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In-situ Power Analysis of Green-electricity using Cu-Zn Electrodes as Conducting Materials

Ma. Ritchel F. Aliman [a,1,*], Teodoro A. Amatosa, Jr [a,2], Jordan H. Sihombing [b,3]

[a] College of Engineering and Technology, Northwest Samar State University, Calbayog City, Samar, 6710 Philippines
[b] Materials and Metallurgical Engineering, Institut Teknologi Kalimantan, Balikpapan 76127, Indonesia
[1]ritchel_fuellas@yahoo.com*;[2]teody.amatosajr@nwssu.edu.ph;[3]06221029@student.itk.ac.id

* corresponding author

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ABSTRACT

This study evaluates the essential energy and climate impacts of living plants that are gathered together and used for electricity. The tropical desert plant (aloe-vera, AV) derived natural bio-organic material used to convert the waste mechanical energy into green electrical energy. Due to increased demands for energy and the current limitations of batteries, a self-design energy harvester that converts kinetic vibration energy from Aloe Vera into green electrical energy. These energy harvesters have the potential to be used in powering small-scale electronic devices such as measurement equipment in just a Lit-ion battery were available. Throughout this research work, nonconventional style of producing electricity with green engineering materials like Aloe Vera may stand as one of the new start renewable energies. Low voltage application that could generate power without having waste materials, and also protect the environment through pollution. The fore knowledge associated with critical conditions (i.e. the thickness and number of leaves by Cu-Zn electrodes) have been connected against the experiments result. Results clearly confirm the expectations from the resonance condition though, the plant and tree power is improbable to replace the power sources the most applications. Copper-Zinc cells are considered as good conducting materials for preparation and analyzes of electrodes and cells to influence the power performance from Aloe Vera.

1. INTRODUCTION

The natural resources available in the world are abundant and diverse, offering numerous benefits such as environmental sustainability, favorable technical performance, and renewable characteristics (Ernawati, Laksono, Parmita, Susanti, & Qadir, 2024; Laksono et al., 2023; A. D. Laksono et al., 2022; Andromeda Dwi Laksono et al., 2022). Natural bio-organic materials (NBOM) for clean energy conversion/storage energy devices (CED) play a vital role in building a low carbon emission society (Chu and Majumdar, 2012; Shin et al.

2015; Kholkin et al. 2015) and in our daily lives in various applications, from huge capacity up to the smallest or what we called nano-electronics. Field experiments such as ecological, ecosystem assessment, climatic monitoring system, deployed electronics that need a reliable power source, a convenient alternative experiments is to find a sustainable power supply in the environment to keep the electronics devices operational. Therefore, there is a need of energy sources that is a mobile, abundant, and widely available. The wide range of energy sources provides energy services, offer long-term security of supply, affordable and have minimal impact in the environment (Adegbululgbe et al. 2007).

Recently, new form of low energy source harvested from living plants was studied. Choo and Dayou (2013) studied a method to harvest electrical energy from living plants by embedding pairs of electrodes into the plants where electrical energy is harvested and shows result that Copper-Zinc and Aloe vera (*Aloe barbadensis)* plant was best combination of electrodes and source of energy by completing the connection with conditioning circuit. However, the study of using plants for directly powering nano-electronics circuits were energy is harvested from the tissues of living plants with the aid of nano-electronic circuits capable of working within the constraints of the power supply and successfully operated them using a living tree as the sole power source and was presented by Himes, et al. (2010). While Ying et al. (2015) studied to Improve the efficiency of harvesting electricity from living trees has been observed that there exists electrical potential difference between the phloem of a living tree and the surrounding soil. This kind of bioelectricity finds a practical set up of providing the largest possible sustained voltage level by treating both electrodes inserted into the trunk of the tree or one electrode was placed in the soil with the other in the trunk. It can be harvested by charging a capacitor.

Kumar et al. (2015) also proved that there exists an electrical energy in living plants on their study green electricity from Aloe vera due to the present of some of chemical properties (Calcium, Magnesium, Zinc, Chromium, Selenium) in the leaf helps in generating electricity. Hence, previous studies show some fundamental procedures of harvesting energy from living plant, this work is going to propose an energy storage device for voltage harvested from a living *Aloe Barbadensis* plant.

This paper was to determine the voltage of a living Aloe Vera plant and characterization the time variation on voltage generation and functionality. This also covers the development of green energy storage device that was energized for organic material. This device was working by accumulating electrical energy from aloe vera by means of embedding pairs of electrodes to harvest these sustainable energies and supply a low voltage load intended for nano-electronic devices. Hence, it was needed in the forests and remote sites for researchers as a source of energy lightings and low voltage devices that could also be beneficial to the community, located in the far-flung areas where there is no electricity.

2. METHODS

2.1 Materials

Fresh aloe vera (*A. barbadenis* Mill.) was obtained from a local market (Calbayog City, Samar, Philippines) as shown in Figure 1 (a, b, c). Plant A, B, and C is the same variant of

Aloe Vera with almost the same sizes of leaves. Plant A consists of nine (9) leaves, plant B composed of eleven (11) leaves and plant C with eight (8) leaves. Four (4) samples of leaves for each plant were randomly selected as shown in Table 1. An open-circuit test method was applied in this experiment wherein the pair of electrode was embedded in aloe vera leaves, and Fluke 115 true RMS multimeter was used to measure the voltage generated. Copper and Zinc (Cu-Zn) were selected and used in this study as electrode pair because of its low cost and the availability of these materials in local market. In addition, Choo and Dayou, (2013) was studied also the properties of different pair of electrode materials in generating electrical energy. And the results of this study revealed that Cu-Zn pair electrode produces the highest voltage, combined with aloe vera as a soul source of energy.

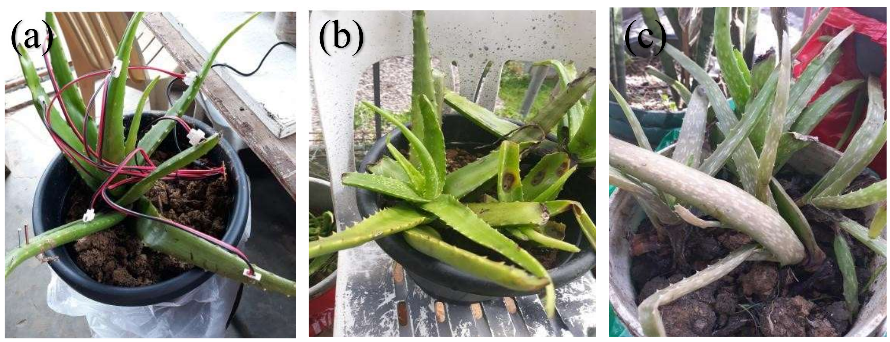

Figure 1. Activated green organic material utilized for an open-circuit test method from (a) plant A consists of 9 leaves; (b) plant B composed of 11 leaves; and (c) plant C with 8 leaves.

Table 1. *Aloe vera* plant with different leaves thickness

Plant designation	Thickness of leaves, mm
Plant A	ranges from 10 mm to 17 mm
Plant B	ranges from 11 mm to 15 mm
Plant C	ranges from 12 mm to 16 mm

2.2 Methods

Determination of green voltage

The determination of voltage generated from Aloe vera plant was conducted in two (2) different experiments. The first experiment was determination of voltage according to thickness of leaves and the second was the determination of voltage according to the number of leaves connected in series. The procedure was done by embedding a pair of electrode into the leaves and connected in series. Then the voltage was measured by connecting the positive probe of the multimeter to the embedded copper and the negative probe to the zinc using a Fluke digital multimeter and alligator clips as temporary connectors.

Characterization of green voltage through effect of time variation

An open-circuit test method was applied for two different experiments. The first experiment was conducted for one (1) hour and the second experiment lasts for four (4) days. And digital multimeter was used to measure the voltage generated.

Development of portable green energy storage device

The developed energy storage storage device has proved that organic energy can be a conventional source intended for low energy electronic devices. It was capable of storing energy harvested from living plants and supply low energy. This device can be stationary or mobile that was convenient to use and easy to carry in distant location because of its light weight feature. The pairs of electrodes were connected in series-parallel to maximize harvesting the energy and the electrode connector was detachable to the main body of the device for convenience handling. Male USB cable port was installed in the output side of the electrode connector, as plug into the device during charging.

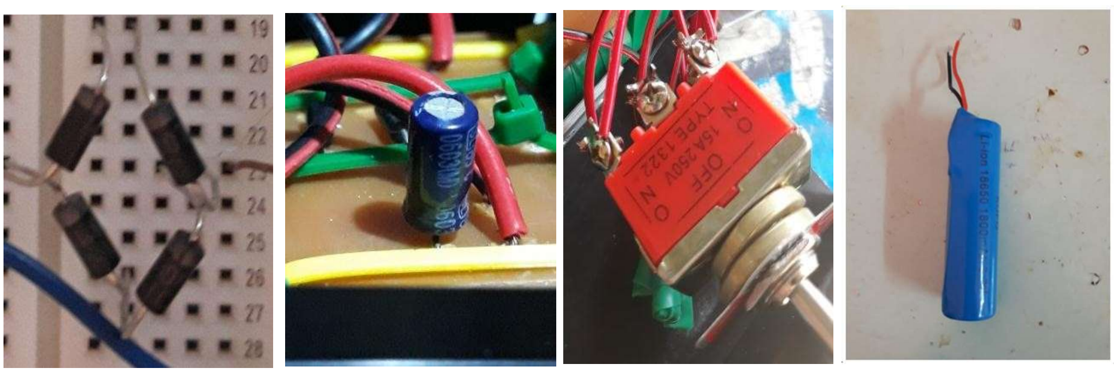

Figure 2. Main components of the green energy storage device (a) bridge rectifier; (b) electrolytic capacitor; (c) doble pole double throw (DPDT) switch; and (d) lithium-ion battery (Li-Ion)

3. RESULTS AND DISCUSSION

3.1 Voltage generated from Aloe vera

(a) Thickness of leaves

This experiment was conducted with a pair of electrode, copper and zinc (Cu-Zn) embedded in the leaves of an Aloe vera plant with respect to their thickness. Selection of the materials Cu-Zn and Aloe vera was based on the previous study of Choo & Dayou (2013) that Cu-Zn produces the highest voltage with Aloe vera as energy source among the tested combination of electrode pairs and plants. Series of tests were conducted to three (3) different aloe vera plants to determine the variation of voltage.

Based on the experiment conducted to three different plants with similar variant and sizes of leaves, result implies that thickness doesn't affect the voltage generation of Aloe vera. Plants A, B and C based on the data presented inTable 3, every leaves in aloe vera plant generates more or less the same voltage. Regarding also the size of the leaves belongs in one plants generates nearly the same voltage.

Table 2. Voltage generated of Aloe vera plant according to thickness of leaves

Aloe vera plant	Thickness of leaves, mm						
	11	12	13	14	15	16	17
	Voltage						
Plant A	1.018		1.018	1.008			1.016
Plant B	1.018		0.999	0.988	0.958		
Plant C		0.953	0.966		0.968	0.958	

Table 2 shows the voltage generated of Aloe vera plant with respect to different thickness of leaves. Results revealed that voltage generation of Aloe vera plant were numerically higher at 11mm of leaf thickness as reflected by Plant A (0.018V) and Plant B (0.018V). Another observation was all the selected leaves in plant A have nearly the same voltage, same observation in plant B and C. Thus, plants A, B and C differ in range on voltage generated, and they may be classified by plants and not by leaves.

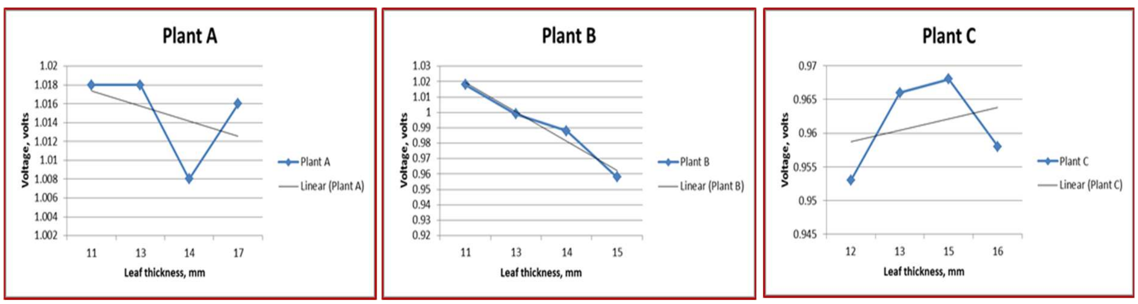

Figure 3. Voltage generated from green material

(b) Number of leaves

The test was conducted to different Aloe vera plant with different number of leaves. Using the open-circuit test method to determine the voltage generated for each plant and by averaging their voltage to show the difference of generated voltage and their efficiency.

The summation of leaves voltages was divided by five (5), the number of leaves randomly selected in every plant to get the average voltage. And based from the result of averaging, it was found that the average voltage of plants every five (5) leaves was more or less same to their individual voltages as reflected in Table 3 below.

Table 3. Voltage generated of Aloe vera plant according to thickness of leaves

Leaf	Plant A	Plant B	Plant C	Plant D	Plant E	Plant F
			Aloe vera plant / Voltage per leaf			
1	1.014	0.974	0.997	0.975	0.988	0.993
2	1.018	0.994	0.993	0.965	0.970	0.968
3	1.013	0.972	0.995	0.976	0.972	0.976
4	1.017	0.989	0.999	0.990	0.994	0.976
5	1.023	1.019	1.013	0.975	0.993	0.950

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Avarage	1.017	0.989	0.999	0.976	0.983	0.973

Another test was conducted on the efficiency of output voltage with respect to the number of leaves connected in series. From efficiency formula, it is a measure of how much work or energy is conserved in a process. It is the energy output, divided by the energy input, and expressed as a percentage. A perfect process would have an efficiency of 100%.

It was conducted on two different instances, the first one was a series connection of two to five (2-5) leaves, and another test was a series connection of two to six (2-6) leaves. Figure 18 and 19 results revealed the efficiency of generated voltage is almost identical, it shows that the more leaves generate a lower voltage than the few leaves.The more leaves give a higher output but having a huge voltage drop. As Himes, et al. (2010) describe from his study that the resulting voltages did not add in series. That contradicts with the hypothesis of Choo and Dayou (2013) that it is analogous to the number of ordinary dry cell batteries such as AA. By increasing the number of electrodes embedded into the plants, the harvested electrical energy should increase proportionately. And when more number of electrodes embedded, higher power output can be harvested.

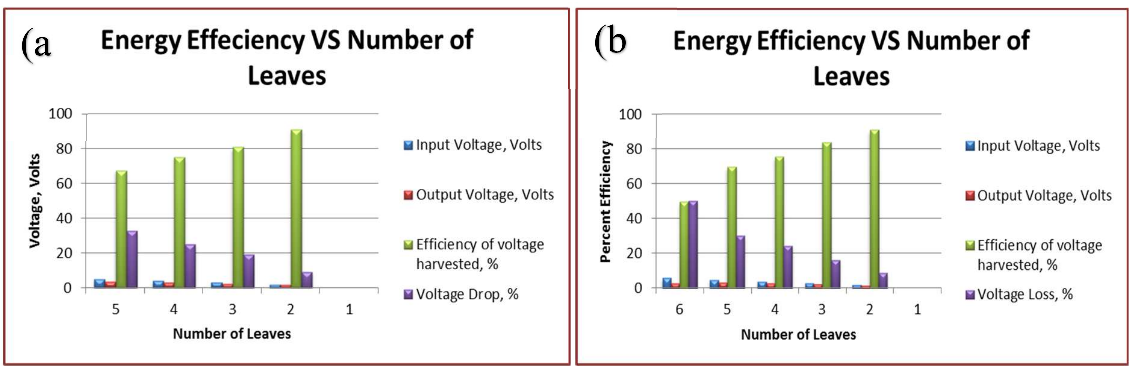

Figure 4. Efficiency and losses of the harvested voltage for green energy vs number of leaves (a) 2 – 5 leaves and (b) 2 – 6 leaves.

3.2 Effect of time variation on green energy voltage generation

An open-circuit test was conducted for two instances. The first one was tested for a duration of one (1) hour with an interval of ten (10) minutes to measure the voltage generated using a digital multimeter connected to single pair of electrode embedded to different sizes of leaves to determine the variation of voltage generation was shown in (table 4) below.

The first tests were conducted to different thickness of leaves for an hour with an interval of ten (10) minutes and it was observed that, it was stable for the first ten (10) minutes, the next thirty (30) minutes was still tolerable. But the succeeding minutes the voltage generated was already unstable as reflected in Table 4 and illustrated by the trend line. To produce enough resistance and generate heat, any conductive wire and some metals can be utilized for heating that has great efficiency to conduct electricity as explained by Amatosa et al. (2019). It was incompatible with the study of Choo and Dayou (2013) to three different pairs of electrode and best energy source. The tests were conducted to three (3) different plants

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namely; Pulai trees, banana and aloe vera as energy source and pairs of electrode, between Cu-Zn, Cu-Fe, Cu-Al and Al-Zn. It was also found that for all combination, the harvested voltage was stable up to 60 minutes while in this experiment the stability of voltage generated was 10 to 30 minutes only.

Table 4. Voltage generated of Aloe vera per leaves vs time

Time, min	Thickness of leaves, mm				
	9	10	11	13	15
			Voltage		
0	1.001	1.022	0.984	1.023	1.019
10	0.991	1.022	0.984	1.023	1.019
20	0.991	1.018	0.982	0.956	1.018
30	0.992	1.008	0.975	0.984	1.015
40	0.979	1.001	0.991	1.017	1.016
50	0.997	0.999	0.987	0.996	1.017
60	0.946	0.995	0.978	1.009	0.946

The second test was conducted for duration of four (4) days with an interval of one (1) day measurements using a single pair of electrode embedded to different sizes of leaves to determine the variation of voltage generation was shown in (table 6) below.

From series of tests conducted for four (4) days, it was found that the generated voltage for different sizes of leaves was already unstable during the first day as shown in Table 6, in relation to the same experiment conducted previously for one (1) hour that its stabilizes for 10 to 30 minutes only. In succeeding minutes and days the voltage was already decreasing as shown in the trend line which is almost identical for all samples of five (5) leaves with different thickness.

Table 4. Voltage generated of Aloe vera per leaves vs day

Day	Thickness of leaves, mm				
	9	10	11	13	15
			Voltage		
0	1.037	1.058	1.023	1.037	1.034
1	0.949	0.620	0.998	0.798	0.615
2	0.667	0.665	0.611	0.598	0.450
3	0.483	0.385	0.430	0.530	0.410
4	0.464	0.440	0.448	0.384	0.328

It was also observed that the gel material of the leaves was flowing outside due to the penetration of the electrodes. And if exposed into the sun the gel in the open part of leaves evaporates, until such time that the injected portion of the leaves becomes dry. It was hypothesize that absence of the *aloe vera* gel causes the excrement of voltage generation. The inhibitive effect also of *aloe vera* gel to copper with the values of percentage inhibition efficiency and corrosion rate obtained from weight loss method. It is also observed that the inhibition efficiency increases as the concentration of the Aloe gel is increased (Hart and James, 2014).

3.3 Development of portable green energy storage device and functionality

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Based on the experiment conducted and presented in Figure 4 (a) and (b), results revealed that the efficiency and losses of the harvested voltage connected in series was nearly equal at six (6) six leaves. For five (5) leaves, efficiency was 67.32% and 67.73%, losses of 32.68% and 30.27% as reflected in Table 7 and 8. The succeeding decreasing number of leaves, the efficiency was increasing and losses was decreasing but the problem is the output voltage was proportional to the voltage loss, tabulated data was shown in Table 5 and 6 below.

Figure 5. Developed portable green energy storage device

Table 5. Efficiency and losses of voltage harvested from 2-5 leaves

Number of leaves Connected in series	∑ of individual leaves voltages (input), volts	Measured voltage (output), volts	Efficiency of harvested voltage, %	Losses of harvested voltage,%
5	5.085	3.432	67.32	32.68
4	4.062	3.046	75.00	25.00
3	3.045	2.459	80.76	19.24
2	2.032	1.847	90.90	9.10

Table 6. Efficiency and losses of voltage harvested from 2-6 leaves

Number of leaves Connected in series	∑ of individual leaves voltages (input), volts	Measured voltage (output), volts	Efficiency of harvested voltage, %	Losses of harvested voltage,%
6	5.952	2.951	49.60	50.40
5	4.948	3.450	67.73	30.27
4	3.929	2.968	75.54	24.46
3	2.940	2.461	83.71	16.29
2	1,968	1.792	91.06	8.94

Table 7. Functionality of the portable green energy storage device

Functions	Operations

Voltage source	Aloe vera (Aloe barbadensis) plant
Charging time	10 minutes to 30 minutes
Supplied voltage	Maximum of 7.4 volts DC
DPDT switch	Switching between charging and supplying a load
Application	Nano-electronics devices

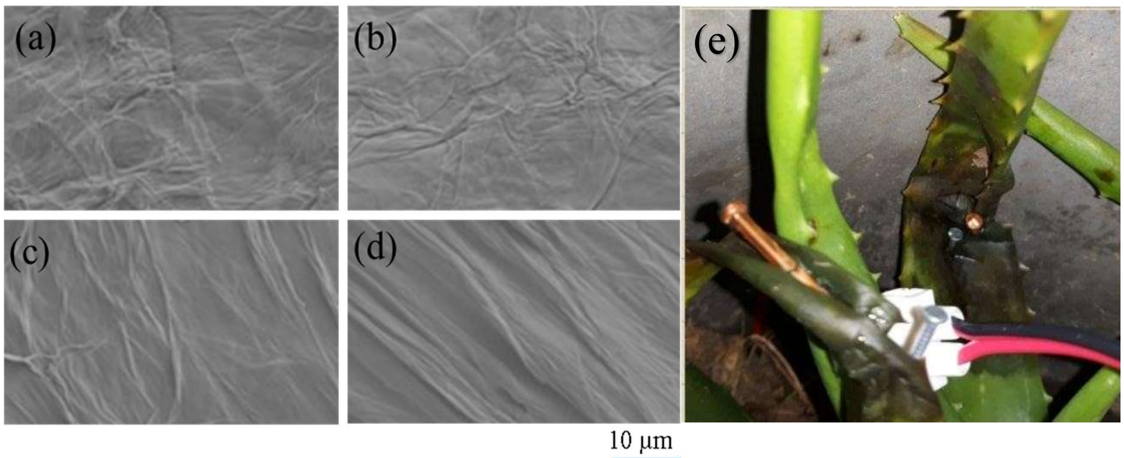

Figure 6: Aloe vera gel examined with SEM (x1000): (a) younger aloe vera gel; (b) older aloe vera gel; (c) aloe gel extracted with hexane; (d) aloe gel extracted with mixture of hexane and ethanol; and (e) deterioration stage at 4th day

Source: Yuharmon, N. A. S., Mohamed, N. M., Chong, F. K., & Cheong, K. Y. (2018, November). Scanning electron microscopy of soxhlet extracted aloe vera gel for electrolyte application. In Journal of Physics: Conference Series (Vol. 1123, No. 1, p. 012070). IOP Publishing*

In the previous study, the results of observations of the microstructure of aloe vera gel with a variety of processes are shown in Figure 6. Figure 6 (a) and (b) show an image of the SEM microstructure of aloe vera gel on the surface. It can be seen that the Aloe gel layer consists of organic fibers and particles in irregular and disintegrating shapes, Figures 1 (c) and (d) show a uniform image of the lamella structure, while in (e) is the deterioration stage of the aloe vera after continues usage for four (4) days. This might be caused by the degradation of the pectin material during the extraction process. It mentions that looking at the performance for electrolyte applications, the average refractive index of aloe vera gel is 1.3337 ± 0.0002 for the younger and 1.3334 ± 0.0002 for the older ones, respectively. In this case, the gel with the lowest refractive index is the best treatment for the extraction process. This is due to the refractive index showing impurities in the extracted gel. Besides the older aloe vera gel was chosen because it has a lower refractive index, it also contains a higher viscosity value and the older aloe vera gel obtained characteristics suitable for electrolyte applications according to Yuharmon et al. (2018).

Hence, the electrode connector was designed based on these data presented. The maximum set of electrode connected in series was five (5) pairs, and to maximize the harvested voltage, additional set of electrode would be connected in parallel. Therefore, the developed electrode connecter was composed of two (2) sets connected in parallel with five (5) pairs of electrode connected in series per set.

The selection of a suitable of energy storage device was conducted in experiment between the two (2) most common materials which is the super capacitor and the li-ion battery. The first experiment was charging a 500 Farad, 2.7 volts super-capacitor, wherein 9 pairs of electrode was connected in series and the same experiment was conducted to an 1800mAh, 3.7 volts li-ion battery.

Table 8. Comparison of voltage generated from portable green enegry storage device vs different types of living plants

Name of plant	Voltage, V	Current, uA	Reference
Bigleaf maple tree	0.05 – 0.23	0.5 – 2.3	Himes et al., 2010
Pachira tree	0.80	3.0	Tanaka et al., 2012
Poplar tree	0.897 – 0.932	47.37 – 49.55	Hao et al., 2015
Avocado plant	0.52 – 0.67	1.54 – 2.08	Konstantopoulos et al., 2016
Pulai tree	0.80	Non-available	Choo and Dayou, 2013
Banana tree	0.913	Non-available	Choo and Dayou, 2013
Aloe vera	1.6 – 2.5	Non-available	*Present study

From Table 8. it is observed that the Aloe Vera leaf, which is inserted with a single pair of copper-zinc electrodes, is able to harvest approximately 1.6 V to 2.5 V, which is higher in magnitude compared to other plants. Upon experiment, the initial voltage from the Aloe vera was 3.6 volts, and it was observed that the charging rate of Li-ion Battery is higher than that of the super capacitor. The same test was repeated to both storage device but on a lower supplied voltage from the plant which 2.5 volts only, and the super capacitor did not accumulate energy from the source because of its fast charging/discharging characteristics, and as mentioned by Hester, et.al., (2015) that Larger capacitors also charge more slowly, incur longer power outages, and waste more energy (leakage), charge quickly, but may not be able to store enough energy for more power-hungry tasks. While the Li-ion battery keeps on charging even if the source voltage is below of its rated voltage. It is because the super capacitor has a low energy density unlike the battery which has a higher energy density. As described by Kelly (2007) that their energy density is very low. Hence they store very small amounts of energy and are not useful for applications in which significant energy storage is needed.

4. CONCLUSION

In summary, the effect of Natural Bio-Organic Material (NBOM) (i.e., aloe vera) experimentally proved to harness the waste mechanical energy into useful electrical green energy. The interactive interactions of the rotational effects on these chains between the thickness and the number of leaves doesn't affect the voltage generated wherein the highest voltage generated from the organic material (Aloe vera) was observed constant within ten (10) to thirty (30) minute of charging. The portable green energy device was intended to

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accumulate energy from organic material (Aloe vera) and supplied energy to low voltage load only due to the limited number of lithium-ion battery incorporated at the device, it seems that still need two (2) or more lithium-ion batteries needed for the portable green energy storage device to generate much higher voltage.

Recommendation for the said study based on the conclusions to have further study on the chemical and electrical characteristics' of an Aloe vera gel to generate higher voltage. Additional charging indicator was recommended to facilitate charging performance for suitable boost converter for the device to have a higher output. Anisotropy is the one that could add up for this research to develop more flexible and unique materials that are comparable to the results (Amatosa et al. 2019) for the generated energy. This weak energy might be useful to our nano-electronics devices. Hence, it was needed in forests and remote sites for researchers as a source of energy lightings and low voltage devices that could also be beneficial to the community, located in the far flung areas where there is no electricity.

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