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Visible light absorption and photo-sensitizing properties of spinach leaves and beetroot extracted natural dyes

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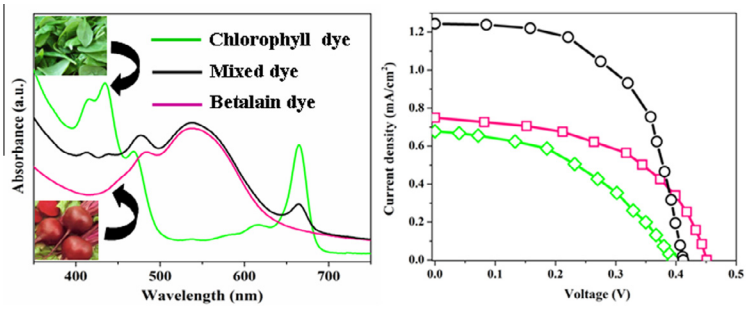
HIGHLIGHTS

- Chlorophyll and betalain dyes are extracted from spinach leaves and beet roots.
- Temperature and pH dependent UV characteristics of these dyes are investigated.
- Zinc oxide (ZnO) particles are synthesized and characterized using XRD, FTIR, SEM.
- Dye sensitized solar cells are fabricated using extracted dyes and ZnO particles.
- Mixture of aforesaid dyes shows better efficiency than individual dyes.

GRAPHICAL ABSTRACT



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ABSTRACT

Herein, chlorophyll and betalain dyes are extracted from fresh spinach leaves and beetroots. Fourier transform infrared spectra are used to identify the characteristic peaks of the extracted dyes. UV–vis light absorption characteristics of the dyes and their mixed counterpart are investigated by varying their pH and temperature. These dyes are used as photo sensitizer for fabrication of zinc oxide photo-anode based dye sensitized solar cells (DSSCs). The photo-voltaic characteristics of the developed DSSCs are measured under simulated solar light (power of incident light 100 mW cm^{-2} from Air Mass 1.5G). The solar to electric conversion efficiencies for the chlorophyll, betalain and mixed dye based solar cells are estimated as 0.148%, 0.197% and 0.294% respectively. The highest conversion efficiency for mixed dye based solar cell is attributed due to the absorption of wider range of solar spectrum.

Introduction

The most abundant source of renewable energy on earth is sun light. The proper use of solar energy in a well organized, economical manner is a challenging research issue. Various kinds of solar cells (e.g., inorganic, polymer based p–n junction photovoltaic cells, quantum dot and dye sensitized solar cell, etc.) are developed till date for harvesting of solar light into electrical energy [1–4]. In this regard, dye sensitized solar cells (DSSCs) have attracted significant academic and technological attention due to their simple and cost-effective fabrication [5]. A typical DSSC is usually composed of photo-anode (semiconducting metal oxides coated on transparent conducting glass substrate), photo-sensitizer (dye), counter electrode and electrolyte [6]. The operating principle of DSSC is described well in various literatures [7]. As reviewed, for DSSCs, dye and metal oxide play significant role in the generation, injection and transportation of photo-excited electrons. The choice of photo-sensitizers in solar cells is directed mostly based on their visible light absorption characteristics, stability and cost. Several

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synthetic inorganic metal complexes as well as organic dyes have been studied as photo-sensitizer in such type of solar cells. Among these synthetic dyes, Ru-based complexes are considered most efficient photo-sensitizers for DSSC application due to their long lifetime and highly efficient metal-to-ligand charge transfer (MLCT) [8]. The performances of few synthetic organic dyes are also found promising for the solar cell application [9]. However, the use of such synthetic dyes seems undesired due to their high cost and complex synthesis processes. As compared to such synthetic inorganic and organic dyes, the dyes extracted from natural resources could be effective to produce low cost solar cells. Viewing in the same line, various dyes (e.g., anthocyanin, carotenoid, betalain, chlorophyll, etc.) are extracted from natural sources (e.g., achiote seeds, *Rosa xanthina*, bamboo leaves, red-*Perilla*, red cabbage, etc.) and investigated in terms of their photo-sensitizing behavior for DSSC application [10–14]. The performances of natural dyes in DSSCs are studied mostly when these are anchored with titania (TiO_2) based photo-anode. As compared to TiO_2, ZnO retains higher electron mobility which should enable it for faster transport of photo-excited electrons. For DSSC application, the performance of ZnO based photo-anodes sensitized with commercial/synthetic dyes are reported elsewhere [15–17]. Therefore, the performance of natural dye loaded ZnO photo-anode need to be investigated for DSSC application. In the present work, the photo-sensitizing properties of chlorophyll and betalain dyes on ZnO based photo-anode are studied for DSSC application. The chlorophyll and betalain dyes are extracted from spinach (*Spinacia oleracea*) leaves and beet (*Beta vulgaris*) roots. Temperature dependent UV–vis spectroscopy is used to investigate the light absorption characteristics of the extracted dyes. The extracted chlorophyll and betalain dyes are mixed together to improve their visible light absorption behavior. ZnO particles are synthesized through cost effective precipitation route and characterized in terms of their phase formation behavior and morphological features. The photo-anode is prepared by coating ZnO particulate layer on FTO coated glass substrate. Sandwiched type solar cell is fabricated and the photo-voltaic parameters are measured under simulated solar light.

Experimental

Extraction and characterization techniques for dyes

Chlorophyll and betalain dyes are extracted from fresh spinach leaves and beetroots. For the extraction of chlorophyll, the fresh spinach leaves are cleaned using distilled water, sliced into small pieces and dried at 60 °C for an hour. The leaves are crushed using grinder machine. The crushed mass is kept at 60 °C for 2 h under rotary evaporation and mixed with absolute ethanol. The ethanolic mass of the chopped leaves is filtered and the filtrate is kept at −4 °C for further use. For the extraction of betalain, beetroots are cut into small pieces and pulverized using grinder machine. The thick jelly like mass is then kept in rotary evaporator at ∼40 °C for 5 h and mixed with ethanol for further use.

The characteristic peaks of the extracted chlorophyll and betalain dyes are identified in Fourier transformed infrared (FTIR) (IRPrestige-21, Shimadzu, Japan) spectra. The light absorption characteristics of chlorophyll and betalain dyes are studied using UV–vis (UV-3600, Shimadzu, Japan) spectroscopy. With the variation of the pH, the natural dyes are found to alter their light absorption characteristics. Additionally, the light (UV–vis) absorption properties of few natural dyes are found to loss with temperature also. Since the incident of solar light often produce local heat on the cell, it is important to study the light absorption behavior of the extracted dyes by varying the temperature. Here, the light absorption characteristics of the dyes are studied by varying the temperature (in the range 25–70 °C) and pH (3–12) of the extracted dyes.

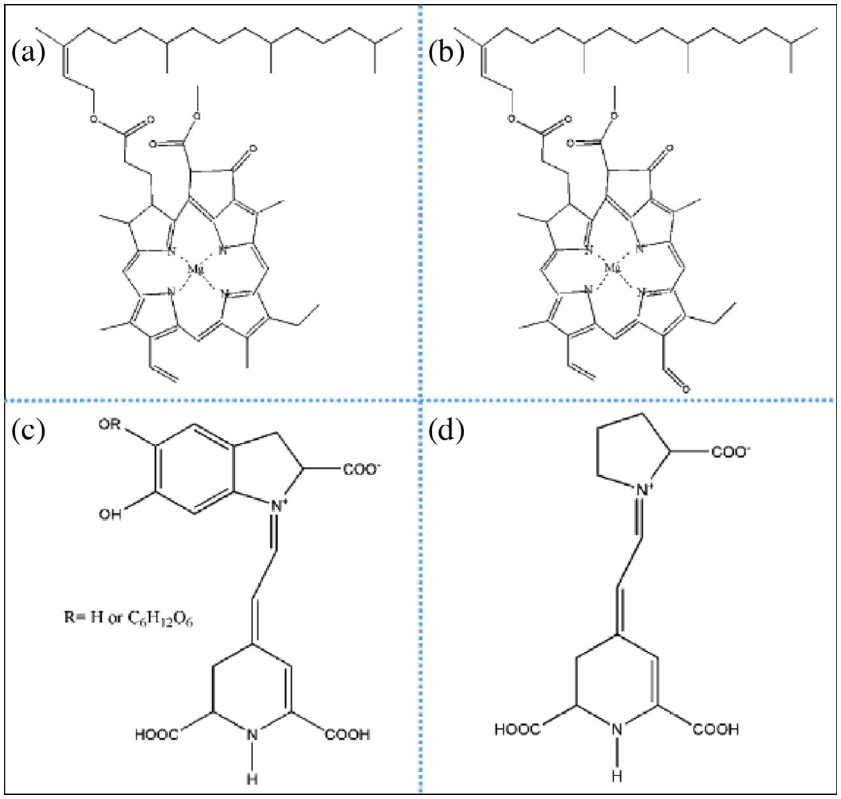

Fig. 1. Chemical structures of (a) chlorophyll a (b) chlorophyll b (c) betanin (d) betaxanthin.