Asian Journal of Chemistry; Vol. 35, No. 4 (2023), 877-881

ASIAN JOURNAL OF CHEMISTRY

https://doi.org/10.14233/ajchem.2023.27484

Use of Acai Berry Photosensitizer Conjugated with KCl in Different Solvents for Fabrication of Dye Sensitized Solar Cell

VARSHA RAJORIYA, CHANCHAL MAHAVAR, VIRENDRA SONI and K.R. GENWA*

Department of Chemistry, Jai NarainVyas University, New Campus, Jodhpur-342005, India

*Corresponding author: E-mail: krg2004@rediffmail.com

Received: 8 January 2023; *Accepted*: 10 February 2023; *Published online*: 30 March 2023; AJC-21184

Now a day, researchers concentrating on energy harvesting from a variety of sources since the ever-increasing world's population demands the use of energy in diverse forms. Dye sensitized solar cell (DSSC) is constantly an excellent option to other thin film solar cells because of its high conversion efficiency, simple fabrication method and low-cost price. Due to the aforementioned benefits, several studies have been conducted globally to improve cell function. The anthocyanin dye isolated from the acai berry was used as photosensitizer in the present study, which involves the fabrication of dye sensitized solar cells (DSSCs) using metallic solution of KCl and deoxycholic acid (DCA) in various solvents such as distilled water, ethanol and dimethyl sulfoxide. (DMSO). In ethanol as solvent with deoxycholic acid (DCA) and KCl solution, the electrical output was shown extremely effective. The fill factor (FF) was found to be 0.64 and photoconversion efficiency was 2.311%.

Keywords: Acai berry, Anthocyanin, Dimethyl sulfoxide, Fill factor, Photoconversion efficiency.

INTRODUCTION

Searching for inexpensive, efficient energy alternatives that can provide clean, unlimited electricity and play a crucial part in the development of a globally sustainable society is more important than ever [1-3]. The renewable energy source that is currently the most accessible, long-lasting, peaceful, environmentally acceptable and adaptable to many uses is solar energy harvesting using a photovoltaic cell [4-7]. However, Grätzel *et al*. [5] developed the dye-sensitized solar cell in 1991, which was a new form of solar cell (DSSC), in recent years; it has drawn a lot of interest [6]. It has minimal production costs, is simple to make, performs well in diffuse lighting and has aesthetic elements that can be changed, including colour, transparency and flexibility [7-12].

Normally, a transparent conducting glass electrode with a porous layer of semiconductor (like TiO_2) coated with a dye (either organic, inorganic or hybrid), an electrolyte layer containing the iodine/triiodine (I^-/I_3^-) redox couple and a counter electrode that is frequently coated with graphite or platinum make up a DSSC [13-18]. It was discovered in the 1960s that organic dyes can generate electricity at oxide electrodes [19]. The greatest efficiency ever obtained using organic/inorganic hybrid semiconductors was 18.1% [20]. With the addition of blackberry juice as a natural photosensitizer on a semiconducting TiO_2 plate, the photoconversion efficiency was found to increase from 0.92% to 1.07% [21]. TiO_2 and ZnO semiconducting materials were used along with the natural dye photosensitizer *Solanum melongena* (eggplant). The photoconversion efficiency (1.10%) obtained from TiO_2 plate and 0.67% photoconversion efficiency was obtained from ZnO semiconductor. These results showed TiO_2 electrode was good semiconductor for natural dyes [22]. Three dye sensitizers are often utilized in DSSCs: metal complex sensitizers, metal-free organic sensitizers and natural sensitizers. DSSCs that have been made using many synthetic and modified organic dyes have been reported [23]. β-(Ethynylbenzoic acid)-substituted push-pull porphyrins [24], organoimido-substituted hexamolybdates based dyes [25], amphiphilic Ru(II) heterolepticbipyridyl complexes, HD-14 and HD-15 [26] are some examples of dyes were used in DSSC. Metal transition materials have been used to achieve the highest photosensitization [27].

Ruthenium(II) is the most effective dye due to a variety of beneficial characteristics, including strong metal to ligand charge transfer, long excited-state lifetime and excellent absorption. Because of the long-term chemical stability of oxidized Ru(III) and the stability of the excited states of the complexes, Ru-bipyridyl complexes are good photosensitizers [28]. As a result, Ru-bipyridyl complexes as photosensitizers are used for the homogenous photocatalytic and dye-sensitization processes. These complexes do have certain drawbacks, though, namely their high cost and the demand for advanced processing methods. Anthocyanins from jabuticaba (*Plinia cauliflora*) fruit used as light-absorbing dyes connected to the nanostructured mesoporous TiO_2 film of the photoanode [29]. Recently, Bose & Genewa [30] and Soni *et al*. [31] were used metal free organic dyes based DSSC. Curcumin [32] and chlorophyll obtained from the extraction of spinach, grass jelly leaves, broccoli and anthocyanin from shoe flower and blue pea flowers were also used as natural photosensitizer in DSSCs [33].

When a cell is exposed to sunlight, the dye in the cell absorbs photons, which causes optical excitation. The dye then injects electrons into the semiconductor's (nanocrystalline-TiO_2) conduction band, where they travel to the external circuit and arrive at the counter electrode. Electron donation from a liquid electrolyte based on I^-/I_3^- redox couple allows for the regeneration of this electron to its ground state [34]. The cycle keeps producing power. Although using liquid electrolyte lacks stability owing to evaporation and leakage, it is nonetheless seen to be beneficial because of its mobility.

The objective of this research work is to fabricate more efficient DSSC based on natural dye sensitizer by optimizing several cell fabrication parameters, titanium dioxide photoanode (working electrode), natural dye solution prepared with metallic solution and counter electrode materials. The solution of acai berry extract was prepared in three solvents (distilled water, ethanol and DMSO) separately using deoxycholic acid (DCA) and KCl with platinum and metallic solution cobalt nitrate based counter electrode along with electrolyte [I^-/I_3^-].

EXPERIMENTAL

Preparation of photosensitizer: Dyes are important part of the DSSC that release electron and produce electricity in photovoltaic cells. Acai berries, as photosensitizer washed with distilled water and then ethanol. The dried berries was grind in pestle mortar to make finely powder and then added KCl and deoxycholic acid (DCA). In this research, two types of dye solution used. In first dye solution, 0.5 g photosensitizer in 80 mL distilled water containing 10 mL solution of KCl and 10 mL solution of DCA and stirred the solution uniformly. In second dye solution, 0.5 g photosensitizer in 90 mL distilled water and 10 mL DCA solution were mixed uniformly. Like distilled water, prepared two sets of ethanol solvent and two sets of dimethylsulphoxide (DMSO) solvent. In this way, a total of six sets of dye solutions were made.

Preparation of photoanode/working electrode: Before fabricating the working electrode, the FTO glass slides were washed in an ultrasonic with a mixture of water and ethanol. After that, 2 g of TiO_2 nanoparticles stirred with 2 mL of glacial acetic acid for 2-3 h, 2-3 drops of HCl were added to maintain its pH 3-4; this paste mixed with 2 mL ethanol and 2-3 drops of surfactant Triton X-100 stirred for 24 h for homogeneity at room temperature. Apply this paste to conductive side of the FTO glass slide with the help of 'doctor blade technique'. Firstly, the conductive side was checked by using multimeter. Now leaving 1 cm^2 surface area of FTO glass side, cover the remaining space with scotch tape. Then a drop of TiO_2 paste pour on one edge of FTO plate and spread through the glass rod till the end. Adsorbed conductive plate with TiO_2 paste was cooled at room temperature. Then remove the scotch tape and the slide was calcined in an electric furnace at 500 ºC for 1 h.

Then, the TiO_2 adsorbed plate was placed (TiO_2 adsorbed side upwards) in a beaker containing different 6 set dye solutions and kept in dark for 48 h. After the slide has been taken out of the solution in which dye was dissolved and washed to eliminate any excess dye, it was allowed to dry at room temperature in dark. In order to prevent the electrical problems, scotch tape should be used to thoroughly cover the edges of the plate (except one side).

Preparation of counter electrode: To prepare the counter electrode, firstly 2 mL chloroplatinic acid solution was mixed in 8 mL of propanol and secondly, 0.1 g of cobalt nitrate was dissolved in 10 mL of propanol. Now mixed 5-5 mL of each solution; thus it became a Pt-based solution. This solution was applied on the conductive side of FTO plate with the help of paint-brush. It was dried at room temperature and then calcined in an electrical furnace at 350 ºC for 30 min.

Preparation of electrolyte: Liquid electrolytes act as charge carriers. To prepare it, 0.05 M I_2 and 0.5 M KI were dissolved in 20 mL polyethylene, stirred well and then kept in dark bottle.

DSSC assembly: A drop of electrolyte was pouring on the dye adsorbed TiO_2 plate with the help of dropper. A counter electrode is placed over this plate and two sides were left for connectivity. With the help of alligator clips connect both the plates together and clean the electrolyte that has come out with tissue paper. Evaluate the characteristics of the fabricated cell by using multimeter in sunlight.

The photoconversion efficiency was calculated for the fabricated cells with acai berry dye using eqn. 1:

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

where η = photoconversion efficiency; I_{sc} = short circuit current; V_{oc} = open circuit voltage; FF = fill factor; P_{in} = power of incident light (W/m^2). To calculate the efficiencies of solar cells, the electrical characteristics (I-V measurements) were used under the sun light/spectrum. The I-V curves for dyes in various solvents were obtained.

RESULTS AND DISCUSSION

UV-visible spectral analysis of photosensitizers: Using an ELICO-SL-244 UV spectrophotometer, the absorption spectra of acai berry dye in various solvents were obtained and are shown in Fig. 1, which shows the gradual hyperchromic shift is observed in solvent in following order: ethanol > distilled water > DMSO. This observation states that ethanol

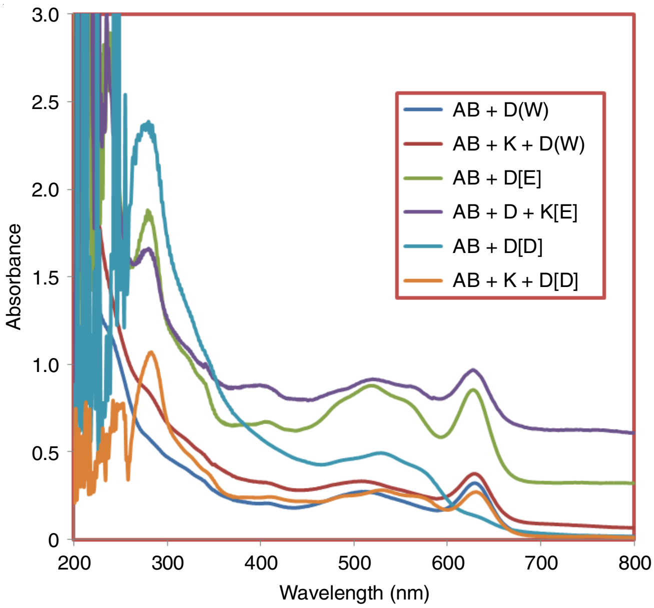

Fig. 1. UV-vis spectra of acai berry in different solvents (W = distilled water, E = ethanol and D = DMSO (D = DCA, K = KCl)

not only shows high wavelength range but also highest absorbance peak (E_{max}). The spectra obtained show that a mixture of KCl and DCA in ethanol has a strong absorption characteristic.

SEM studies of TiO_2 film: SEM is employed in single-particle analysis as well as to characterize and visualize surface morphology, particle size distribution, particle/crystal form, agglomeration of nanoparticles and surface functionalization. The SEM images were obtained at magnifications of X1000 and X100,000 (Fig. 2), which demonstrate the morphology of the TiO_2 layer on the DSSC's semiconducting plate.

Photovoltaic characterization of DSSC

Electrical parameters for acai berry: The measuring I-V curve of each fabricated DSSC using natural photosensitizer *i.e.* acai berry under the sunlight in different solvents like distilled water, ethanol and DMSO. As mentioned earlier, two dye system, acai berry + DCA + KCl and acai berry + DCA used in each solvent. The open circuit voltage (V_{oc}), short circuit current (I_{sc}), fill factor (FF) and photoconversion efficiency (η) (eqn. 1) were used to determine the functionality of natural dye as a photosensitizer in dye sensitized solar cell. Table-1 depicts that the highest short circuit current, open circuit voltage, fill factor and conversion efficiency exhibited by solvent ethanol. The results indicate that the solvent used to dissolve the dyes has an impact on the conversion efficiencies values. The solution of natural dye with KCl gives good voltage and current, due to which high value of conversion efficiency is also obtained.

I-V curve for acai berry in different medium: The I^-/I_3^- coupled redox system was used as the electrolyte for the evaluation of two cells manufactured using differences in the chemical composition of dye mixture. Platinum solution was also added to cobalt nitrate solution to deliver metal to the counter elect-

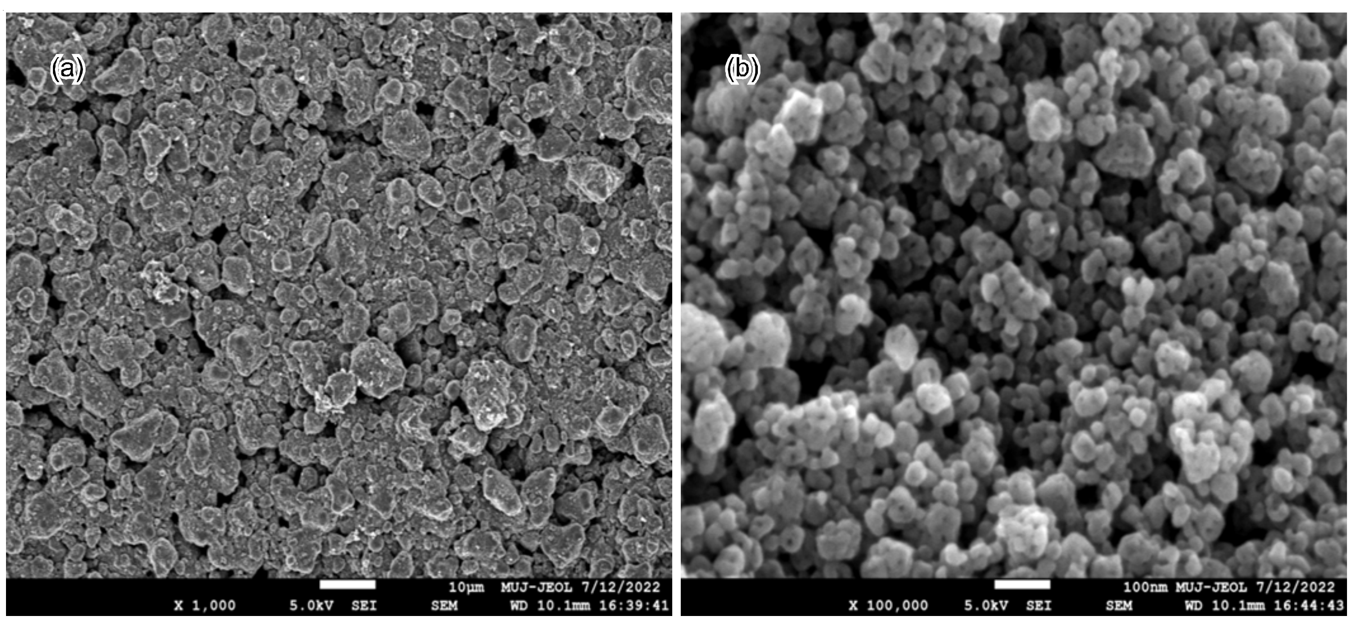

Fig. 2. Scanning electron microscopic images of TiO_2 layer on FTO glass slide (a) X1000 (b) 100,000

TABLE-1
ELECTRICAL PARAMETERS OF ACAI BERRY IN VARIOUS SOLVENTS

Solvent	Photosensitizer	V_{oc} (V)	I_{sc} (mA)	FF	η (%)
Distilled water	Acai berry + DCA + KCl	1.571	1.763	0.64	1.772
	Acai berry + DCA	1.776	1.074	0.57	1.087
Ethanol	Acai berry + DCA + KCl	1.813	1.992	0.64	2.311
	Acai berry + DCA	1.462	1.885	0.54	1.488
DMSO	Acai berry + DCA + KCl	1.752	1.606	0.51	1.434
	Acai berry + DCA	1.792	0.869	0.65	1.012

rode, greatly increasing the efficiency of solar cell. The I-V curve of both dyes system are shown in Fig. 3, this data depicts cell containing KCl shows high conversion efficiency (η = 1.772%) than cell containing only DCA (η = 1.087%).

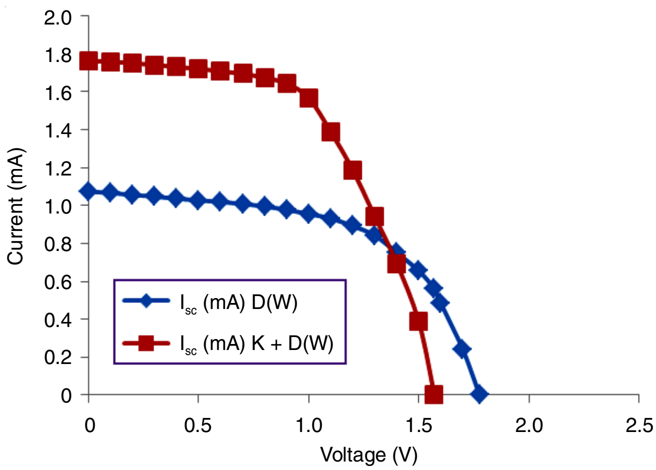

Fig. 3. I-V curve of natural photosensitizer acai berry in distilled water (W = distilled water, D = DCA, K = KCl)

In ethanol cell having acai berry + KCl + DCA shows the high short circuit current (I_{sc}) as 1.992 mA, open circuit voltage (V_{oc}) as 1.813 V, fill factor and photoconversion efficiency (η) as 0.64 and 2.311%. These electrical parameters calculated by I-V curve from Fig. 4.

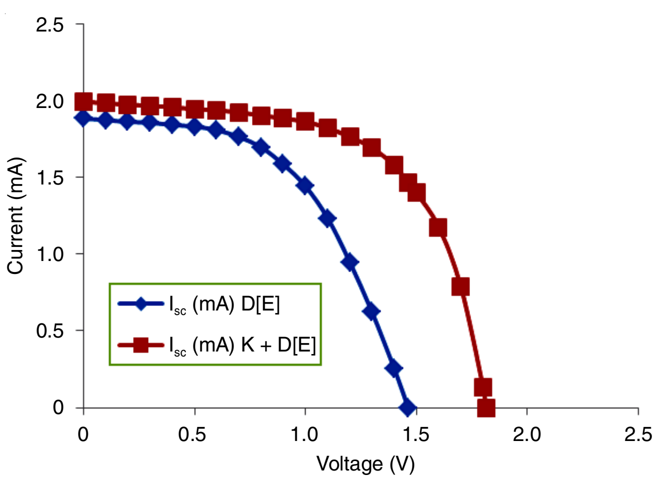

Fig. 4. I-V curve of natural photosensitizer acai berry in ethanol (where E = ethanol, D = DCA, K = KCl)

In solvent DMSO, for the first system, having acai berry + KCl + DCA in DMSO, V_{oc} as 1.752 V, I_{sc} as 1.606 mA and the fill factor and conversion efficiency as 0.51 and 1.434% were obtained, respectively. In the second system, having acai berry + DCA in DMSO, V_{oc} as 1.792V, I_{sc} as 0.869 mA and the fill factor and conversion efficiency as 0.65 and 1.012% were obtained, respectively. The I-V curve for the cell fabricated with natural dye acai berry in DMSO solvent is shown in Fig. 5.

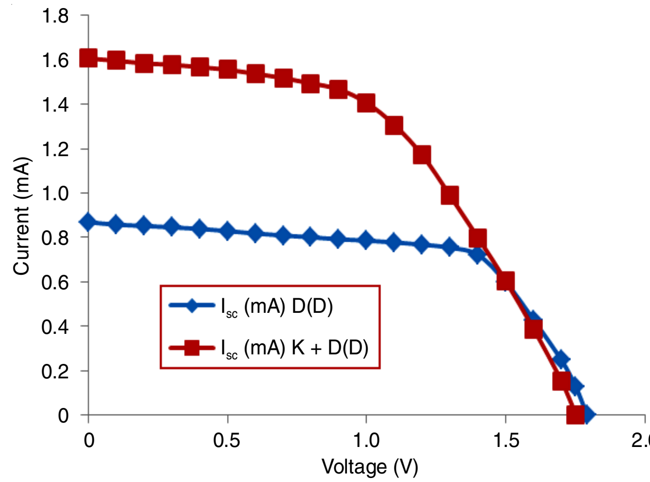

Fig. 5. I-V curve of natural photosensitizer acai berry in DMSO (D); D = DCA, K = KCl)

Conclusion

In this work, acai berry dye extract was used as a photosensitizer for the TiO_2 photoanode to construct dye-sensitive solar cells. Based on the experimental results and data analysis, natural dye is low cost and most efficient dye for DSSC. Due to the fact that metallic dyes function better with DSSC, several investigations on the synthesis of different dyes including metals were conducted. In this experiment metal solution *i.e.* KCl was used or indirectly metal entity was given to the dye, which increased I_{sc} and V_{oc}. Incorporating platinum solution with $Co(NO_3)_2$ solution to supply metal to the counter electrode has significantly raised solar cell efficiency. The dye solution containing KCl + DCA in ethanol gives highest I_{sc} = 1.992 mA, V_{oc} = 1.813V, FF = 0.64 and photoconversion efficiency η = 2.311%. Acai berry is more effective when ethanol is utilized as solvent, as shown by the fact that the conversion efficiency attained for DSSC constructed with ethanol is larger than DSSC fabricated with distilled water and DMSO.

ACKNOWLEDGEMENTS

The authors acknowledge to The Head, Department of Chemistry, Jai Narain Vyas University, Jodhpur, India for providing the laboratory facilities. Thanks are also due to Manipal University, Jaipur, India for providing the instrumentation characterization techniques.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

REFERENCES

1. A. Reda, S. Tadesse and T. Yohannes, *J. Photon. Energy*, **4**, 043091 (2014); https://doi.org/10.1117/1.JPE.4.043091
2. M.J.B. Kabeyi and O.A. Olanrewaju, *Front. Energy Res.*, **9**, 743114 (2022); https://doi.org/10.3389/fenrg.2021.743114
3. A. Lim, N.T.R.N. Kumara, A.L. Tan, A.H. Mirza, R.L.N. Chandrakanthi, M.I. Petra, L.C. Ming, G.K.R. Senadeera and P. Ekanayake, *Spectrochim. Acta A Mol. Biomol. Spectrosc.*, **138**, 596 (2015); https://doi.org/10.1016/j.saa.2014.11.102
4. N.A. Ludin, A.M. Al-Alwani Mahmoud, A.B. Mohamad, A.A.H. Kadhum, K. Sopian and N.S. Abdul Karim, *Renew. Sustain. Energy Rev.*, **31**, 386 (2014); https://doi.org/10.1016/j.rser.2013.12.001

5. M. Grätzel, *J. Photochem. Photobiol. C: Photochem. Rev.*, **4**, 145 (2003); https://doi.org/10.1016/S1389-5567(03)00026-1
6. J. Gong, K. Sumathy, Q. Qiao and Z. Zhou, *Renew. Sustain. Energy Rev.*, **68**, 234 (2017); https://doi.org/10.1016/j.rser.2016.09.097
7. N.A. Treat, F.J. Knorr and J.L. Mchale, *J. Phys. Chem. C*, **120**, 9122 (2016); https://doi.org/10.1021/acs.jpcc.6b02532
8. N. Mariotti, M. Bonomo, L. Fagiolari, N. Barbero, C. Gerbaldi, F. Bella and C. Barolo, *Green Chem.*, **22**, 7168 (2020); https://doi.org/10.1039/D0GC01148G
9. H. Iftikhar, G.G. Sonai, S.G. Hashmi, A.F. Nogueira and P.D. Lund, *Materials*, **12**, 1998 (2019); https://doi.org/10.3390/ma12121998
10. H.-J. Kim, Y.-T. Bin, S.N. Karthick, K.V. Hemalatha, C.J. Raj and S. Venkatesan, *Int. J. Electrochem. Sci.*, **8**, 6734 (2013).
11. S. Shalini, R. Balasundara prabhu, S. Prasanna, T.K. Mallick and S. Senthilarasu, *Renew. Sustain. Energy Rev.*, **51**, 1306 (2015); https://doi.org/10.1016/j.rser.2015.07.052
12. K.-H. Park, T.-Y. Kim, J.-Y. Park, E.-M. Jin, S.-H. Yim, D.-Y. Choi and J.-W. Lee, *Dyes Pigments*, **96**, 595 (2013); https://doi.org/10.1016/j.dyepig.2012.10.005
13. M.A.M. Al-Alwani, A.B. Mohamad, A.A.H. Kadhum and N.A. Ludin, *Spectrochim. Acta A Mol. Biomol. Spectrosc.*, **138**, 130 (2015); https://doi.org/10.1016/j.saa.2014.11.018
14. N.A. Karim, U. Mehmood, H.F. Zahid and T. Asif, Solar Energy, 185, 165 (2019); https://doi.org/10.1016/j.solener.2019.04.057
15. V. Shanmugam, S. Manoharan, A. Sharafali, S. Anandan and R. Murugan, *Spectrochim. Acta A Mol. Biomol. Spectrosc.*, **135**, 947 (2015); https://doi.org/10.1016/j.saa.2014.07.096
16. H.J. Kim, D.J. Kim, S.N. Karthick, K.V. Hemalatha, C.J. Raj, S. Ok and Y. Choe, *Int. J. Electrochem. Sci.*, **8**, 8320 (2013).
17. K. Kakiage, Y. Aoyama, T. Yano, T. Otsuka, T. Kyomen, M. Unno and M. Hanaya, *Chem. Commun.*, **50**, 6379 (2014); https://doi.org/10.1039/c4cc02192d
18. M.K. Hossain, M.F. Pervez, S. Tayyaba, M.J. Uddin, A.A. Mortuza, M.N.H. Mia, M.S. Manir, M.R. Karim and M.A. Khan, *Mater. Sci. Pol.*, **35**, 816 (2017); https://doi.org/10.1515/msp-2017-0086
19. D. Devadiga, M. Selvakumar, P. Shetty and M.S. Santosh, *J. Power Sources*, **493**, 229698 (2021); https://doi.org/10.1016/j.jpowsour.2021.229698
20. S. Mathew, A. Yella, P. Gao, R. Humphrybaker, B.F.E. Curchod, N. Ashari-Astani, I. Tavernelli, U. Rothlisberger, M.K. Nazeeruddin and M. Grätzel, *Nat. Chem.*, **6**, 242 (2014); https://doi.org/10.1038/nchem.1861
21. G. Calogero, J.H. Yum, A. Sinopoli, G.D. Marco, M. Gratzel and M.K. Nazeeruddin, *Solar Energy*, **86**, 1563 (2012); https://doi.org/10.1016/j.solener.2012.02.018
22. A. Pervez, K. Javed, Z. Iqbal, M. Shahzad, U. Khan, H. Latif, S. Abbas Shah and N. Ahmad, *Optik*, **182**, 175 (2019); https://doi.org/10.1016/j.ijleo.2018.12.044
23. I.N. Obotowo, I.B. Obot and U.J. Ekpe, *J. Mol. Struct.*, **1122**, 80 (2016); https://doi.org/10.1016/j.molstruc.2016.05.080
24. M. Ishida, D. Hwang, Y.B. Koo, J. Sung, D.Y. Kim, J.L. Sessler and D. Kim, *Chem. Commun.*, **49**, 9164 (2013); https://doi.org/10.1039/c3cc44847a
25. J. Wang, H. Li, N.N. Ma, L.K. Yan and Z.M. Su, *Dyes Pigments*, **99**, 440 (2013); https://doi.org/10.1016/j.dyepig.2013.05.027
26. H. Cheema, A. Islam, R. Younts, B. Gautam, I. Bedja, R.K. Gupta, L. Han, K. Gundogdu and A. El-Shafei, *Phys. Chem. Chem. Phys.*, **16**, 27078 (2014); https://doi.org/10.1039/C4CP04120H
27. A. Mbonyiryivuze, I. Omollo, B.D. Ngom, B. Mwakikunga and S.M. Dhlamini, *Phys. Mater. Chem.*, **3**, 25 (2015); https://doi.org/10.12691/pmc-3-2-2
28. S.A. Taya, T.M. El-Agez, H.S. El-Ghamri and M.S. Abdel-Latif, *Int. J. Mater. Sci. Appl.*, **2**, 37 (2013); https://doi.org/10.11648/j.ijmsa.20130202.11
29. D.M. Sampaio, R. S. Babu, H.R.M.Costa and A.L.F. deBarros, *Ionics*, **25**, 2893 (2019); https://doi.org/10.1007/s11581-018-2753-6
30. S. Bose and K.R. Genwa, *Int. Res. J. Pure Appl. Chem.*, **11**, 1 (2016); https://doi.org/10.9734/IRJPAC/2016/24519
31. V. Soni, C. Mahavar, V. Rajoriya and K.R. Genwa, *Orient. J. Chem.*, **38**, 1094 (2022); https://doi.org/10.13005/ojc/380502
32. K.E. Jasim, S. Cassidy, F.Z. Henari and A.A. Dakhel, *J. Energy Power Eng.*, **11**, 409 (2017); https://doi.org/10.17265/1934-8975/2017.06.006
33. C. Cari, K.T.Y.Septiawan, P.M. Suciatmoko, D. Kurniawan and A. Supriyanto, *AIP. Conf. Proc*., **2014**, 020106 (2018); https://doi.org/10.1063/1.5054510
34. S.N. Karthick, K.V. Hemalatha, S.K. Balasingam, F.M. Clinton, S. Akshaya and H.J. Kim, eds.: A. Pandikumar, K. Jothivenkatachalam and K. Bhojanaa, Dye-Sensitized Solar Cells: History, Components, Configuration and Working Principle; In: Interfacial Engineering in Functional Materials for Dye-Sensitized Solar Cells, Wiley Online Library, Chap. 1, pp. 1-16 (2019).