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Optimization of Mangosteen Dye-Sensitized Solar Cells

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Abstract: *Garcinia mangostana*, commonly known as mangosteen, is often referred to as the "queen of fruits" for its delicious flavor and numerous health benefits. Mangosteen has also attracted attention in recent dye-sensitized solar cells (DSSC) studies as the dye extracted from the purple-red pericarp has exceeded many natural dyes in DSSC efficiency.[1,5] The purpose of this study was to optimize the dye extraction from the mangosteen pericarp for use in DSSC applications. Previous studies have indicated that rutin is main contributing factor to DSSC efficiency.[1] However, these results suggest that extracting cyanidins in acidic conditions increases DSSC current substantially when compared to extractions of rutin in ethanol.

Introduction:

Mangosteen pericarp has been used in traditional medicine for many years in East Asian countries such as India, Myanmar, Malaysia, Philippines, Sri Lanka, and Thailand to treat abdominal pain, skin infections and diarrhea. The dye extract from the pericarp is also common in traditional methods of dyeing silk and cotton.[2]

In a study by Ma et. al (2011) mangosteen pericarp extracts were found to have the highest rate of DSSC efficiency compared to 20 other dyes. The molecule found to be the primary active component in this extract was rutin (Fig. 1) whereas the molecules extracted with traditional methods is cyanidin-3-sophoroside and cyanidin-3-glucoside (Fig. 2).[1,2]

The purpose of this study was to optimize the DSSC current from dye extracted from mangosteen pericarp. This was done by comparing the proficiency of rutin as the dye component of DSSC's to cyanidin. Dye molecule characterization was performed with UVVis, matching absorbance spectra of the molecules to literature, and in the case of rutin, to spectra obtained from purified rutin powder.

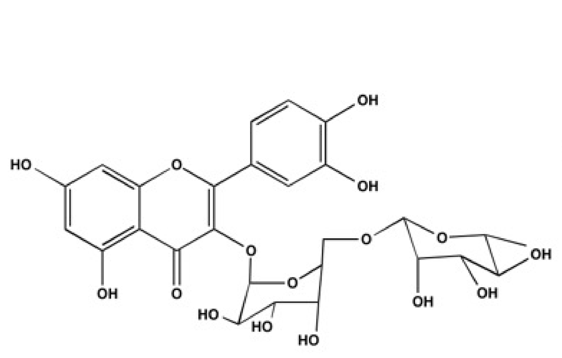


Figure 1: Rutin

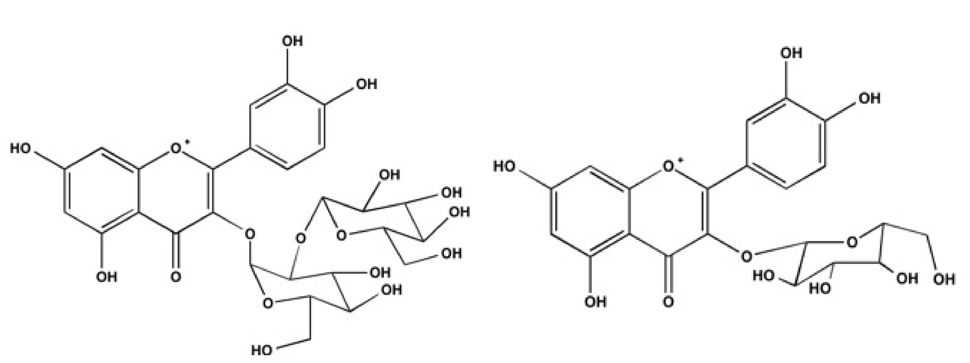


Figure 2: Cyanidin-3-sophoroside (left) and cyanidin-3-glucoside (right)

References:

1. Ma, T.; Gao, Y.; Wu, L.; Zhou, H. Dye-Sensitized Solar Cells Using 20 Natural Dyes as Sensitizers. Journal of Photochemistry and Photobiology A: Chemistry 219, **2011**, 188-194.
2. Chairat, M.; Bremner, J.; Chantrapromma, K. Dyeing of Cotton and Silk Yarn with the Extracted Dye from the Hulls of Mangosteen, *Garcinia mangostana* Linn. Fibers and Polymers **2007**, Vol. 8, No. 6, 613-619.
3. Cherepy, N.; Smestad, G.; Gratzel, M.; Zhang, J. Ultrafast Electron Injection: Implications for a Photoelectrochemical Cell Utilizing an Anthocyanin Dye-Sensitized TiO_2 Nanocrystalline Electrode. J. Phys. Chem. B **1997**, 101, 9342—9351.
4. Lisensky, George. "Titanium Dioxide Raspberry Solar Cell." University of Wisconsin Madison Materials Research Science and Engineering Center. The Board of Regents of the University of Wisconsin System, 24/01/2011. Web. 22 May **2011.**
5. Malazan, M.; Noh, M.; Wahab, Y.; Norizan M.; Mohamad, I. Development of Dye-Sensitized Solar Cell (DSSC) Using Patterened Indium Tin Oxide (ITO) Glass. IEEE Conference on Clean Energy and Technology (CEAT) **2013**.
6. Alia, J.; Walsh, A. Unpublished data, **2015**.
7. Slimestad, R.; Solheim, H. Anthocyanins from Black Currants (*Ribes nigrum L.*). J. Agric. Food Chem. **2002**, 50, 3228-3231.

Methods:

Mangosteen hulls were air-dried and ground into small pieces. Dye was extracted in both 15% citric acid and ethanol in both light and dark conditions for one week. Dye was also extracted in 15% citric acid for one hour at 80 °C and at room temperature (33.7°C) (Fig. 3-4).

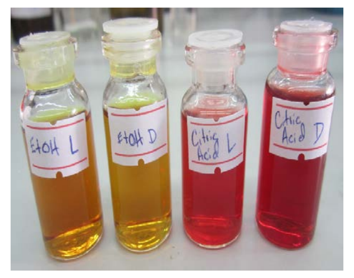
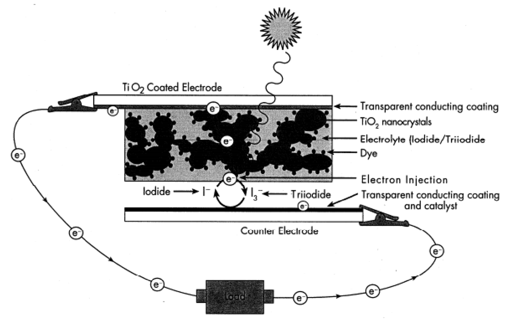


Figure 3: Ethanol and acid extracts after one week extraction

Figure 4: 15% Citric acid 1hr. extracts, Room T. (left), 80°C (right)

Figure 5: TiO_2 layer before and after dye absorption. Cyanidin (left), Rutin (right)

Once extracted, the dye was applied to the TiO_2 layer of the solar cells (10 min.), which were assembled following standard procedures (Fig. 5-6).[4] Light and dark current (uA) and voltage (V) were measured using a Triplett Multimeter, with n = 4 cells for each trial.



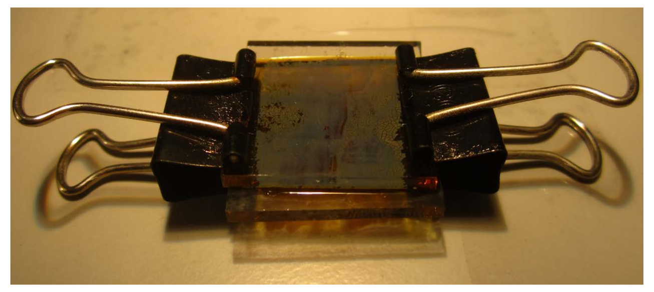
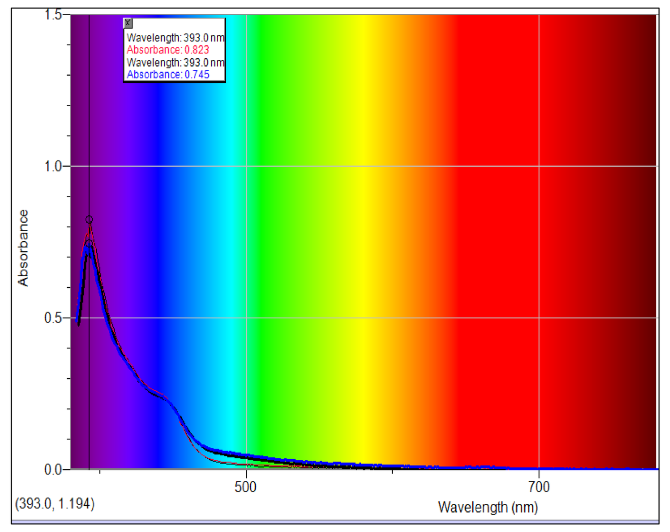


Figure 6: Assembled DSSC

UV-Vis absorption of the ethanol and citric acid extracts was measured with a Red Tide spectrophotometer (Fig. 7).



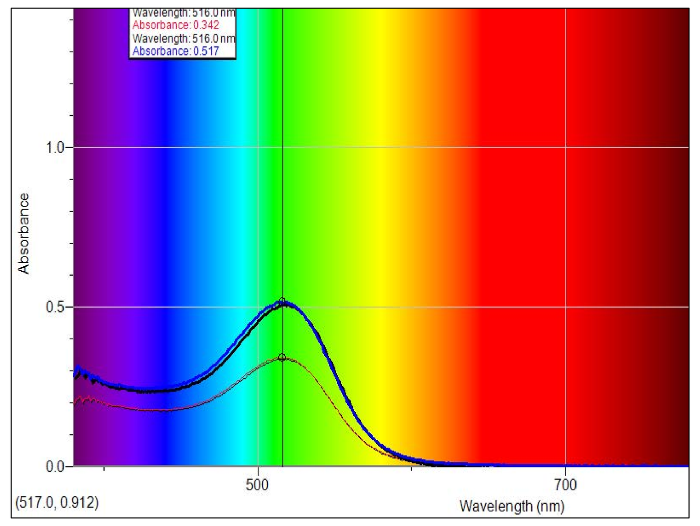


Figure 7: UV-Vis spectra of rutin extracts (left) and cyanidin extracts (right). Rutin λ_{max}: 393 nm, Cyanidin λ_{max}: 516 nm

Results and Conclusion:

Dye Characterization:

The identities of the extracted molecules were confirmed by the following observations:

- The rutin extract gave a 393 nm λ_{max} matching closely to that of tested purified rutin (407 nm) as well as to literature values.[1]
- A bright yellow precipitate was observed in some aqueous extracts, corresponding to rutin's known limited solubility in water.
- The cyanidin extracts λ_{max} of 516 nm matched with literature values for cyanidin-3-sophoroside and cyanidin-3-glucoside (516 nm).[7]
- ZINDO and TFDDT calculations of both rutin and the cyanidins roughly agree with these values[6]
- The color change of the TiO_2 layer upon absorption of the acid extract agrees with suggested binding of cyanidins to the TiO_2 layer at the choromophore.[3]

Solar Cells

Table 1: Solar Cells and Currents

Cell	Current (uA)
Ethanol – Light	23.1
Ethanol – Dark	59.4
Citric Acid – Light	103
Citric Acid -- Dark	95.6
Citric Acid, 1hr, Room T.	133
Citric Acid, 1hr., 80 °C	169

Table 1: Recorded values are the average difference between current under ambient light and current under applied light source.

The greater current produced by the cyanidin extracts in Table 1 agrees with literature suggesting a one-step mechanism, direct injection, of excited electrons into the TiO_2 semiconductor from the absorption of a photon.[3] As such, these results suggest that cyanidins are more suitable molecules than rutin for DSSC applications.

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