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Fabrication of Dye-Sensitized Solar Cells (DSSCs) from Water Leaf (*Talinum Triagulae*) and African Spinach (*Amarathus Hybridus*) Leaf using Titanium dioxide (TiO_2)

B. Akinwonmi [1], R. K. Odunaike[1], Q. A. Adeniji [2]*, R. T. Feyisola[3]

1. Department of Physics, Olabisi Onabanjo University, Ago-Iwoye, Ogun State, Nigeria.
2. Department of Physics, Federal University of Kashere, Gombe State, Nigeria.
3. Department of Plant Science, Olabisi Onabanjo University, Ago-Iwoye, Ogun State, Nigeria.

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- ✓ *Dye-Sensitized Solar Cells,*
- ✓ *Talinum Triangulae,*
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qadeniji@yahoo.com;

Abstract

This paper reported the suitability of Dyes made from locally available plants-Water leaf (*Talinum Triangulae*) and African spinach leaf (*Amaranthus Hybridus*) as better alternatives to the sensitizer of the conventional Ruthenium in solar cell. 30 g each of the leaves were weighed separately on an electronic weighing balance and mixed with 400 ml of ethanol for 24 hours at room temperature and obtained their respective filtrates which were sensitizer dyes solution for the cells. Titanium Dioxide (TiO_2) was prepared by blending the commercial TiO_2 powder of about 0.2 g and 0.1 M of 0.4 ml HNO_3. 0.5 cm of two parallel ends of each of the glasses were taped to reduce the dimension of the surface to making the surface area 0.25 cm^2 and left for 20 minutes, the paste settled to reduce the irregularity of the surface and left to air-dried. Carbon electrode was obtained by applying soot onto the conductive side of the second FTO glass and cooled at room temperature. Highest power conversion efficiencies (η) of 0.3 % was achieved for the DSSCs fabricated using anthocyanin extracts of the leaves. Dyes extracted from Amarathus Hybridus (African spinach) exhibited highest efficiency. It has been observed that darker colored anthocyanins lead to higher efficiency. This is because darker color corresponds to increased light absorption leading to enhanced photo current densities. The two naturally occurring anthocyanin dyes extracted from Water leaf (*Talinum Triangulae*) and African Spinach (*Amarathus Hybridus*) have demonstrated the capability of serving as photosensitizers for solar cells.

1. Introduction

A dye-sensitized solar cell (DSSC) is a low-cost solar cell belonging to the group of thin film solar cells [1], [2]. It is based on a semiconductor formed between a photo-sensitized anode and an electrolyte, a photo-electrochemical system. The solar energy is a free gift of nature to humankind, which is pollution-free, can be sensed, controlled and used to produce power using solar cell modules [3], [4]. Solar cells made from silicon are very expensive due to high cost in process of purification from sand and wafer production [5], [6], [7]. Though highly effective, with current maximum efficiency of about 11%, the costly synthesis and undesired environmental impact of the prototypes call for cheaper, simpler, and safer dyes as alternatives [8]. Natural pigments, including chlorophyll, carotene, and cyanin, are freely available in plant leaves, flowers, and fruits and fulfill these requirements [9], [10], [11]. Hence, the study of fabrication of Dye-Sensitized Solar Cells (DSSCs) from local dyes using anthocyanin extracts of the leaves extracted from water leaf (*Talinium Triagulae*) and african spinach (*Amarathus Hybridus)* leaf Using Titanium dioxide (TiO_2). Solar cells using natural anthocyanin show the most promising future for electricity generation because such solar cells have lower environmental concern, lower maintenance cost, and readily available raw materials.

2. Experimental Details

30 g each of Water leaf and Africa spinach leaf were weighed separately on an electronic weighing balance and mixed with 400 ml of ethanol for 24 hours at room temperature and obtained their respective filtrates which were sensitizer dyes solution for the cells. The Titanium Dioxide (TiO_2) was prepared by blending the commercial TiO_2 powder of about 0.2 g and 0.1 M of 0.4 ml HNO_3. 0.5 cm of two parallel ends of each of the glasses were taped to reduce the dimension of the surface to making the surface area 0.25 cm^2 and left for 20 minutes so that the paste could settle to reduce the irregularity of the surface and left to air-dried. Carbon electrode was obtained by applying soot onto the conductive side of the second FTO glass and allowed to cool at room temperature. This acts as a catalyst that was needed to accelerate the reaction kinetics Tri-Iodide reduction process at TCO. The substrate which acts as a counter electrode was to facilitate the conduction of the electric current in the assembled DSSC [12]. The cathode and the counter electrode were placed in holes (overlapped) so that the titanium dioxide covered area of the cathode was the only part that was in contact with the counter electrode and binded together with clips. The sandwiching of the two plates was offset so that each one has a space for the crocodile clip to be attached, the negative clip goes onto the TiO_2 positive sensitizer plate and the positive clip goes onto counter electrode plate so as to ensure the fall of incident light on the side of the photoanode from which the sensitized TiO_2 could be seen. The current flow was obtained by measuring the respective voltages and resistances with the use of a multimeter and resistance box.

3. Results and Discussion

Figures 1 and 2 present the absorption spectra obtained for the two natural dyes made from water leaf (*Talinum triangulae)* and African spinach (*Amarathus hybridus*) respectively after UV illumination. The main component of these two extracts was chlorophyll. From these figures, it is evident that these natural extracts absorb in the visible region of light spectrum and hence fulfill the primary criterion for their use as sensitizers in DSSCs.

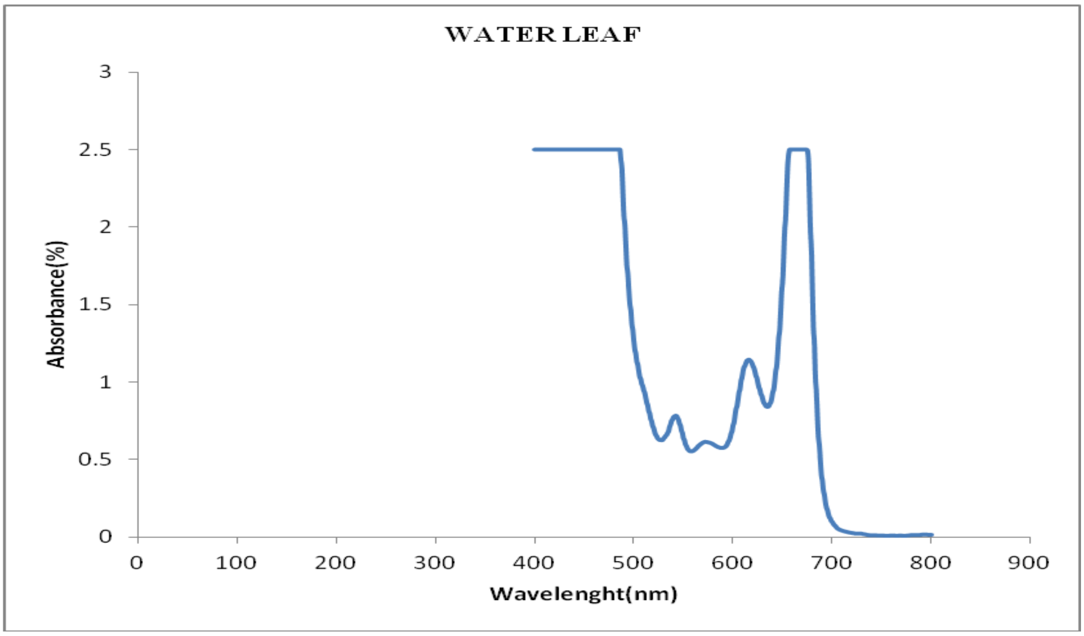

Figure 1(a)): Absorbance of Dye on TiO_2 (Water leaf*)*

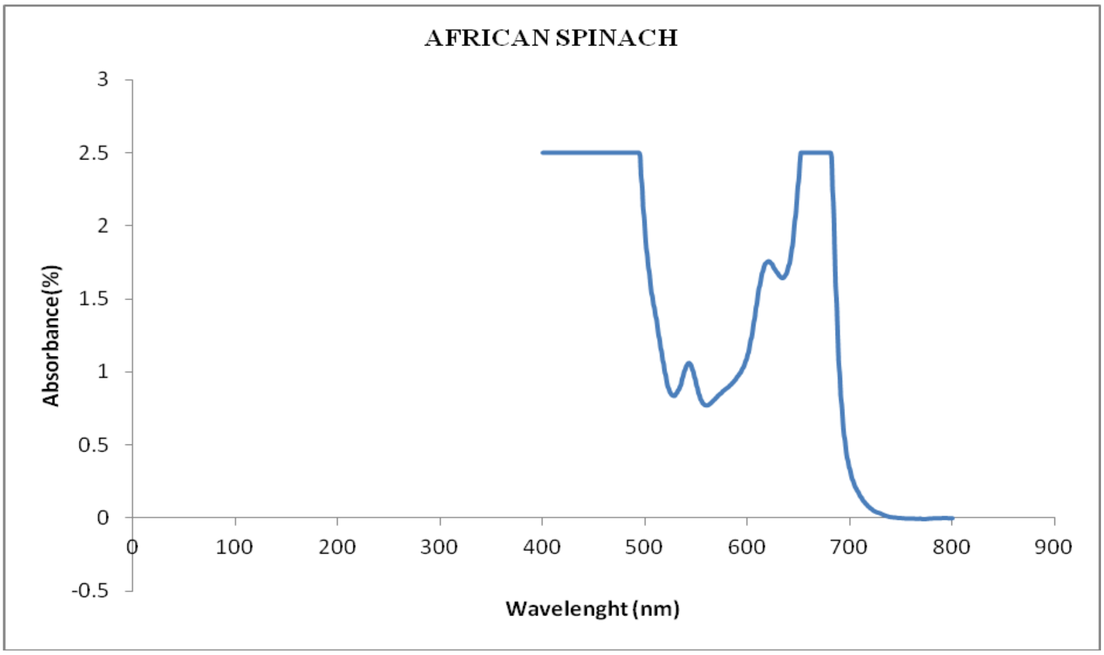

Figure 1(b)): Absorbance of Dye on TiO_2 (African Spinach)

Figure 1(a) shows the UV-Vis absorption spectra of water leaf (*Talinum triangulae).* It was observed that the water leaf extract absorbs across a wide range of wavelengths in the visible region of the spectrum, notably between 400 – 440nm and 640 – 680nm. That is blue-green wavelengths. Figure1(b) shows the UV-Vis absorption spectra of African spinach *(Amarathus Hybridus).* It was also observed that the African spinach leaf extract absorbs across a wide range of wavelengths in the visible region of the spectrum in the region 400 – 440 nm and 620 – 640nm. That is blue-green wavelengths. Figure 1(c) shows clearly that there is no significance difference in the absorption spectrum intensity of the water leaf and African spinach dye. The UV-Vis absorption maximum at 680 nm and 700 nm for water leaf and African spinach respectively could be attributed to the presence of 3-galactosides of malvidin and delphidin and this is in agreement with the study of [13].

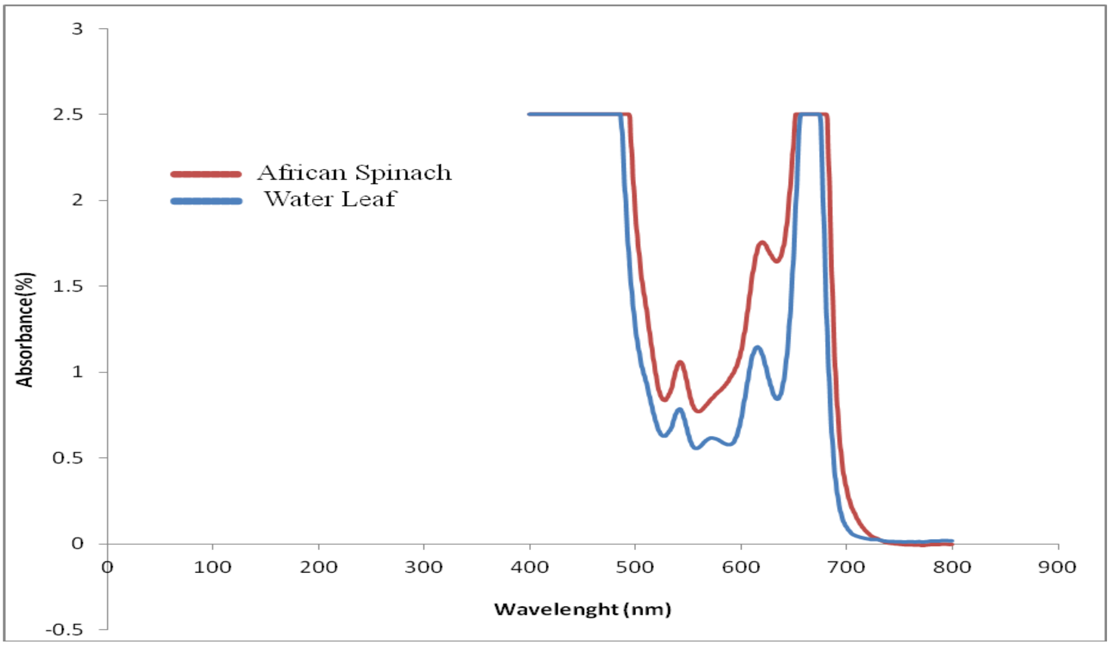

Figure 1(c): Comparison between the Absorbance of Water leaf (Blue) and African Spinach (Red) Dye on TiO2

Since the anthocyanin isomers were not isolated before taking their absorption spectra; therefore, instead of sharp absorption peaks, broader peaks were observed which are indicative of a mixture of isomers. However, the characteristics features of the absorption spectra between 510 and 540 nm are indicative of the presence of high concentration of anthocyanin isomers in the above extracts [11]. The main component of these two extracts is chlorophyll. From the Figures, it is evident that these natural extracts absorb in the visible region of light spectrum and hence fulfilling the primary criterion for their use as sensitizers in DSSCs.

Figures 2(a) and 2(b) depict the I-V characteristics of the DSSCs made from extracts of Talinum Triangulae (Water leaf) and Amarathus Hybridus (African Spinach) respectively. Whereas Figure 2(c) shows insignificance difference in the comparison of the I-V characteristics of the leaves' extracts. Whenever the resistance of the load increases, the produced current decreases and the output voltage across the DSSCs increases. Hence, the relationship between the produced voltage and current is inversely proportional which is noticeable in the I-V characteristics curve of the DSSCs. Highest power conversion efficiency *(η)* of 3.0 % and 3.1 % were obtained for these cells with *Voc.* of 0.510 V and 0.604 V, *Isc*. of 0.000649 A and 0.000669 A, *Jsc*. of 0.10384 Am^{-2} and 0.10704 Am^{-2} and Fill Factor (FF) of 0.567 and 0.475 respectively, see Table 1. The short circuit current density *(Jsc)* of DSSCs depends on the intensity of the incident light.

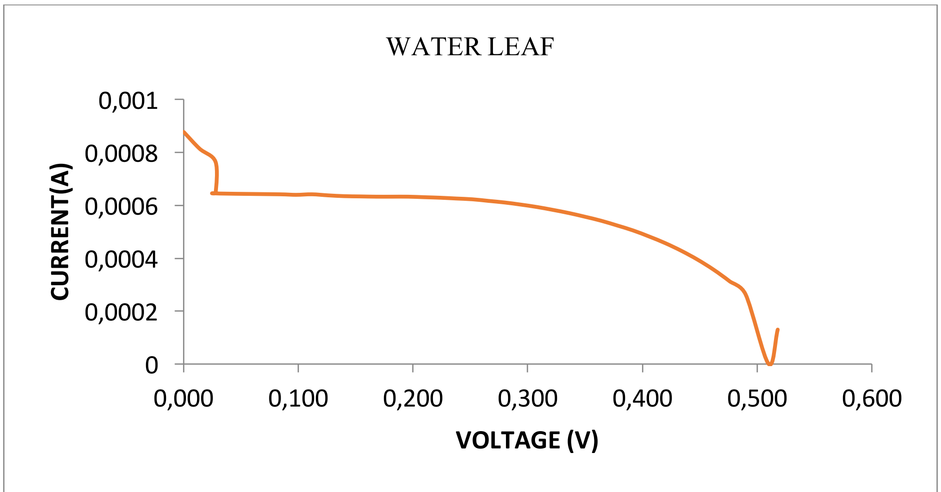

Figure 2 (a) Characteristics of the DSSC (water leaf)

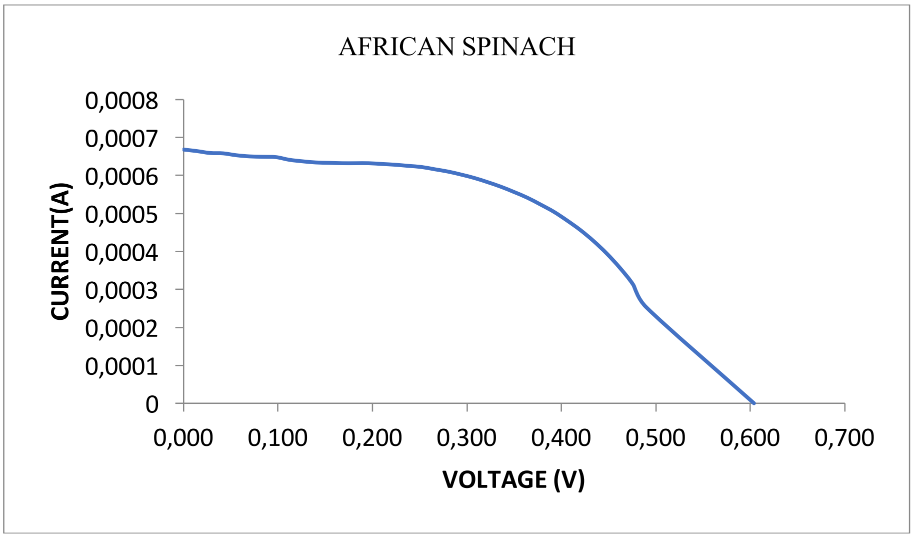

Figure 2 (b) ***Characteristics of the DSSC (African spinach)***

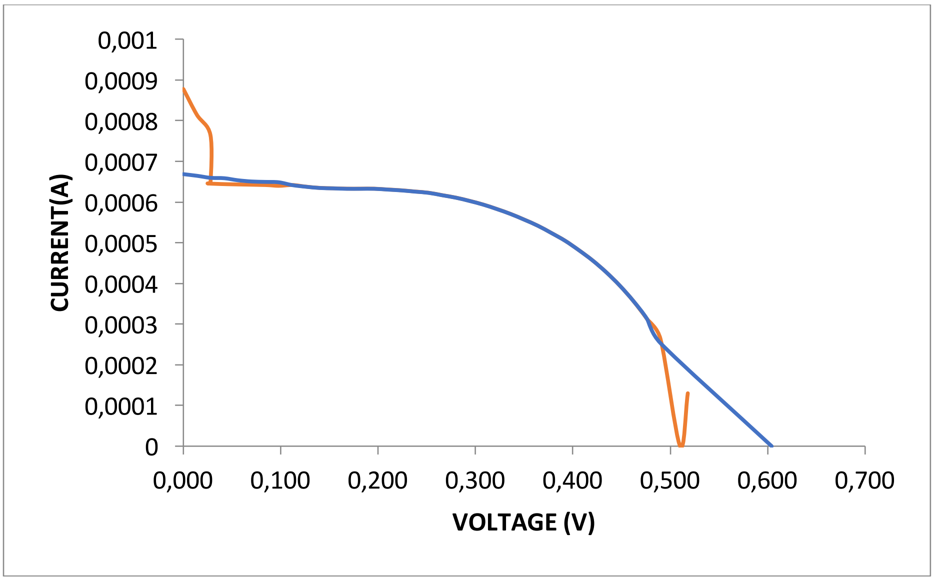

Figure 2 (c) **Comparison in the characterization of the DSSC (Water leaf & African spinach)**

The overall power conversion efficiency *(η)* of Talinum Triangulae sensitized DSSC is lower than that of Amarathus Hybridus due to lower stability of anthocyanin based DSSC and this is expected because of the presence of deeper and darker coloration of the leave due to the presence of anthocyanins which have an increased absorption of light in visible spectra [14]. This result leads us to believe that darker dyes are preferable candidates due to their increased absorption of visible light as compared to lighter ones leading to increased photo-current densities. Also, solar cell output voltage and current both depend on temperature, the actual output power will vary with changes in ambient temperature. Figures 3(a) and 3(b) show relationship among power, current and voltage of the leaves' extracts respectively. There is a point in the curve where the output voltage and output current produces the maximum output power which represents Maximum Power Point, MPP [15]. It was observed from Figures 3(a & b), Maximum Power Point, MPP (0.2 V, 6×10^{-4} A, 1.5×10^{-4} W) and (0.3 V, 6×10^{-4} A, 1.8×10^{-4} W) were obtained for water leaf and African spinach DSSCs respectively.

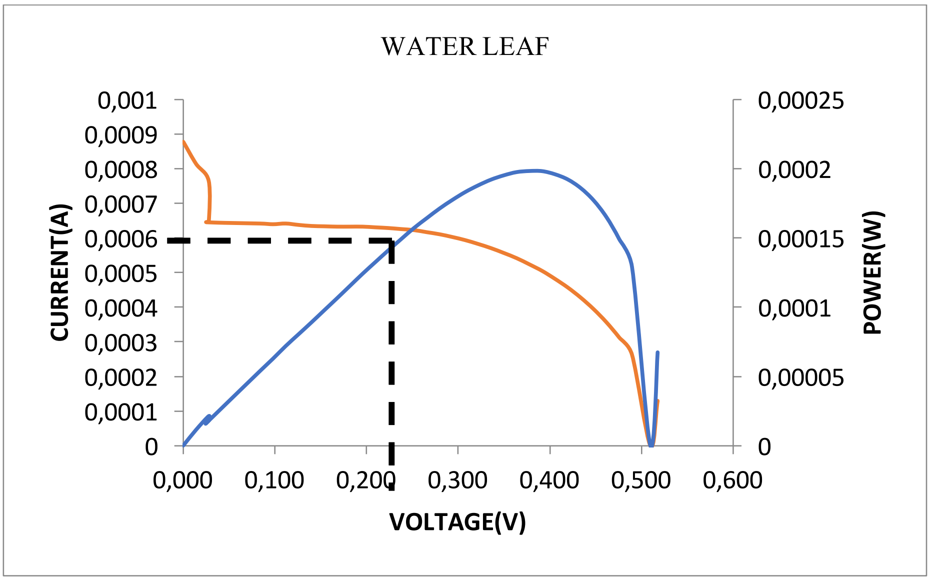

Figure 3 (a) **(Water leaf)**

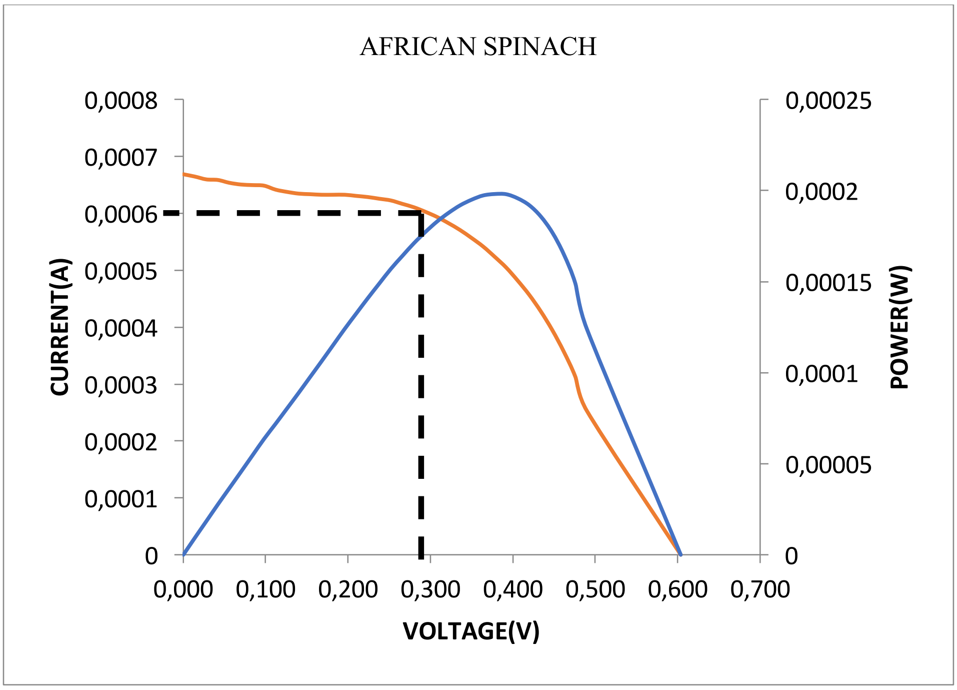

Figure 3 (b) ***Relationship between Power, Current & Voltage (African Spinach)***

Table 1: Results of Photovoltaic parameters of Solar Cell at 1000Wm^{-2} illumination

Dye Sample	I_{sc} (A)	J_{sc}(Am^{-2})	V_{oc} (V)	I_{max}. (A)	V_{max}. (V)	FF	η (%)
Talinum Triangulae	0.000649	0.10384	0.510	0.322	0.000583	0.567	3.0
Amarathus Hybridus	0.000669	0.10704	0.604	0.336	0.000571	0.475	3.1

Conclusion

Two naturally occurring anthocyanin dyes extracted from Talinum Triangulae (Water leaf) and Amarathus Hybridus (African Spinach) have demonstrated the capability of serving as photosensitizers for solar cells. Solar cells using natural anthocyanin show the most promising future for electricity generation because such solar cells have low environmental hazard, low maintenance cost, and readily available raw materials. Even though the electricity output for DSSCs was lower than that of thin film silicon solar cells, ongoing research on combining two or more dyes together could help obtain extended light absorption along the visible light spectrum**.**

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Conflicts of Interest

Authors declare no conflict of interest.

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