Mucuna Pruriens as Photo-Sensitizer in Dye Sensitized Solar Cell

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Abstract- In a dye sensitized solar cell (DSSC), the dye sensitizer plays important role in absorbing sunlight and transporting electrons into the conduction band of the semiconductor thus converting the solar energy into electric energy by photovoltaic effect. This study focus on the investigation made on the leaves and stem of *Mucuna Pruriens* extract as photosensitizers for dye sensitizer solar cell (DSSC). The DSSC was based on titanium dioxide nanopowder as the photoanode semiconductor material and potassium iodide solution as electrolyte. The pigment was extracted from dry leaves and stem of *Mucuna Pruriens* in water, ethanol and acetone. The photo absorption spectral of *Mucuna Pruriens* was investigated in cold and hot extraction media. Dye sensitized solar cell was fabricated using Michael Gratzel method. The cell was connected to a variable external load and exposed to illumination at 100mW/m^2. As the load is varied, the short circuit current I_{sc} and the corresponding open circuit voltage V_{oc} were observed. An *IV* characteristics was plotted and the fill factor and efficiency were computed as 0.8 and 0.37% for *Mucuna pruriens* extracted in water, 0.88 and 1.16% for *Mucuna pruriens* extracted in ethanol, 0.93 and 2.08% for *Mucuna pruriens* extracted in acetone respectively. The pigment extracted in cold acetone has the best light absorption and efficiency. This study shows that *Mucuna Pruriens* has prospect as sensitizer in DSSC.

Keywords Photosensitizer, Photoanode, Nanopowder, Mucuna Pruriens, Titanium dioxide.

1. Introduction

A Dye sensitized solar cell (DSSC) is a low cost solar cell which belongs to the thin film solar cell group [1]. It is a photo-electrochemical system which is based on a semiconductor formed between a photo sensitized anode and an electrolyte. The low cost material components, simple method of fabrication and availability of major materials have made DSSC receive much attention from researchers in resent time. DSSC also has the unique feature of having photon absorption and electrons transport carried out by different components of the cell [2]. This feature also allows each components of DSSC to be improved upon and possibly substituted for better performance of the cell without necessarily affecting the system structure. The main components of DSSCs are; the working electrode which is made of semiconductor oxide (TiO_2) on transparent conductive surface), the organic dye sensitizer, the electrolyte and the counter electrolyte.

A very good feature of dye sensitized solar cell is the fact that every stage and process is carried out by different component. On exposure to sunlight, the incident photons travel the transparent glass substrate (which is conductive on one side) of the working electrode to the dye. Depending on the colour of the pigment, light photons of certain wavelengths are absorbed. That is, not all incident photons are absorbed. The photo absorption capacity of a particular colourant is its light harvesting efficiency (LHE) [3]. The dye molecules therefore gain energy resulting in the liberation of electrons and the dye becomes oxidized. The liberated electrons travels through the TiO_2 to the conducting surface of the glass substrate of the working electrode. There is an external load connected across the working electrode and the counter electrode. These mobile electrons travel through the external load to the counter electrode and back to the system. The dye regains its lost electrons through the electrolyte and the electrolyte from the graphite coated surface of the counter electrode and the cycle continues.

Although, the supply of the raw material which is sunlight is unlimited, the dye plays two major roles of photon absorption and release of electrons which are transported through the electrode to the conductor to produce electricity[4] & [5]. This process is represented in the equations (1) to (5):

If C.E = Counter Electrode

TiO_2 = Electrode

S = Dye

S^* = Excited Dye

$$S + \text{light} \rightarrow S^* \quad (1)$$

$$S^* + TiO_2 \rightarrow e^- (TiO_2) + S^* \quad (2)$$

$$e^- (TiO_2) + C.E \rightarrow TiO_2 + e^- (C.E) + \text{electrical energy} \quad (3)$$

$$S^* + {}^3/_2 I^- \rightarrow S + {}^1/_2 I_3^- \quad (4)$$

$$ {}^1/_2 I_3^- + e^- (C.E) \rightarrow {}^3/_2 I^- + C.E \quad (5)$$

In producing a DSSC, the choice of the organic dye sensitizer is very crucial to obtain good light harvesting efficiency (LHE) which is a determinant of photo conversion efficiency[6]. Because of the importance of the role of dye in DSSC, efforts have been directed towards developing different organic dyes and metal complexes. Although most of these complexes have good absorbance, yet they suffer from the disadvantages of high cost and sophisticated method of preparation [6]. Hence, studies have been carried out on alternative organic pigments that will foster a good DSSC performance with cheap and easier method of preparation. The main features of a good sensitizer is good photo absorption, low cost, availability and environmental friendliness [7]. In this study, the photo absorption spectral of *Mucuna Pruriens* extract was observed and the extract also used to sensitize a titanium dioxide based DSSC.

Mucuna Pruriens (Velvet beans) is a tropical legume of West Africa origin. It is found in abundance in the Southern Nigeria. It belong plant family of *Fabaceae*. This climbing plant is notorious for the extreme itchiness it causes on contact especially with its young foliage and seed pods. Its seeds are used as soup thickeners while the leaves and stem of *Mucuna pruriens* are used for various medicinal purposes such as curing diseases like diabetes, arthritis, dysentery, and cardiovascular diseases[8]. Its extract is a very strong pigment which is used in the local African dye but has never been considered for any photovoltaic purpose. As shown in Table 1, previous research findings revealed that phytochemical compositions of Velvet beans (*Mucuna pruriens*) extracts posesses *Saponins* (a compound responsible for bitter taste), likewise *Terpenoids* (a phenolic compound that gives flavor and yellowish red dye). The extract is very rich in *Tannins* (a deep brown dye, also gives flavor), *Anthraquinones* (a strong dye with colours ranging from yellow to gray-green), *Flavonoids* (a plant dye with red, purple and blue colouration. It is also a phenolic compound), and *Phlobatanins* (a greenish black dye) [8].

Table 1: Phytochemical composition of water and ethanol extracts of *Mucuna pruriens*.

Phytochemical	WMP	EMP
Alkaloids	-	-
Saponins	*	*
Phlobatanins	***	***
Terpenoids	*	*
Tannins	***	***
Anthraquinones	***	***
Flavonoids	**	**
Cardiac glycosides	*	*

*** Detected in abundant concentration

** Detected in moderate concentration

* Detected in slight concentration

- Not detected

2. Method

2.1. Extraction and Characterization of Dyes

The plant, *Mucuna Prurien* was collected Akure, a city in the south western Nigeria. The extraction of dye was done by Soxhlet extraction method.The plant part – leaves and stem were washed with distil water and dried at room temperature for about two weeks. After drying, the collections were crushed in a wooden mortal to smaller pieces which were further grounded in a ceramic mortal to almost powdery form. After grinding, about 25g of the sample was weighed into the chamber of the Soxhlet extractor. Before the extraction was carried out, the plant sample was defatted with N-Hexane in the extractor for about two hours to remove the plant fat and oil [9]. After these, the sample was dried and loaded into the extractor with 250ml of ethanol as the extracting solvent.

During extraction the solvent is heated to reflux and the solvent vapour travels up a distillation arm and floods into the chamber housing the thimble of solid. The condenser ensures that any solvent vapour cools, and drips back down into the thimble housing the solid material. The chamber containing the solid material slowly fills with warm solvent. Some of the desired compound dissolves in the hot solvent. When the Soxhlet chamber is almost full, the chamber is emptied by the siphon. The solvent is returned to the distillation flask. The thimble ensures that the rapid motion of the solvent does not transport any solid material to the still pot. This cycle was repeated many times for six hours. The soxhlet extraction method was also modified for cold extraction. The cold extraction was carried out by weighing 25g of the semi-powder sample and soaked in 250ml of n-Hexane for about 6 hours at room temperature. After that the mixture was stirred vigorously then separated by sheaving. Clean n-Hexane was further added and stirred and then sheaved out to remove the fat. The sample was allowed to dry at room temperature for about 3 hours. The defatted sample was soaked in 250ml of ethanol for 24 hours. After 24 hours, the mixture was stirred vigorously and the solid sheaved out. The remaining solution was filtered and dried at a room temperature in a dark room. Three extracting solvents namely; water, ethanol and acetone were used in this study. The pH of the extracted sample was analyzed using pH meter manufactured by Jenway Instrument Inc. Japan, model 3510. The spectrophotometric study was also carried out by scanning the pigment across visible and ultra violet region using computerized UV-Vis-Nir Spectrophotometer double beam model Schimadzu UV 1800 manufactured by Schimadzu.

2.2. Fabrication of Dye Sensitised Solar Cell

A self-assembled dye sensitized solar cell (DSSC) was fabricated using titanium dioxide as the semiconductor deposited on a transparent conductive glass substrate and the *Mucuna Prurien* extract under study as the sensitizer. About 2g of nanoparticle Titanium dioxide was mixed with 8ml of Acetic Acid in a mortar while grinding with pestle to break the aggregates and to produce a uniform and lump-free suspension. A drop of surfactant, like colourless detergents in 1ml of distill water was then added. The conductive side of the electrode substrate tested with a continuity tester then cleansed with ethanol and two third coated with the Titanium dioxide paste using Doctor Blade technique [10]. This technique consists of a flat sharp object like a razor blade or a round thin object like a glass stirrer, which is used to lay a layer of slurry with a thickness determined by the spacer. The spacer is an adhesive tape normally with a thickness of 8-10 nm. It is placed opposite sides of the area where the film is to be laid and the doctor blade dragged across. After deposition, it was sintered at 450°C for 30 minutes. The electrode was then placed faced down in a filtered dye solution and allowed to soak the Titanium dioxide surface for about five minutes and then allowed to dry in a dark at room temperature. The conductive side of the counter-electrode was tested with continuity tester. The conductive surface was cleansed with ethanol, coated with graphite and gently placed face down on the Titanium IV Oxide coated part of the electrode so as to offset leaving one third uncoated conductive surface exposed on both the electrode and the counter electrode. They were then held firmly together with two alligator clips. Two drops of the electrolyte were introduced at one edge of the slides and allowed to spread by capillary action.The assemblage was then tested with the electrode faced up for light photons collection as the positive terminal while the counter electrode will be the negative terminal connected to a digital multimeter. A highly sensitive and versatile digital multimeter from Fluke Instruments England was utilized to measure the open-circuit voltage (V_{oc}) and short-circuit photocurrent (I_{sc}) of the DSSC. A light intensity of 100 mW/m^2 was used to illuminate the solar cell. The conversion efficiency of the solar cell was computed by equation (6)

$$\eta = \frac{Voc \times Isc \times ff}{Pin} \times 100\% \qquad (6)$$

3. Results and Discussion

At equal concentration, the UV-visible absorption spectral of *Mucuna pruriens* extracted in cold ethanol shows a stronger light absorption than the one extracted in a hot ethanol. The photo absorption occurred at wavelength range of 595 – 600 nm which is in the visible region of the electromagnetic spectrum ems [11] & [12]. The wavelength of maximum absorption (λ_{max}) is 535 nm. Cold extraction of *Mucuna pruriens* gave a stronger photo absorption than hot extraction as shown in Figures 1 and 2.

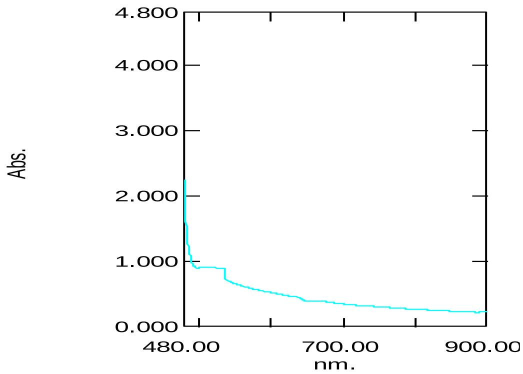

Fig 1. UV-vis absorption spectra of Mucuna Prurien extracted in hot ethanol

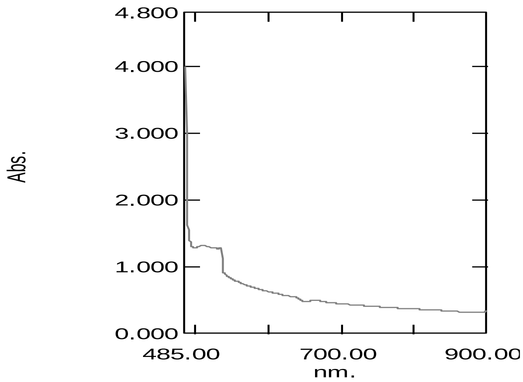

Fig 2. UV-vis absorption spectra of Mucuna Prurien extracted in cold ethanol.

The results of the extracts obtained in three cold media – cold water, cold ethanol and cold acetone (Figures 2, 3 and 4). The absorption in water was very weak with no recorgnised peak. The UV-visible absorption spectral of Mucuna pruriens extracted in cold ethanol show a fairly strong peak of absorption at a wavelength range of 595 – 600 nm as shown in Figure 2. In Figure 4, the sample extracted in cold acetone shows very strong light absorption with three distinct absorption peaks. The photo-absorption covers a wavelength range of 590 – 690 nm which is in the visible region of the electromagnetic spectrum ems.

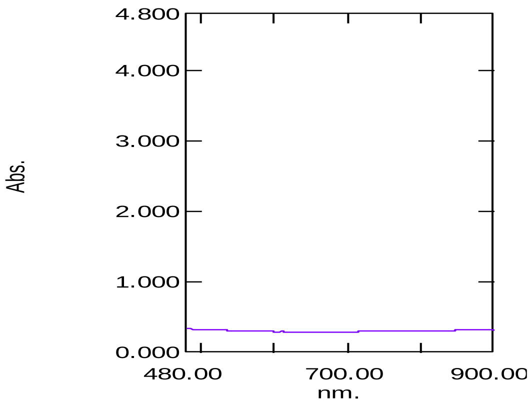

Fig 3. UV-vis absorption spectra of Mucuna Prurien extracted in cold water.

The wavelengths of maximum absorption (λmax) are 505, 535, and 640 nm. The light absorption fell in the green end of the electromagnetic spectrum while magenta is transmitted. The implication of this that *Mucuna pruriens* extracted in cold acetone was able to absorb light in a wider range of wavelenght in the electromagnetic spectrum than those of ethanol and water. Stronger absorption in cold acetone also shows that the *Mucuna pruriens* are highly non polar substances that dissolve better in strong non polar solvent like acetone. That is, *Mucuna pruriens* has a high photon harvesting efficiency which is a major determinant of the conversion efficiency of dye sensitsed solsr cell when it is extracted in cold acetone[7].

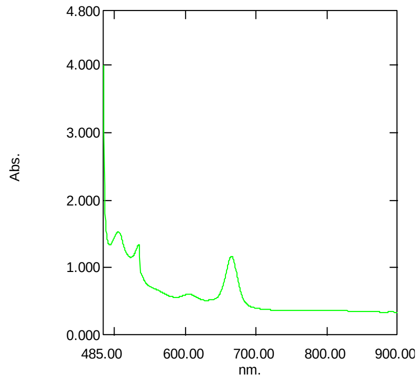

Fig 4. UV-vis absorption spectra of Mucuna Prurien extracted in cold Acetone.

Mucuna Pruriens whose physco-chemical parameters were shown in Table 2, recorded better performance in term photon harvesting when extracted in acetone. The electrical measurement recorded from the solar cells fabricated using *Mucuna Pruriens* pigment extracted in cold water, cold ethanol and cold acetone are as shown in Table 3. An efficiency of 0.8% was recorded from the DSSC sensitized with cold water extracted *Mucuna Pruriens,* 1.16% from the DSSC sensitized with cold ethanol extracted *Mucuna Pruriens* and 2.08% efficiency from the DSSC sensitized with cold acetone extracted *Mucuna Pruriens.*

Table 2: The Physco-chemical properties of *Mucuna pruriens.*

Botani-cal Name	**Engli-sh Name**	**Local Name (Yoruba)**	**Plant Part Utilized**	**Place of collect-ion (Nigeria)**	**Pigment's colour**	**Extraction medium**	**pH**	**Wavele-ngth of maxim-um absorption (λ_{max}) *nm***
Mucuna Pruriens	Velvet beans	Ijokun	Leaves & stem	Akure	Blueish-black	Water/ Ethanol/ Acetone	6.5	663

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Table 3: Electrical measurement from the DSSCs sensitized by the three extracts

Dye	**$V_{oc(max)}$ (*mV*)**	**$I_{sc(max)}$ (*mA*)**	***FF***	**Efficiency (η)**
Mucuna Pruriens extracted in Water	361.00	0.30	0.86	0.80
Mucuna Pruriens extracted in ethanol	385.00	0.30	0.88	1.16
Mucuna Pruriens extracted in Acetone	546.00	0.38	0.93	2.08

4. Conclusion

The conclusion The UV-visble absorption spectra of *Mucuna Pruriens* pigment extracted in different media consistently show its prospect as sensitizer in dye sensitized solar cell. However, cold extraction yielded stronger light absorption than hot extraction. The UV-visible absorption spectral and the efficiencies measured from the fabricated solar cells have consistently shown the potential of *Mucuna Pruriens* as dye sensitizer in dye sensitized solar cell. They also reveal that *Mucuna Pruriens* extracted in acetone is stronger in term of light absorption and consequently photon harvesting.

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