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Proceeding Paper

Co-Sensitized DSSC with Natural Dyes Extracted from Beetroot, Pomegranate and Cranberry †

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Abstract: The aim of this study is to boost the power conversion efficiency of a dye-sensitized solar cell (DSSC) by using the co-sensitization strategy with appropriate natural dyes extracted from pomegranate, beetroot and cranberry. The fabricated DSSCs were evaluated using current–voltage characteristics and UV-Vis spectroscopy. The co-sensitized DSSC with beetroot and cranberry showed higher short-circuit current density and power conversion efficiency than their individual dye-based DSSCs. This improvement in the performance is due to the lower aggregation of the dyes, broader absorption in the visible region and lower value of impedance. However, co-sensitized DSSCs of pomegranate with beetroot and cranberry did not show any improvement in performance.

Keywords: DSSC; natural dye; co-sensitized DSSC; co-sensitizer

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1. Introduction

Dye sensitized solar cell (DSSC) was introduced for the first time by Michael Grätzel and his team. Since 1991, DSSC has become a favorite area of research because of the lower cost, easy fabrication process, environmentally benign nature, and flexibility in terms of its structure and materials [1]. To date, DSSCs have achieved a maximum PCE of 14.7% with co-sensitization by silyl-anchor and carboxy-anchor dyes. Low stability and low efficiency are the main obstacles for the commercialization of DSSCs. DSSCs consist of four main components (photoanode, dye, electrolyte and counter electrode) and each component has been modified to improve the performance and stability of the device [2]. Poor light absorption and low carrier collection are the main reasons for the low efficiency of DSSCs, and to overcome these obstacles many techniques have been employed, such as scattering layers, optimizing thickness of photoanodes, nano architecting, back reflectors and co-sensitization [3]. The schematic of a DSSC is shown in Figure 1. Dye is the active area and plays a key role in the performance of DSSC by absorbing solar radiation. Each dye has a specific range of absorption and it is difficult for a dye to cover the whole solar spectrum individually [4]. Hence, to obtain maximum absorbance, a mixer of different dyes having varying absorbance spectra is used [5]. Co-sensitization also called dye-cocktail, is an important technique to enhance the PCE in DSSC by increasing the light absorption capability in visible and NIR regions [6–9]. In co-sensitization, two or more appropriate dyes are combined with an optimized ratio to harvest solar radiation in various regions of the spectrum [10].

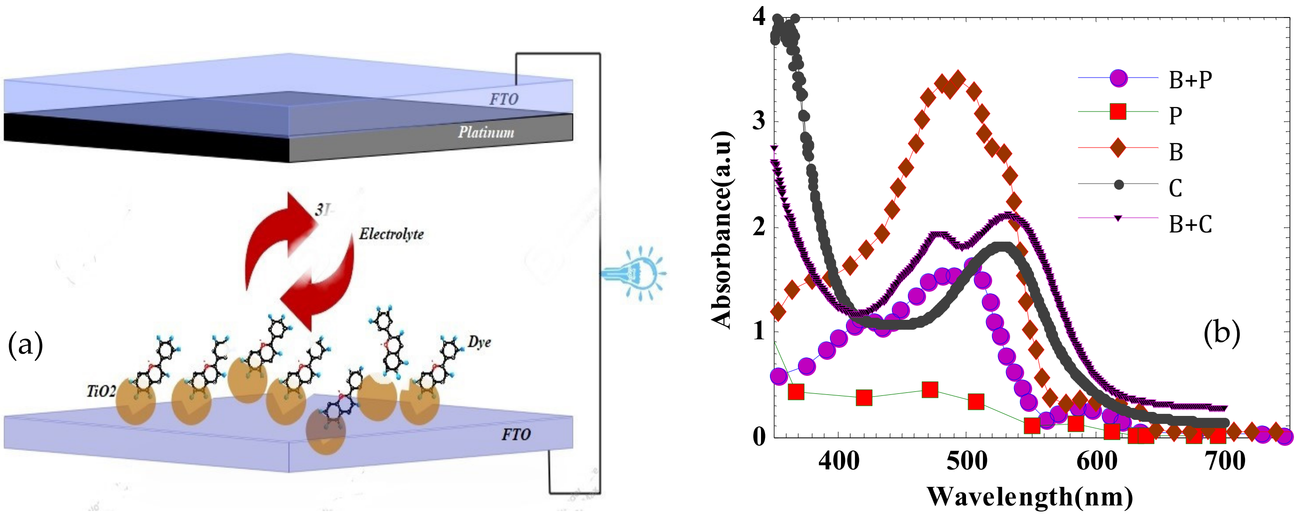

Figure 1. (**a**) Schematic of DSSC (**b**) UV-Visible spectra of the natural dyes.

This method helps in minimizing recombination kinetics, boosting the current output and overall efficiency of the cells [11,12]. The co-sensitization in DSSC stops the growth of aggregates on the mesoporous oxide layer, reduces resistance, and increases the current density [13]. The extract of pomegranate, kumkum, and beetroot were separately mixed with synthetic Eosin Y dye and used in DSSC. The co-sensitized DSSC with Eosin Y and beetroot dye, Eosin with pomegranate and Eosin with kumkum dye showed PCEs of 0.3%, 0.1% and 0.2%, respectively [14]. Something similar was reported by Richhariya et al.: co-sensitized DSSC fabricated using synthetic organic dye (Eosin Y) and bromophenol dye obtained higher power conversion efficiency than their individual dye-based DSSC [15]. DSSC fabricated with cocktail dye extracted from beetroot and spinach achieved a higher PCE (3.20%) than their individual dye [16].

Co-sensitization is an active area of research but it is in its infancy, and there are still a number of issues that need to be resolved, such as the usage of various dyes on the same mesoporous oxide layer. It can play a key role in increasing the efficiency and stability of DSSCs, which are the main hindrance to DSSCs' commercialization. In this research work, we extracted natural dyes from pomegranate, cranberry and beetroot and used them as a sensitizer in DSSC. We further investigated the performance of the co-sensitized DSSCs with cranberry + beetroot, cranberry + pomegranate, and pomegranate + beetroot.

2. Experimental Section

Most of the required materials were purchased from Solaronix, Switzerland, such as mesoporous Titania past, drilled platinum coated Fluorine doped Tin Oxide (FTO) counter-electrodes, sealing, caps, gaskets, and Iodolyte AN-50 electrolyte. The required solvent was purchased from Sigma-Aldrich. Fresh beetroot, pomegranate and cranberry for the extraction of natural dyes were collected from a local fruit market. After cleaning the FTO, the first layer of transparent TiO_2 past was deposited using the doctor blading technique and then annealed for 15 min at 470 °C. This step was repeated to obtain the required thickness. To harvest maximum light, scattering layer was deposited using doctor blading and annealed at 470 °C for 15 min. Maceration technique was used to extract the natural dyes [17]. Fruits were washed and then crushed in methanol for 24 h. After this, dyes were filtered to obtain a clear solution. The TiO_2-coated FTO were immersed in the dye solution and kept undisturbed for 24 h at room temperature. After removing from the dye solution, the photoanodes were washed with ethanol to remove any unattached dye molecules. Photo anode and counter electrode were sandwiched with the help of 60 um thick meltonix. Then, electrolyte was injected through the hole of the counter electrode and sealed the hole with aluminum tap. The schematic of the DSSC is shown in Figure 1a.

3. Results and Discussion

3.1. UV-Vis Spectrometry

UV-vis spectrometry is used to study the optical behavior of the dyes used in DSSCs. For the application of DSSC, dyes should absorb light in the visible region. The absorption spectra of the natural dyes extracted from beetroot, pomegranate, cranberry, and their cocktail dyes are shown in Figure 1b. Beetroot shows absorption peak in the visible region at 479 nm and 534 nm which confirms the presence of betanin pigment [18]. Cranberry shows absorption peak in the visible region at 427 nm. The natural dye extracted from pomegranate showed an absorption peak at 472 nm which is in agreement with the reported value [19]. The cocktail dye of cranberry and beetroot shows a broad absorption in the visible region of 427–574 nm. However, mixed dye of beetroot and pomegranate did not show any significant enhancement in the absorption region.

3.2. Photovoltaic Performance

The IV measurement of the fabricated DSSCs were measured using Keithley 4200 source meter equipped with solar simulator having illuminations (AM 1.5) 100 mW/cm^2. Current density–Voltage (Jsc–V) characteristic curves of the fabricated DSSCs with mono-sensitized and co-sensitized strategy are shown in Figure 2. Other performance parameters, such as Fill Factor (FF), short-circuit current density (Jsc), open circuit voltage (Voc), and efficiency (η) were determined from the I–V characteristics curve and shown in Table 1.

Comparatively, co-sensitized DSSC with beetroot and cranberries extract showed better performance than their individual dyes. The photovoltaic performances of the co-sensitized DSSC with cranberry and beetroot showed an increasing order of Jsc than their individual dye-based DSSC. However, mixed dyes of pomegranate with beetroot and cranberry did not show any enhancement in the performance of DSSCs. The power–voltage characteristic curves of the fabricated DSSCs with single and cocktail dyes are shown in Figure 3. It is concluded from the results that only mixing of appropriate dyes will enhance the performance of DSSCs.

Variations in open circuit voltage (Voc) of the fabricated DSSCs with natural dyes extracted from beetroot, cranberry, and pomegranate, and their mixed dyes are shown in Figure 4a. It is clear from the figure that no enhancement in open circuit voltage has been achieved from the co-sensitization for all dyes. Pomegranate-based DSSC showed the highest open circuit voltage (Voc) and beetroot had the lowest open circuit voltage (Voc). Figure 4b shows the variation in short-circuit current density (Jsc) of the fabricated DSSCs with natural dyes and their mixed dyes. Cranberry + beetroot, and pomegranate + cranberry showed an enhancement in the short-circuit current density as compared to their individual dyes. However, in the case of pomegranate + beetroot, the short-circuit current density (Jsc) decreased as compared to their individual dye.

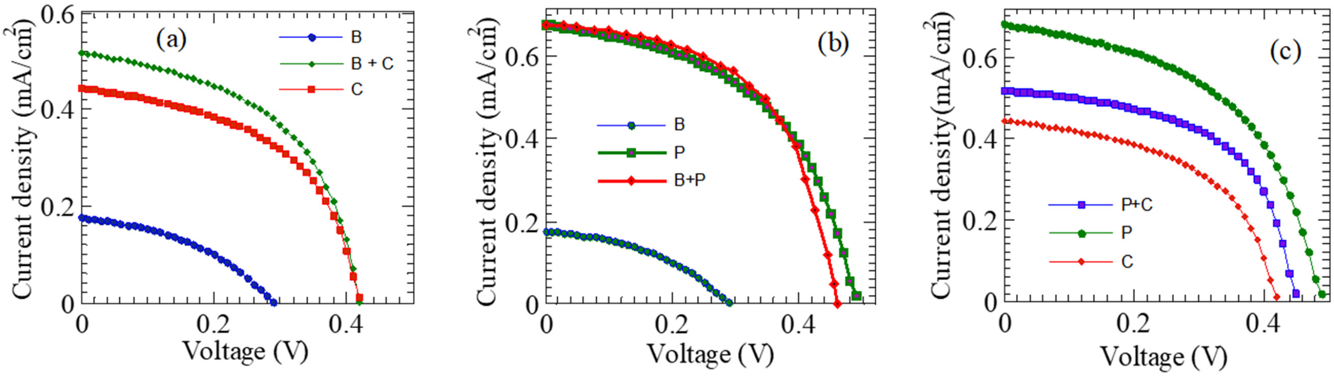

Figure 2. J–V curve of DSSCs with (**a**) Beetroot, Cranberry and B + C, (**b**) Beetroot, Pomegranate and B + P (**c**) Pomegranate, Cranberry and P + C.

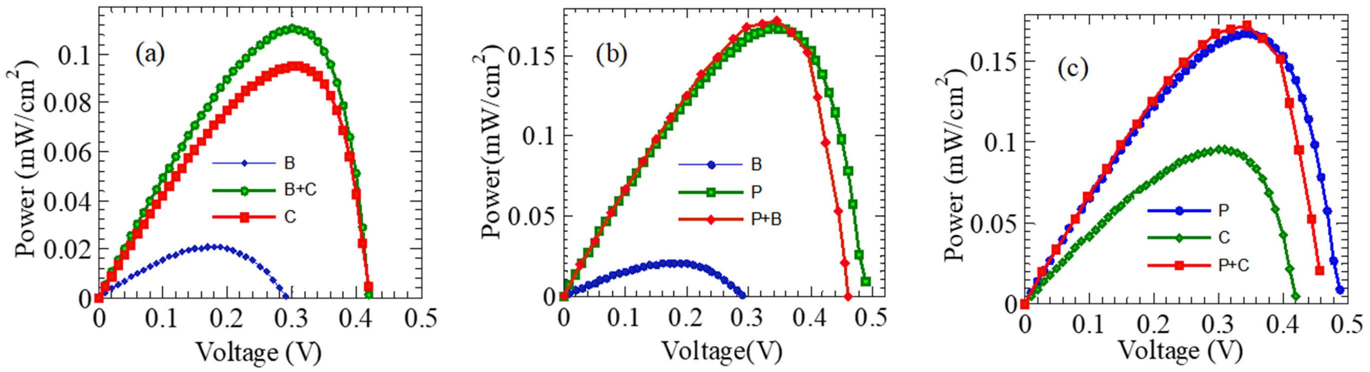

Figure 3. P–V curve of DSSCs with (**a**) Beetroot, Cranberry and B + C, (**b**)Pomegranate, Cranberry and B + C and (**c**) Beetroot, Pomegranate and B + P.

Table 1. Photovoltaic performance of the fabricated DSSCs with mono-sensitized and co-sensitized DSSCs.

Dye	Jsc (mA.cm^{-2})	Voc (V)	FF (%)	Eff (%)
Beetroot	0.175	0.29	40	0.0203
Cranberry	0.31	0.42	51	0.066
Pomegranate	0.67	0.49	50	0.164
B + C	0.36	0.42	51	0.076
P + C	0.359	0.45	55	0.090
P + B	0.167	0.45	55	0.041

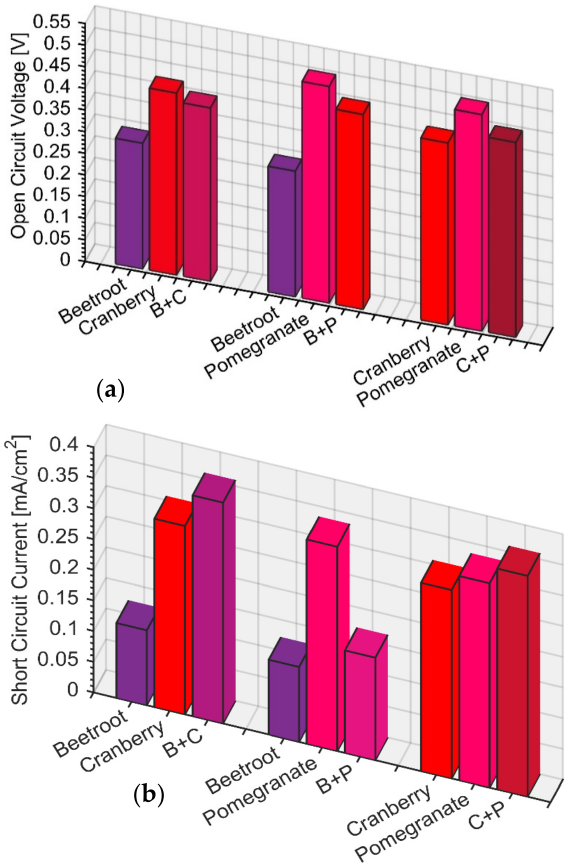

Figure 4. Comparison of the (**a**) open circuit voltage (Voc) and (**b**) short-circuit current (Jsc) of the fabricated DSSCs with individual and their cocktail dyes.

4. Conclusions

In this study, DSSCs have been fabricated with natural dyes extracted from beetroot, cranberry, and pomegranate. From the obtained result, pomegranate-based DSSC showed the highest efficiency. We further investigated the effect of the co-sensitization approach with beetroot and cranberry, beetroot and pomegranate, and cranberry and pomegranate dyes. Only the beetroot and cranberry-based co-sensitized DSSC showed an enhancement in performance as compared to their individual dyes. The other two combinations of the natural dyes (beetroot + pomegranate and pomegranate + cranberry) did not show any enhancement in the performance of the DSSCs.

Author Contributions: W.S. designed the study, performed synthesis, fabrication and characterizations, analyzed the result and wrote the original draft. S.M.F., S.A., S.S.H. and M.H.S. conceptualized the study, performed formal analysis, assisted in methods and supervision. All authors contributed to discussions and critically proofread the manuscript. All authors have read and agreed to the published version of the manuscript.

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