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Spectral responses of *B. vulgaris* dye-sensitized solar cells to change in electrolyte

T.J. Abodunrin^{1,*}, A.O. Boyo², M.R. Usikalu¹, O. Kesinro¹

¹Department of Physics, Covenant University, Ota, Ogun State, Nigeria

²Department of Physics, Lagos State University, Ojo, Lagos State, Nigeria

temitope.abodunrin@covenantuniversity.edu.ng

Abstract. Dye-sensitized solar cells still offer an encouraging option in the photovoltaic family. It is endowed with several attributes such as ability to generating green energy at low cost, ease of fabrication and yearlong availability of raw materials. Betalain an important constituent of *B. vulgaris* shows diverse changes to temperature and solvents as they alter the fluidity of its membrane. This experiment seeks to explore the latter with a keen interest on the IPCE and efficiency of beetroot dye-sensitized solar cells (DSCs). The Doctor blade method of application of TiO₂ photoanode using ethanol as precursor and high temperature sintering reveals diverse spectral responses in the efficiency of the DSCs with the most efficient *B. vulgaris* dye recording 0.27% and the highest IPCE of the dye revealed as 28.34%.

1. Introduction

Till date, efficiency of solar cells is an utmost limiting factor in dye-sensitized solar cells. In order to be effective, the monolayer of organic dye must be able to harvest a wide crop of insolation. Diverse photo sensitizers differ in their characteristic absorption of available light, output efficiency and cost. Our choice of *B. vulgaris* is based on its efficiency and low cost from previous research work [1].

A lot of organic, inorganic and hybrid dyes have been used as photo sensitizers [2-3]. This is as a result of the potential high cost and scarcity of ruthenium, N719 and N3 dyes, which are also not ecologically friendly. Thus, several metal-free organic dyes have been applied in DSCs [4]. In recent studies, natural organic dye extracts examples include anthocyanin, chlorophyll, tannin, and carotene from various parts of plants such as seeds, fruits, flowers and leaves have been productively used as sensitizers in DSCs [5]. Hao and some researchers successfully extracted dye sensitizer from the leaves of capsicum, black rice, Rosa xanthina, kelp and Erythrina variegata flower for application in DSCs. The result was an IPCE of 0.327 % from Black rice [6]. Another researcher Wongcha-ree and some others used a dye cocktail from natural extracts of blue pea and rosella in ratio 1:1 as sensitizer in DSCs, the result was a slight improvement over the last, the IPCE recorded was 0.37% [7].

A crucial factor that affects the performance of DSCs is the choice of photoanode material. TiO₂ is a preferred photoanode because of its wide band gap of 3.2 eV and biocompatibility with other organic products [8]. We report here the results of a series of experiments carried out on raw extracts of the *B. vulgaris* specie. Beta vulgaris belongs to phyla Chenopodiaceae and comes in an assortment of bulb with colours alternating from yellow to red. The most popular variety is deep red *B. vulgaris* which is usually either cooked or served raw in salad or juice. There is more awareness in the choice of natural



food colours due to the prevalent danger of ingesting indigestible synthetic dye compounds. This research seeks to explore *B.vulgaris* because it is less used in food processing relative to anthocyanins and carotenoids even though, it water-soluble and is stable between pH 3 and 7 [9].

2. Materials and Method

63.7 g of *B.vulgaris* was blended without the peel. It was mixed with 1000 ml of water to extract the dye. The mixture was fed into a Stuart RE 300 B series rotary evaporator to extract the dye. The dye extract was dissolved in 1:10 distilled water (DW) to obtain the phytochemicals. The same ratio was used to obtain the UV/VIS spectrograph with Thermoscientific Evolution 60S spectrophotometer. The *B.vulgaris* DSCs were fabricated using an active area of 3.14 cm². The TiO₂ paste was uniformly blended and applied via doctor blade method of standard laboratory procedure and high temperature sintering at 450 °C [10]. The counter electrode was evenly coated with soot over a naked Bunsen flame and allowed to cool. The two electrodes were coupled together with binder clips. Four different electrolytes dissolved in ratio 1: 100 DW was injected in-between the conducting slides. A Voltcraft M-3850 digital multimeter was used to obtain the value of potential differences as the load was varied.

3. Results and Discussion

3.1 Phytochemical Analysis

The phytochemical screening result revealed the presence of a compound rich in chromophores as shown in Table 1.

Table 1: Phytochemical Screening Result of *B.vulgaris*

Flavono id	Saponi n	Steroi d	Pheno l	Caroteno id	Tanni n	Alkaloi d	Triterpen oid	Cardiac Glycosi de	Quinon es
+	+	+	+	+	+	+	+	+	-

Key: + means presence while – means absent

3.2 UV/VIS Spectroscopy

The UV/VIS spectrograph revealed that *B.vulgaris* records maximum absorbance at 316 nm wavelength. This is a near ruthenium absorption characteristic behaviour [11]. According to Beer Lambert's law,

$$A_{\lambda} = -\log T \quad (1)$$

$$A = \epsilon cl \quad (2)$$

where A is absorbance in a.u, T is the transmittance in %, ϵ is the molar absorption coefficient in mol/cm³, c is the concentration of the solution in mol/cm³ and l is the path length in cm. A (*B.vulgaris*) from Figure 1=3.252 a.u.

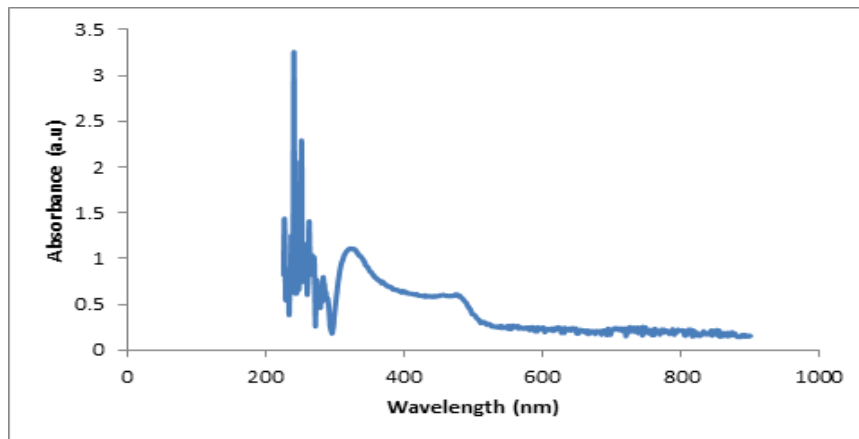


Figure 1: UV/VIS of *B.Vulgaris* leaf extract

3.3 Photovoltaic Result

Photovoltaic Result for different electrolyte sensitized DSCs are illustrated in Figure 2 (a) to (d). The interboundary kinematics and redox reactions produce the differences in the I-V curve which provides the parameters for determining efficiency and IPCE from Equations (3) and (4).

$$\eta = \frac{I_{sc} V_{oc} ff}{A \times P_{in}} \quad (3)$$

$$IPCE = \frac{1240 \times I_{sc}}{P \times \lambda} \quad (4)$$

where η is efficiency in %, I_{sc} is the short circuit current in mA, V_{oc} is the open circuit voltage in volts, ff is the fill factor, A is the area of exposure in cm^2 , P_{in} is the power input in Watts and λ is the wavelength in nm. The results are shown in Table 2. The best ff , I_{sc} , V_{oc} , P_{max} and η was produced by *B.vulgaris* with KI although it is a non-uniform curve attributed to redox reactions occurring spontaneously all through charge transport. The best incident photon to conversion efficiency was recorded in KBr although the efficiency was poor. This is probably due less favourable redox reactions and interboundary kinematics such as trap sites and recombination losses.

Table 2: Photovoltaic Spectra of *B.vulgaris* with Four Electrolytes

Parameters	I_{sc} (mA)	V_{oc} (V)	P_{max} (W)	ff	η (%)	IPCE (%)
KI	0.090	320	8.5	2.95	0.27	4.15
KCl	0.047	165	0.99	0.128	0.003	18.62
KBr	0.052	190	0.72	0.073	0.002	28.34
HgCl2	0.018	120	1.97	0.91	0.06	3.59

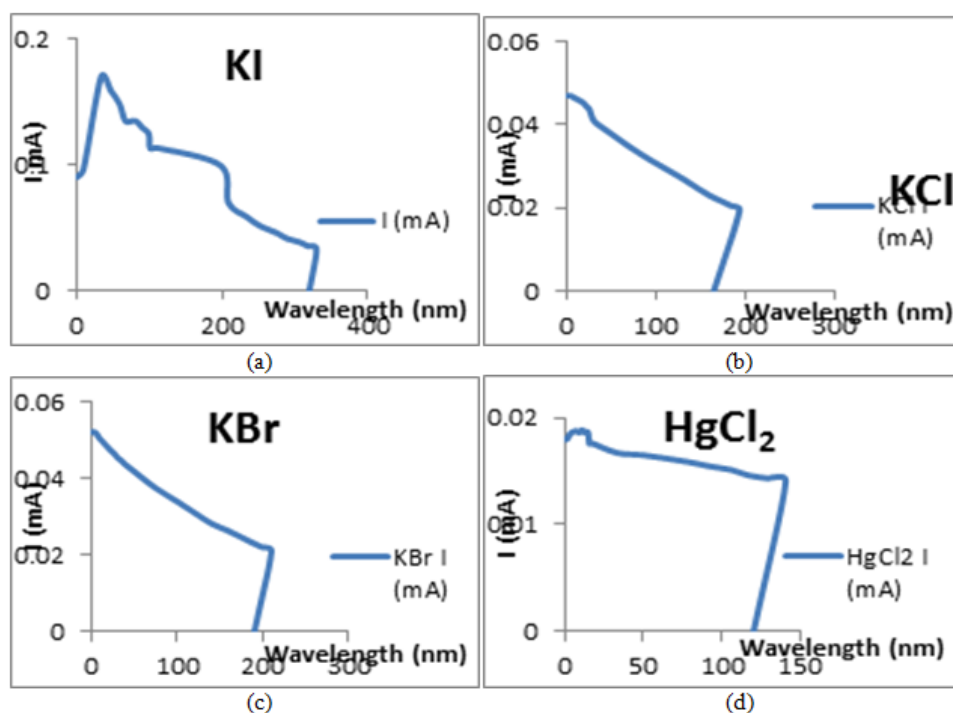


Figure 2: Illustrates *B.vulgaris* I-V curve with (a) KI electrolyte, (b) KCl electrolyte, (c) KBr electrolyte and (d) HgCl₂ electrolyte respectively.

4. Conclusion and Recommendations

B.vulgaris leaf extract records a relatively high V_{oc} with the different electrolyte used as sensitizer. The best electrolyte recommended for future use either in dye cocktails or for a different photoanode is KI. It produces the fastest charge transport which promotes better interfacial boundary relationship with the molecules of the dye, TiO₂ and electrolyte.

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