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Research Article

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Dye-sensitized solar cells using dye extracted from male flower of cured banana (*Musa x paradisiaca* L.)

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ABSTRACT

A research on natural dye extracted from male flowers of cured banana (Musa x paradisiaca L.) as a photosensitizer in the dye-sensitized solar cells (DSSC) has been conducted. The solar cell was constructed with components consisting of working electrode ZnO, counter electrode graphite and electrolyte solution I^- / I_3^-. The natural dye of male flower of cured banana extract showed an absorbtion bands in the UV-Vis region of spectrum (200-700 nm) where is the maximum wavelength found at 529 nm. Parameters of the DSSC such as voltage, electric current, and power based on soaking time (5, 10, 15, and 20 minutes) were measured. It was found that the soaking time of 20 minutes was the optimum condition gave voltage of 349 mV, the current of 0.021 mA, and power of 7.329 mV. In the current vs voltage graph for the entire investigation soaking time it was found that a short circuit current is generated within the range of 0.0025 to 0.02 mA whereas for open circuit range is from 155 to 332 mV. Furthermore, where is the DSSC was soaked in 5 minutes gave the higher number of fill factor (FF) but the highest efficiency was observed from one which was soaked in 20 minutes.

Keywords: Male flowers of cured banana, DSSC, Natural dye, FF, Soaking time

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INTRODUCTION

In recent years, the world has experienced a crisis of energy, so it is necessary to find the alternative energy sources, so as not to rely on fossil fuels, because it can damage environment through air pollution, carbon dioxide emissions, and heating. One of the most important alternative energy is solar energy. Where is sun light energy converted into electrical energy. Judging from the geographical location of Indonesia at the equator that allow optimal intensity of sunlight throughout the year. The sun is the main source of energy for most life on Earth, abundant and renewable [1].

DSSC is composed of a dye, semiconductor of TiO_2, the working electrode, electrolyte solution, and a counter electrode. At the DSSC, the dyes used are from organic and inorganic compounds serves as a sensitizer which absorbs sunlight and convert it into electrical energy. It can be seen that the highest efficiency of the compound Ru, and semiconductor of TiO_2 at DSSC reach 11- 12% [2,3].

However, the dye derived from inorganic compound are limited and expensive. While organic dye are not limited, inexpensive, and environmentally friendly [4]. Natural dyes can be found on flowers, fruits and leaves. And can be extracted in a simple way [5,6]. This natural dye, efficient, environmentally friendly, and became a popular subject today.

Semiconductor of ZnO constitute very promising photoanode at DSSC, because the band gap (3.34 eV), electron affinity, high electron mobility, and stable against corrosion. Where the efficiencies gained by using semiconductor of ZnO ranged from 0.02% to 7% [7].

The main purpose using ZnO in DSSC, because bandgap is almost the same as TiO_2. Where electrons from the HOMO (Highest Occupied Molecular Orbital) excited to a higher energy level, LUMO (Lowest Unoccupied Molecular Orbital), when the dye absorbs photons with energies corresponding [8], and can see at fig.1.

Chemical reactions that occur in the DSSC, can be described as follows : [10]

$TiO_2 + hv \rightarrow TiO_2 / D^*$ (1)

$TiO_2 / D^* \rightarrow TiO_2/D^+ + e^-$ (2)

$TiO_2/D^+ + e^- \rightarrow TiO_2/D$ (3)

$TiO_2/D^+ + \frac{3}{2} I^- \rightarrow TiO_2/D + \frac{1}{2} I_3^-$ (4)

$\frac{1}{2} I_3^- + e^- \rightarrow \frac{3}{2} I^-$ (5)

$I_3^- + 2e^- \rightarrow 3I^-$ (6)

Parameters obtained from the solar cell performance is the short circuit current (I_{SC}) and the open circuit voltage (V_{oc}) obtained in standard conditions. Fill factor is obtained from a full characterization of current and voltage calculated by equation:

$$FF = \frac{Vmax\ .\ Imax}{Voc\ .\ Isc}$$

By using the *fill factor*, the maximum power from the solar cells obtained from the equation:

$$Pmax = Vmax\,.\,I\,max = Voc\,.\,Isc.\,FF$$

Thus, the efficiency of solar cells is defined as the maximum power (P_{max}) divided by the input power (P_{in}) :

$$\eta = \frac{Pmax}{P\ in}\ x\ 100\%$$

Natural dyes plays an important role in the capture sunlight and convert it into electrical energy.[11,12].

In this study, using dyes that contain anthocyanins from male flower of cured banana (*Musa x paradisiaca* L.), because not find information about the use of male flower of cured banana dyes. so, I want to develop solar cells using this dye.

EXPERIMENTAL SECTION

Preparation of pasta zinc oxide (ZnO)

0.2 grams of poly vinyl alcohol (PVA) were added 4 ml of distiled water, then stir until homogeneous using a magnetic stirrer with a temperature of 40°C for 30 minutes. Then, were added 2 grams of ZnO powder and 5 mL ethanol in stirring to form a suspension at 40°C, thus forming a good pasta to coated.

Preparation of dye solution

Male flower of fresh cured banana as much as 10 grams cut into small pieces with scissors. Then added 25 mL of 95% ethanol, 4 ml of acetic acid, and 21 mL of a distiled water (25: 4: 21), soaked for 24 hours**.** After that, the extract from male flowers of cured banana filtered using Whatmann filter paper and stored in dark bottles.

Preparation of electrolyte solution
0.8 grams of potassium iodide (KI) is mixed with 10 ml of acetonitrile and stirred. then, 0.127 grams of iodine (I_2) was added to the solution and stirred again**.** Thereafter, an electrolyte solution (I^- and I_3^-) that has been created is stored in sealed bottles.

Preparation of counter-electrode
Where the counter-electrode is derived from the carbon source that is graphite from the pencil 2B. The pencil then shaded to a conduction glass surface until it blended. Then, the conductive glass burned on the fire, where the position of the shaded portion facing to the fire. This is done until the conduction glass burned completely.

Fabrication of DSSC
On the conductive glass will be formed an area of 2 x 1.7 cm with the help of scotch tape, this area is a place to put down ZnO pasta. Scotch tape serves as a regulator of the thickness of ZnO pasta. Then ZnO pasta is put on the areas that have been created on the conductive glass with a *doctor blade method*, ie with the help of Slide glass to flatten pasta. Then the layer is dried for 10 minutes and heated on an electric hot plate at a temperature of 200^{o}C for 2-5 minutes.

ZnO layers have been soaked in dye solution for 5, 10, 15, and 20 minutes. After that, the conduction glass rinsed with destiled water, ethanol and dried. Then the carbon electrodes placed over the ZnO layer, thus forming a sandwich structure, and both ends are given an offset of 0.5 cm for electrical contacts. Then on both sides of the cell are clamped with clips. And the electrolyte solution was dropped about 2-3 drops into the space between the two electrodes, solar cells ready to be tested.

Testing and characterization
a. Test of dye absorption.
Dye absorption was analyzed by UV-Vis spectrometer, where the wavelengths of 400-700 nm.
b. Measurement of electric current
Solar cells that have been assembled, measured voltage and current using potentiometer as varied barriers and view the changes. The light source used is direct sunlight.

RESULTS AND DISCUSSION

UV-Vis absorption spectra from male flowers of cured banana
It was found that the dye extracted from male flowers of cured banana wich used as a sensitizer has the absorption bands in UV-Vis region of 230-750 nm. Measurement results can be seen in Fig. 2.

Based on the spectrum of the male flowers dye of cured banana it can be seen that in general the dye absorbs in two main areas that are UV and visible regions. In the latter area, the dye absorbs the maximum at a wavelength of 529 nm. Because dye substance of the male flowers of cured banana is anthocyanin which absorb in the region of 500-560 nm, it can be said that the male flowers of cured banana dye can be used as a sensitizer in the area seemed so appropriate in DSSC.

The existence of anthocyanin compounds in the male flowers of cured banana extract predicted based on the pattern of spectrum UV-Vis between 400-700 nm which is caused by the presence of conjugated double bonds in the compound. In the structure of anthocyanin contained functional group of carbonyl of that can serve as a donor to form a coordination bond with zinc (II) in the system DSSC of ZnO.

Measurement of current and voltage
ZnO has a fairly wide band gap (3.4 eV) with physical properties similar to TiO_2, but better in electron mobility. Energy loss in the process of recombination that occurs shortly after photoconduction of band gap ZnO can be reduced. If the substance were included into the system and produce a conversion efficiency of DSSC be 0.4 to 5% [13,14]. To maximize the use of light source, then the system is irradiated at 11: 00-13: 00 (2 hours).

Table 1. Measurement results of voltage and current of DSSC system

Soaking time (minutes)	Voltage (mV)	Current (mA)	Power (mW)
5	290	0.004	1.16
10	306	0.007	2.142
15	338	0.018	6.084
20	349	0.021	7.329

From Table 1 it can be seen that by soaking 20 minutes, voltage, current, and power generated high. Where current is generated 0,021 mA, voltage is 349 mV, and the power is 7.329 mW. While the 25-minute soaking, ZnO existing on the conductive glass when soaked in the dye, all of them soluble and can not be measured. Thus, soaking 20 minutes is the optimum time from dyes extracted from male flowers of cured banana. Effect of soaking time with voltage, current, and power can be seen in Fig. 3.

From Fig. 3 it can be seen that the 20-minute soaking time higher voltage, current, and power generated from the soaking 5, 10, and 15 minutes. It can be seen that the longer the soaking time, the higher of the current, voltage, and power generated. This low value due to not function optimally a dyes and electron injection into ZnO electrodes, as well as the transfer of electrons in layers photoelectrode not run well, and a big obstacle. If the major obstacles will result in the transfer of electrons from the dye oxidized ZnO layer has not gone well, so that the number of electrons that flow to the outside circuit becomes small [15].

Characterization by I-V curve

Characterization by I vs V curve is in order to determine the ability of solar cells in connecting the solar cells with a potentiometer and the values of resistance are changed. Results of current and voltage measurement of solar cells for each substrate soaking in the dyes extracted from male flowers of the cured banana, can be seen in Fig. 4.

Seen from Figure 4 that the 20-minutes soaking has a curvature that is an ideal, because I_{max} and V_{max} is high, so it can be determined the MPP (Maximum Power Point). And the parameters of these measurements can be seen in table 2.

Table 2. Characterization of DSSC

Characteristics of I-V curve	Soaking time (minutes)			
	5	10	15	20
V_{max}(mV)	77	100	76	128
I_{max} (mA)	0.002	0.005	0.008	0.015
P_{max} (mW)	0.154	0.5	0.608	1.92
V_{oc} (mV)	155	256	252	332
Isc (mA)	0.0025	0.0058	0.01	0.02
Fill Factor	0.3974	0.3367	0.2413	0.2891
Eficiency(%)	0.0026	0.0078	0.0095	0.0299

Based on the table 2 the maximum voltage and current generated in 20 minutes soaking is respectivelly of 128 mV and 0.015 mA. While in the 10-minute soaking, V_{max} is only 100 mV, it is because the ZnO layer and the electrolyte solution is not too homogen, so that the value of V_{max} will varies. Natural dyes based solar cells appear to be limited from V_{oc} and I_{sc} were low[16].

Potentiometer used in this measurement has a resistivity of 100 KΩ. When the light carrying the photon energy of the DSSC, there will be an urgent electrons lost from the dye. Then, the electrons of ZnO excited from the valence band to the conduction band and the working electrode produce current in the DSSC. Then flows out of the circuit and the voltage measured by the voltmeter and current measured by the ammeters are arranged in series with obstacles in the form of a potentiometer.

In the process of measurement obtained by the short circuit current (I_{sc}) where the highest is 0.02 mA and a low of 0.0025 mA. While the open-circuit voltage (V_{oc}) the highest, 332 mV and a lowest 155 mV. So, ISC and Voc comparable, the greater the flow, the voltage produced is also large.

In this study is obtained value *Fill factor* (FF) was 0.3974 at the time soaking 5 minutes. And the value of the lowest in the *fill factor* (FF) on soaking 15 minutes, in which curve I vs. V formed less ideal. The intensity of the sun is 1170 ftcd with P_{in} is 0.006403.

The efficiency of solar cells depends on the quality of light captured by the solar cell. If the captured light is high, then the current, voltage, and power generated high. From the calculation process, the value of the highest efficiency is 0.0299%.

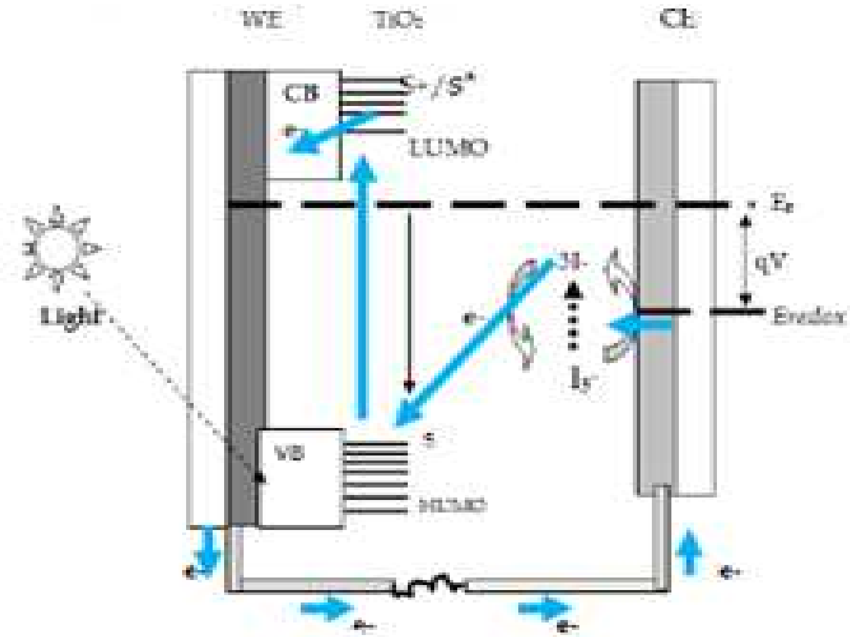

Fig. 1. The principle of dye-sensitized solar cells[9]

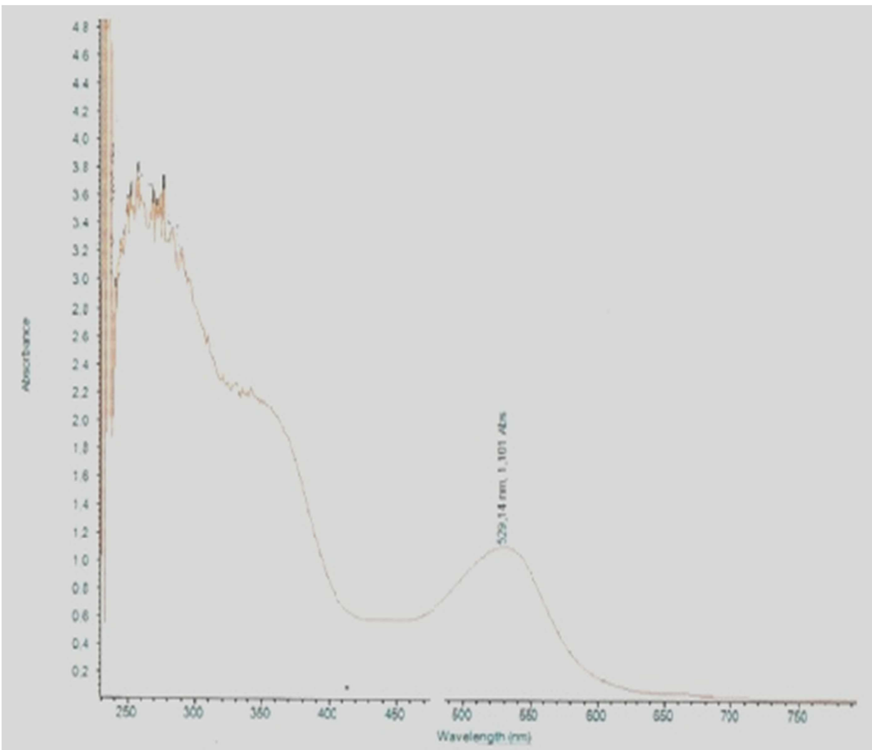

Fig.2. The Absorption spectrum of dye extracted from male flower of cured banana

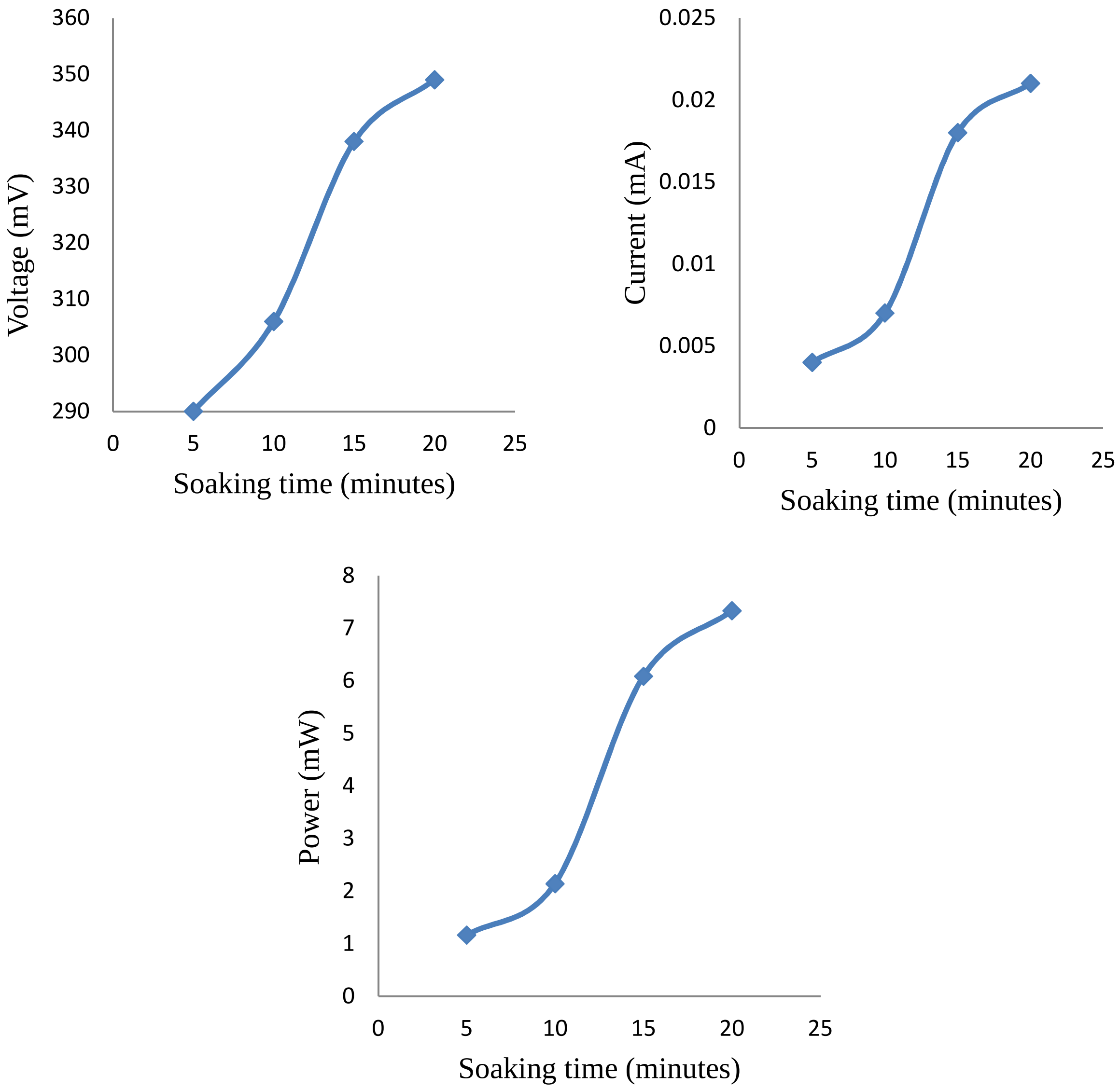

Fig 3. Effect of soaking time on (a) voltage, (b) Current and (c) power

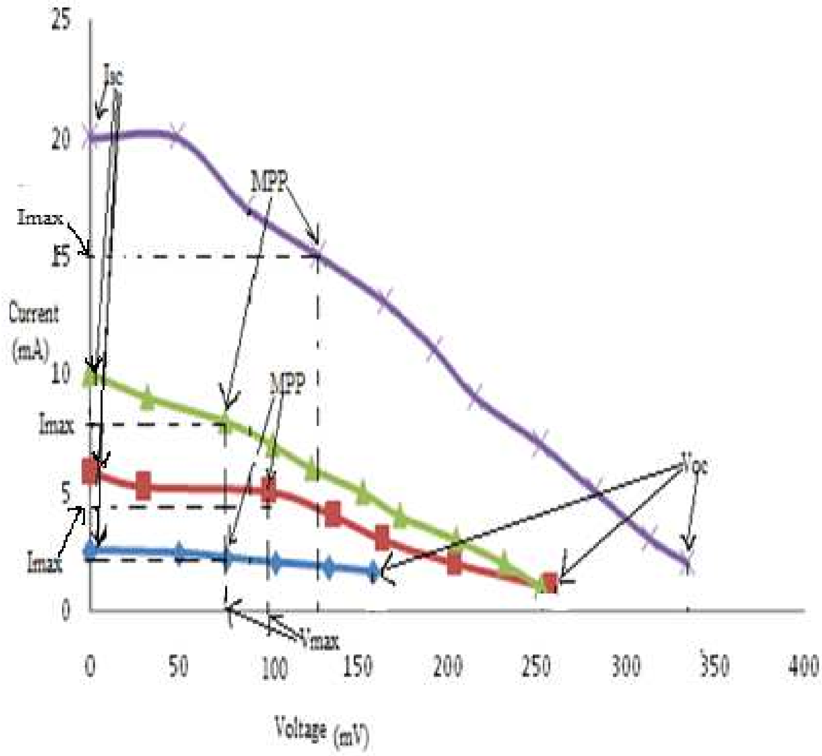

Fig. 4. I vs V curves of DSSC by variation of soaking time in male flower of cured banana dyes solution, ( ) 5 minutes, ( ) 10 minute ( ) 15 minutes, and ( ) 20 minutes.

CONCLUSION

From these results it can be concluded that the dye extracted from male flower of cured banana has an UV-Vis absorbtion spectra in the range of 200-700 nm, where is the maximum wavelength was found to be 529 nm. This abpsorption spectra correspond to the dye extracted from male flower of cured banana wich may contain an anthocyanin compound. The pparameters of DSSC such as voltage, electric current, and power based on the soaking time (5, 10, 15, and 20 minutes) were measured. It was found that soaking time in 20 minutes has an optimum condition given 349 mV voltage, current 0.021 mA, and the power of 7.329 mV. The current vs voltage curves for the entire investigation found that soaking time for short circuit current is generated in the range of 0,0025-0,02 mA, while for various open circuit is 155-332 mV, and the highest efficiency is 0.0299%. While in 5-minutes soaking found high value of *fill factor* (FF) as 0.3974.

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