Journal of Sustainable Agriculture and Biosystems Engineering
Journal homepage: https://talenta.usu.ac.id/jsabe

Study of Fruit Waste as Bio-battery Materials for Alternative Electricity

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ARTICLE INFO

Article history:
Received 09 December 2023
Revised 07 February 2024
Accepted 29 February 2024

E-ISSN: 3026-4065

How to cite:
R. Sigalingging and Y. Sitorus, "Study of Fruit Waste as Bio-battery Materials for Alternative Electricity", Journal of Sustainable Agriculture and Biosystems Engineering, Vol. 02, No. 01, 2024.

ABSTRACT

Organic vegetable and fruit waste may be used for green energy. Electrolyte-rich fruits can be used to make pollution-free bio-batteries. This study measures fermentation temperature and environment, pH before and after fermentation, electrical voltage, current, power, resistance, and energy in starfruit (Averrhoa carambola), mango (Mangifera indica), and strawberry (Fragaria) waste for 8, 10, and 12 days. A fully randomized factorial design was used for the experiment. The investigation concluded that 8-day strawberry waste fermentation was the optimum treatment. Temperature after fermentation was 28°C, ambient temperature was 29°C, pH before fermentation was 4, after fermentation was 3.2, voltage was 2.97 volts, current was 3.65 mA, power was 10.84 mW, resistance was 1,297 Ohm, and electrical energy was 73.32 mWh. The statistical analysis reveals that the duration of fermentation for star fruit, mangoes, and strawberries significantly influences voltage, current intensity, resistance, flame duration, and electrical energy generated. The findings of this study serve as a valuable point of reference for the future advancement of biobattery energy on a large-scale industrial level.

Keyword: Organic waste, alternative electrical energy, bio-battery, fruits waste, renewable energy

ABSTRAK

Limbah sayuran dan buah organik dapat digunakan untuk energi hijau. Buah-buahan kaya elektrolit dapat digunakan untuk membuat bio-baterai bebas polusi. Penelitian ini mengukur suhu dan lingkungan fermentasi, pH sebelum dan sesudah fermentasi, tegangan listrik, arus, daya, hambatan, dan energi pada limbah belimbing wuluh (Averrhoa carambola), mangga (Mangifera indica), dan stroberi (Fragaria) selama 8, 10, dan 12 hari. Rancangan acak lengkap faktorial digunakan untuk percobaan ini. Hasil penelitian menunjukkan bahwa fermentasi limbah buah stroberi selama 8 hari merupakan perlakuan yang optimal. Suhu setelah fermentasi 28°C, suhu lingkungan 29°C, pH sebelum fermentasi 4, setelah fermentasi 3,2, tegangan 2,97 volt, arus 3,65 mA, daya 10,84 mW, hambatan 1,297 Ohm, dan energi listrik adalah 73,32 mWh. Statistika analisis menunjukkan bahwa lama fermentasi pada buah belimbing, mangga dan stroberi sangat signifikan dampaknya terhadap tegangan, kuat arus, hambatan, lama nyala dan energi listrik yang dihasilkan. Hasil penelitian ini dapat digunakan sebagai acuan pada pengembangan energi bio batarei di masa mendatang dalam skala industri.

Keyword: Limbah organik, energi listik alternatif, bio-baterai, limbah buah-buahan, energi terbarukan

http://doi.org/10.32734/jsabe.v2i01.14683

1. Introduction

Organic waste, especially from vegetables and fruits, may be converted into ecologically acceptable energy resources. Electrical energy is vital and utilized every day. Alternative electrical energy research is crucial since household and business consumption of electrical energy has grown. Batteries convert chemical energy into electrical energy directly via electrode oxidation and reduction processes [1]. Batteries are sometimes called dry or leclanche cells [2, 3]. Bio-batteries use enzymes to make battery redox processes, bacteria to generate power, readily oxidized materials, and biomolecules to reduce [4, 5]. Carbon (CO_2), Manganese dioxide (MnO_2), and Ammonium chloride (NH_4C) with battery electrolytes form a paste when blended [3, 6]. Conventional batteries included lead (Pb), nitronium (Ni), hydrargyrum (Hg), and cadmium. Conventional batteries use B3 (hazardous and toxic materials), which is toxic inorganic waste [7, 8]. Battery pollution and improper handling will harm humans and the environment.

Fruits with acid produce energy [1], including citric acid $HOC(CH_2CO_2H)_2$, nicotinamide $C_6H_6N_2O$, adenosine $C_{10}H_{13}N_5O_4$, dinucleotides $C_{21}H_{27}N_7O_{14}P_2$, hydrogen H_2, and ascorbic acid $C_6H_8O_6$, which are essential and electrolytes. Due to physical and chemical processes during fruit breakdown, electrolytes will rise and affect fermentation. Thus, bio-batteries made from fruits with electrolytes may provide sustainable electrical energy and benefit society. An electrolyte is a substance capable of facilitating the flow of electric current. Ions have a crucial role in facilitating the flow of electric current between electrodes, thereby enabling the transmission of electrical energy [9-11]. Every electrolyte is comprised of ionic substances. During the process of transmitting electricity, the electrolyte complex undergoes a conversion process, causing it to break down into components on the electrode [12]. Conductivity or mobility may be classified as anions and cations. An *electrolyte* is defined as a chemical that does not undergo decomposition with the passage of electric current, unlike conductors such as metals. Electrolytes may be classified into three categories: vital electrolytes, weak electrolytes, and non-electrolytes [13]. The current transmission, or conductivity, may occur due to the ion breakdown when ionic substances dissolve. Nevertheless, in this scenario, $CaCO_3$, an ionic molecule that is not soluble, can conduct an electrical current (conductivity) even in a liquid form [14, 15].

The conductivity of an electrolyte is determined by the concentration of ions in the solution and the ability of the ions to move. Conductivity increases with both the concentration and mobility of ions. For instance, a salt solution with a high ion concentration exhibits more excellent conductivity than a solution with a low ion concentration [16-18]. Non-electrolyte compounds are substances in aqueous or wet solutions that cannot conduct electricity [18, 19]. Non-electrolyte substances, such as sugar or ethanol, serve as examples. During the process, non-electrolyte chemicals do not generate ions, even though the molecular compounds in the solution dissolve in water [19].

Bio-battery generates electricity from biological or inorganic elements. Bio-battery conversion uses anode and cathode conductivity material to generate a potential difference and electric current. Because bio-batteries are made from decomposable fruits, they do not pollute the environment, which is excellent for an ecosystem. The electrodes must have reactive electrolyte strength, which might happen during fermentation to increase voltage using traditional means. Longer fermentation increases acidity. Electric current strength and acidity are the precursors to bio-battery energy; the more acidic (lower pH) the solution, the higher the electric current strength, and vice versa. This study was done to use fruit waste from Carambola (*Averrhoa carambola*), Mango (*Mangifera indica*), and Strawberry (*Fragaria*) as energy sources. Strawberry includes ascorbic, ellagic, citric, malic, and pantothenic acids with a pH of 3.00–3.90. Green mango pH varies from 3.40 to 4.80 [20], whereas mature mango pH is 5.80 to 6.00 [21]. Mangoes include organic, phenolic, and fatty acids [22]. Starfruit contains acetic acid, citric acid, formic acid, lactic acid, and oxalic acid [23]. Green star fruit has a pH of 2.40, whereas mature star fruit has 2.71 [24].

Temperature affects solution microorganisms during fermentation. Saccharomyces cerevisiae bacterium, which affects fermentation, grows best around 30-35 ^oC. The solution to be tested will ferment slowly at low temperatures, whereas Saccharomyces cerevisiae bacteria die at high temperatures, preventing fermentation. According to [25], although not considerably, the fermentation period affects pH and material content. Fermentation solution pH decreases.

This study aims to find the best treatment fermentation and environmental temperature values, pH before and after fermentation, electrical voltage (V), current (mA), power (mW), resistance (ohm), and energy (mWh) in mango, starfruit, and strawberry fruit waste with fermentation times of 8, 10, and 12 days.

2. Materials and Methods

2.1. Materials

The materials used in this study included two pairs of electrode materials, where one pair of electrodes consisted of zinc (Zn) and copper (Cu); a green LED, which functioned as the actual load of the fruit waste bio-battery samples of Mango (F1), Starfruit (F2), and Strawberry (F3) as the research objects. NaCl solution was used as an electrolyte enhancer for the sample solution. The experimental method was used in this study. The innovation derived from this research is in the field of renewable energy that utilizes fruit waste from Starfruit (Averrhoa carambola), Mango (Mangifera indica), and Strawberry (Fragaria) as alternative bio-batteries. The alligator clips and cables served as connectors for the multimeter, load, and bio-battery circuit. The weighing scale was used to measure the sample weight to be tested, while the blender was used to blend several samples for the study. The pH meter was used to measure the acidity level of the fruit samples being tested. Plastic containers were used as the sampling containers, while measuring cups were used to measure the volume of the samples. The filter was used to separate the waste solution extract. Acrylic was used as the container for the bio-battery prototype experiment.

2.2. Experimental design

Prior to commencing this empirical investigation, many preparations must be undertaken. First and foremost, it is essential to classify the electrodes. Copper (Cu) was used as the cathode (+), whilst zinc (Zn) was utilized as the anode (-), with each being trimmed to measurements of 3 cm x 5 cm. Furthermore, adequate material preparation is of utmost importance. The first phase involves acquiring fruit waste, namely mango (F1), starfruit (F2), and strawberry (F3) was fermented in different time of 8 (T1), 10 (T2) and 12 days (T3) with 3-time repetition and the data was ANOVA-analyzed. The fruits underwent blending, filtration, and subsequent pouring into individual containers, to begin the study material preparation. The fruit extracts obtained were divided into nine containers and supplemented with NaCl. Each fruit extract was partitioned into 200 ml volumes, yielding nine samples for the three fruit wastes. Following the separation process, each sample was appropriately labelled. Finally, the prototype of the bio-battery was created. Three cells were fabricated, each comprising three pairs of Cu-Zn electrodes organized in a series configuration and linked to a green LED light and multimeter. The experiment used an acrylic container with dimensions of 12x5x7 cm, where a distance of 4 cm separated each cell (Figure 1).

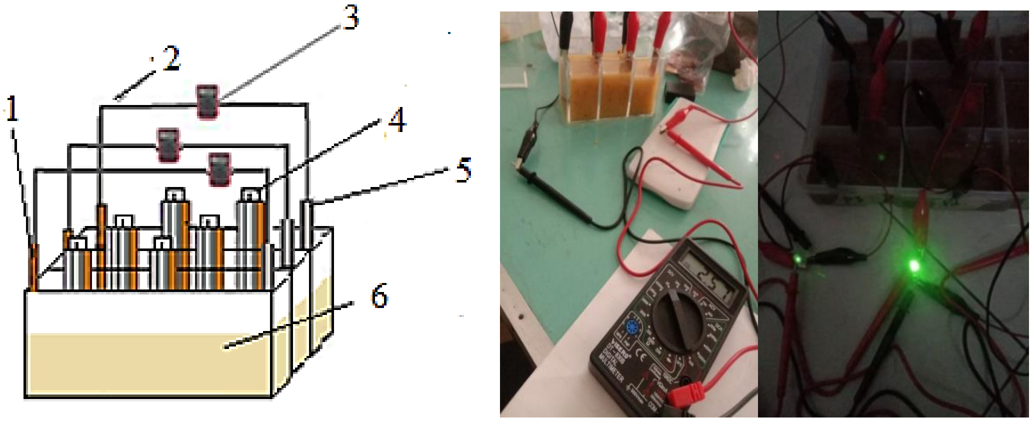

Figure 1. Protype of Bio-battery with 1) Cu, 2) Cable, 3) Multimeter, 4) Electrode conductor, 5) Zn, 6) fruit waste fermentation

In order to ensure the integrity of the study, many factors were used to get precise and dependable results. The study variables included fermentation temperature, ambient temperature, pH levels before and after, electrical voltage, electric current, electrical power, solution resistance, and electrical energy. The fermentation and ambient temperatures were assessed using a thermometer to ascertain their impact on the material under investigation and the pH level. The pH meter was used to monitor changes in the solution's pH values. In order to gauge the electric current and voltage characteristics of the fruit waste being examined, the negative wire was linked to the anode (Zn).

In contrast, the positive cable was linked to the cathode (Cu). The readings obtained from the multimeter were shown on the device's monitor. An electric current was detected in fruit waste, and its measurement was facilitated by connecting the negative cable to the anode (Zn) and the positive cable to the cathode (Cu) using a multimeter. The multimeter's output findings were shown on the device monitor. The interaction between ions in the solution led to the phenomenon of electrostatic force, which led to the hindrance of electric current flow. Ultimately, the motion of electrons inside an electrical conductor or circuit is a consequence of electrical energy. Electrical energy generation may be achieved by multiplying the power with the duration of the LED being turned on.

3. Results and Discussion

During fermentation, the ambient temperature and the temperature of the solution play a critical role in influencing the activity of bacteria and the pace of biochemical processes. Inhibited microbial activity caused by low ambient temperature will result in a deceleration of the fermentation process. Conversely, excessive ambient temperature may be lethal to the bacteria participating in fermentation and harm their cells, compromising the integrity of the cell membrane.

Table 1 displays the temperature measurements taken before and after fermentation for each treatment of fruit waste. The data was obtained using a thermometer, with the temperature recorded in degrees Celsius (°C). The data indicate that the temperature on Day 8, Day 10, and Day 12 stayed stable and did not undergo any alterations. The maximum recorded value was 30°C, representing the mean temperature of fruit waste across all treatments prior to the initiation of fermentation. Conversely, the lowest figure documented was 28°C, representing the mean temperature of mango fruit waste during an 8-day fermentation period. The temperature fluctuations in several treatments were ascribed to the distinct kinds of fruit waste used and the length of the fermenting process. The data was gathered from authentic fruit waste without using any substances or apparatus that may alter its characteristics.

Table 1. Data on the temperature of the waste solution before and after fermentation

Treatment	Temperature (^{0}C)			
	Enviroment		Solution	
	Before fermentation	After fermentation	Before fermentation	After fermentation
T1F1	29	28	30	28
T1F2	29	28	30	29
T1F3	29	28	30	29
T2F1	29	28	30	29
T2F2	29	28	30	29
T2F3	29	28	30	29
T3F1	29	28	30	29
T3F2	29	28	30	29
T3F3	29	28	30	29

T1=Mango waste, T2=Starfruit waste, T3=Strawberry waste, F1=8 days fermentation, F2=10 days fermentation, F3=12 days fermentation

The pH of a solution is strongly correlated with the concentration of CO_2 in the surrounding atmosphere. Consequently, the substrate may be affected by external CO_2, leading to changes in the pH of fruits. pH is a quantitative indicator of the level of acidity or alkalinity in a solution, whereas CO_2 is a gaseous component present in the atmosphere that can combine with water to generate carbonic acid, hence reducing the pH of the solution. The investigation included measuring the pH values of fruit waste both before and after fermentation using a digital pH meter. The results obtained indicated that fermentation of fruit waste resulted in a decrease in pH values (Table 2).

Table 2. pH before and after fermentation

Treatment	Average pH	
	Before	After
T1F1	3.4	2.7
T1F2	3.4	2.9
T1F3	3.4	2.7
T2F1	3.4	2.9
T2F2	3.7	2.9
T2F3	4.0	3.0
T3F1	4.0	3.2
T3F2	3.9	3.2
T3F3	3.9	3.3

T1=Mango waste, T2=Starfruit waste, T3=Strawberry waste, F1=8 days fermentation, F2=10 days fermentation, F3=12 days fermentation

According to the pH measurements conducted before and after fermentation (as shown in Table 2), the starfruit waste treatment with 12 days of fermentation and the strawberry waste treatment with eight days of fermentation had the highest pH value of 4 before fermentation. Conversely, the mango fruit waste had the lowest pH value of 3.4 before fermentation in all treatments. The treatment of strawberry fruit waste with 12 days of fermentation yielded the most excellent pH value, while the treatment of mango fruit waste with 8 and 12 days of fermentation resulted in the lowest pH value. The notable decline in pH in mango fruit waste during fermentation is attributed to producing organic acids, including lactic acid, acetic acid, and propionic acid, via the fermentation process, resulting in a reduction in pH. Furthermore, the elevated acidity of mango fruit also impacts the reduced pH level.

A reduction in the average pH after fermentation was observed, suggesting that fermentation impacts the concentration of hydrogen ions in the solution. On average, the acid concentration in 100 grams of mango waste is 1 gram. The molarity of the HCl solution in which the acid is present is 0.027 M. On average, the acid content in 100 grams of strawberry waste is 0.5 grams. The molarity of citric acid in the solution is 0.0000135 M. The starfruit waste has an average of 2 grams of acid per 100 grams, with a molarity of oxalic acid in the solution of 0.000244 M. This demonstrates the disparity in acid composition across various fruit residues. The voltage in a circuit may arise from either a voltage source or an electric potential differential (Figure 2). A voltage elevation may arise due to an augmentation in the concentration of electrolyte ions.

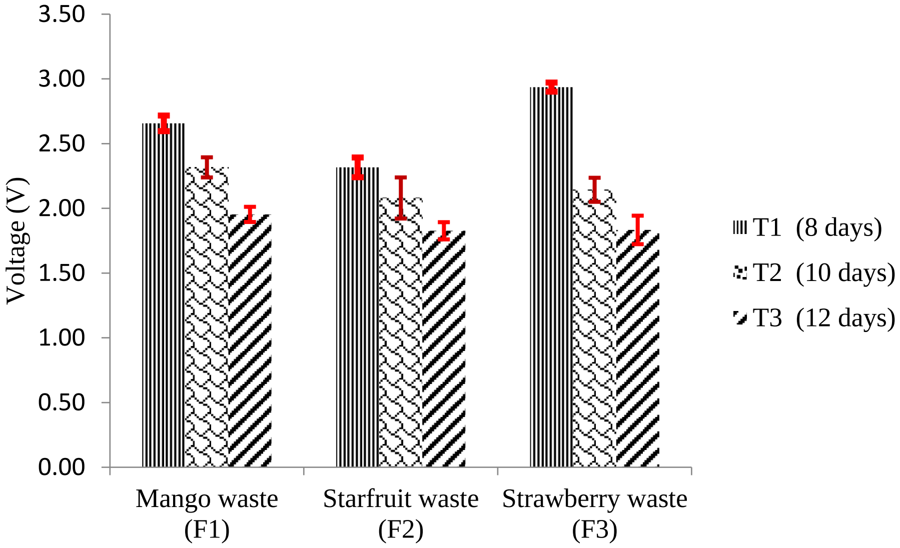

Figure 2. The electric voltage of various fruit waste

Figure 2 and Table 3 show the results of the electric voltage measurements conducted on different treatments of fruit waste. The treatment T3F1, which included strawberry waste with 8-day fermentation, had a maximum electric voltage of 2.94 volts. On the other hand, the treatments T2F3 and T3F3, which involved carambola waste with 12-day fermentation and strawberry waste with 12-day fermentation, respectively, had the lowest electric voltage of 1.83 volts. The electric voltage in fermented waste is influenced by factors such as the fruit choice and the fermentation duration. Carambola trash has the potential to produce a greater electric voltage compared to waste from mango or strawberry. Extended fermentation duration often results in elevated electric voltage due to the proliferation of microorganisms. The analysis of variance demonstrates that every treatment and interaction had a substantial influence on electrical voltage. Nevertheless, the specific kind of waste did not have a significant effect.

The treatment T1F1 (8-day fermented mango waste) has the most significant value at 3.58 milliamperes, while the treatment T2F3 (12-day fermented starfruit waste) has the lowest value at 1.62 milliamperes. The changes in fruit variety and fermentation period are responsible for these discrepancies since fruit waste's nutritional content and microorganisms might impact the electric current produced. The length of fermentation may also impact the electric current output since more extended fermentation periods allow more microbe proliferation and consequent power production. According to the statistical analysis, each treatment, waste type, and fermentation length strongly influence the electric current produced. Furthermore, the correlation between waste kinds is greatly influenced by several variables, including the specific types of fruit waste used in the experiment, variations in the fermentation period, and environmental parameters such as temperature, humidity, and pH. These variables influence the activity of microorganisms throughout the fermentation process and lead to variations in the average notation values across different treatments.

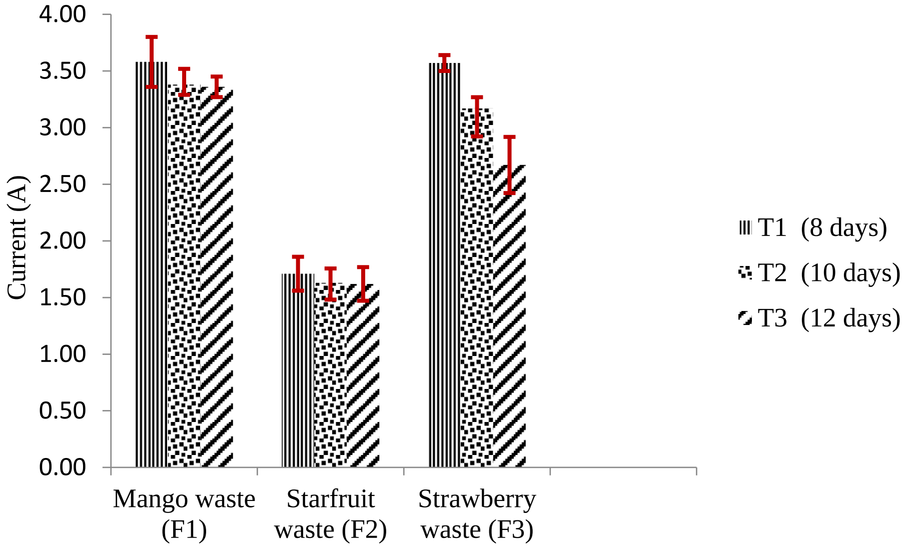

Figure 3. The electric current of various fruit waste

Figure 3 and Table 3 show variations in the electric current values across the different treatments.

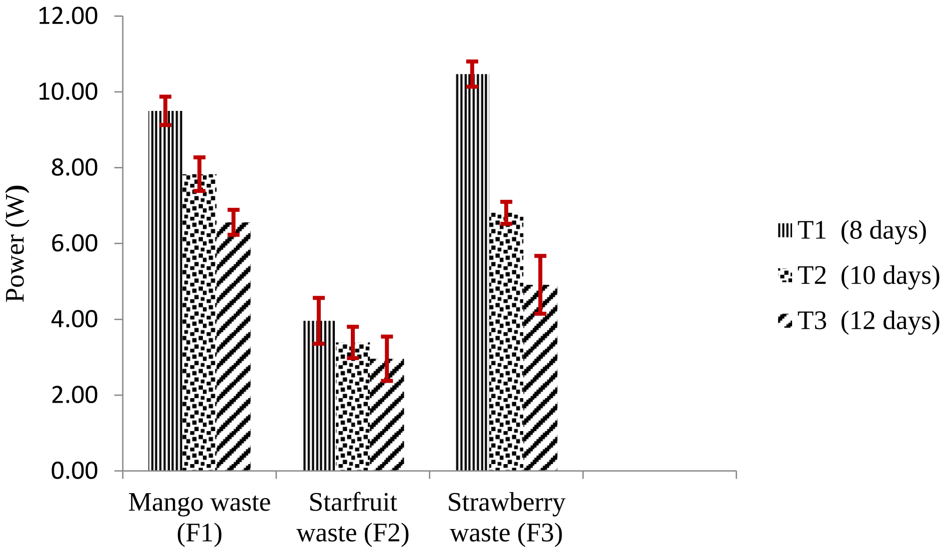

Figure 4. Electric power of various fruit waste

The data shows variations in the electric current values across the different treatments. Power quantifies the exertion or energy used within a certain duration. In the context of electric power created by fruit waste fermentation, power refers to the quantity of energy accessible inside an electrical system. Therefore, the electric power created from the process of fermenting fruit waste represents the quantity of energy that is accessible inside the system and may be used for a variety of purposes. The electric power levels exhibited variability among the various treatments. Figure 4 and Table 3 show that the treatment using strawberry waste and an 8-day fermentation process yielded the maximum power output, while the treatment using starfruit waste and a 12-day fermentation process resulted in the lowest power output. The disparity in mean values may be ascribed to several variables, including the kind of fruit waste, fermentation period, temperature, pH, and microbe concentration.

The barrier develops due to the electrostatic attraction between ions and the collision and frictional forces between ions and solvent molecules. As the resistivity of a solution increases, the current that can pass through the solution at a specific voltage decrease. Table 3 displays the resistivity statistics of fermentation waste. The variance test determined that each treatment, fermentation time, and the interaction between waste and fermentation had a notable impact on the inhibition of the solution. Nevertheless, the specific kind of waste did not substantially influence the solution's inhibition.

Table 3. The value of voltage, current, resistance, power and energy of various fruit waste

Treatment	Voltage (V)	Current (mA)	Resistant (Ohm)	Power (mWatt)	Time electrical energy produce (h)	Energy (mWh)
T1F1	2.66±0.06	3.58±0.22	1,148±132.84	9.50±0.37	6.5±0.46	62.17±6.41
T1F2	2.32±0.08	3.38±0.15	1,106±22.54	7.83±0.60	4.7±0.58	36.77±7.09
T1F3	1.95±0.06	3.36±0.07	1,766±342.58	6.56±0.33	4.0±0.00	26.24±1.33
T2F1	2.32±0.08	1.71±014	1,253±108.13	3.78±0.44	2.0±0.15	7.86±1.46
T2F2	2.08±0.16	1.63±0.13	1,353±124.71	6.57±0.41	1.9±0.10	7.46±1.18
T2F3	1.82±0.07	1.62±0.10	1,548±213.77	2.96±0.29	1.2±0.06	3.67±0.53
T3F1	2.93±0.04	3.57±0.09	1,297±58.07	10.47±0.33	7.0±0.00	73.32±2.31
T3F2	2.14±0.09	3.17±0.15	1,384±162.82	6.81±0.59	4.3±0.52	29.46±6.07
T3F3	1.83±0.11	2.67±0.25	1,176±130.28	4.91±0.76	3.2±0.29	15.68±3.95
ANOVA	$P_{value}<0.01$	$P_{value}<0.01$	$P_{value}<0.01$	$P_{value}<0.01$	$P_{value}<0.01$	$P_{value}<0.01$

T1=Mango waste, T2=Starfruit waste, T3=Strawberry waste, F1=8 days fermentation, F2=10 days fermentation, F3=12 days fermentation

The presence of electrical energy arises from the existence of a potential difference or voltage between two specific places. The electric charge will flow from a region of low potential to a region of high potential when there is a potential difference (Table 3 and Figure 6). The term used to describe this phenomenon is electric current. Based on the results, it is evident that mango (T1) and strawberry (T3) waste provide greater electrical energy values compared to star fruit waste (T2) across all fermentation procedures. The T3F1 treatment, which included strawberry fruit waste fermented for eight days, had the maximum electrical power, measuring 73.32 mWh.

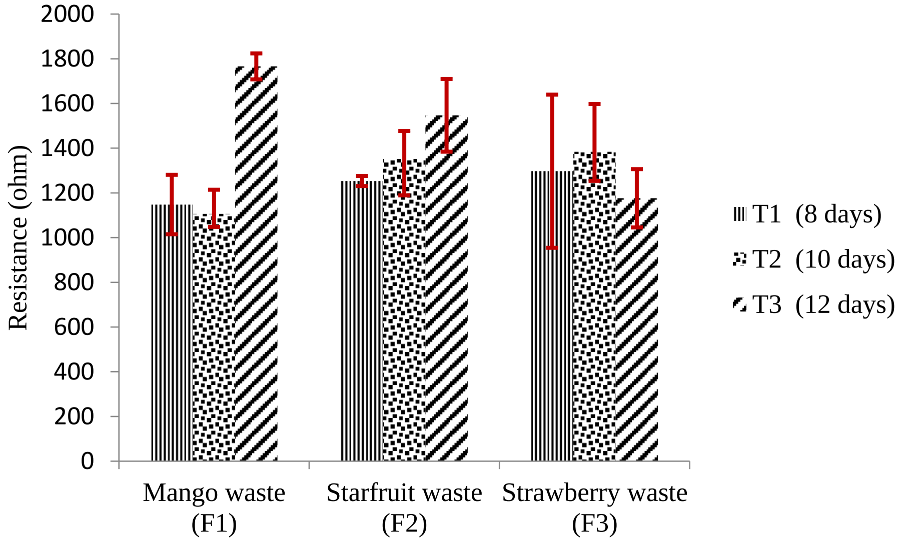

Figure 5. Resistance of various fruit waste

Conversely, the treatment with the lowest electrical energy value was F2T3, which included fermenting star fruit waste for 12 days, resulting in a value of 3.29 mW. Furthermore, there is an inverse relationship between the duration of fermentation and the amount of electrical energy generated. Displayed is an image illustrating the correlation between electrical energy and the duration of fermentation.

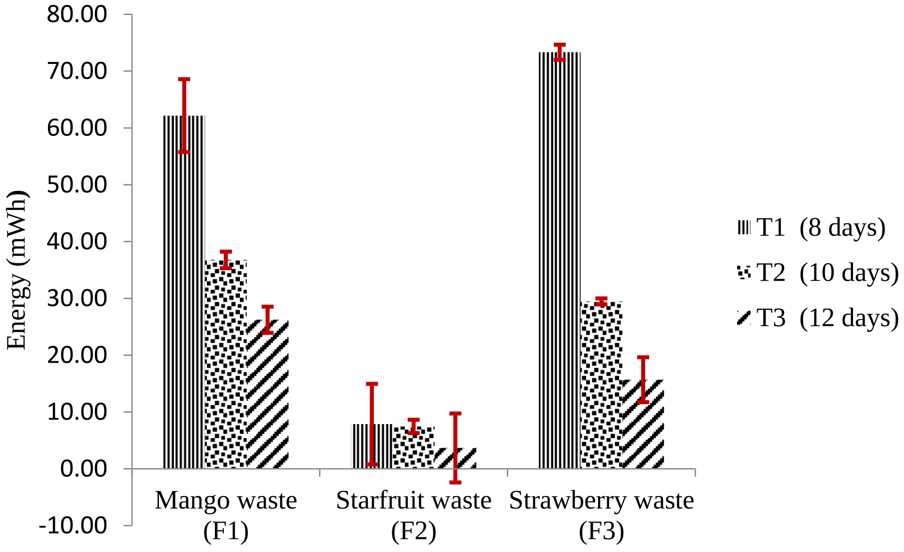

Figure 6. The electrical energy generated of various fruit waste

The relative efficacy of electrical energy for fermentation is variable in Figure 6. Every kind of fruit waste has its chemical makeup, including the levels of sugar, protein, and other essential components. Variations in chemical composition may impact fermentation efficiency and lead to disparities in electrical energy generation. The sustenance of microorganisms involved in the fermentation process necessitates the presence of nutrients. Variations in the nutritional composition of fruit waste may impact the fermentation rate and electrical energy generation. Several factors, including temperature, humidity, pH, and aeration, may influence fermentation. Variations in electrical energy generation may arise due to different fermentation conditions across treatments. The ferment microorganisms might exhibit variability in their species and metabolic behaviour. Variations in the microbial composition found in fruit waste and variances in their metabolic activity may impact the effectiveness of fermentation and the generation of electrical energy. Varying the duration of fermentation (8 days, 10 days, or 12 days) might impact the efficiency of converting organic material into electrical energy. The ANOVA test revealed a significant impact of each treatment, type of waste, and fermentation period on electrical energy at α=1 % (Table 3). Using strawberry fruit waste with eight days of fermentation results in the most effective treatment for generating the most significant average electrical energy value of 73.32 milliwatt-hours. The duration of fermentation of spoiled fruit waste directly affects the amount of electrical energy generated.

4. Conclusion

Mango, star fruit, strawberry waste solution and environment temperatures range from 28°C to 30°C before and after fermentation. The pH after fermentation was highest in the T3F3 (strawberry fruit waste with 12 days of fermentation) at 3.3 and lowest in the T1F1 (mango fruit waste with eight days) at 2.7. High pH provides 15.68 mWh of electrical energy, and low pH is 62.17 mWh. Longer fruit waste fermentation reduces pH and boosts electricity. The highest voltage was 2.94 V in T3F1 (strawberry fruit waste with 8 days of fermentation), and the lowest was 1.82 V in T2F3 (starfruit fruit waste with 12 days of fermentation): electrical voltage and energy decrease as fruit waste ferments longer. Treatment T1F1 had the highest electric current at 3.58 mA, and T2F3 (starfruit fruit waste with 12 days of fermentation) had the lowest at 1.62 mA. Energy and electricity decrease with longer fermentation durations. The highest electrical output was 10.47 mWatt from T3F1, while the lowest was 2.96 from T2F3 (starfruit fruit waste with 12 days of fermentation). Power and energy are saved by fermenting fruit waste longer. T1F3, mango fruit waste fermented for 12 days, had the most excellent solution resistance of 1,766 ohms, whereas T1F1 had the lowest. Longer fermentation improves solution resistance. Electrical energy was highest in T3F1 (starfruit fruit waste with 8 days of fermentation) (73.32 mWh) and lowest in T2F3 (3.67). Longer fruit waste fermentation lowers electricity generation. LED on time is lowest at T2F3 (1.2 hours) and maximum at T3F1 (7 hours). Longer fruit waste fermentation decreases LED flame time. The statistical analysis reveals that the duration of fermentation for star fruit, mangoes, and strawberries significantly influences voltage, current intensity, resistance, flame duration, and electrical energy generated. The findings of this study serve as a valuable point of reference for the future advancement of biobattery energy on a large-scale industrial level.

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