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RESEARCH ARTICLE

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Organic Solar Cell Performance of *Musa acuminata* bracts Extract by Microwave Irradiation Treatment

Sutikno Madnasri | **Laras Ati**

Physics Department, Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Semarang City, Indonesia

Correspondence
Sutikno Madnasri, Physics Department, Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Semarang City, Indonesia
Email: smadnasri@yahoo.com

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Summary
The purpose of this study is to fabricate DSSC which performs well from natural pigments by giving exposure to microwave irradiation in materials to increase pigment uptake. In this research, the microwave irradiation was applied in coating banana flower extract (*Musa acuminata* bract) on the electrode, to increase light absorption of anthocyanin pigment. It is expected that the device can absorb more solar energy. The banana flower extract was characterized using Ocean Optic Vis-Nir USB 4000 to observe the optical properties. The irradiation treatment was carried out using Electrolux Microwave (EMM 2308X) at power 150 W. The DSSC samples were characterized using I-V meter Nacrieble 101. The maximum absorbance of 1.55 a.u. is found for the mass fraction of 0.45. The microwave irradiated device has an efficiency of about 3.69×10^{-6}%, whereas which is no microwave irradiation has a maximum efficiency of about 0.57%. It shows that microwave irradiation can improve DSSC performance. The banana flower extract is available as an alternative organic photosensitizer in the fabrication of DSSC.

KEYWORDS
DSSC, Microwave irradiation, *Musa acuminata* bract, Pigment, Solar energy

1 | INTRODUCTION

Solar cell plays an important role as a solar energy converter into electrical energy. Based on the material type, it can be classified into a silicon-based device and a non-silicon-based device. The first DSSC was built by Gratzel in the cell form of cheaper and eco-friendly materials.[1] Natural dye has the potential to be used as a light converter and replace silicon-dominated material due to its low assembling cost, lightweight, and flexibility.[2] A simple procedure is used in the DSSC fabrication of plant parts such as roots, stems, twigs, leaves, flowers, fruits, and barks.[3] The organic color pigments that are available for sensitizers of solar cells include anthocyanin,[4] betacyanin, betalain, and chlorophyll[5,6] and their derivatives. The anthocyanin can be extracted from blueberry,[7] eggplant leave,[4] raspberry,[8] and hibiscus flower,[9] whereas chlorophyll can be extracted from spinach leaf.[10] The banana flower contains also anthocyanin based on an indicator of its purplish-red color. They are easily found in all regions of the country and that is an underutilized part. We have synthesized and used this banana flower extract for DSSC fabrication using spin coating[11,12] and spray method.[13] The efficiency achieved by previous

The authors declare no competing financial interest.

NOVELTY STATEMENT
The banana flower extract anthocyanin used for DSSC has a relatively stable redox process. The efficiency of DSSC by microwave irradiation treatment is larger than that of without microwave irradiation treatment. This is caused by the microstructures of microwave irradiated-working electrodes have more pores, so that the banana flower extract can insert inside it.

researchers in the development of DSSC by utilizing natural materials showed a significant increase from the smallest to the largest namely (tomatoes, 0.002%),[14] (cypress leaves, 0.062%),[15] (red spinach, 0.416%), (turmeric, 0.921%),[9] (*Phytolacca americana* L., 3.04%)[16] and (co-sensitizer of *A. amentacea* leaves and *P. pterocarpum* leaves, 8.22%).[17,18] There are several DSSCs from natural dyes that show efficiencies achieved higher than 1%, this shows that the development of clean energy of light conversion using natural photosensitizer is very promising. The achieved highest efficiency of DSSC is 9.8%.[19,20] While there are some DSSCs from natural dyes that show less than 1% performance, this is because the organic dye absorbed by the working electrodes is very small.

Microwave irradiation is one of the heating modes which is employed in the preparation of porous carbon materials. The activated carbon materials prepared using microwave heating are highly capable to serve as an adsorbent, or as an anode material in energy storage applications such as supercapacitors, and lithium-ion batteries.[21] The microwave irradiation is non-contact heating technology which is available for controllable rapid thermal and no temperature gradient. In some applications, due to it is produced by dipole oscillation under the external field, microwave irradiation can induce porosity and generate electron-hole pair[22] and accelerate the crystallization process.[23] The pore size, water porosity, and moisture loss increase with rising microwave power and irradiation time.[24] The pore volume of mesopores, macropores, super macropores, and total pore volume increases with increased temperature or microwave power.[25]. Here, the microwave irradiation is used to accelerate the dye absorption on the TiO_2.[26] This research aims to increase organic dye absorption inside the working electrode by applying the microwave irradiation so that the achieved efficiency DSSC expected will be relatively better.

2 | MATERIALS AND METHOD

The banana flowers were taken from Gunungpati Sub District, Semarang City, Indonesia, and Indium Titanium Oxide (ITO) glass substrate in the size of 100 mm × 100 mm × 1.1 mm was purchased from Zhuhai Kaivo Optoelectronic Technology Co. Ltd. PEDOT:PSS 655201, carboxy-methyl-cellulose (CMC), acetate acid, methanol, acetone and ethylene glycol 1 L were supplied by Sigma-Aldrich.[27] Kapton tape was acquired by a company from China. The dimension of fabricated DSSC is 20 mm x 10 mm x *t* mm, where *t* is the total thick of films.

In this study, the solar cell was designed as shown in Figure 1. The dye (anthocyanin of banana flower extract) infiltrated into TiO_2 paste and it could convert incoming sunlight into electrical energy. Here, PEDOT: PSS and ethylene glycol function as electrolytes, and the carbon was fixed as a counter electrode.

Dyes were extracted of banana flowers in five mass fractions using formula (1) as the following:[28]

$$X = \frac{a}{a+b} \tag{1}$$

where X = mass fraction; a = mass of banana flower (g) and b = solvent mass (g).

The solvent to extract banana flower is an amount of 186 g in the mass ratio of ethanol, distilled water, and acetate acid (150:30: 6).[28]. The composition of banana flower extract is shown in Table 1. The pH of the banana flower extract solution (pH 3) was determined according to the procedure as in the previous research reports.[29] and as in[4]

The electrochemical properties of banana flower extract anthocyanins were characterized using Nova Cyclic Voltammetry (AUT87891) at the Metallurgy and Mineral Research Center, Indonesian Institute of Sciences (Serpong, Jakarta). The unirradiated and irradiated banana flower extract was characterized in the range of

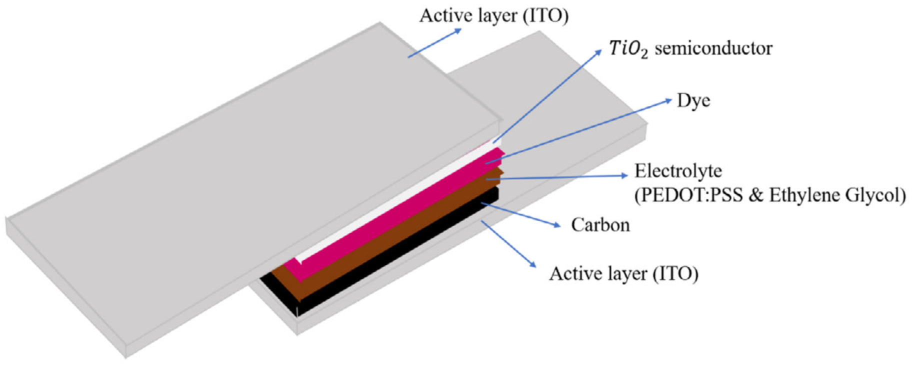

FIGURE 1 Multilayers structure of DSSC design [Colour figure can be viewed at wileyonlinelibrary.com]

applied electric potential 0 V - 1 V and 20 mVs^{-1} - 180 mVs^{-1}. The specifications of the equipment used were the Pt working electrode, the 302 multi ba autolab potentiostat, and the measurements were made using the supporting electrolyte 1 M KCl. The measured fluid concentrations were varied in 1,2 mL - 1,8 mL, and measurements were made at several scan rates, 20 mVs^{-1} - 180 mVs^{-1}, to determine their effects on the electrochemical properties of banana flower extract. Measurement results are analyzed and compared.

The working electrodes were formed differently for every sample and their effects on the DSSC performances were observed. The working electrodes were made using TiO_2, CMC, ethanol, and acetate acid. The binder masses of TiO_2 (CMC) were varied between 2 g up to 3 g as shown in Table 2. The working electrodes were fabricated by depositing TiO_2 paste on the ITO glasses. The TiO_2 pastes were produced by mixing TiO_2 and solvent using a heated magnetic stirrer at speed 1500 rpm for one hour. The TiO_2 pastes were deposited using a modified Doctor blade technique. The films were heated at 120°C for 20 mins. The next process is dye inserted into the working electrode after dropped and then irradiated by using microwave oven EMM 2308X at power 150 W for 15 mins.

The counter electrodes were produced of active carbon, CMC, and ethanol. After the carbon pastes were formed, deposited on the ITO glasses and heated up to 180°C for 1 h.[31] The optical properties of banana flower extracts have been characterized using Spectrometer Ocean Optic Vis-Nir 4000 and Fourier Transform Infrared (FTIR). The working electrode and the counter electrode were characterized by using CCD Microscope MS-804 to investigate surface structures, and the electrical properties of DSSC were characterized using I-V Meter Nacrieble 101.

The quality of solar cells is represented by fill factor (*FF*) which indicates the absorption capability of incoming light and this is the ratio between maximum output power (P_{max}) and theoretical power (P_{th}) as written in formula (2). The DSSC efficiency is computed based division of P_{max} and P_{light}. The DSSC efficiency can be calculated based on the following formula (3).[28]

$$FF = \frac{P_{max}}{P_{th}} = \frac{V_{max} I_{max}}{V_{oc} I_{sc}} \tag{2}$$

$$\eta = \frac{P_{max}}{P_{light}} 100\% \tag{3}$$

The maximum current and voltage are denoted as I_{max} and V_{max} respectively. The electrical properties of DSSC were measured using I-V Meter Nacrieble 101. The power input is generated of halogen lamp 50 W on the box in the dimension of 20 cm × 20 cm × 20 cm and the resulted average input power is about 125 mW/cm^2 white light source.[23]

3 | RESULTS AND DISCUSSION

The absorbance curves of banana flower extracts in the different mass fractions (0.25 up to 0.45) were exhibited in Figure 2. In this research, the varied mass fractions are used to improve the content of dye anthocyanin to achieve higher DSSC efficiency. The more the mass fraction of banana flower extract, the greater the absorption of light. Every curve has characteristically two sharp peaks and the same curve patterns. In Figure 2, two sharp peaks are at the wavelength range between 400 nm and 600 nm namely blue and purple wavelengths. The

TABLE 1 The composition of banana flower extract

Mass Fraction	Mass of Banana Flower (g)
0.25	62
0.30	79.7
0.35	100.15
0.40	124
0.45	152.18

TABLE 2 The composition of TiO_2 paste ingredients

Sample	TiO_2 powder (g)	CMC (g)	Ethanol (ml)	Acetate acid (ml)
B1	4	2	10	0.4
B2	4	2.2	10	0.4
B3	4	2.4	10	0.4
B4	4	2.6	10	0.4
B5	4	2.8	10	0.4
B6	4	3	10	0.4

Note: B_n (Sample codes for n different CMCs).

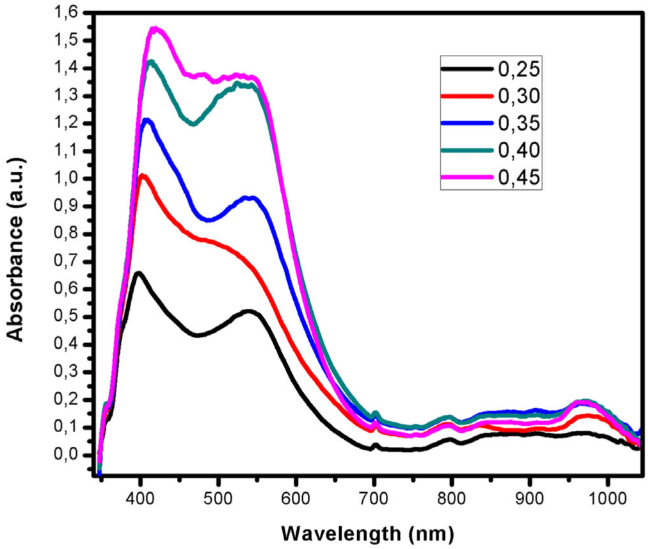

FIGURE 2 Absorbance curves of banana flower extracts [Colour figure can be viewed at wileyonlinelibrary.com]

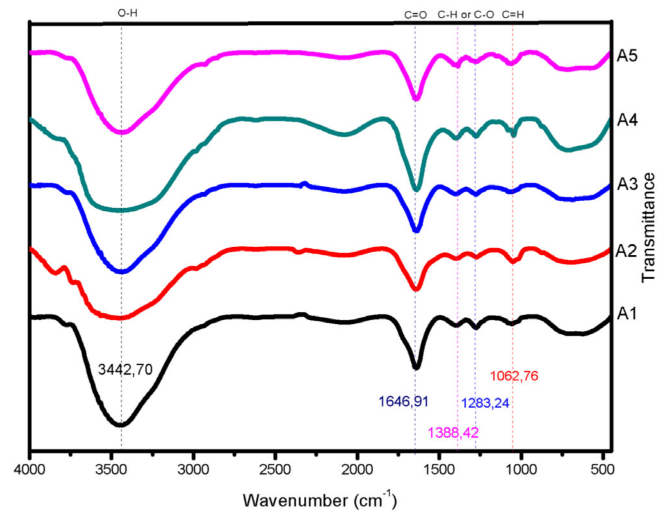

FIGURE 3 Functional group of banana flower extract [Colour figure can be viewed at wileyonlinelibrary.com]

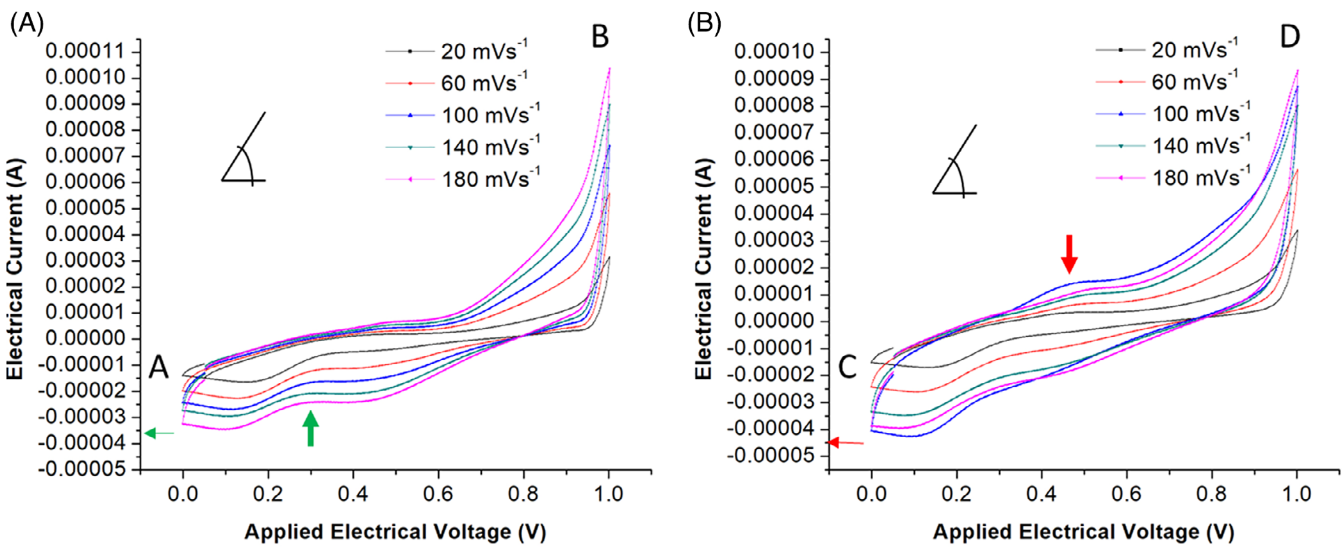

FIGURE 4 Cyclic voltammograms of anthocyanins in various scan rates: A, without microwave irradiated and B, with microwave irradiated [Colour figure can be viewed at wileyonlinelibrary.com]

UV-Vis absorption spectrum shows a similar trend, except that the crocetin peaks shift to blue.[32] This is also almost the same as the spectra of the extracts of Pelargonium Hortorum and Pelargonium Grandiflorum flowers.[33] It means the absorbed energies relatively large. Anthocyanins are chemical compounds derived from plant parts and show the color of visible light in the range of red to blue wavelengths and are predicted to be potential compounds for photosensitizer material.[19] Anthocyanins are the most plentiful and extensive dye type of the flavonoids and they are the most important cluster of water-soluble pigments in plants. They absorb light at the longest wavelengths and are the source for most orange, pink, red, magenta, purple, blue, and blue-black floral colors. The hue and structure of anthocyanins be influenced by pH and the existence of pigments. When the pH is lower than 2, anthocyanins endure as the stable flavylium cation. It is a very distinctive and one of the most important natures in the anthocyanin chemical structure which initiates a high absorption response at low pH.[34]

As the mass fraction of banana flower extract increases, the highest absorption peak moves toward the higher wavelength position. Based on Figure 2, it is known that the highest absorbance (0.155 a.u.) found a sample with a mass fraction of 0.45 namely sample with the highest level of banana flower extract. The anthocyanin absorption spectrum extracted from *Musa acuminata* bracts is at wavelengths of 400 nm to 650 nm, this is under the results of Al-Alwani et al. (2017).[30] The maximum light absorption by anthocyanin in this study, 1.55 a.u., was higher when compared to light absorption in eggplant leaf anthocyanins, 1.00 a.u.[4,35]

The voltammogram curves in Figure 4A show the relationship of generated electric current at scan rates between 20 mV/s to 180 mV/s with increments of 40 mV/s. Cyclic scans were made at the applied potential between 0 and 1 V. At the lowest scan rate (20 mV/s), the generated initial current shows the highest value (11.46 μA) among all. No sharp peaks were found. The shape of the voltammogram curves of the banana flower extract anthocyanins is almost the same as the voltammogram curves of phenylalanine, histidine, and tryptophan.[35] The higher the initial scan rate, the smaller the initial current generated. On a positive scan between 0.2 V to 0.4 V, a weak peak appears, and as the applied scan rate increases, the generated peak current shifts to the left as well. The microwave-irradiated anthocyanin voltammogram curve showed a higher slope gradient than the microwave un-irradiated anthocyanin voltammogram curve as shown in Figure 4. This means that the electric current at the end of the scan generated by the irradiated anthocyanins is higher than the electrical current at the end of the scan resulting from the microwave unirradiated anthocyanins. Anthocyanins of banana flower extract that were not irradiated had a fully reversible behavior,[36] as shown in Figure 4A. On the other hand, for materials irradiated, a weak oxide growth was found when the reverse scan applied as seem in Figure 4B and Figure 5.[37] For microwave unirradiated anthocyanin, oxide growth on the surface of the electrode occurs relatively slowly so that the exchange of electrons between the electrode and the solution is still ongoing.[38] Peak potential gradually shifted to a higher potential as the scanning speed increased.[39]

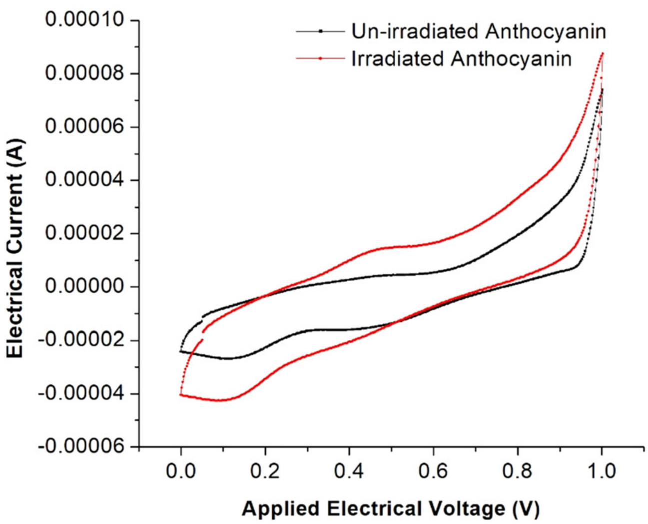

FIGURE 5 Cyclic voltammograms for 1 mL anthocyanin with microwave un-irradiated and irradiated at the same scan rate 100 mVs^{-1} [Colour figure can be viewed at wileyonlinelibrary.com]

The microwave un-irradiated and irradiated anthocyanin were both cyclically scanned at a scan rate of 100 mV/s, the two different voltammogram curves were found as seen in Figure 5. The voltammogram curve of

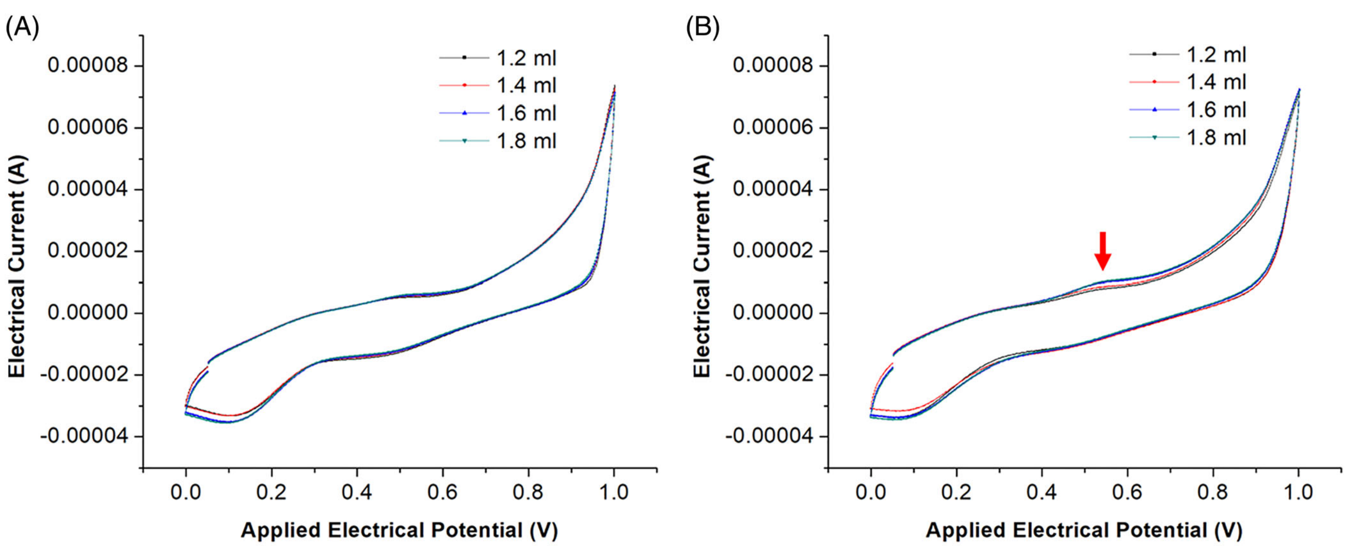

FIGURE 6 Cyclic voltammograms of anthocyanin in various volumes: A, without microwave irradiated treatment and B, with microwave irradiation treatment [Colour figure can be viewed at wileyonlinelibrary.com]

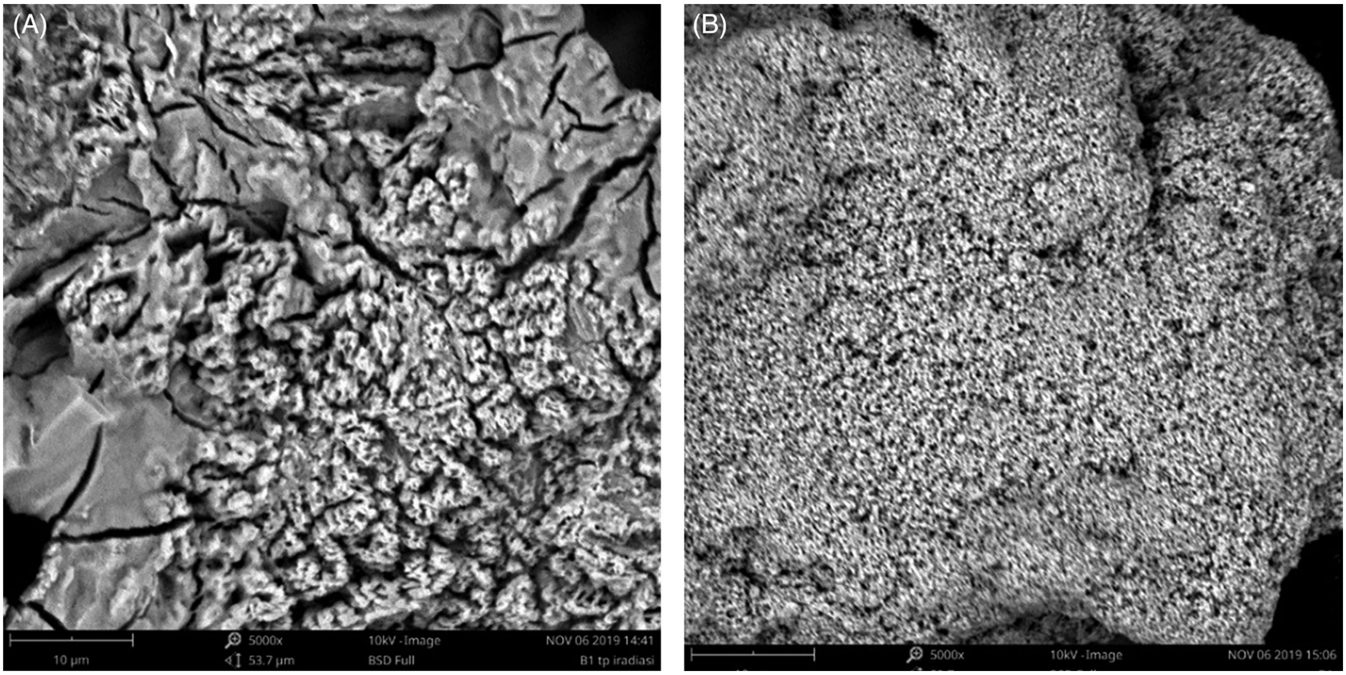

FIGURE 7 The thin film microstructures of working electrodes dropped by banana flower extract: A, without and B, using microwave irradiation treatment

the irradiated liquid shows a weak peak, while the un-irradiated one no peak. The difference between both scan initial currents is about 2 μA. The difference between the current peaks of anodic and cathodic for irradiated anthocyanin is higher than that of un-irradiated anthocyanin. Microwave irradiation has caused anthocyanin degradation. According to Zhao et al (2012), the higher the microwave power used, the greater the rate constant of degradation, and the shorter the time it takes.[40]

In Figure 6, the addition of anthocyanin concentrations into the tested electrolyte did not significantly affect the generated currents. These additions, 1.2 mL, 1.4 mL, 1.6 mL, and 1.8 mL, both before microwave irradiation and after microwave irradiation, did not show a significant effect. A weak peak grows not as a result of increasing anthocyanin concentrations, but this is due to the effect of microwave irradiation. Also, we have observed very stable cyclic voltammograms of anthocyanins from the consecutive scan (up to 3 cycles) in Figures 4, 5, and 6, which means that this material has a relatively stable redox process.

The functional group of the active chemical compound of plant extract can be identified based on the absorption peaks which are shown in the infrared zone (Figure 3) . The spectra of FTIR of banana flower extract indicate almost the same peaks. The peak in the wavenumber range of 3000 cm^{-1} - 3700 cm^{-1} exhibits O-H bond,[30] in the wavenumber of 1646.91 cm^{-1} shows C=O bond, in the wavenumber range of 1283.24 cm^{-1} - 1388.42 cm^{-1} informs the absorption peak for bending vibration C-H methyl or hydroxyl group of stretching vibration,[5] and the absorption peak of 1062.76 cm^{-1} shows aromatic C=H bond.[41,42] The C=H bond specifically appears at wave number 2943 cm^{-1}. Anthocyanins have carbonyl and hydroxyl groups that can certainly join to Ti (IV) sites that can support in excitation and removal of electrons effortlessly to the conduction band of TiO_2.[43,44]

The microstructures of fabricated working electrodes were characterized using scanning electron microscopy (SEM) after dropped by banana flower extract to observe homogeneity of their surfaces. The SEM images are shown in Figure 7. The microwave irradiation treatment has an increased amount of pores on the working electrodes. The microwave irradiation can induce porosities.[22] The material surfaces treated by microwave irradiation have greater cavity or porosity damage than before that material was irradiated.[24] In this study, the microwave irradiation power was set at 150 W and the duration of exposure was 15 mins, while the effects of power and exposure time of microwave irradiation on coal have been reported by other researchers.[25]

The multilayers of DSSCs were fabricated based on the structure design as Figure 1. The relation between the generated current with the applied voltage seem in Figure 8. The efficiencies of such organic solar cells achieve 0.179 up to 0.57 as tabulated in Table 3. DSSC performance measurement can be done whether by

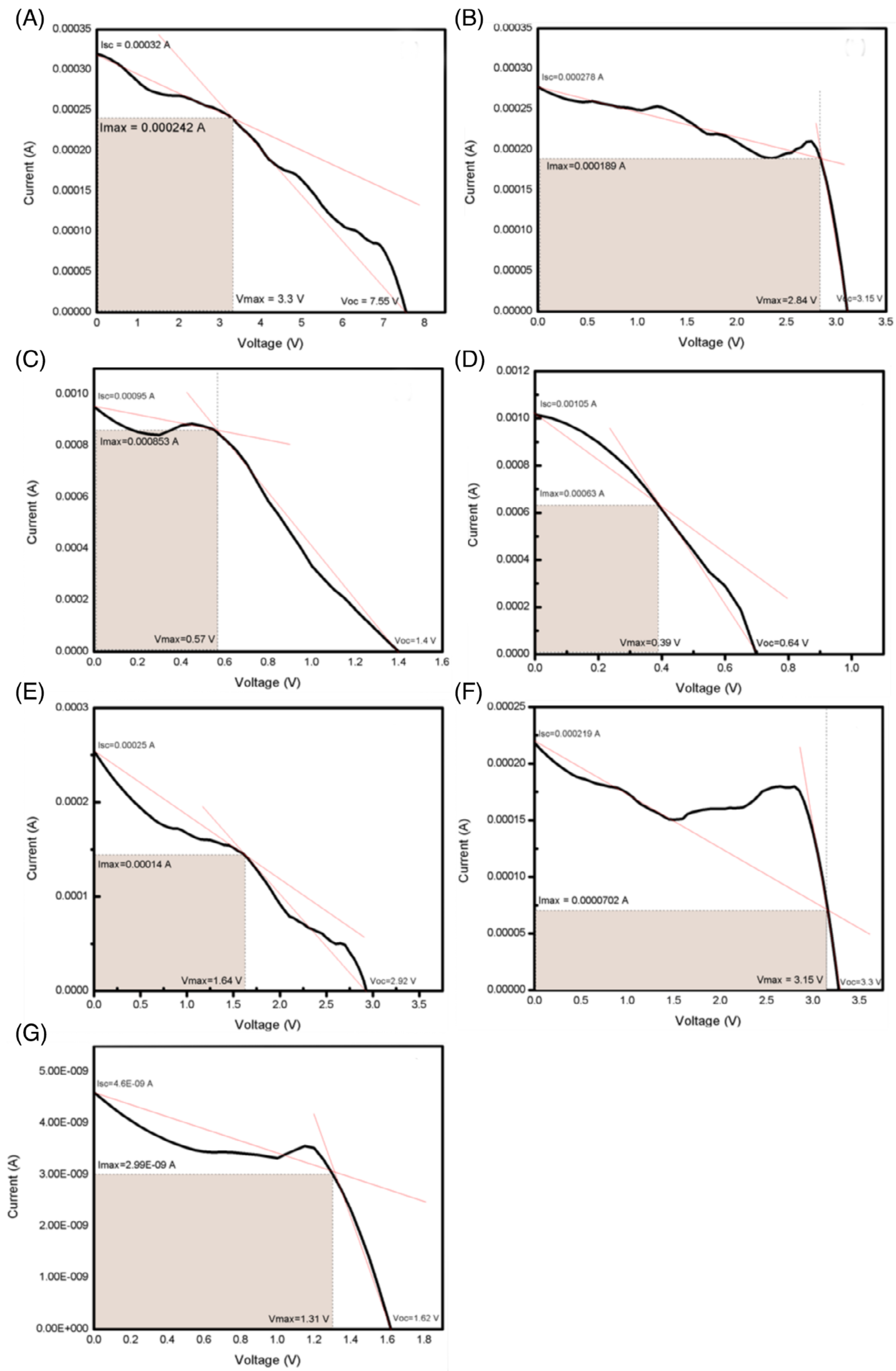

FIGURE 8 I-V curves of banana flower extract-based DSSC (V (10^{-3})) [Colour figure can be viewed at wileyonlinelibrary.com]

exposure to monochromatic or polychromatic (white) light.[45] On the other hand, in dark conditions, no current is generated, so that almost all publications reporting DSSC performance do not report the current generated in the dark condition. It is also emphasized that in dark conditions, cells behave like diodes.[46,47] Under the

TABLE 3 The electrical parameters of banana flower extract-based DSSC

Sample	V_{max} (mV)	I_{max} (mA/cm^2)	V_{oc} (mV)	I_{sc} (mA/cm^2)	*FF*	Ƞ (%)
C1	3.3	0.242	7.55	0.32	0.33	0.57
C2	2.84	0.189	3.15	0.28	0.61	0.43
C3	0.57	0.853	1.4	0.95	0.34	0.36
C4	0.39	0.630	0.64	1.05	0.44	0.24
C5	1.64	0.14	2.92	0.25	0.31	0.181
C6	3.15	0.702	3.3	0.22	0.31	0.179
C1 without irradiation	1.31	2.99×10^{-6}	1.62	4.6×10^{-6}	0.62	3.69×10^{-6}

Note: C_n (DSSC codes for n different CMCs).

illuminated condition, the electrical current generated by DSSC and its performance characteristics are presented in Figure 8.

Based on Table 3, as the CMC mass increases, the DSSC efficiency decreases as well.[47] The efficiency of a sample without microwave irradiation is found the smallest one (3.69×10^{-6}) and the highest efficiency is equal to 0.57% for DSSC by irradiation treatment. This value is higher compared to the efficiency of DSSC from *Reseda luteola*, 0.22%,[48] and still lower than DSSC efficiency that of the reference commercial dye (N719), 6.52%.[49] The highlighted novelty of this study is the finding on the different impacts on DSSC performance due to the irradiation treatment on the material. DSSC efficiency that succeeded in exceeding DSSC efficiency from N719 was 8222% and 7.16%, achieved by Sanjay et al.[17]

4 | CONCLUSION AND FUTURE WORK

In conclusion, microwave irradiation can improve DSSC performances. The efficiency of DSSC by microwave irradiation treatment is larger than that of without microwave irradiation treatment. This is caused by the microstructures of microwave irradiated-working electrodes have more pores, so that the banana flower extract can insert inside it. The amount of absorbed banana flower extract in TiO_2 can enhance the absorption of solar energy, and the efficiency of manufactured DSSC increased significantly from 3.69×10^{-6}% up to 0.57%. The multiplication of efficiency reaches one-fifth million times. In future research, the next experiments will be conducted under changing temperatures to further explore the impacts of temperature on the device stability prediction. Moreover, the future study will investigate device characteristics depend on the viscosity of the solution. The radiative lifetime and carrier-transfer-time measurements will also be the next research agenda.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Sutikno Madnasri https://orcid.org/0000-0003-2652-274X

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