Dye-Sensitized Solar Cells Characterization of Kitolod Leaves (Hippobroma longifora)

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Abstract – *Energy from fossil fuels is decreasing day by day and also causes many environmental problems. In the current era, many environmentally friendly renewable energy sources have been developed, such as the development of DSSC (Dye Sensitized Solar Cells). DSSC is a technology that utilizes colored materials sourced from nature which are used as absorbers of sunlight energy to be converted into electrical energy. In this research, the synthesis and characterization of organic material from kitolod leaves as DSSC will be carried out. Kitolod leaves (Hippobroma longifora) are wild plants that usually grow in home gardens and rice fields. Kitolod leaves which have chlorophyll can support the absorption of sunlight if applied as a sensitizer in DSSC. The methods that will be used in this research are making TiO_2 paste, dye solution preparation, electrolyte solution preparation, DSSC fabrication, testing and characterization. The tests that will be carried out are testing the TiO2 layer, dye absorption, and electric current. Meanwhile, the characterization that will be carried out is dye absorption using UV-Vis, and electric current using a potentiometer. From the results of light absorption shows that when the wavelength is 500 nm or the green light spectrum, the maximum light absorption by the chlorophyll of kitolod leaves is 1.78 (a.u.). The maximum voltage (V_m) and maximum current (I_m) in daylight lamps have greater values compared to warm white lamps. The highest efficiency of the solar light source is shown when the air mass is 1.5 (08.30-08.40). The time of DSSC immersion in dye also influences the resulting of V_m and I_m values which can be shown in that the V_m and I_m values of DSSC 2 (30 minutes) are greater than those of DSSC 1 (10 minutes). The results of open circuit voltage (V_{oc}) and the short circuit current (I_{sc}) in this research still need to be improved to produce better efficiency.*

Keywords*: Dye Sensitized Solar Cells; Kitolod Leaves; Solar Cell Efficiency*

INTRODUCTION

Solar cells have been developed as a novelty in the development of renewable energy. Energy sources from fossil fuels are decreasing and causing a lot of environmental damage (Al Huda, 2023). Solar cells use the principle of converting light energy into electrical energy. In solar cells there are materials called semiconductor materials. One of the developments in solar cells that is widely carried out is manufacturing Dye Sensitized Solar Cell (DSSC). DSSC is a photoelectrochemical-based solar cell that is environmentally friendly and easy to find in nature (Kim et al., 2021). DSSC uses a lot of organic materials from nature such as skin, fruit, flowers (Rajendran et al., 2023). DSSC consists of nanocrystalline semiconductor electrodes, color absorbing dye, electrodes counter, and electrodes containing iodide and triiodide ions (Teja et al., 2023).

Many dyes or dyes used in DSSC have been developed, including pandan leaves (Pratama, 2023), dragon fruit skin and flesh (Hayat et al., 2023), chrysanthemum flowers (Abidin, 2018), and so on. Dye as a sensitizer comes from natural ingredients as an alternative to synthetic dyes which are more expensive. Natural dye is produced from plant extracts which are used as photosentizers in dye-sensitized solar cell systems (Saridewi et al., 2021). Dye can function as an absorber of radiation from sunlight. Pigments in natural dyes that have wide electronic absorption characteristics in the visible light region of the sunlight spectrum will absorb more solar radiation and become good sensitizers.

The processes of light absorption and electrical charge transfer in DSSC occur separately. Light absorption is carried out by dye molecules, while electrical charge transfer is carried out by semiconductors which have a relatively wide band gap. Titanium dioxide (TiO_2) which is often used by previous researchers, because it is relatively cheap, inert and non-toxic. The criteria for the dye used must be able to absorb a wide spectrum of light and match the TiO_2 energy band gap (3,2eV) (Zhang et al., 2021, p. 2).

Research on DSSC has been developed previously using dye sensitizers made from various natural dyes. In DSSC research which used mangosteen peel as a natural coloring agent, it had a fairly high efficiency, namely 1.72% (Rahayu et al., 2019). Apart from that, Andari (2017) has also conducted research on DSSC using natural dyes from butterfly pea flowers and produced an efficiency of 0.18% (Andari, 2017). Apart from that, previous research was also carried out using rosella flowers as a dye source which resulted in a solar cell efficiency of 0.52% (Hayat et al., 2019). Several previous studies have shown that natural dyes produced from plant extracts can provide efficiency in solar cells.

Kitolod leaves contain compounds including flavonoids, alkaloids, tannins, saponins, polyphenols. Flavonoids are one of the largest groups of natural phenolic compounds found in green plants, except algae. There are several subclasses of flavonoids including flavanols, flavanones, flavones, isoflavones, anthocyanidins, and flavanols. Flavanols are widely distributed in plants, both as anthocyanin pigments in petals and in the leaves of higher plants (Gloriana and Sagita, 2021). Anthocyanin is a compound that can absorb sunlight well. Anthocyanins have many π bonds. The more π bonds, the more electrons that will be excited, so the higher the resulting DSSC efficiency (Pramananda et al., 2021).

In this research, organic sensitizer materials from kitolod leaves and TiO semiconductors will be used2 in making DSSC. Kitolod leaves are often found in bushes in home gardens and in rice fields. The green and blue pigments in kitolod leaves can be used to absorb sunlight. Green pigment can absorb purple light (Liu and Van Iersel, 2021). Kitolod leaves are also used in the medical world as a wound medicine (Awwaliyah et al., 2023). With the abundance of kitolod leaves around us, the extraction of dye from kitolod leaves which has not previously been used as a DSSC material can increase its benefits in energy conversion through making DSSC. For characterization in this study, two variations of dyeing were used to extract kitolod leaf dye, namely dipping for 10 minutes and 30 minutes.

RESEARCH METHODS

The stages in this research include making TiO_2 paste, preparation of dye solution from kitolod leaves, preparation of electrolyte solution, preparation of carbon counter-electrodes, DSSC fabrication, and finally testing and characterization.

1. *Making TiO_2 paste*

The TiO_2 paste preparation stage was carried out using a thick layer technique by mixing 3.07 grams of polyvinyl alcohol (PVA) into 30 ml of distilled water, then stirring it for 30 minutes at a temperature of 40◦C using a magnetic stirrer. Then, 3.10

grams of TiO_2 powder added until a paste forms.

2. Preparation of dye solution

A dye solution was prepared for the extraction of anthocyanins from kitolod leaves. Kitolod leaves are washed and dried. Then 10.2 grams of fresh kitolod leaves were crushed by adding 5 ml of 95% ethanol, 4 ml of acetic acid and 21 ml of distilled water. After soaking for 24 hours, the anthocyanins were extracted using Whatman filter paper and stored in a dark colored bottle and wrapped in aluminum foil.

3. Preparation of electrolyte solution

An electrolyte solution made by mixing 0.83 grams of potassium iodide (KI) into 10 ml of acetonitrile and stirred for 10 minutes until dissolved. Then add 0.127 grams of Iodine and stir for 30 minutes. The solution is then stored in a closed bottle.

4. Preparation counter electrode carbon

The carbon source was obtained from 2B pencil graphite which was shaded on the conductive part of the 2x1 cm^2 ITO until it was evenly distributed as in Figure 1. The glass is burned over a candle flame with the shade facing the flame. Burning is carried out until the flame soot covers the ITO conductive surface.

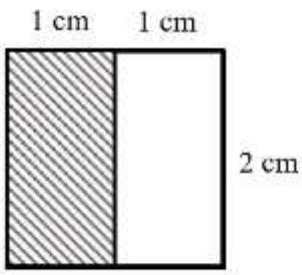


Figure 1. ITO glass as counter-electrode

5. Fabrikasi DSSC

DSSC fabrication was carried out by depositing TiO_2 paste on ITO measuring 2×2 cm^2 in the conductive part so that an area of 2×1 cm^2 is formed as in Figure 2. The deposition process is carried out using the doctor blade method. The layers formed were dried for 24 hours and burned in an electric oven at 480°C for 30 minutes. Then let it sit until it cools. TiO_2 layer Soaked in dye solution for 10 minutes and 30 minutes. Next, ITO was rinsed with distilled water and ethanol and allowed to dry for cyanine adsorption onto the TiO_2 surface. Cyanine replaces the OH^- of the Ti (IV) structure in combination with a proton from the anthocyanin group. The carbon counter-electrode is placed on the TiO_2 layer with a sandwich structure, each end is offset by 0.5 cm for electrical contact as in Figure 3. Then both sides are clamped with clips to stabilize the cell structure. In the space between the electrodes, 2 drops of electrolyte solution are added.

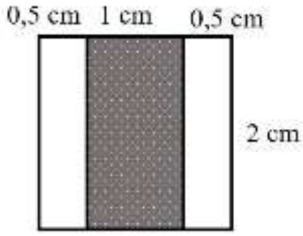


Figure 2. Schematic of the TiO_2 paste deposition area

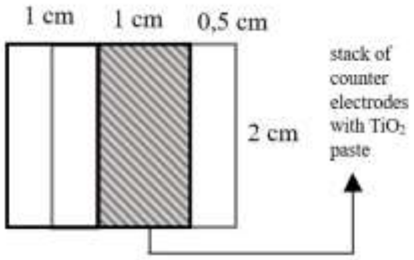


Figure 3. Schematic of ITO DSSC glass sandwich

6. DSSC characterization test

Characterization of DSSC samples from kitolod leaves was carried out for two sample variations, namely immersion for 10 minutes and 30 minutes. Each sample is tested for light absorption which will be converted into electrical energy through potentiometer testing. Apart from that, the dye from kitolod leaves was subjected to UV-Visible testing to determine the absorbance of light.

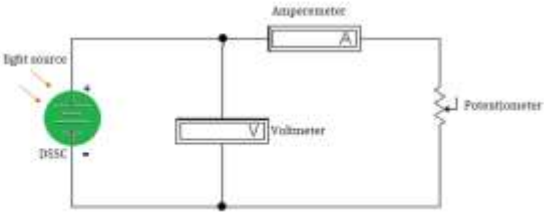
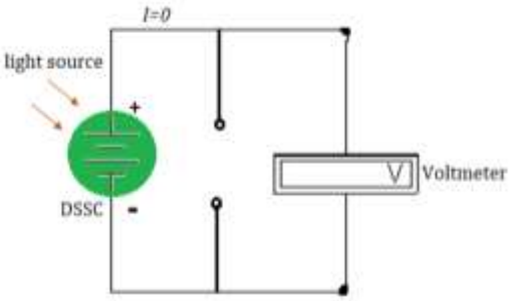
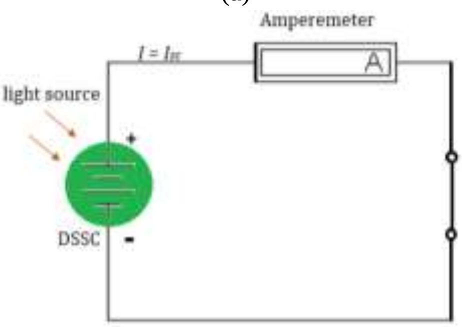


Figure 4. Current and voltage measurement circuit

Electrical testing is carried out using sunlight sources, daylight lamps, and warm white lamps. Electrical testing aims to determine the amount of current produced by the DSSC layer of kitolod leaves. From electrical testing, the current and voltage values for each resistance variation are obtained (figure 4) and the open circuit voltage (V_{oc}) and short circuit current (I_{sc}) (figure 5). The resulting current and voltage values are measured by varying the resistance from 10 Ω to 10 kΩ to obtain the maximum current and maximum voltage. Apart from that, a luxmeter is also used to determine the amount of light produced from a light source.



(a)



(b)

Figure 5. a) Open circuit voltage network and b) short circuit current network

RESULTS AND DISCUSSION

Analysis of dye absorbance of kitolod leaves

Light absorption testing is carried out through UV-Vis spectrometer testing. This test aims to determine what wavelengths of light can be absorbed by the chlorophyll of kitolod leaves. The results of the UV-Vis chlorophyll test on kitolod leaves are shown in Figure 6.

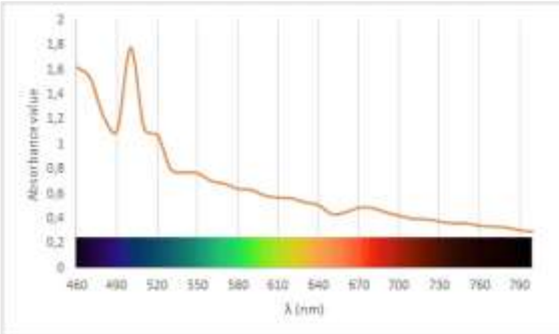


Figure 6. UV-Vis test results on kitolod leaf chlorophyll

The UV-Vis test results in Figure 3 show that when the wavelength is 500 nm or the green light spectrum, the maximum light absorption by the chlorophyll of kitolod leaves is 1.78 (a.u.). Apart from that, at a wavelength of 460 nm (purple light) it also absorbs a lot of light of 1.623 (a.u.). This can be compared with research conducted by (Prayoga, et al), the results of dye absorbance testing on papaya leaf chlorophyll which has a characteristic absorption level of 4 (a.u) at a light wavelength of 450-500 nm (Fitri, 2022).

In accordance with the character of chlorophyll, the results of absorbance at short wavelengths provide quite high results. Most chlorophyll extracts are very good for use as a base material for DSSC dye because they can absorb sunlight which is UV light with a wavelength range between 100 nm – 700 nm (Ardianto et al., 2015). So, it shows that the chlorophyll of kitolod leaves used in this research can be used as a basic ingredient for DSSC dye.

Analysis of DSSC electrical test results for kitolod leaves

The results of electrical testing were carried out to determine the ability to convert sunlight into electrical energy. The presence of electrical energy can be determined if there is current flowing in the kitolod leaf DSSC circuit. The circuit used is as in Figure 4. From this circuit, the voltage and current from the 2 variations of DSSC are obtained. DSSC 1 is a DSSC of kitolod leaves with a duration of immersion in the chlorophyll of kitolod leaves for 10 minutes. Meanwhile DSSC 2 with immersion for 30 minutes because this duration is in accordance with research Prayogo (2014) (Prayogo et al., 2014). while the immersion duration of 10 minutes was chosen to find out the comparative results with less time.

The results of testing the presence of electrical energy from the DSSC that has been made obtained the maximum voltage value (V_m) and maximum current value (I_m). This value is obtained from the area resulting from multiplying the voltage value and current value for each variation. There are 3 light sources used in electrical testing, namely daylight, warm white light and sunlight. The sunlight is taken at 3 times, namely morning (8 a.m.), afternoon (1 p.m.), and evening (4 p.m.).

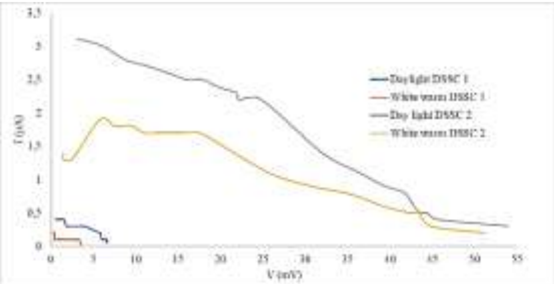


Figure 7. Test results for voltage and current values with a lamp light source

The test results for voltage and current values with variations in light sources are shown in Figure 7. Meanwhile, the results of calculating the maximum voltage and maximum current values for each variation are shown in Table 1.

Table 1. Calculation results of I_m and V_m DSSC with a lamp light source

Light Source	DSSC 1		DSSC 2	
	V_m (mV)	I_m (µA)	V_m (mV)	I_m (µA)
Daylight	3,9	0,3	24,8	2,2
White warm	3,4	0,1	19	1,6

V value V_m and I_m obtained from the I-V curve after testing using load variations. From the light source data obtained, it shows that V_m and I_m Daylight lamps have a greater value than warm white lamps. The illumination from daylight lamps is 5878 lux and warm white lamps are 3225 lux. This shows that the greater the light intensity given, the V_m and I_m values increase. The time of DSSC immersion in dye also influences the resulting V_m and I_m values which can be shown in that the V_m and I_m values of DSSC 2 are greater than those of DSSC 1. The longer the immersion in dye, the greater the level of absorption of chlorophyll contained in DSSC.

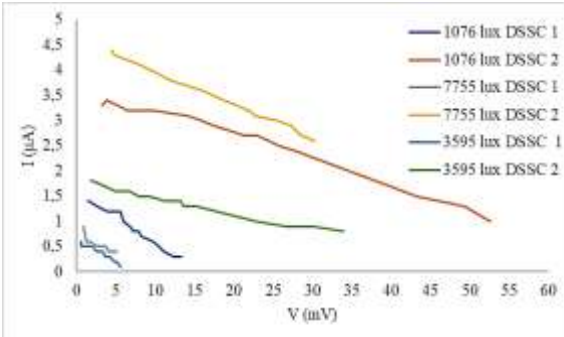


Figure 8. Test results for voltage and current values with a sunlight source

Table 2. Results of Im and Vm DSSC calculations with a solar light source

Ilumination (lux)	DSSC 1		DSSC 2	
	V_m (mV)	I_m (µA)	V_m (mV)	I_m (µA)
1076	5,6	1,2	39,8	1,7
7755	5,1	0,4	27,3	2,9
3595	3,4	0,4	30,2	0,9

Electrical testing with a sunlight source with 3 times variations, namely morning (1076 lux), afternoon (7755 lux) and evening (3595 lux) is shown in figure 8 and the results of the I_m and V_m calculations are shown in table 2. The results obtained show the maximum current value The highest is the DSSC 2 variation during the day because it has the greatest sunlight illumination.

Table 3. Voc and Isc measurement results

Ilumination (lux)	Light Source	Voc (mV)	Isc (µA)
1076	pagi	16,1	1,4
3225	white warm	5,6	0,2
3595	sore	11,6	0,6
5878	daylight	10,5	0,5
7755	siang	14,2	0,9

Electrical testing, apart from obtaining V_m and I_m, is also used to determine the open circuit voltage (V_{oc}) and short circuit current (I_{sc}) values which are shown in table 3. From these measurements it is known that the V_{oc} and I_{sc} values of the white warm light source have lower values. compared to daylight lamps. This is comparable to research conducted by A.F. Prayogo, et al., that the DSSC that has been made provides the highest voltage output (V_{oc}) given Cool Daylight LED light compared to CFL or Warm White LED (Prayogo et al., 2014).

Table 4. Calculation of the DSSC efficiency value of kitolod leaves using a lamp light source

Characteristic	DSSC 1		DSSC 2	
	daylight	white warm	daylight	white warm
Im	0,3	0,1	2,2	1,6
Vm	3,9	3,4	24,8	19
Isc	0,5	0,2	3,1	1,4
Voc	10,5	5,6	60,1	44,4
Fill factor (%)	22,29	30,36	29,28	48,91
efisiensi (%)	1,00	0,53	46,41	47,13

Table 5. Calculation of the DSSC efficiency value of kitolod leaves with a sunlight source

Charac-teristic	DSSC 1			DSSC 2		
	1076	7755	3595	1076	7755	3595
Im	1,2	0,4	0,4	1,7	2,9	0,9
Vm	5,6	5,1	3,4	39,8	27,3	30,2
Isc	1,4	0,9	0,6	3,3	4,4	1,7
Voc	16,1	14,2	11,6	58,6	57,3	43,4
Fill factor (%)	29,81	15,96	19,54	34,99	31,40	36,84
efisiensi (%)	31,23	1,32	1,89	314,4	51,04	37,80

The efficiency value of a solar cell is determined by the Fill factor value which can be known from DSSC maximum power measurements (V_m x I_m). Apart from that, the efficiency value is also determined by the open circuit voltage (V_{oc}) and short circuit current (I_{sc}). The smaller the values of V_{oc} and I_{sc}, the greater the resulting efficiency value.

The efficiency of the solar cells produced by DSSC dye kitolod leaves in table 4 and table 5 with immersion for 30 minutes has a greater value compared to DSSC dye kitolod leaves with immersion for 10 minutes. This happens because the longer dyeing duration causes more dye to be absorbed into the TiO2 layer so that it can absorb more energy (Mujtahid et al., 2022).

From the results, the highest efficiency is shown in DSSC 2 when the light is illumination with 1076 lux when the Air Mass is 1.5. Meanwhile, during the day and evening the efficiency is lower than in the morning, this can be caused by the quality of the dye which has the weakness of being easily oxidized and decreasing in quality when exposed to light. So, with the decreasing ability of Dye to function as a photon catcher from sunlight, the ability of DSSC to produce electric voltage also decreases (Sukardi et al., 2018).

CONCLUSION

The results of light absorption testing carried out through UV-Vis spectrometer testing, it shows that when the wavelength is 500 nm or the green light spectrum, the maximum light absorption by the chlorophyll of kitolod leaves is 1.78 (a.u.). The chlorophyll of kitolod leaves used in this research can be used as a basic ingredient for DSSC dye. Partly because it can absorb sunlight, which is UV light with a wavelength range between 100-700 nm. As for Solar cell efficiency is determined by the FF value which can be known from DSSC maximum power measurements (V_m x I_m). From the light source data obtained, it shows that V_m and I_m in daylight lamps have greater values than in warm white lamps. The efficiency of the highest solar light source is demonstrated when Air Mass 1.5 (08.30-08.40). Apart from that, the efficiency of the solar cells produced by DSSC dyeing kitolod leaves with immersion for 30 minutes has a greater value compared to immersion for 10 minutes. The greater the intensity of light given, the values of V_m and Im increase. The time of DSSC immersion in dye also influences the resulting V_m and I_m values which can be shown in that the V_m and I_m values of DSSC 2 (30 minutes) are greater than those of DSSC 1 (10 minutes).

In this study, only kitolod leaves were used because it aimed to determine the potential of dye contained in kitolod leaves as DSSC. Therefore, further research can be carried out with dyes from other comparators.

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