce power in the form of electric potential and current. The electrons on the electrolyte electrode will be carried by ions which then go through the electrolysis process [8]. As a result of the rotting process, fruit and vegetables will undergo a fermentation process, which produces more concentrated acids. As a result, juice from old or rotten fruit and vegetables will be more reactive to the electrode and produce a higher voltage.

The Open Circuit Potential (OCP) of fresh and aged fruits and vegetables can reflect their biochemical and electrochemical state. These values are influenced by factors such as their chemical composition, ripeness, water content, and the degradation of organic compounds during ageing [9]. Figure 1 shows OCP values for all fresh fruits and vegetables. The freshness of any fruit depends on its storage or preservation time which is known as aging time. In this study, it is observed that the fresh avocado has the lowest voltage difference compared to other fruits and vegetables [9].

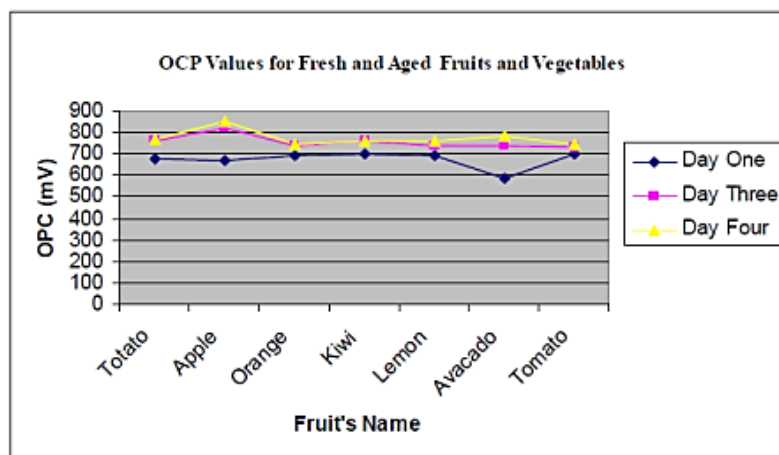


Figure 1: Long life compared to the voltage of fruits and vegetables

## 2.5 Block Diagram

The following block diagram outlines the key stages in the process, starting from the collection of fruit and vegetable waste to the generation of electrical energy in the form of current and voltage. By refining the waste and utilizing bio-battery technology, this method not only addresses waste management challenges but also promotes renewable energy production.

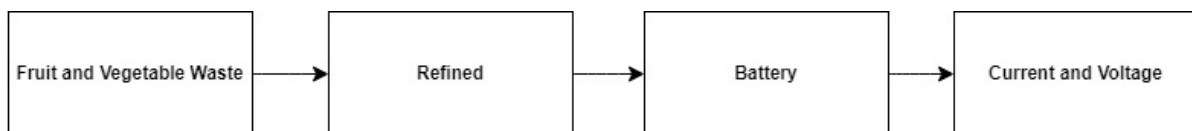


Figure 2: Research block diagram

Figure 2 explains the flow of this research as follows:

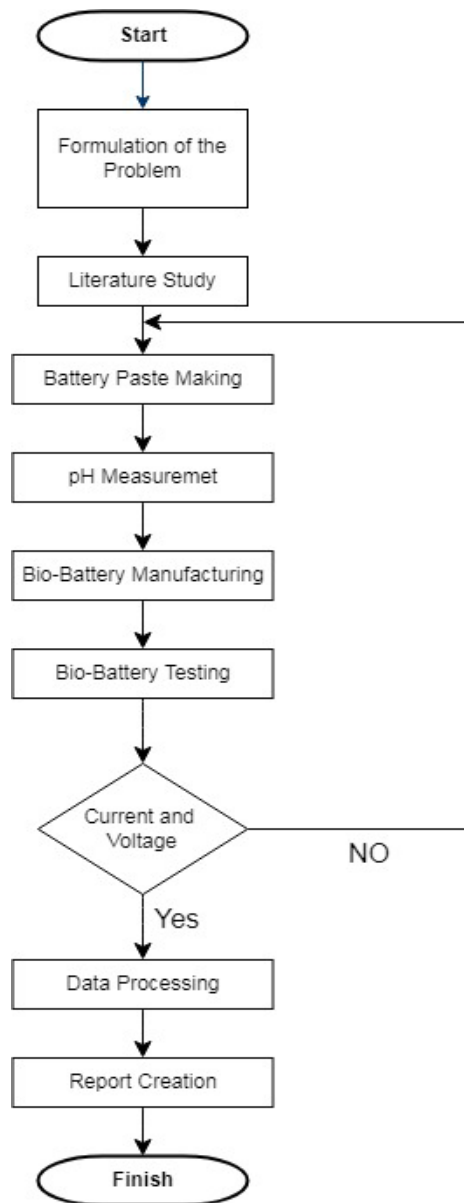
1. Fruit and vegetable waste is the main material for making bio-batteries
2. Processing fruit and vegetable waste
3. Replacing the battery with waste fruit and vegetables that have been consumed
4. Checking the current and voltage of the bio-battery, fruit and vegetable waste

## 2.6 Flowchart

The flowchart below outlines the step-by-step methodology for this study, beginning with problem formulation and literature review. It includes the preparation of battery paste, pH measurement, manufacturing and testing of the bio-battery, and evaluation of its electrical performance (current and voltage). Upon successful testing, the data is processed and analyzed to create a comprehensive report summarizing the findings and potential applications.

In Figure 3, the stages of this research can be explained from the beginning to the end which are divided into several stages, here are some of these stages:

1. **Start:** The process begins with identifying the objectives of the research and the development of bio-batteries using organic waste.
2. **Formulation of the Problem:** At this stage, the main problem is defined, such as how to efficiently utilize fruit and vegetable waste to generate electricity.
3. **Literature Study:** A literature review is conducted to gather information from previous studies related to bio-batteries, the materials used, and relevant manufacturing methods.
4. **Battery Paste Making:** The fruit and vegetable waste is processed into battery paste. This may involve crushing the waste, mixing it with supporting materials like electrolytes, and adjusting the consistency of the paste.
5. **pH Measurement:** The pH of the battery paste is measured to ensure that the chemical conditions are optimal for the electrochemical processes in the bio-battery.
6. **Bio-Battery Manufacturing:** The battery paste is further processed to form the bio-battery components. This includes applying the paste to electrodes and assembling the battery cell.
7. **Bio-Battery Testing:** The bio-battery is tested to measure its performance, including its ability to generate current and voltage.
8. **Current and Voltage Measurement:** The test results for current and voltage are evaluated. If the results are unsatisfactory (NO), adjustments are made in the previous steps, such as improving the paste formulation or manufacturing parameters.
9. **Data Processing:** If the test results are successful (YES), the data from the testing is processed to gain a deeper analysis of the bio-battery's performance.
10. **Report Creation:** The research findings and analysis are compiled into a report that includes methods, results, conclusions, and potential applications of the bio-battery.
11. **Finish:** The process concludes with the creation of the final report containing the results and insights from the research.

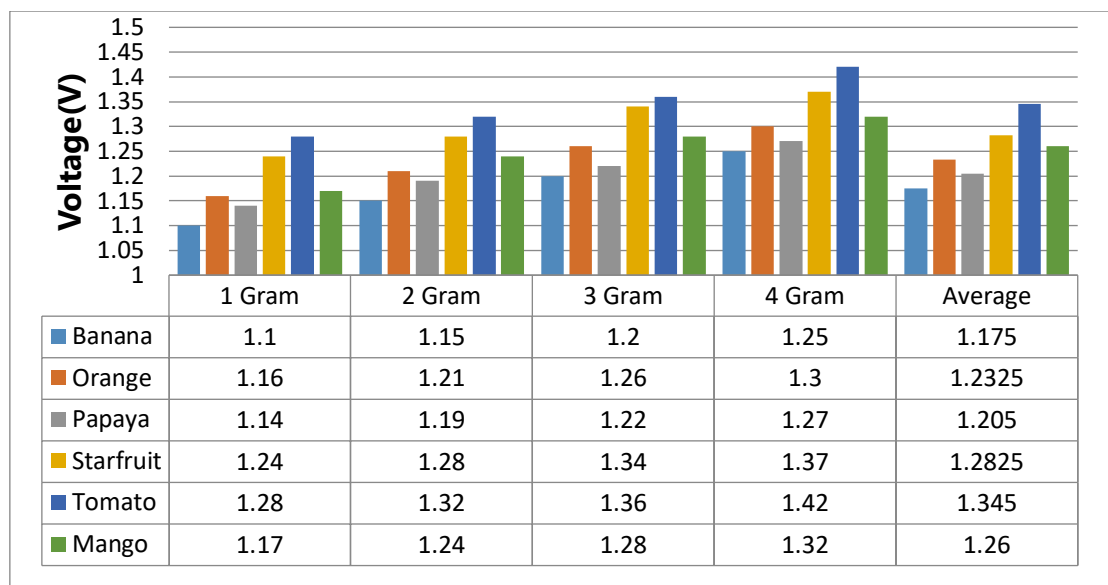


**Figure 3: Research flowchart**

### **3. Results and Discussion**

#### **3.1 Voltage Measurement**

Voltage measurement is a critical step in evaluating the performance of a bio-battery. It involves determining the electrical potential difference between the anode and cathode, which provides insights into the bio-battery's functionality and efficiency. The results of measuring the bio-battery voltage of fruit and vegetable waste are as in Figure 4.



**Figure 4: Graph of voltage measurement result from each bio-battery**

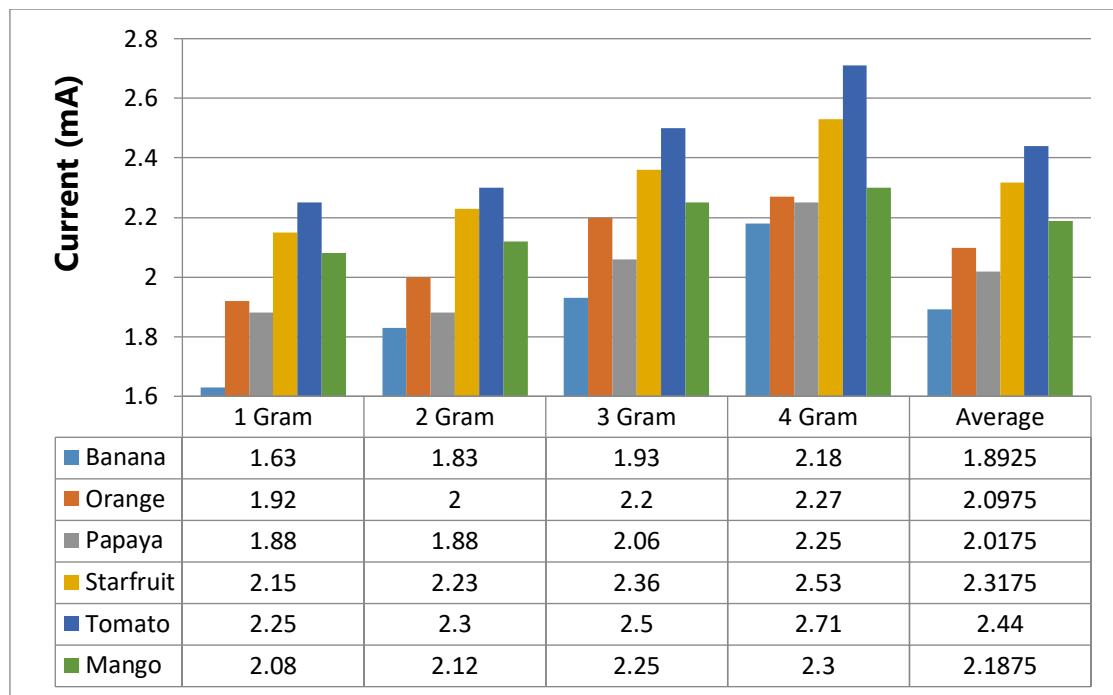
Based on Figure 4, among the six fruit waste types tested, tomato waste generates the highest average voltage of 1.345 V, making it the most effective material for bio-battery applications. Starfruit follows closely with an average voltage of 1.2825 V, while orange and mango exhibit moderately high averages of 1.2325 V and 1.26 V, respectively. Papaya (1.205 V) and banana (1.175 V) produce lower average voltages, making them the least efficient among the tested materials.

The superior performance of tomato and starfruit waste can likely be attributed to their higher concentrations of reactive organic compounds, which enhance the electrochemical reactions necessary for voltage generation. Orange and mango also perform reasonably well, suggesting they could serve as alternative options in bio-battery systems. Although banana and papaya produce lower voltages, they might still be useful in applications where other factors, such as cost-effectiveness, abundance, or ease of processing, are more critical.

Furthermore, the consistent increase in voltage as mass increases underscores the direct proportionality between the quantity of reactive material and bio-battery performance. This finding suggests that optimizing the mass of waste used in a bio-battery could be a key factor in maximizing energy output. Overall, the data provides valuable insight into the potential of different types of fruit waste for sustainable energy production, with tomato and starfruit waste emerging as the most promising candidates for high-performance bio-batteries.

### 3.2 Current Measurement

To measure the current output of bio-batteries, the experimental setup involves connecting the bio-battery terminals to a load resistor or directly to a multimeter set to measure current (in amperes). The procedure ensures that the current generated by the bio-battery under specific conditions is recorded accurately. Current measurements provide essential insights into the performance of the bio-battery, as they indicate how much charge is flowing through the circuit over time. The results of measuring the bio-battery voltage of fruit and vegetable waste are as in Figure 5.



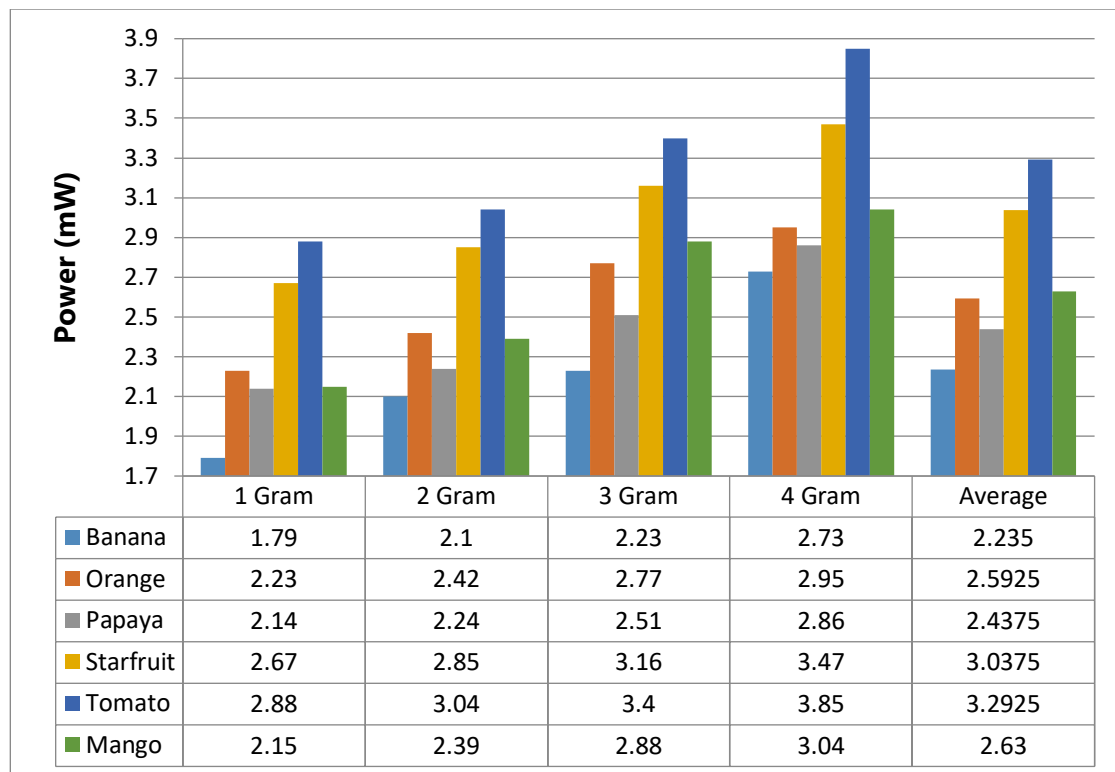
**Figure 5: Graph of current measurement result from each bio-battery**

Based on Figure 5, among the six fruit waste types tested, tomato waste generates the highest average current at 2.44 mA, followed by starfruit with an average of 2.3175 mA. These two fruits exhibit the highest electrochemical activity, likely due to a higher concentration of reactive compounds that enhance the flow of electrons in the battery. Orange and papaya produce moderate current values, with averages of 2.0975 mA and 2.0175 mA, respectively, making them reasonably effective for bio-battery applications. Mango also performs well with an average current of 2.1875 mA, while banana waste generates the lowest current, with an average of 1.8925 mA, indicating it is the least efficient among the tested materials.

The consistent increase in current with the mass of fruit waste reinforces the idea that larger quantities of reactive material lead to higher electrochemical activity. While tomato and starfruit are the most efficient in terms of current production, banana waste, despite its lower current output, could still be valuable for bio-battery systems where cost, availability, or simplicity are prioritized. Overall, these findings suggest that the type and amount of fruit waste used are crucial factors in determining the performance of bio-batteries, with tomato and starfruit emerging as the most promising candidates for applications requiring higher energy output.

### 3.3 Power Calculation

The power output of the bio-batteries was determined by combining the voltage and current values for each type of fruit waste at different masses. The results show that the power increases with the mass of the waste across all fruit types. This trend highlights the importance of the quantity of reactive material, as larger masses produce more significant electrochemical reactions, leading to higher energy output. After obtaining the voltage and current strength values for each bio-battery, power calculations can be carried out. The results of calculating the bio-battery power of fruit and vegetable waste are as in Figure 6.



**Figure 6: Graph of power calculation result from each bio-battery**

Based on Figure 6, the power output of the bio-batteries, measured in milliwatts (mW), demonstrates variations based on the type of fruit waste and its mass. The results confirm that the power increases as the mass of the waste increases, reflecting the relationship between the availability of reactive material and the electrochemical reaction's efficiency.

Among the tested fruit waste, tomato waste exhibited the highest average power output at 3.2925 mW, followed closely by starfruit with an average of 3.0375 mW. These two types of waste stand out as the most efficient for bio-battery energy production. Orange and mango waste generated moderate power outputs, with averages of 2.5925 mW and 2.63 mW, respectively. Papaya waste also performed reasonably well, with an average power of 2.4375 mW, while banana waste recorded the lowest average power output at 2.235 mW, indicating lower efficiency compared to the other materials.

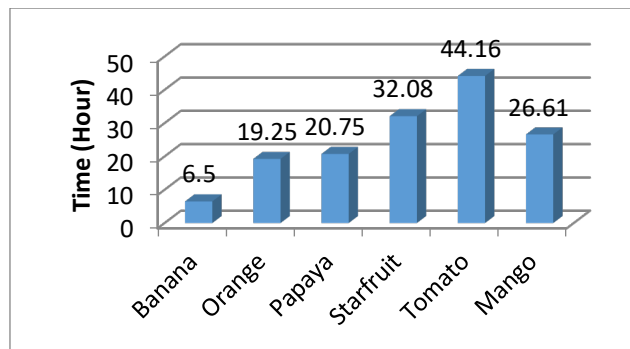
These findings highlight that tomato and starfruit waste are the most promising candidates for bio-battery applications, particularly in scenarios requiring higher energy output. On the other hand, banana waste, despite its lower performance, could still be used in situations where cost-effectiveness or waste availability is prioritized. Overall, the study underscores the potential of fruit waste as a sustainable and renewable source for energy generation, with significant variations in efficiency depending on the type of waste used.

### 3.4 Endurance Testing

This durability test aims to find out how long the fruit and vegetable waste bio-battery can be used for daily life. This test uses two bio-batteries from each waste that have the largest voltage and current strength, namely bio-batteries with a mass of 3 grams and 4 grams which have been added with electrolyte liquid. These bio-batteries are connected in series and used to power the LED lights until the LED turns off and the duration of ignition is recorded. The results of testing the resistance of various types of fruit and vegetable waste bio-batteries are as Table 1 and Figure 7.

**Table 1: Bio-battery endurance test result**

No.	Type of Waste	Endurance
1	Banana	6 hours 30 minutes
2	Orange	19 hours 15 minutes
3	Papaya	20 hours 45 minutes
4	Starfruit	32 hours 5 minutes
5	Tomato	44 hours 10 minutes
6	Mango	26 hours 55 minutes



**Figure 7: LED light duration graph of each bio-battery**

Based on Table 1 and Figure 7, the endurance of bio-batteries varies significantly based on the type of fruit waste used, with tomato and starfruit waste showing the longest durations of power supply. Tomato waste demonstrated the highest endurance, lasting for 44 hours and 10 minutes (44.16 hours), followed by starfruit waste, which maintained power for 32 hours and 5 minutes (32.08 hours). These results indicate that both tomato and starfruit are highly efficient for long-lasting energy applications.

Mango waste showed moderate endurance with a runtime of 26 hours and 55 minutes (26.91 hours), followed by papaya waste, which lasted for 20 hours and 45 minutes (20.75 hours). Orange waste performed similarly, with an endurance of 19 hours and 15 minutes (19.25 hours). Lastly, banana waste had the shortest duration, lasting only 6 hours and 30 minutes (6.5 hours), suggesting its limited capability for prolonged energy production.

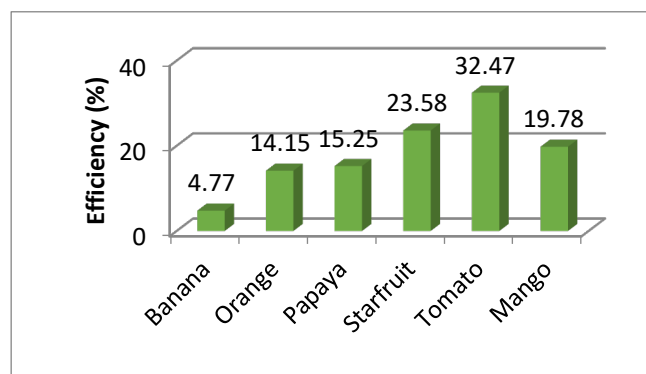
The endurance values highlight the potential of tomato and starfruit waste for applications requiring long-lasting bio-battery performance. In contrast, banana waste may be more suitable for short-term or low-energy applications. These variations reflect the differences in the electrochemical properties of the fruit waste, emphasizing the importance of selecting the appropriate type of waste based on the intended use of the bio-battery.

### 3.5 Efficiency Calculation

After obtaining the results from the voltage testing, the efficiency can be calculated by comparing it with the endurance of a conventional battery (136 hours). This efficiency calculation aims to find out how efficient bio-batteries from fruit and vegetable waste are for use in everyday life. Results of efficiency calculated based on the Equation 1.

$$\text{Bio-Battery Efficiency} = \frac{\text{Bio-battery life (hours)}}{\text{Conventional battery life (hours)}} \times 100\% \quad \text{Eq. 1}$$

- Banana Bio-Battery Efficiency =  $\frac{6.5}{136} \times 100\% = 4.77\%$
- Orange Bio-Battery Efficiency =  $\frac{19.25}{136} \times 100\% = 14.15\%$
- Papaya Bio-Battery Efficiency =  $\frac{20.75}{136} \times 100\% = 15.25\%$
- Starfruit Bio-Battery Efficiency =  $\frac{32.08}{136} \times 100\% = 23.58\%$
- Tomato Bio-Battery Efficiency =  $\frac{44.16}{136} \times 100\% = 32.47\%$
- Mango Bio-Battery Efficiency =  $\frac{26.91}{136} \times 100\% = 19.78\%$



**Figure 8: Efficiency graph on each bio-battery**

Figure 8 shows tomato bio-battery exhibited the highest efficiency, with 32.47%, making it the most effective option for energy generation among the tested materials. Starfruit waste followed with an efficiency of 23.58%, further demonstrating its potential for sustainable power production. Mango waste also showed a respectable efficiency of 19.78%, slightly ahead of papaya waste, which achieved an efficiency of 15.25%. Orange waste displayed a moderate efficiency of 14.15%, while banana waste, with an efficiency of only 4.77%, was the least effective in terms of endurance.

These efficiency values highlight the varying capabilities of fruit waste in bio-battery applications. Tomato and starfruit waste stand out as the most promising options for longer-lasting energy output, while banana waste may be less suitable for extended usage. The results also underscore the potential of bio-batteries as a renewable energy source, albeit with efficiency levels that are currently lower than conventional batteries. Further research and development could improve the performance of bio-batteries, making them more competitive with traditional energy sources.

#### 4. Conclusion

Based on the data obtained from the research and discussion in this study, the following conclusions were drawn; Fruit and vegetable waste which is used as a substitute for electrolytes in used batteries produces the highest efficiency value of 32.47% for tomato waste bio-batteries and the

lowest efficiency value is 4.77% for banana waste bio-batteries. Because the efficiency value of bio-batteries is less than 50%, it can be concluded that fruit and vegetable waste is not an efficient substitute for electrolytes in used batteries. There are differences in the voltage, current, and power values of each type of fruit and vegetable waste bio-battery. The average voltage value produced by bio-batteries from banana waste is 1.175 V, mango 1.26 V, papaya 1.205 V, orange 1.2325 V, star fruit 1.2825 V, and tomato 1.345 V. Average current strength value of the bio-battery produced from banana waste is 1.8925 mA, mango 1.9975 mA, papaya 1.8225 mA, orange 1.8975 mA, star fruit 2.145 mA, and tomato 2.25 mA. Meanwhile, the average power value produced by bio-batteries from banana waste is 2.235 mW, mango 2.63 mW, papaya 2.4375 mW, orange 2.5925 mW, star fruit 3.0375 mW, and tomato 3.2925 mW.

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