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Investigation of effect of batch-separation on the micro-energy
generation in *M.indica L.* dye-sensitized Solar Cells

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Abstract

The technology of silicon panels has improved over the years with the application of silicon into several material architecture. However, the high cost of the technology has limited its wide adoption. Recent advances have shown that natural materials employed as dye sensitizers for solar cells provide viable alternatives at low cost. This study focused on implementing Mango (*Magnifera indica Linn.*) leaf dye as dye sensitizer for solar cells. Unlike previous approaches, it employed batch-separated *M.indica L.* to sensitize two groups of dye-sensitized solar cells (DSCs). Parameters such as short circuit current (I_{sc}), open circuit voltage (V_{oc}), maximum power (P_{max}), fill factor (ff), incident photon to conversion efficiency (IPCE) and output efficiency (η) were used to determine the outcome of the *M.indica L.* DSCs. The doctor blade method and high temperature sintering at 450 °C was used in the preparation of both photoanodes. Photovoltaic results reveal DSCs with a higher efficiency of $4.75 \times 10^{-3} \%$ in crude *M.indica L.* than $0.07 \times 10^{-3} \%$ for batch separated hexane fraction of *M.indica L.* under same conditions of standard air mass. Remarkably, the hexane *M.indica L.* DSC recorded larger values of I_{sc} and V_{oc} . The significance of this result is that crude *M.indica L.* DSCs are more affordable, have a facile production process and is an ecologically safe alternatives to silicon solar cells. Although the efficiencies are comparatively low, further research with a solar simulator and co-sensitization with other dyes is recommended for a better outcome.

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1. Introduction

A Dye-sensitized Solar Cell (DSC) is a photovoltaic device that converts photons from sunlight to electricity directly. Gratzel and some other researchers discovered DSC based on TiO_2 in 1991. Their efforts produced an encouraging output efficiency of 11%, which brought keen scientific interest to the field of solar cells [1, 2]. Since then, photovoltaic technology has witnessed a lot of progressive trends [3]. In many parts of the world, electricity is still being produced at very high cost and at times the techniques deployed are detrimental to the environment. The present-day photovoltaic market is dominated by silicon solar cells, which though efficient are relatively expensive and still out of reach of a lot of people in developing parts of the world. In addition, extreme temperature conditions cause solar panels to cut off their supply. Also, at the moment, the techniques for depositing expired silicon solar panels are either nonexistent or undeveloped. In view of these limitations in silicon technology, there is a progressive search for a viable substitute for silicon solar cells that would compete more favorably in terms of cost and waste disposal. There are several essential attributes that qualify DSC technology as a prospective choice. The qualities include quantum efficiency, low cost, facile method of preparation, availability of raw materials and most importantly, environmental friendliness. This work thus aims at generating energy from ecologically non-toxic *M.indica L.* to offset the conventional high electricity cost, and provide a viable option in remote areas from the national grid. A need for optimization of *M.indica L.* dye brought about the process of batch separation to improve on the dye efficiency. Existing results have shown marked improvement in the DSC performance consequent of batch-separation [4]. This is a comparative study of the outcome of batch-separation on the photovoltaic characterization of *M.indica L.* DSCs under standard condition of air mass.

2. Materials and Method

2.1. Preliminary procedure

1000 g of *M.indica L.* were harvested and air dried in the laboratory until they assumed constant weight. The dry leaves were milled before being soaked in methanol solvent inside thin layer chromatography (TLC) tanks to extract the dye. Careful examination revealed that enough of the dye had dissolved after 11 days. The dye was recovered from the mother liquor with a rotary evaporator and batch separated by methods described in Abodunrin et al. [5]. The preliminary phytochemical screening was carried out using methods described in Najm et al. [6].

2.2. UV/VIS and FTIR Spectroscopy

The UV/VIS and FTIR spectroscopy sample of *M.indica L.* was obtained by dissolving 1-10 parts in methanol. The Genesys and Shimadzu spectrophotometers were used respectively for the UV/VIS and FTIR respectively.

2.3. Fabrication of photoanode

The fabrication of DSC was carried out on an active area of 5.14 cm^2 of indium doped tin oxide (ITO) conducting glass. Concentrated trioxonitrate (V) acid was integrated into TiO_2 paste in the ratio 20 ml to 50 g until a smooth colloidal paste was obtained. This paste was applied to the marked area on the side of the conducting glass by the doctor blade method [7]. The set up was allowed to dry for 6 hours before it was sintered at $450 \text{ }^\circ\text{C}$ for 1h 30 mins. The characteristic brown to white colour changes in the photoanode indicated that it was ready for use. After sintering, the photoanode was left for 1 h. to assume room temperature in order to prevent delamination. The counter electrode was prepared by coating the second pair of ITO with even epitaxial layer of soot over a naked Bunsen flame in a vacuum-like enclosure. The *M.indica* dye was deposited on the photoanode via capillary action. When it dried, the two electrodes were fastened together with binder clips and connected in parallel to a variable resistor and a digital multimeter to obtain readings. Four electrolyte solutions were prepared in the ratio 1-100 distilled water and injected in-between the ITO with hypodermic needles. The experiment was carried out under standard air mass conditions.

3. Results and Discussion

3.1. UV/VIS Spectroscopy of *M.indica L.*

Figure 1 presents the characteristic absorbance of *M.indica L.* within the electromagnetic spectrum. This is similar to the result of methanolic dye extracts of spinach and spinach-black myrtle dye-sensitized solar cells [8]. The *M.indica L.* shows characteristic porphyrin absorbance in solet (403 nm), and Q band (666 nm) respectively as presented in Figure 1. It shows that the absorbance in solet band is more intense than the absorbance in Q band which describes typical porphyrin behaviour. Several literature postulates that the solet band is permissible because it only requires a small change in momentum for transition to occur. This is particularly suitable as *M.indica L.* shows a larger absorbance in this region, and would promote the red bathochromic shift necessary for appropriate redox reactions. On the other hand, it requires a large change in momentum for transition to occur in the Q band. *M.indica L.* illustrates one such peak, as such no transition is allowed in Q band [9]. A lot of studies have revealed that changes in the conjugation pathway and symmetry of a porphyrin can influence its UV/VIS absorption spectrum and dye aggregation, thereby altering their spectral and energetic characteristics. In effect, dye aggregation which is a peculiar porphyrin challenge can be minimized by sensitization with an electrolyte or modelling.

3.2. FTIR spectroscopy of *M.indica L.*

Figure 2 displays the functional groups present in *M.indica L.* which eventually aided charge transport in the DSC. It shows that the spectrograph in 2(a) demonstrate strong appearance of esters in broad peak. This suggests a favorable redox reaction. In the presence of carboxylic acids and alcohols, this is an equilibrium reaction that propels the forward kinematic chemical reaction. The second prominent reaction is the thiocarbonyl strong broad appearance. Usually, thiocarbonyl, C=O, replaces an ester (C=S) in a replacement reaction. This illustrates the regenerative nature of crude *M.indica L.* Moreover, Figure 2 (b) displays hexane fraction of *M.indica L.* having a strong broad appearance of alcohols and phenols. This is probably because the solvent is methanol. Thus, there is an abundance of –OH group without any other species to neutralize the effect. Hence, the redox reaction is unfavorable in the backward reaction. The differences in the spectrograph are further summarized as shown in Table 1. The factors responsible for the charge transport are delineated, they make all difference to the output performance. Thus, the results indicate that the sulphide, alkenes, alkynes, alcohols and phenols chromophores aided porphyrin aggregation which caused recombination and impede charge transport in *M.indica L.* hexane DSCs were. On the otherhand, the chromophores that supported more efficient charge transport were S-OR esters, thiocarbonyls and alkanes.

3.3. Electron Microscopy (SEM) of *M.indica L.*

Figure 3 displays the SEM micrographs at 20x, 30x and 50x magnifications. It shows the microstructure of *M.indica L.* at a width depth (WD) of 2×10^{-9} m and the different magnification reveals different structure formation across the grain boundary. There are no visible trap sites but the dye roughness factor is high due to several protrusions of the chromophore along the interface as shown in Figure 3. Speedy charge transport would be greatly impeded but recombination would be promoted in *M.indica L.* structure. A predominant outline of a mango drupe is common to all the micrographs. The turgor pressure of the membrane would facilitate speedy charge transport, except where the excited electron recombines with a hole. The speed impediment due to the roughness factor of *M.indica L.* is higher for the crude fraction. This is responsible for the lower I_{sc} current recorded relative to *M.indica L.* hexane DSC in Figure 4(a) and 4(b).

Table 1. FTIR spectroscopy of *M. indica* crude and hexane fraction of *M.indica L.*

Crude <i>M.indica L.</i>	Compounds Present	<i>M.indica L.</i> Hexane	Compounds Present
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588.31±50	Weak disulphide bonds	439.78±60	Weak disulphide bonds
698.25	S-OR esters in strong appearance	607.6±10	Strong C-H deformation in Alkynes
769.62	Same as (2)	721±25	Same as (2)
827.49	Same as (2)	885.36	Strong Alkenes appearance. CH and CH ₂ out of plane bending
877.64	Same as (2)	1039.67	Alcohols and phenols in strong appearance. H-bonded and strong C-O broad peaks
1033.88	Strong C=S thiocarbonyl bond appearance	1082.1	Same as (5)
1168.9	Same as (6)	1166.97	Same as (5)
1240.27	Same as (6)	1244.13	Same as (5)
1319.35	Medium appearance of alkanes, CH ₂ and CH ₃ deformation with CH ₂	1379.15	Medium appearance of Alcohols and Phenols. O-H bending in plane.

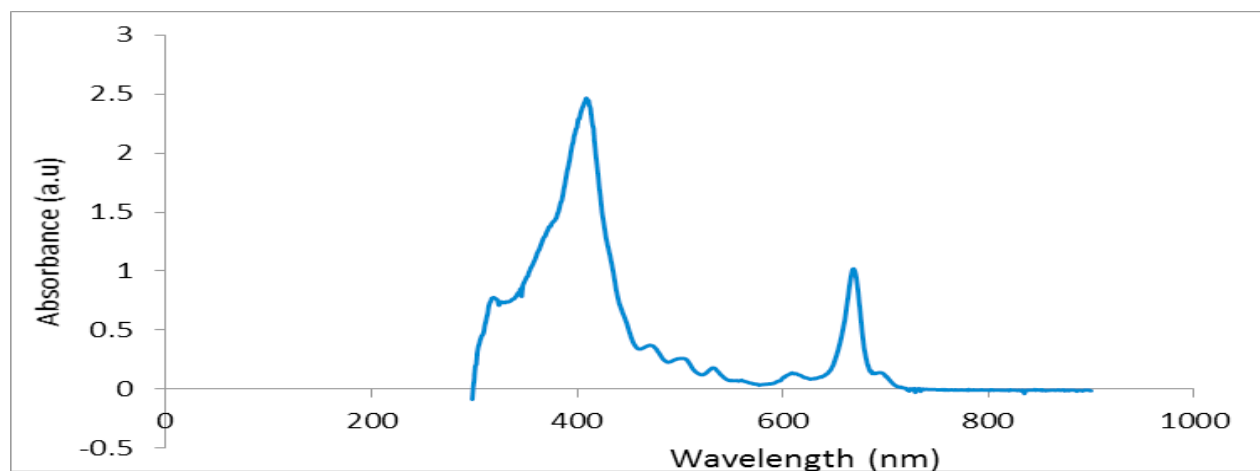


Figure 1: UV/VIS Spectroscopy of *M.indica L.* dye

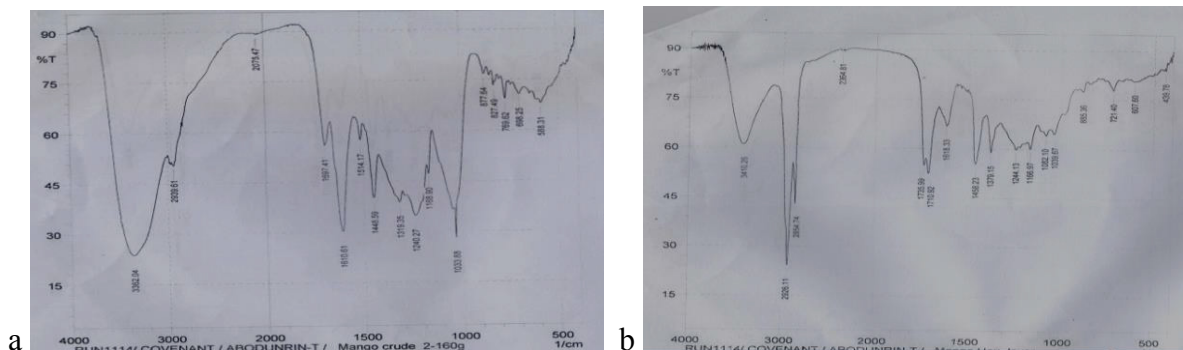


Figure 2: FTIR of *M.indica L.* (a) Crude and (b) hexane fraction

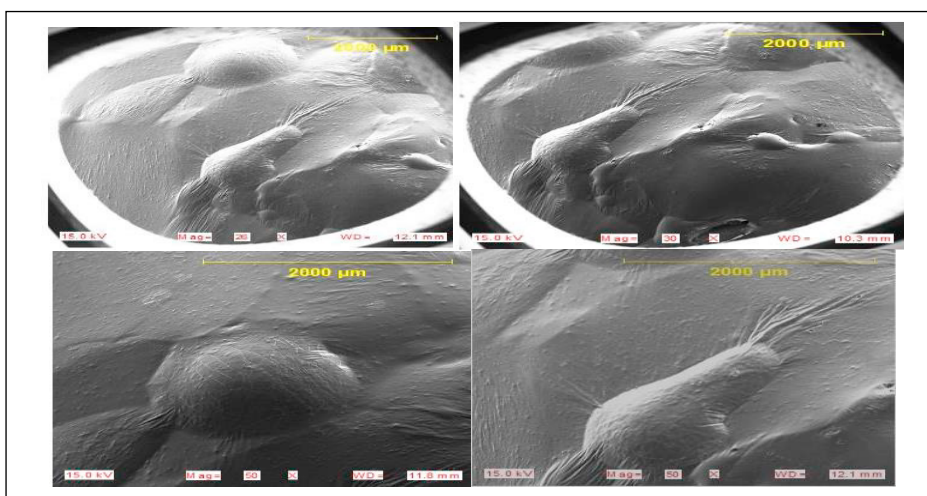


Figure 3: SEM of *M.indica L.* at different magnifications

Conclusion

M.indica L. DSCs were successfully characterized into the crude and hexane fractions. The crude fraction revealed contrary to existing norms higher efficiency than the purer or batch-separated hexane fraction. This is because elongation of the Porphyrin molecule played a more prominent role in charge transport than the solvent effect. Although the result obtained for *M.indica L.* DSCs is relatively low in efficiency, the I_{sc} , V_{oc} and ff for the batch-separated *M.indica L.* DSC is comparative with existing values. Thus, co-sensitization of crude *M.indica L.* with other organic or synthesized dyes is recommended for higher efficiency in future research.

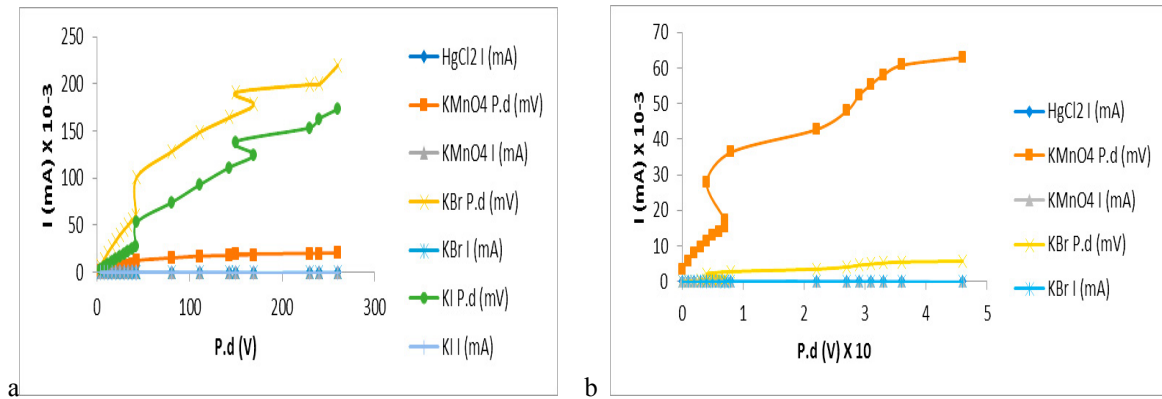


Figure 4: Combined I-V plots of *M.indica L* with different electrolytes (a) crude and (b) hexane fraction

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