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Chlorophyll's Dependency Towards Electrical Characteristics of Ananas Comosus Waste-Based Dye-Sensitized Solar Cell

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ABSTRACT

The presence of chlorophyll in the Ananas Comosus waste is useful in the fabrication of Dye Sensitized Solar Cell (DSSC) which is an alternative technology of solar cell. The purpose of the research is to fabricate DSSC from the waste. Mechanical extraction is applied here to extract the chlorophyll from the waste by using a saccharum machine. Ultraviolet-Visible Spectrophotometer (UV-VIS) is used to measure the content of chlorophyll a and chlorophyll b. The expected result of this experiment is to achieve higher chlorophyll content which is able to absorb more light energy from the sunlight. The extraction time to collect the juice sample is 3 times. The content of chlorophyll will eventually decrease if it is stored unused for a long period. DSSC will be fabricated with doped Titanium Dioxide, TiO_2 which are based on natural dyes from Malaysia tropical fruits, wherein contain chlorophyll which enhances the photosensitization effect due to the high interaction on the surface of the film. Such a natural dye extracted from Ananas Comosus can be subjected to molecular tailoring to give a superior dye preparation, offering a wide range of spectral absorption, covering the entire visible region (400-700 nm). Furthermore, the additive (4-tert-butylpyridine) in potassium iodide, KI electrolyte, affects the rate of electron injection into the oxidized dye sensitizer. Fluorine-doped tin oxide (FTO) conductive glass will be used to fabricate the solar cells. After the fabrication process is done, the solar cell was measured by multimeter to obtain the value of output voltage.

1. Introduction

Using oil, natural gas, or electricity (from power plants that utilize oil and coal) in our everyday lives increased the greenhouse effect, which is the cause of global warming and climate disruption, which has been more widespread in recent years. Apart from other renewable energy sources such as water, wind, biomass, geothermal, and others, many people feel that solar cells are one of the finest solutions for fixing difficulties [1]. Solar energy is believed to be a hope for a future source of

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renewable energy. The real challenge is to convert the light energy into electrical energy with a low cost. Photovoltaic (PV) cells (Crystalline silicon based) are widely used all over the world to capture the light energy [2]. It has reached the limits of technological advancement, but their high manufacturing costs limit their ability to compete with existing energy sources. There are several constraints such as heavy weight per area panels, fragile and also very low return of investment (ROI).

Post-harvest of Ananas Comosus plantation, Ananas Comosus waste (leaves) contribute to a large part of the plant that is unused. According to Crop Statistics 2022 reported by Jabatan Pertanian Malaysia, ananas comosus, has become the second highest in production of main fruits in Malaysia for 2022 with 377,300 tonnes harvested from 16,205 hectares of plantation areas. Waste is typically disposed of by burning or decomposing which eventually contributes to environmental problems. The DSSC is an economical PV cell that performs the same functions as conventional crystalline based PV cells [3]. This is due to its advances in nanostructured semiconductors, high-efficiency sensitizers, and strong electrolytes made from low-cost materials. Chlorophyll and anthocyanin are natural pigments that function as photosensitizers in DSSC, nevertheless chlorophylls are environmentally friendly, easily available and cheap [4,5].

The waste leaves are manipulated by fabricating the DSSC and the performance of the cells are analysed with different chlorophyll concentration. Solar cells based on natural dye sensitized photovoltaic, TiO_2 semiconductor material with KI liquid electrolyte and Carbon black as counter electrodes were fabricated [6,7]. Using the doctor rolling blade method which results in thin film morphology, there is also emphasis on natural dye extracted from Ananas Comosus as dye sensitizer [8]. The physical and electrical characteristics were performed to gain maximum efficiency in order to construct a competitive solar cells' panel.

2. Methodology

2.1 Collection and Preparation of Ananas Comosus Plantation Waste

Ananas Comosus plantation waste was manipulated as the sample of this study. The samples were collected at an industry in Pekan Pina Sdn Bhd, Pahang. The Ananas Comosus waste was collected in all parts such as leaves, roots and stamps around 10 kg. For the preparation of the sample, 10 kg of all the waste parts were separated into 3 parts which are leaves, roots and stamps by using a knife. The sample must be put in 3 different containers for cleaning. Label all the containers for leaves, roots and stamps. All the samples were cleaned by using tap water to remove the fungi, contaminants and soil [9]. Next, the cleaned sample needs to dry by using a paper towel and cut into small pieces by using a knife or scissors. Put all the samples into the label container. The sample was ready to extract by using a saccharum machine.

2.2 Extraction of Chlorophyll from Ananas Comosus Plantation Waste

The extraction of chlorophyll from the Ananas Comosus plantation waste was conducted in the laboratory and involved mechanical extraction method [10]. The material needed to be used was a saccharum machine to make juice from the sample. The steps to use the saccharum machine starting from the switch on the switch at the right side. Next, put the sample which was already prepared into the saccharum machine and pressed. The juice was produced at the middle part of the saccharum machine and filtered. The juice is flowed through the pipe and placed into the container by using a water hose. Then, the samples are ready to analyze the chlorophyll contained.

2.3 Analysis of Chlorophyll Content using UV-VIS Spectrophotometer

The chlorophyll content in the Ananas Comosus juice was examined by using the UV-Vis Spectrophotometer as in Figure 1. The color of the juice will help to identify the chlorophyll contained in the sample [11]. The chlorophyll was identified from the wavelength setting in the UV-VIS Spectrophotometer [12]. Before analyzing chlorophyll in the sample juice, water must be prepared as the blank in the UV-VIS Spectrophotometer. In general, the blank is a cuvette which contains everything in the sample juice, except the material that needs to be measured (Ananas Comosus waste juice) [13]. The function of blank is to measure the difference between blank and sample to avoid the calculation like zeroing an electronic scale [14]. The value of wavelength must be set up and run in the UV-VIS Spectrophotometer. The value of chlorophyll-a and -b must be read and recorded. According to Roskan *et al.,* [8], the total chlorophyll contents are divided into two which are chlorophyll a and chlorophyll- b. The wavelength must be set up in range 645 nm and 663 nm. Figure 2 shows the preparation of pineapple plantation waste in the laboratory.

Fig. 1. UV-VIS Spectrophotometer

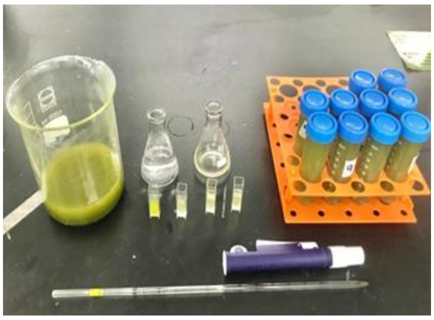
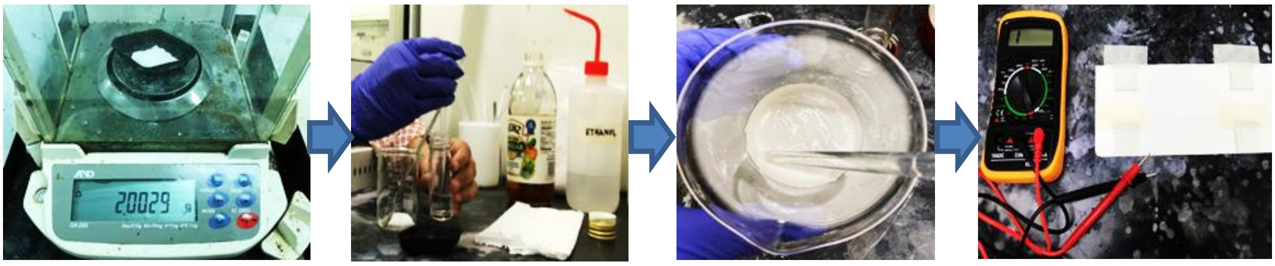


Fig. 2. Preparation of the pineapple plantation waste

2.4 Fabrication of DSSC

Titanium oxide (TiO_2) was used as photo electrode on fluorine oped tin oxide (FTO) as conductive glass [15]. The FTO conductive glasses used in this project are (2.5 cm × 2.5 cm) in size. Preparation of TiO_2 layers process is Titanium Dioxide (TiO_2) powder is weighted approximately 2 g by using analytical balance and placed into a beaker. The beaker is then gradually filled with 4 ml of ethanol and 2 ml of acetic acid. For 15 minutes, the mixture is stirred with a glass rod until it forms a paste. The beaker is covered by using aluminium foil and let it in fume hood for a while to let the particles equilibrium. The FTO conductive glass was cleaned by using ethanol because to remove any dust or material. Multimeter was used to measure the conductivity of FTO glass. Using the doctor blade method, TiO_2 paste is applied to the FTO glass [16]. Then, the uses of the tape to tape one side of the dye-sensitized solar cell are to make the FTO glass not moving and stay at that placed. Before heating, allow the paste to dry naturally in a fume hood at room temperature. FTO glass is heated by using a hot plate for 45 minutes at temperature 450 °C, as shown in Figure 3.

Preparation of photoelectrode and counter electrode process were performed to immerse the TiO_2 glass in a petri dish with three different dye extraction after done heating process, as shown in Figure 4. Next, the petri dish was wrapped using aluminium foil to prevent exposure to air and store it in a dark place for 24 hours [17]. Following that, rinse the FTO glass with distilled water to remove the juice that remains on the FTO glass during immerse process. Then, the other FTO glass is shaded to serve as a counter electrode. After that, clip between working electrode glass and counter electrode glass together to form a sandwich. Drop KI that react as electrolyte before measurement.



TiO₂ powder is weighted by using analytical balance

2 ml of ethanol and 4 ml of acetic acid is added gradually

The mixture is stirred for 15 minutes until it becomes a paste

Conductivity test of FTO glass by using a multimeter

Application of doctor rolling blade method

Let the paste dry in fume hood at room temperature

Heat by using a hot plate for 45 minutes at 450 °C

Immerse in dye solution using petri dish for 24 hours

Fig. 3. Preparation of TiO_2 layers and photoelectrode

Conductivity test of TiO_2 glass by using a multimeter.

The conductive side of the glass is coated with the carbon.

Counter electrode glass is heated on hot plate for 30 minutes at 450 °C.

TiO_2 glass is rinsed with distilled water and ethanol to remove excessive particles.

A drop of electrolyte KI is added, bind the two glasses by using alligator clip.

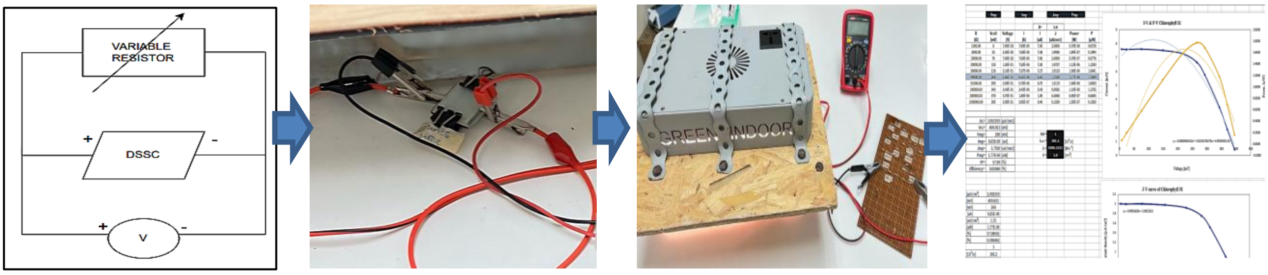
Fig. 4. Preparation of photoelectrode and counter electrode

After the fabrication has been successfully completed, the fabricated DSSC undergo electrical analysis. The photovoltaic test of dye-sensitized solar cells was carried out by measuring the I-V characteristic and J-V characteristic curves [18]. An indoor LED growlight was used as a lighting source, and the intensity of the incident light was approximated to around 1006.5311 W/m^2, the active areas of the cells are about 3.8cm^2. The completed DSSC was connected in series with the shunt resistor. Then, the multimeter was connected in parallel to measure the voltage across the resistor. Next, the DSSC was placed under the LED growlight-based solar simulator and measured. By varying the values of shunt resistor from 1 until 1M ohm, the short circuit current (Isc) can be soon determined using Ohm's law and the output power (P) value as well [19,20]. Next, the values of fill factor (FF) and efficiency can be determined using Eq. 1 and Eq. 2, respectively.

$$FF = \frac{V_{max} \times J_{max}}{V_{\propto} \times J_{SC}} \times 100\% \quad (1)$$

$$\eta = \frac{V_{\propto} \times J_{SC} \times FF}{P_{in}} \times 100\% = \frac{V_{max} \times J_{max}}{G \times A} \times 100\% \quad (2)$$

where J_{sc} is the short-circuit current density in milliamperes per square centimeter, Vα is the open-circuit voltage in volts, and Pin is the incident light power. J_{max} and V_{max} refer to the maximum values of current and voltage, respectively, indicated by the J–V curve. The fill factor (FF), related to the electron transfer mechanism and internal resistance of dye-sensitized solar cells, is a DSSC efficiency-influencing metric. The FF may thus be improved by lowering the internal series resistance, value of ≤ 1 and represents the squareness of the J-V curve. Furthermore, the ratio of the maximum power generated by a cell at its maximum power point to the power of stimulated illumination is the power conversion efficiency [21]. Next, the graph of I-V and J-V can be plotted from the measured parameter. Other critical parameters that must be determined are current at maximum point (Imp) and voltage at maximum point (Vmp). Figure 5 shows the I-V characteristics analysis of DSSC.



The constructed circuit for measurement of DSSC voltage

The completed DSSC was connected in series with the resistor

The developed solar simulator

Calculated and plotted the current-voltage (I-V) characteristic based on parameters measured under solar simulator

Fig. 5. Electrical analysis of I-V characteristics of DSSC

3. Results

3.1 Standard Calibration Curve of Chlorophyll-a and Chlorophyll-b

Figures 6 and 7 illustrate the calibration curve of Chlorophyll-a and Chlorophyll-b respectively. The concentration of chlorophyll and absorbance are the variables used to plot this calibration curve. The readings from the UV-Vis Spectrophotometer are tabulated in Table 1.

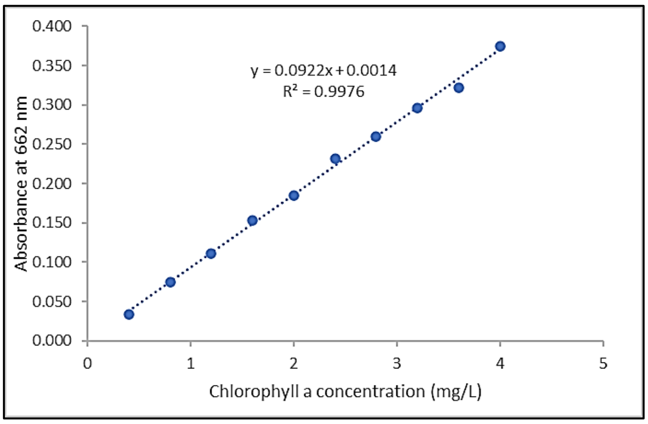


Fig. 6. UV-vis absorption spectra calibration curve of Chlorophyll-a

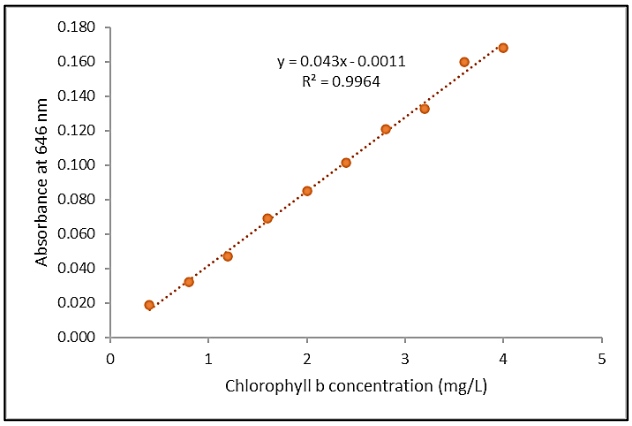


Fig. 7. UV-vis absorption spectra calibration curve of Chlorophyll-b

Table 1
Reading of chlorophyll absorbance

Chlorophyll-a						
Wavelength (nm)	Standard: Acetone	Chl-a con (mg/L)	Abs 1	Abs 2	Abs 3	Abs
662	0.1	0.4	0.033	0.034	0.036	0.034
662	0.2	0.8	0.073	0.074	0.076	0.074
662	0.3	1.2	0.110	0.111	0.113	0.111
662	0.4	1.6	0.152	0.153	0.155	0.153
662	0.5	2	0.183	0.185	0.186	0.185
662	0.6	2.4	0.230	0.232	0.233	0.232
662	0.7	2.8	0.259	0.259	0.261	0.260
662	0.8	3.2	0.296	0.297	0.297	0.297
662	0.9	3.6	0.322	0.321	0.322	0.322
662	1	4	0.390	0.366	0.367	0.374
Chlorophyll-b						
Wavelength (nm)	Standard: Acetone	Chl-b con (mg/L)	Abs 1	Abs 2	Abs 3	Abs
646	0.1	0.4	0.017	0.019	0.021	0.019
646	0.2	0.8	0.03	0.032	0.034	0.032
646	0.3	1.2	0.045	0.047	0.049	0.047
646	0.4	1.6	0.067	0.069	0.071	0.069
646	0.5	2	0.083	0.085	0.087	0.085
646	0.6	2.4	0.1	0.101	0.104	0.102
646	0.7	2.8	0.119	0.121	0.123	0.121
646	0.8	3.2	0.131	0.133	0.135	0.133
646	0.9	3.6	0.155	0.161	0.164	0.160
646	1	4	0.164	0.167	0.173	0.168

A standard solution was prepared and measured using UV-vis spectrophotometer. Based on Figure 8, the absorbance level of Chlorophyll-a is higher as compared to Chlorophyll-b. These two molecules absorb light at different wavelengths. Chlorophyll-a has two absorption peaks, the first one at 430 nm and the second one at 663 nm [22]. Chlorophyll-b has absorption peaks at 480 nm and 650 nm. Hence, Chlorophyll-a has the ability to absorb more sunlight than Chlorophyll-b.

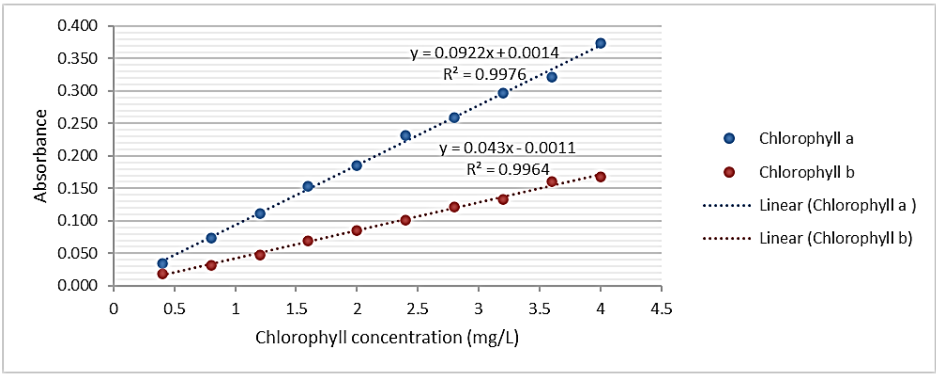


Fig. 8. UV-vis absorption spectra calibration curve of Chlorophyll-a (blue) and Chlorophyll-b (red)

3.2 Results and Discussion of I-V and J-V Characteristics of DSSC

Values of open circuit voltage (Voc) was determined using the setup apparatus of solar simulator connected with shunt resistors and multimeter. Next, the current of the short circuit (Isc) was derived based on the recorded series of shunt voltage data as calculated by using the formula of Ohm's law. Then, to obtain the power value, use the formula of power output. The power-voltage (P-V), and current density-voltage (J-V) curves were used to analyse the DSSC's overall photovoltaic performance. The J-V curve of the DSSC using sample is displayed in the Figure 9. The trendline is included separately from the dotted blue line. The linear degradation is included to obtain an approximated value of short circuit current (Isc), and the nonlinear degradation is included to obtain an approximated value of open-circuit voltage (Voc) [23,24]. Both trendlines are derived from the dotted blue line. Figure 10 represents the physical results of each of the sample's electrolytes. The description of the samples is as follows:

i. Sample 1: Leaves only, 3 times extraction, pre-heated, 8 hours storage.
ii. Sample 2: Leaves only, 1 times extraction, pre-heated, 8 hours storage.
iii. Sample 3: Leaves only, 3 times extraction, non-heated, 8 hours storage.
iv. Sample 4: Leaves only, 1 times extraction, non-heated, 8 hours storage.

Based on this figure, times of extraction and pre-heat treatment had been manipulated to achieve a better chlorophyll content. As a result, the optimum extraction time obtained was 3 times with non-pre-heat treatment.

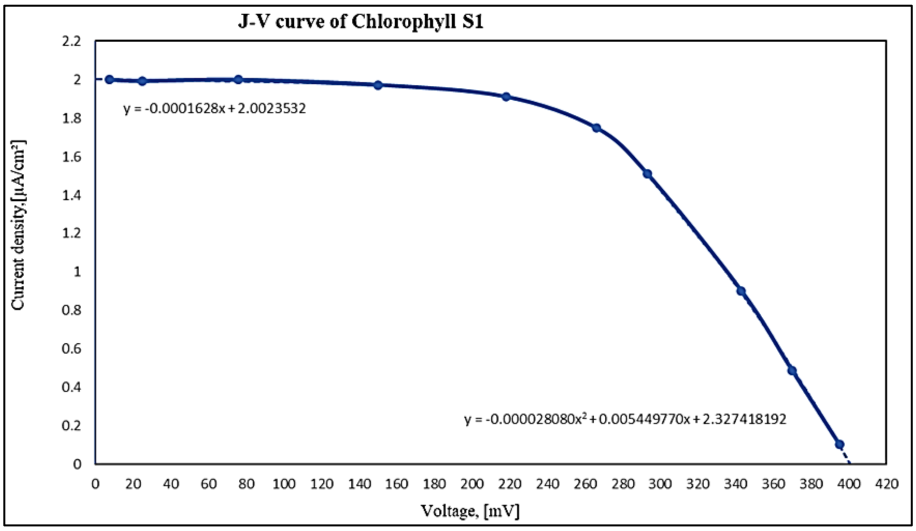


Fig. 9. J-V characteristic of chlorophyll sample 1

Fig. 10. Fabricated DSSC and electrolyte of each sample

3.2.1 Fabricated DSSC of chlorophyll sample 1

The electrical parameters varied and measured of the chlorophyll sample 1 are represented in Table 2. There are several fixed values of resistor used in this measurement (1k ohm to 1M ohm).

Th0e changing resistance affects the total amount of power produced by the solar cell. The way to calculate the maximum power point (Pmp) is to find the highest point at which the product of the voltage and current. Therefore, the measured data resulting in the maximum power point was Pmp = 1.7689µW and had a voltage of maximum point, Vmp = 266mV, and a current of maximum point, Imp = 1.75007µA.

Table 2
Parameter of chlorophyll sample 1

R [Ω]	Vcell [mV]	I [uA]	J [uA/cm2]	P [µW]
1000.00	8	7.60	2.0000	0.0578
3300.00	25	7.58	1.9936	0.1894
10000.00	76	7.60	2.0000	0.5776
20000.00	150	7.50	1.9737	1.1250
30000.00	218	7.27	1.9123	1.5841
40000.00	266	6.65	1.7500	1.7689
51000.00	293	5.75	1.5119	1.6833
100000.00	343	3.43	0.9026	1.1765
200000.00	370	1.85	0.4868	0.6845
1000000.00	395	0.40	0.1039	0.1560

Based on Figure 9, the J-V curve, the short circuit current shows the value of Jsc= 2.002353µA/cm² and the value of the open circuit voltage is 400.921mV. Table 3 presents the summarization of the performance parameter of the chlorophyll sample 1. The table shows the fill factor and efficiency value are 57.99% and 0.000462%, respectively.

Table 3
Performance of electrical parameters for chlorophyll sample 1

Jsc	[µA/cm²]	2.002353
Voc	[mV]	400.921
Vmp	[mV]	266
Imp	[uA]	6.65E-06
Jmp	[uA/cm²]	1.75
Pmp	[uW]	1.77E-06
FF	[%]	57.98561
Efficiency	[%]	0.000462
AM		1
Lux	[10^3 lx]	181.5
G	[Wm^{-2}]	1006.531
A	[cm^2]	3.8

3.2.2 Fabricated DSSC of chlorophyll sample 2

The electrical parameters varied and measured of the chlorophyll sample 2 are represented in Table 4. There are several fixed values of resistor used in this measurement (1k ohm to 1M ohm). The changing resistance affects the total amount of power produced by the solar cell. The way to calculate the maximum power point (Pmp) is to find the highest point at which the product of the voltage and current. Therefore, the measured data resulting in the maximum power point was Pmp = 1.6129µW and had a voltage of maximum point, Vmp = 254mV, and a current of maximum point, Imp = 1.67117µA.

Table 4
Parameter of chlorophyll sample 2

R [Ω]	Vcell [mV]	I [uA]	J [uA/cm2]	P [µW]
1000.00	7	7.22	1.9000	0.0521
3300.00	24	7.20	1.8939	0.1709
10000.00	71	7.10	1.8684	0.5041
20000.00	141	7.05	1.8553	0.9941
30000.00	205	6.83	1.7982	1.4008
40000.00	254	6.35	1.6711	1.6129
51000.00	276	5.41	1.4241	1.4936
100000.00	326	3.26	0.8575	1.0618
200000.00	356	1.78	0.4688	0.6346
1000000.00	374	0.37	0.0985	0.1401

Figure 11 represents the J-V curve of chlorophyll sample 2. Based on the J-V curve, the short circuit current shows the value of Jsc= 1.6711µA/cm² and the value of the open circuit voltage is 254mV. Table 5 presents the summarization of the performance parameter of the chlorophyll sample 2. The table shows the fill factor and efficiency values are 58.86% and 0.00042%, respectively.

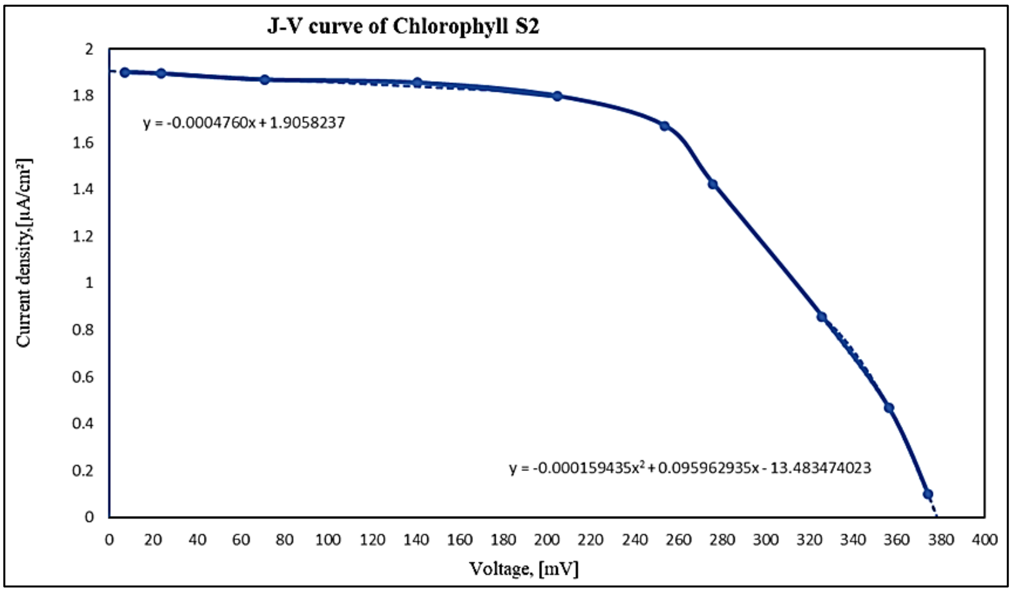


Fig. 11. J-V characteristic of chlorophyll sample 2

Table 5
Performance of electrical parameters for chlorophyll sample 2

Jsc	[µA/cm²]	1.905824
Voc	[mV]	378.398
Vmp	[mV]	254
Imp	[uA]	6.35E-06
Jmp	[uA/cm²]	1.6711
Pmp	[uW]	1.61E-06
FF	[%]	58.86
Efficiency	[%]	0.00042
AM		1
Lux	[10^3 lx]	181.5
G	[Wm^{-2}]	1006.531
A	[cm^2]	3.8

3.2.3 Fabricated DSSC of chlorophyll sample 3

The electrical parameters varied and measured of the chlorophyll sample 3 are represented in Table 6. There are several fixed values of resistor used in this measurement (1k ohm to 1M ohm). The changing resistance affects the total amount of power produced by the solar cell. The way to calculate the maximum power point (Pmp) is to find the highest point at which the product of the voltage and current. Therefore, the measured data resulting in the maximum power point was Pmp = 0.5929µW and had a voltage of maximum point, Vmp = 154mV, and a current of maximum point, Imp = 1.0132µA.

Table 6
Parameter of chlorophyll sample 3

R [Ω]	Vcell [mV]	I [uA]	J [uA/cm2]	P [µW]
1000.00	5	4.56	1.2000	0.0208
3300.00	15	4.55	1.1962	0.0682
10000.00	44	4.44	1.1684	0.1971
20000.00	85	4.25	1.1184	0.3613
30000.00	131	4.36	1.1474	0.5703
40000.00	154	3.85	1.0132	0.5929
51000.00	178	3.49	0.9185	0.6213
100000.00	205	2.05	0.5395	0.4203
200000.00	225	1.13	0.2961	0.2531
1000000.00	236	0.24	0.0622	0.0559

Figure 12 represents the J-V curve of chlorophyll sample 3. Based on the J-V curve, the short circuit current shows the value of Jsc= 1.209354µA/cm² and the value of the open circuit voltage is 241.1424mV. Table 7 presents the summarization of the performance parameter of the chlorophyll sample 3. The table shows the fill factor and efficiency values are 53.50% and 0.00016%, respectively.

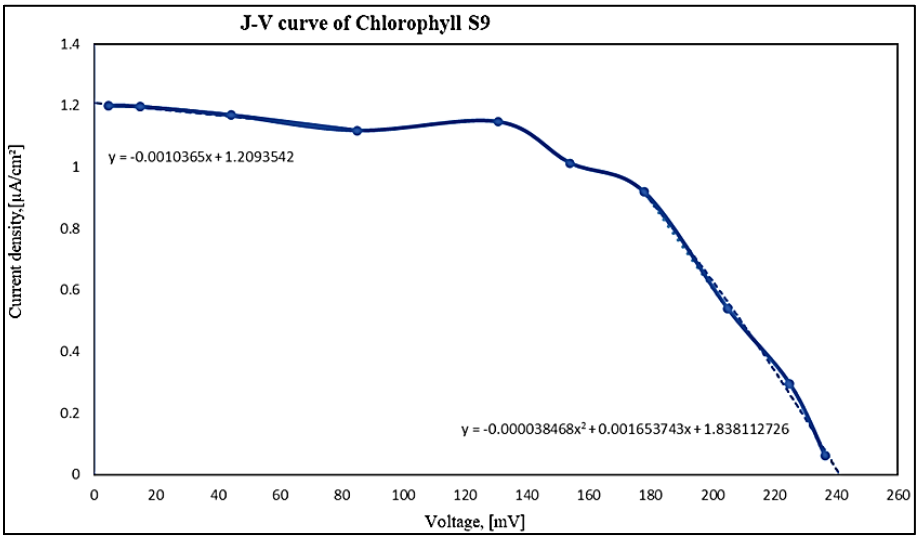


Fig. 12. J-V characteristic of chlorophyll sample 3

Table 7
Performance of electrical parameters for chlorophyll sample 3

Jsc	[μA/cm²]	1.209354
Voc	[mV]	241.1424
Vmp	[mV]	154
Imp	[uA]	3.85E-06
Jmp	[uA/cm²]	1.0132
Pmp	[uW]	5.93E-07
FF	[%]	53.50
Efficiency	[%]	0.00016
AM		1
Lux	[10^3 lx]	181.5
G	[Wm^{-2}]	1006.531
A	[cm^2]	3.8

3.2.4 Fabricated DSSC of chlorophyll sample 4

The electrical parameters varied and measured of the chlorophyll sample 4 are represented in Table 8. There are several fixed values of resistor used in this measurement (1k ohm to 1M ohm). The changing resistance affects the total amount of power produced by the solar cell. The way to calculate the maximum power point (Pmp) is to find the highest point at which the product of the voltage and current. Therefore, the measured data resulting in the maximum power point was Pmp = 0.0992μW and had a voltage of maximum point, Vmp = 63mV, and a current of maximum point, Imp = 0.4145μA.

Table 8
Parameter of chlorophyll sample 4

R [Ω]	Vcell [mV]	I [uA]	J [uA/cm2]	P [μW]
1000.00	2	1.90	0.5000	0.0036
3300.00	6	1.89	0.4984	0.0118
10000.00	19	1.85	0.4868	0.0342
20000.00	35	1.75	0.4605	0.0613
30000.00	55	1.82	0.4781	0.0990
40000.00	63	1.58	0.4145	0.0992
51000.00	73	1.44	0.3780	0.1052
100000.00	84	0.84	0.2211	0.0706
200000.00	94	0.47	0.1234	0.0439
1000000.00	99	0.10	0.0259	0.0097

Figure 13 represents the J-V curve of chlorophyll sample 4. Based on the J-V curve, the short circuit current shows the value of Jsc= 0.505114μA/cm² and the value of the open circuit voltage is 101.176mV. Table 9 presents the summarization of the performance parameter of the chlorophyll sample 4. The table shows the fill factor and efficiency values are 51.09% and 0.00003%, respectively.

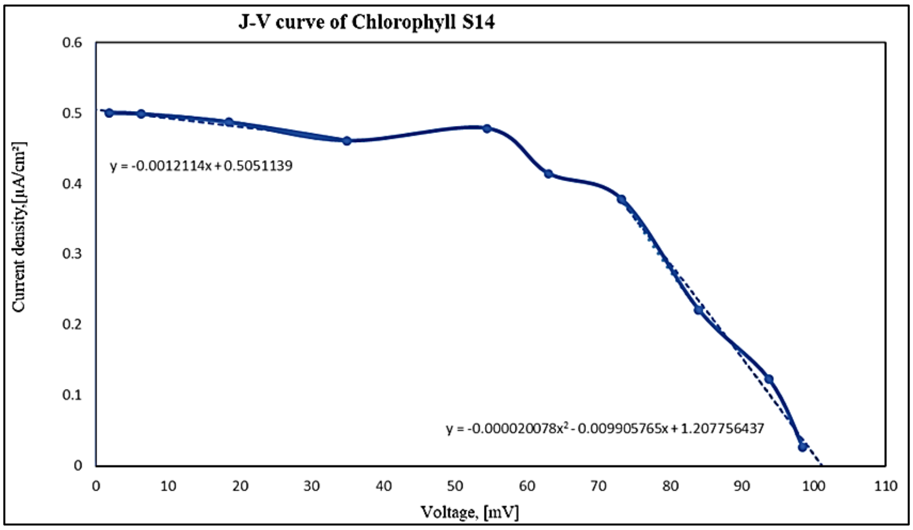


Fig. 13. J-V characteristic of chlorophyll sample 4

Table 9
Performance of electrical parameters for chlorophyll sample 4

Jsc	[µA/cm²]	0.505114
Voc	[mV]	101.176
Vmp	[mV]	63
Imp	[uA]	1.58E-06
Jmp	[uA/cm²]	0.4145
Pmp	[uW]	9.92E-08
FF	[%]	51.09
Efficiency	[%]	0.00003
AM		1
Lux	[10^3 lx]	181.5
G	[Wm^{-2}]	1006.531
A	[cm^2]	3.8

3.3 Discussion J-V Characteristics of DSSC

Table 10 and Table 11 exhibit performance of electrical parameters for all samples. The extraction time and pre-heat-treatment of chlorophyll sample has greatly influenced the performance of chlorophyll concentration DSSC samples. From both tables, it can be suggested that the 3 times extraction time without pre-heat-treatment gives higher values of Voc, Jsc, Pmp, and efficiency. Therefore, it can be justified that when the higher the extraction time of chlorophyll, the higher the values of Voc and Jsc. It is proven that the sample 1 has better performance compared to that of Sample 2 with Voc = 401mV, Jsc = 2.002 µA/cm², FF = 57.99%, and η= 0.000462%.

Table 10
Comparison of factor towards chlorophyll concentration

Electrolyte Sample	Factor				Chl-a (mg/L)	Chl-b (mg/L)	Jsc (µA/cm²)
	Type of waste	Time of extraction	Time of storage	Pre-heat treatment			
1	Leaves only	3	8	No	10.51	21.75	2.002
2	Leaves only	1	8	No	7.37	13.23	1.906
3	Leaves only	3	8	Yes	9.74	20.15	1.209
4	Leaves only	1	8	Yes	4.11	8.64	0.505

Table 11
Comparison of chlorophyll electrolyte sample

Parameter	Sample of chlorophyll electrolyte			
	Sample 1	Sample 2	Sample 3	Sample 4
Voc (mV)	401	378	241	101
Jsc (μA/cm²)	2.002	1.906	1.209	0.505
Pmp (μW)	1.77E-06	1.61E-06	5.93E-07	9.92E-08
FF (%)	57.99	58.86	53.50	51.09
η (%)	0.000462	0.000422	0.000155	0.000026

4. Conclusions

In conclusion, four samples of DSSCs have been successfully fabricated. Those samples include leaves only with 3 times extraction of pre-heated at 8 hours storage, leaves only with 1 time extraction of pre-heated at 8 hours storage, leaves only with 3-time extraction of non-pre-heated at 8 hours storage, leaves only with 1 time extraction of non-pre-heated at 8 hours storage.

After a few methods of measurements, it has been found that the DSSC sample with 3 times extraction of non-pre-heated at 8 hours storage achieves the highest efficiency and has the tendency to generate the highest output compared to the other samples. The sample with pre-heated dye solution used to be immersed in TiO_2 tends to show low efficiency in comparison to non-pre-heated dye solution. This is because pre-heating can damage the chlorophyll particles and reduce the green colour of the leaves. 3 times extraction is found to has higher chlorophyll content as opposed to 1 time extraction due to the fact that 3 times extraction produces more concentrated dye solution.

All factors studied in this project which are storage time and heat pre-treatment towards output voltage have been validated. By completing this experiment, we are able to achieve all the objectives in this project.

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