Communication in Physical Sciences, 2023, 9(2):163-171

Improved Photochemical Performance of Dye-Sensitized Solar Cell using *Tectona grandis* and *Magnifera indica* Dye Mix

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Received: 02 February 2023/Accepted 05 May 2023/Published online: 26 May 2023

Abstract: *The generation of electrical energy from photo-voltaic conversions was achieved by fabricating a variety of dye-sensitised solar cells (DSSC) using natural dye extracts from Magnifera indica (M. Indica) and Tectona grandis (T. Grandis). This study explores the spectral characteristics of the dyes in Ultraviolet, Visible and infrared regions. An Incident Photon-Current Efficiency (IPCE) of $\eta = 0.0307\%$ was obtained with a short circuit current of up to Jsc = 6.597 mA cm^{-2}, an open circuit voltage of Voc = 0.05 V and a fill factor of 0.537 for the DSSC using the mixed dye. DSSC from M. Indica showed the highest open circuit voltage (Voc) of 0.1V. The efficiency for the DSSC when dyes were individually used was 0.0004 and 0.0241% for T. Grandis and M. Indica dyes respectively.*

Keywords: Dye-Sensitized Solar Cells, DSSC, *Mangifera indica, Tectona grandis*, efficiency and dye-mix

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1.0 Introduction

Solar irradiation onto the earth for one day is estimated to be more than the annual global demand for energy (NEED, 2017). This impressive energy supply is supposed to be the panacea to our global energy demands. Photo-voltaic (solar) cell technology is the key to harvesting this enormous energy, yet the efficiencies of solar cells which serve as solar energy collectors and converters are low (about 26.81% % for silicon-based solar cells which is almost at its theoretical limit of 33%) (Emiliano, 2022; Shockley and Queisser, 1961). The other alternatives which include Dye-Sensitized Solar Cells (DSSC), although very promising have relatively low efficiencies which are a result of partial contributions from the nature of the photoanode, the dye, the electrolytes and the type of cathode.

Currently, the most efficient single and triple junction photovoltaic cells are 27.6% (a thin-film Gallium-Arsenide, GaAs, cell) and 39.5% respectively (Kayes *et al.*, 2011; NREL, 2022). In 2017 the highest efficiency for DSSC single junction solar cells was reported to be 14.3% (Agarwal *et al*, 2022; Kakiage *et al*, 2015; Jihuai *et al*., 2017). It has been reported that one of the most limiting factors to the growth of many solar technologies is the high cost of materials needed which is generally a function of the scarcity of those materials (IEA, 2021). Another observed problem is the conductivity of the photo-anode and cathodes used in DSSCs. Since the photo-anode requires two properties: good electrical conductivity and transparency, for the dye to be sensitized by the light passing through it and for conducting away the electric current generated from the cell, the anode type employed has been very thin layers of semi-conducting oxides like Fluorine-doped Tin Oxide (FTO) or Indium doped Tin Oxide (ITO), which do not have as much conductivity as metals have limited the chances for a better incident photon to current efficiencies (IPCE). At the moment the need for Dye-Sensitized Solar Cells using plant-based dyes and very cheap electrodes has become obvious to meet up with the expectations of low cost, very low toxicity, availability of raw materials and compatibility with the ecosystem while pressing toward better efficiencies (Shubhangi *et al*, 2015).

In this study two dyes are mixed and employed as sensitizers in a dye-sensitized solar cell, the performance of these dyes is studied both in their solo and mixed forms using Graphene coated Indium-doped Tin oxide as counter-electrode, the DSSC with the mixed dye is also modified by changing its counter electrode from ITO to Aluminium.

2.0 Materials and Methods

2.1 Dye extraction process

M. Indica and *T. Grandis* dyes were extracted using the solvent extraction technique. About 10g of fresh plant leaves were pulverized in a mortar with a pestle, then soaked for about 20 minutes in 20 ml of ethanol solution to eliminate the dyes. Decantation was used to meticulously collect the dye solution.

2.2 Determining UV-Vis Absorbance

The dye solutions were tested for absorption using a Thermo Scientific Evolution 260 Bio UV-Visible spectrophotometer to acquire absorbance spectra from 200nm to 1100 nm.

2.3 Photo-anode Preparation and Analysis

A modified version of the technique described by Sakthivel *et al* (2015) was adopted to produce the TiO_2. Titanium tetrachloride was used to create a TiO_2 nano-suspension. At 0^oC, an ammonia solution is gently poured into a solution of Titanium tetrachloride in ethanol while being constantly stirred with a magnetic stirrer until a whitish slurry forms. The slurry solution was gently stirred constantly at room temperature for about 40 minutes before being rinsed with deionized water by centrifugation at 3200 rpm. The cleaned debris was dried in a 70 ^oC oven. The prepared TiO_2 powder was combined with trioxonitrate (v) acid (HNO_3) to make a consistent paste that was then applied to the ITO glass slide using the doctor blade method.

2.4 Cathode Preparation

The cathode (counter electrode) was made using by coating the surface of indium-doped tin oxide layered glass with graphite.

2.5 Construction of Dye-Sensitized Solar Cells

The Gratzel technique was used and adapted to make the cell (O'Regan and Gratzel, 1991), in which the photo-anode is immersed into the extracted dye for 5 minutes. The photo-anode with the adsorbed dye was positioned face to face with the counter electrode, showing half of the electrode's sides. A few droplets of I_2/I_3^- electrolyte were applied to the slides' sides, enabling them to disseminate by capillary action, before the edges were cleansed, waxed, and held with alligator clips.

2.6 Dye-Sensitized Solar Cell Measurements

The current-voltage characteristics were obtained from the I-V curve produced by two multimeter readings and about 100mW/cm2 solar intensity indicating A.M 1.5 solar radiation. The current was varied with the voltage by adjusting the resistance in the electrical circuit depicted in Fig. 1.

3.0 Results and Discussions

3.1 Ultraviolet and Visible Spectra

Fig. 1 shows a comparison between single normalized absorbances of *T. Grandis*, *M. Indica* and a mixture of the two.

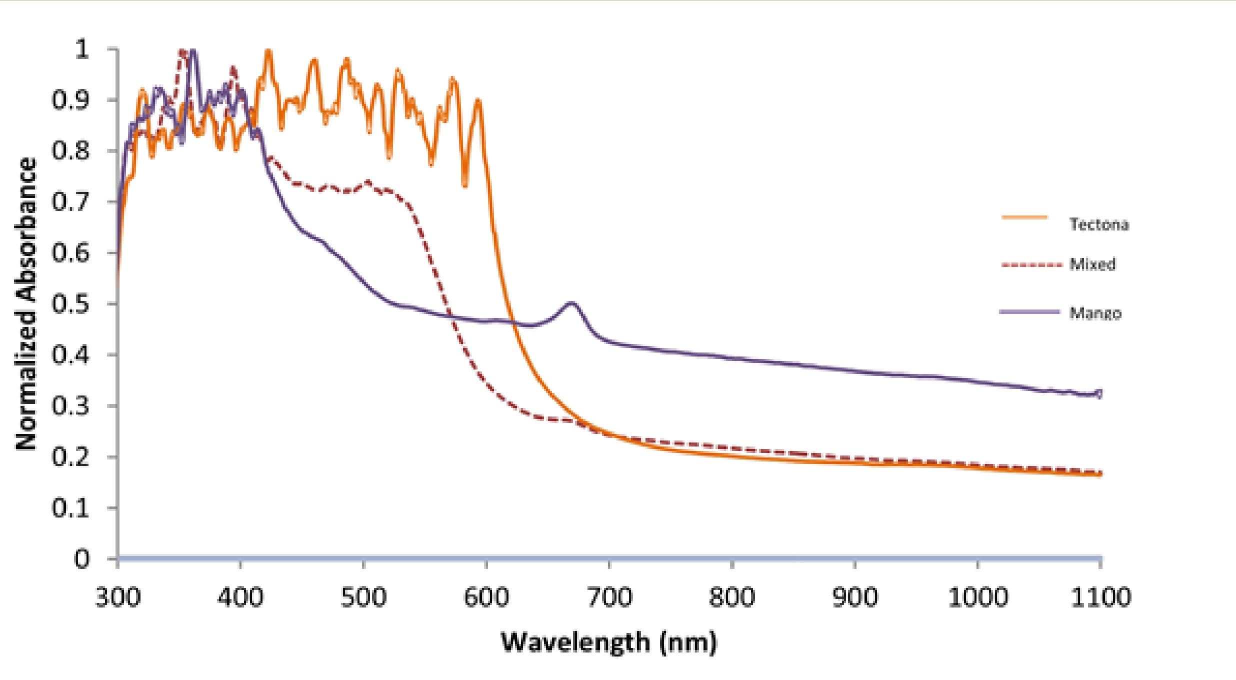

Fig. 1: Comparison between single normalized absorbance of *T. Grandis*, *M. Indica* and the mixture of the two

M. *Indica* dye is observed to have relatively higher absorbance across the UV-Vis spectrum (300-1100nm) when compared to *T. Grandis* and the mixed dye; even though *T. Grandis* exhibit better absorbance between 300 and 600nm, which explains one possible factor affecting the generally improved performance of *M. Indica* dye over *T. Grandis* Dye, since wider ranges of absorbance result in more light to electricity energy conversions (Hagfeldt and Gratzel, 2000). The Mixed dye on the other hand shows a compromise in the absorbance of the two dyes as shown in Fig. 1, it indicates an improved absorption spectrum across the ultraviolet and Visible spectrum.

3.2 Fourier Transform – Infrared (FT-IR) Spectra of the dyes

M. Indica and *T. Grandis* dye exhibited significant and similar ranges of transmittance, showing absorbance in the mid-infrared (MIR) region (4000-200cm^{-1}).

Absorbance in the Near Infrared (NIR) region was not shown by the FT-IR spectrum of this study, whereas absorbance in the NIR has been reported to show a significant contribution to improvements in Incident Photon to Current Efficiency (IPCE) (Tabuku and Yutak, 2003).

FT-IR spectra of *M. Indica* and *T. Grandis* dyes are shown in Figs. 2 and 3 From the FT-IR spectra of the *M. Indica* dye, as shown in Fig. 2, the broad and strong absorption peaks (A.P.) at 565.96 cm $^{-1}$ and the strong A.P. at 878.52 cm $^{-1}$ indicate C-H bending in unsaturated alkene groups. The absorption peak (A.P.) at 1043.75cm $^{-1}$ shows C-O stretching of alcohol groups. The A.P. at 1086.cm $^{-1}$ shows the presence of C-N stretching in aliphatic amines. Small to medium absorption peak at 1380.84 indicates C-H bending, while 2896.06 and 2974.11cm^{-1} shows C-H stretching all in aliphatic alkanes. A strong and broad absorbance at 3334.71cm^{-1} indicates the presence O-H stretching of the alcohol group.

Fig. 2 shows the FTIR Spectrum for M. Indica Dye while Fig. 3 shows the FTIR Spectrum for *T. Grandis* Dye

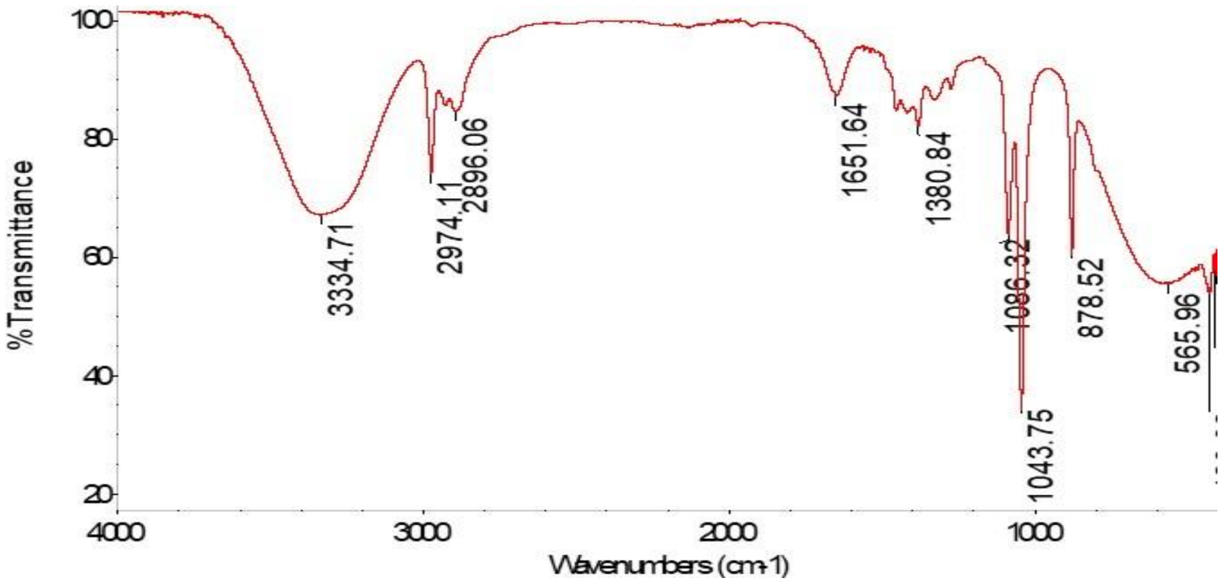

Fig. 2: FTIR Spectrum for *M. Indica* Dye

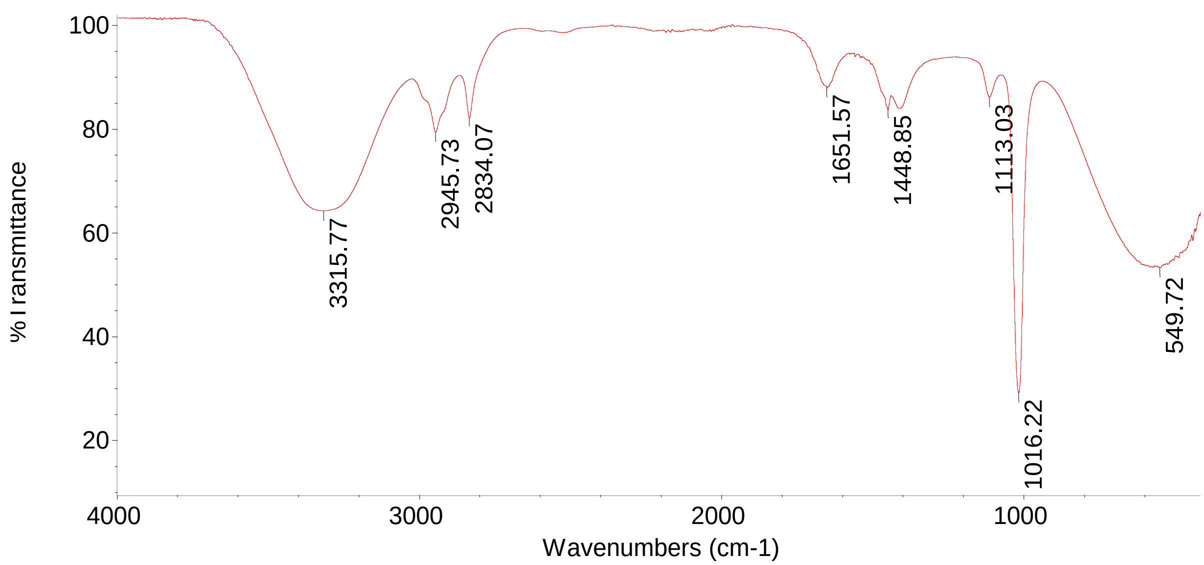

Fig. 3: FTIR Spectrum for *T. Grandis* Dye

From Fig. 3, where the FT-IR spectra of *T. Grandis* are shown, a broad and strong absorbance peak (A.P.) at 549.72 cm^{-1} indicates the presence of C-H bending in alkene, which indicates unsaturation. The strong, narrow absorbance peak at 1016cm^{-1} shows C-N stretching of aliphatic amines. Small absorbance peaks at 1113.03 cm^{-1} show C-O stretching of Carboxylic acids, ethers, esters or alcohols. A medium A.P. at 1444.85cm $^{-1}$ indicates C-H bending and rocking, while A.P. at 1651.57 cm $^{-1}$ shows the presence of C-C stretching of alkenes. Absorbance peaks at 2834.07 and 2945.73 correspond to C-H stretching of aldehyde and C-H stretching of aromatic groups respectively. The strong and broad absorbance peak at 3315.77 cm $^{-1}$ indicates O-H stretching of a phenolic group; showing the presence of aromatic groups.

3.3 Current-Voltage (IV) and Power-Voltage(PV) Curve Analysis

I-V and P-V curve analyses were conducted on varieties of the DSSC and their curves are shown in Figs. 4 to 6 The I-V curve analysis of different varieties of DSSC obtained were those of DSSC made with *M. Indica* dye and Indium doped- tin oxide(MITO) cathode (Fig. 4);

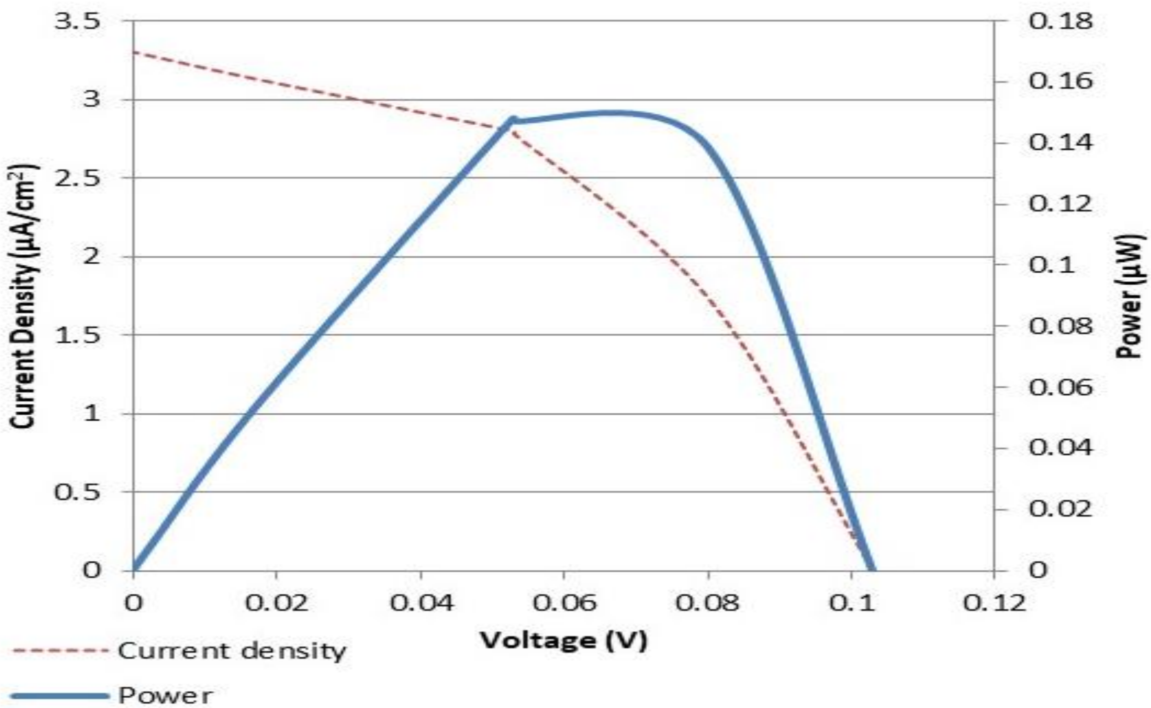

Fig. 4: *M. Indica* Dye and ITO Cathode

T. Grandis dye and Indium doped- Tin oxide(TITO) cathode (Fig. 5); Mixed dye and Indium doped- Tin oxide (MXIT) cathode (Fig. 5); The measurements of I-V characteristic curves of 3 DSSCs were carried out under the illumination with the sunlight of intensity of about 1000W/m^2. The power output was calculated as P = I.V using information gathered from the IV curve to form the PV curve (Power-Voltage curve). Then, from the P-V curve, each cell's photocurrent (I_m) and photovoltage (V_m) values at the maximum power point (P_m) were determined. The equations below were then used to compute the values of the fill factor and the cell conversion efficiency.

$$FF = \frac{P_{mp}}{V_{oc}I_{sc}} \quad (1)$$

$$P_{mp} = V_{mp}I_{mp} \quad (2)$$

$$P_{max} = V_{ov}I_{sc}FF \quad (3)$$

$$n = \frac{P_{max}}{P_{in}} \quad (4)$$

where V_{oc} is defined as open-circuit voltage; I_{sc} is defined as short-circuit current FF is defined as the fill factor, P_{max} is the maximum power output and I_{mp} is current at maximum power, V_{mp} is voltage at maximum power and n is defined as the efficiency. MITO shows an efficiency of 0.0241% with Fill Factor of

0.409, Jsc of 3.3mAcm^{-2} and Voc of 0.10V. TITO shows an efficiency of 0.0004% with Fill Factor of 0.176, Jsc of 0.347µAcm^{-2} and Voc of 0.034V. MXITO shows an efficiency of 0.0307% with Fill Factor of 0.537, Jsc of 6.597mAcm^{-2} and Voc of 0.05V.

The efficiency improvement associated with Aluminum is due to an increase in the conductivity of the Cathode. Indium doped-Tin oxide (ITO) has a conductivity of 1.4×10^{5}S/m (Zhengxian *et al*., 2013) while Aluminum has a conductivity of 3.5×10^{7}S/m (TaiSin, 2023).

Fig. 5 shows the IV and PV curves of the DSSC made with *T. Grandis* Dye and ITO Cathode. Fig. 6 shows the I-V and P-V curves of the DSSC made with the mixed dye and ITO cathode. Fig. 7 shows the IV and PV curve of the DSSC made with the mixed dye and aluminium cathode.

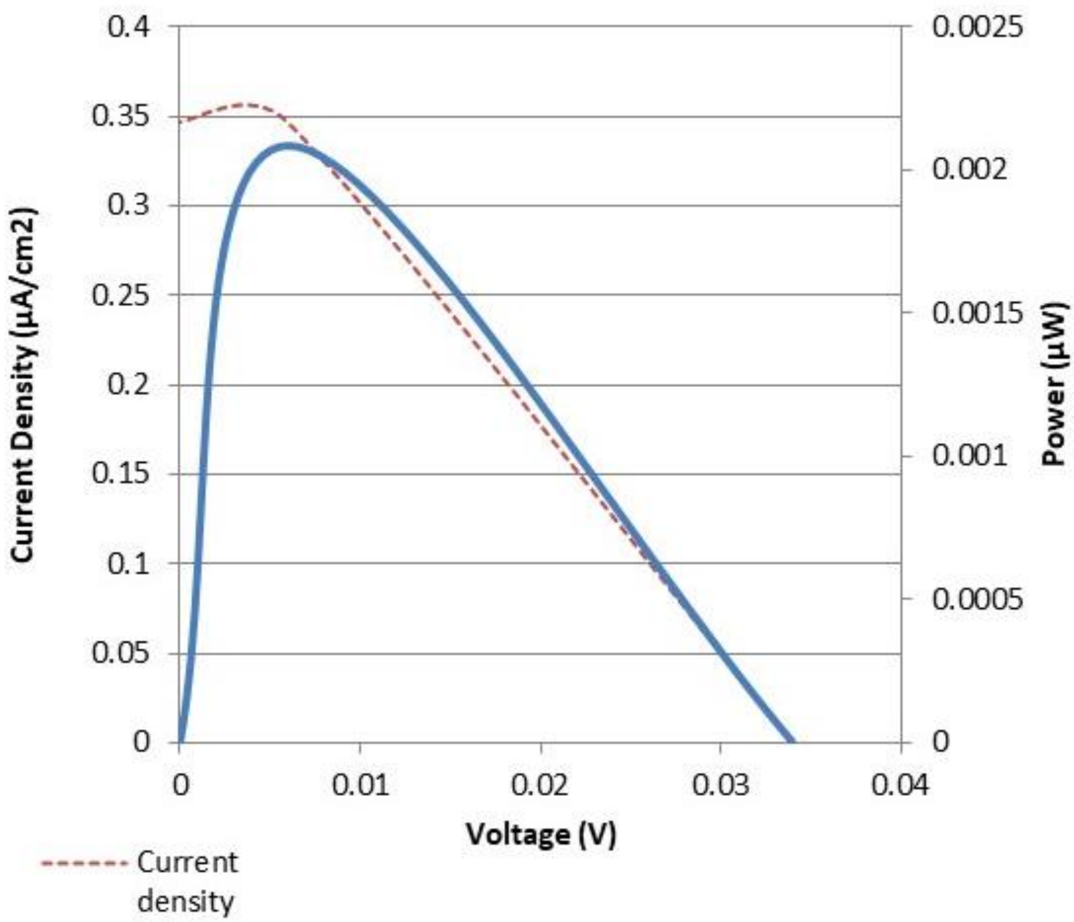

Fig. 5: IV and PV curve of DSSC with *T. Grandis* Dye and ITO Cathode

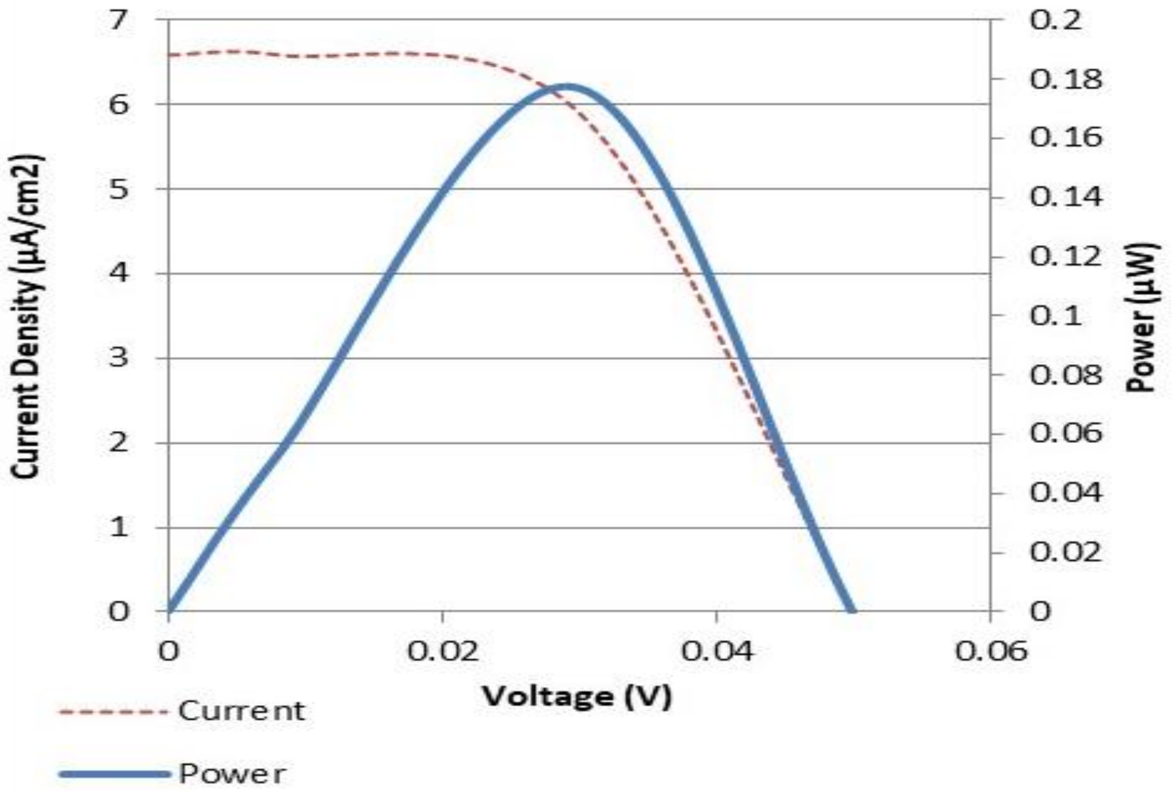

Fig. 6: IV and PV curve of DSSC made with Mixed Dye and ITO Cathode

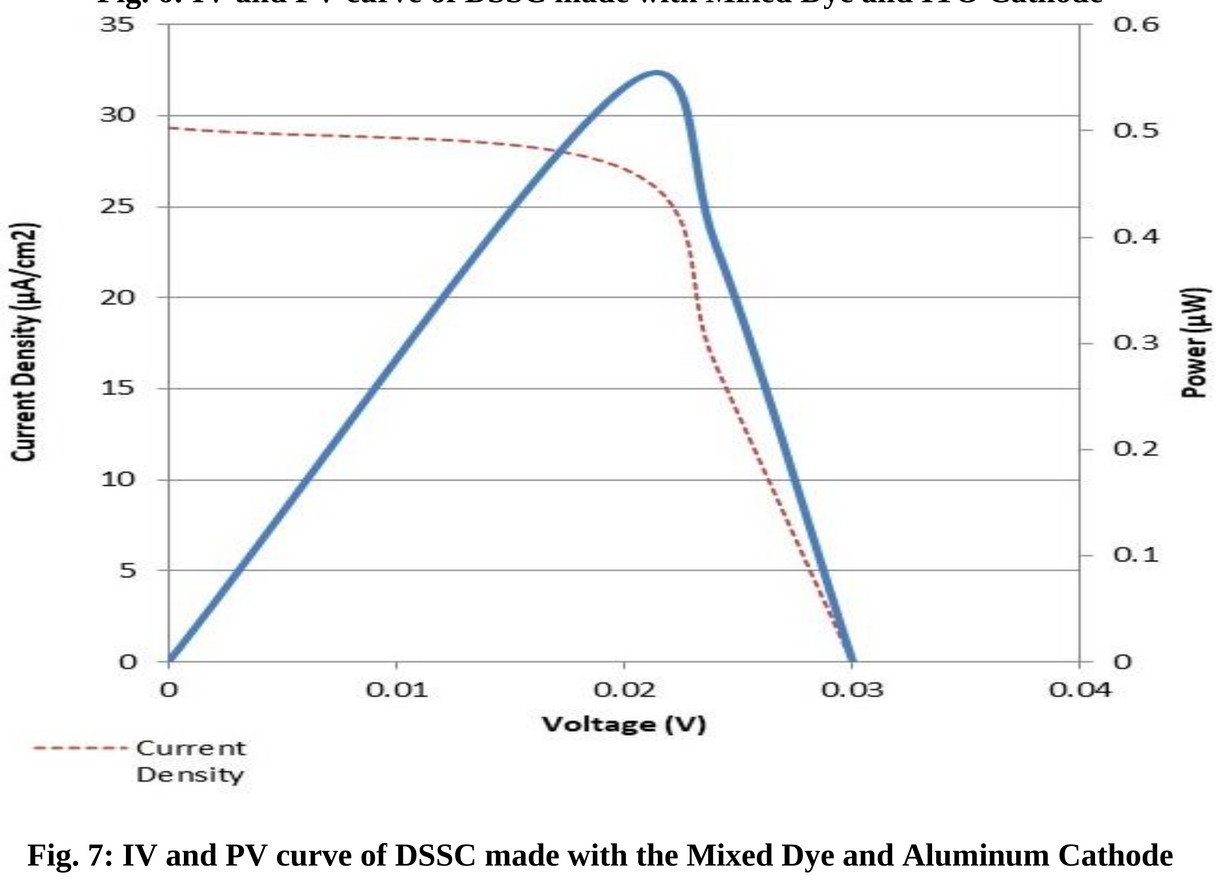

Fig. 7: IV and PV curve of DSSC made with the Mixed Dye and Aluminum Cathode

Table 1 shows the efficiency, short circuit current, open circuit voltage and fill factors of the various DSSC type used in this study

Table 1: Efficiencies of various DSSC type

DSSC Type	% n	J_{SC} (mA)	V_{OC} (V)	FF
Mixed dye and ITO	0.0307	6.597	0.05	0.537
***M. Indica* dye and ITO**	0.0241	3.300	0.10	0.409
***T. Grandis* and ITO**	0.0004	0.347	0.034	0.176
Mixed dye and Aluminium	0.0940	29.34	0.03	0.615

4.0 Conclusion

M. Indica and *T. Grandis* dye have demonstrated appreciable sensitization properties on TiO_2, yet the mixture shows an overall better performance. The M. Indica dye shows an Incident Photon-Current Efficiency (IPCE) of η = 0.0241%, while the T. Grandis dye had an efficiency, of η = 0.0004%. The efficiency of the mixed dye under the same preparation conditions was higher with η = 0.0307%. The highest efficiency was reached when the aluminium cathode was used for the mixed dye (η = 0.0940%). *The Mixed dye* is therefore a better option for sensitizing photo-anodes as it harnesses the complementary activity of the M. Indica and T. Grandis dyes when using ITO as cathode, while an even better efficiency is achievable with cathodes of higher conductivity like aluminium.

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Consent for publication

Not Applicable

Availability of data and materials

The publisher has the right to make the data public.

Competing interests

The Author declared no conflict of Interest.

Funding

There is no source of external funding

Authors' contributions

This work was carried out in collaboration among all authors. Author Abah Abraham Victor conceived the idea, initiated the study, wrote the literature and carried out all the research experiments. Author Alfred Ikpi Onen supervised the research including all methodology. Author Etim Emmanuel Edet co-supervised the research. Author Ogofotha Godwin Oghenekeno contributed throughout the research. All authors approved the final Manuscript.