



## DEVELOPMENT OF SOLAR CELLS USING ADAPTABLE LOCALLY SOURCED MATERIALS

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### Abstract

This paper focused on the development of an adaptable solar cell for renewable energy, using materials easily accessible in Nigeria. Several parts of Nigeria continue to struggle with power supply. Due to insufficient electrical energy supply, business investors are leaving Nigeria for the neighbouring countries. The Nigeria environment suite electricity generation using solar energy. Despite this avalanche of solar radiance, many Nigerians are yet to fully harness the technology of solar for electricity and power supply. This may be due to the high cost associated with purchasing imported solar panels from China, USA, Canada. It is on this basis that this study developed an adaptable solar cell for Nigerians and the Nigeria environment. The key objectives include development of a solar cell using local available materials like dye. Dye from Moringa was selected for fabrication of dye sensitize solar cells (DSSC). The study fabricated solar cells were characterized and evaluated to ascertain the performance. The Moringa dye was analyzed using X-ray fluorescence (XRF) to ascertain the materials present. Other key materials include an Indium Tin Oxide (ITO) and glass substrate used as the conducting substrate; nitric acid used to convert the Titania into Titania paste. Iodine and Potassium Iodide was used as the redox electrolyte alongside Graphite (the catalyst). The dye sensitize solar cells was formed using the anode and cathode. The anode composed of the Titania paste was annealed for about 350°C on a conducting glass substrate, last for 10 minutes. This temperature ensures a strong adhesion between the anode electrode and the Titanium paste while promoting the crystallization of the TiO<sub>2</sub> for better conductivity and performance annealed for 10 minutes before dyeing the cell with the Moriga paste. The cathode was made using Graphite. A redox electrolyte is used to ensure uniform mixing of both the anode and cathode when they were brought into contact. The elemental analysis done using the scanning electron microscope reveals the presence of key elements that confirms the successful deposition of Moringa dye-sensitize solar cells. The fabricated solar cells device was characterized to ascertain the current-voltage (I-V) characteristics. The key characteristics obtained are the short circuit current  $I_{oc}$ ,  $V_{sc}$ ,  $V_{max}$ ,  $I_{max}$ , FF, and the efficiency. The fabricated solar cells exhibit the short circuit current ( $J_{sc}$ ) 16.8 mA, the open circuit voltage ( $V_{oc}$ ) 350 mV, fill factor (FF) 0.39 and conversion efficiency ( $\eta$ ) 2.30 %.

**Keywords:** Adaptable, material, solar cell, development

### Introduction

Nigeria is a country with abundant solar energy resources, with an average daily solar irradiation of 5.8 kWh/m<sup>2</sup> and home to about 200 million people. However, the country is currently heavily reliant on fossil fuels for its energy needs. Solar energy could play a significant role in reducing Nigeria's reliance on fossil fuels and improving its energy security, according to Nigeria's National Renewable Energy and Energy Efficiency Policy. NREEEP 2015.

Currently, the electricity supply in Nigeria still poses a major challenge. The installed electricity capacity of Nigeria is 13,097 MW, according to the

Nigerian Electricity Regulatory Commission (NERC 2022 report). The installed electricity capacity of Nigeria is made up of a mix of thermal (gas and coal), hydroelectric, and renewable energy sources. Thermal energy accounts for the majority of installed capacity, at 11,972 MW. Hydropower accounts for 2,062 MW, and renewable energy sources, such as solar and wind, account for 2,350 MW. However, only around 4,000 MW is generated on most days, due to a number of factors, including the poor condition of the country's power generation and transmission infrastructure, and the lack of investment in the sector, according to World Bank – 'Nigeria Power Sector Recovery Program

(PSRP)' (2017): This is insufficient to meet the needs of a country of over 195 million people. The study recognised certain number of factors that contribute to Nigeria's electricity supply challenges. One factor is the poor condition of the country's power generation and transmission infrastructure. Another factor is the lack of investment in the sector. Nigeria has not invested significantly in new power generation capacity in recent decades. The electricity supply challenges have a significant impact on the Nigerian economy and society. Businesses are often forced to rely on expensive generators, which increases the cost of doing business. Power outages are also common, which can disrupt economic activity and make it difficult for people to go about their daily lives.

Solar energy is a sustainable source of energy that can help Nigeria to meet its growing energy needs and reduce its environmental impact. One way to promote the use of solar energy in Nigeria is to develop solar cells that are affordable and efficient. Moringa dye is a promising material for developing low-cost and high-performance solar cells. It is a natural dye that can be extracted from the leaves of the *Moringa oleifera* tree, which is native to Nigeria. This can be made using dye sensitize solar cells (DSSC).

Dye-sensitized solar cells (DSSCs) are a type of thin-film solar cell that uses a photosensitizing dye to absorb light and generate electricity. DSSCs are relatively inexpensive to produce and can be used to generate electricity in a variety of settings, including on buildings and in remote areas.

DSSCs work by converting sunlight into electricity in a three-step process via light absorption, electron injection, and electron transport. The photosensitizing dye absorbs light and becomes excited. The excited dye injects an electron into the semiconductor electrode. And finally, the electron travels through the semiconductor electrode and to the counter electrode, where it is collected. The redox electrolyte acts as a bridge between the semiconductor electrode and the counter electrode. It transports the electrons from the semiconductor electrode to the counter electrode, where they are used to reduce the oxidized form of the redox electrolyte according to Gratzel, M. (2001). "Photoelectrochemical cells," *Nature*, 414(6861), 338-344. DOI:

DSSCs have a number of advantages over traditional silicon solar cells. They are less expensive to produce, more flexible, and more tolerant of shade. However, DSSCs are also less efficient than silicon solar cells. The typical efficiency of a DSSC is around 10-15%, while the typical efficiency of a silicon solar cell is around 20-25%.

Despite their lower efficiency, DSSCs have a number of potential applications. They can be used to generate electricity in remote areas, on buildings, and in portable devices. DSSCs can also be used in conjunction with other renewable energy sources, such as wind and hydro power, to create a more reliable and sustainable energy supply.

Research on dye-sensitized solar cells is ongoing, and scientists are working to improve their efficiency and stability. One promising area of research is the development of new photosensitizing dyes. Scientists are also working to develop new semiconductor electrodes and electrolytes that can improve the efficiency and stability of DSSCs.

The development of solar cells using moringa dye for Nigeria could help to address the country's electricity supply challenges. Moringa dye solar cells are relatively inexpensive to produce, and they can be used to generate electricity in rural areas that are not connected to the national grid. By developing and commercializing moringa dye solar cells, Nigeria can reduce its reliance on fossil fuels and improve access to electricity for its citizens.

Moringa dye has a number of advantages over traditional solar cell materials, such as silicon. One of the benefits of developing solar cells using moringa dye for Nigeria is that moringa is a readily available and renewable resource. Moringa trees can be grown in a variety of climates, and they are relatively easy to cultivate. This means that Nigeria could produce its own moringa dye for solar cells, without having to rely on imports. Another benefit is that moringa dye solar cells are relatively inexpensive to produce. This is because moringa dye is a natural product, and it does not require the use of expensive chemicals or materials. Moringa dye can be extracted from moringa leaves using simple and inexpensive methods. Moringa dye can be easily processed into thin films, which are essential for solar cells. Moringa dye is non-toxic and biodegradable.

The development of solar cells using moringa dye is still in its early stages. However, there has been significant progress in recent years. A number of research groups around the world have developed moringa dye-based solar cells with efficiencies of over 10%.

The following are some of the key steps involved in developing solar cells using moringa dye:

1. Extraction of moringa dye: Moringa dye can be extracted from moringa leaves using a variety of methods. One common method is to soak the leaves in a solvent, such as ethanol. The dye is then extracted from the solvent using a process called liquid-liquid extraction.

2. Purification of moringa dye: The extracted moringa dye needs to be purified before it can be used in solar cells. This involves removing impurities from the dye, such as chlorophyll and other pigments.

3. Fabrication of solar cells: Moringa dye-based solar cells can be fabricated using a variety of methods. One common method is to use a spin coater to deposit a thin film of the dye onto a substrate. The substrate is then coated with a metal electrode, such as gold or silver.

Challenges and opportunities of Moringa Solar Cells: The development of solar cells using moringa dye faces a number of challenges. One challenge is that the efficiency of moringa dye-based solar cells is still lower than that of traditional silicon solar cells. However, the efficiency of moringa dye-based solar cells is improving rapidly. Another challenge is that the long-term stability of moringa dye-based solar cells needs to be improved. Moringa dye-based solar cells are currently susceptible to degradation when exposed to sunlight and moisture. However, researchers are developing ways to improve the stability of moringa dye-based solar cells. Despite the challenges, there are a number of opportunities for the development of solar cells using moringa dye in Nigeria. Moringa dye is an abundant and renewable resource in Nigeria. Additionally, the development of moringa dye-based solar cells could create jobs and promote economic growth in Nigeria. The development of solar cells using moringa dye for Nigeria has the potential to provide a sustainable and affordable source of energy for the country. Moringa is a fast-growing tree that is native to Africa and Asia, and its leaves are a good source of natural dyes. Moringa dye has been shown to be effective in absorbing light, which makes it a potential candidate for use in solar cells.

As the demand for sustainable energy solutions rises globally, developing countries play a crucial role in the advancement and adoption of solar cell technologies. This literature review explores recent research trends, challenges, and opportunities in the field of solar cells within the context of developing countries. Access to reliable and affordable energy is a fundamental challenge in many developing countries. Solar photovoltaic (PV) technology presents a viable solution due to its abundance, scalability, and decreasing costs (IEA, 2021).

Research in developing countries often focuses on off-grid solar solutions, aiming to provide electricity to remote and rural areas where traditional grid infrastructure is lacking. Off-grid solar technologies, including solar home systems and microgrids, have demonstrated significant

potential in improving energy access (Komendantova et al., 2019).

Technology transfer and local innovation are essential components of solar research in developing nations. Studies emphasize the importance of adapting solar technologies to local conditions, considering factors such as climate, infrastructure, and socio-economic dynamics (Sovacool and Dworkin, 2015).

Challenges such as financing constraints, lack of technical expertise, and intermittency issues have been identified. Research investigates innovative financing models, capacity-building initiatives, and energy storage solutions to address these challenges (Karekezi and Kimani, 2002; ESMAP, 2018). Community engagement and social acceptance are integral aspects of solar implementation in developing regions. Research highlights the importance of involving local communities in project planning and addressing cultural factors to ensure the success and sustainability of solar initiatives (Acheampong and Boateng, 2019).

Numerous case studies from developing countries showcase successful solar projects. Examples include India's National Solar Mission, Kenya's off-grid solar expansion, and Bangladesh's solar home systems program. These cases offer insights into effective strategies and lessons learned in different regional contexts (MNRE, 2021; Wamukonya et al., 2009). Solar research in Nigeria extends beyond energy access to economic opportunities. Studies assess the potential for job creation, local manufacturing of solar components, and the establishment of a solar industry that contributes to Nigeria's economic development (Adekoya et al., 2019).

Solar cells operate based on the photovoltaic effect, where certain materials generate an electric current when exposed to sunlight. As shown in figure 1. The core components of a solar cell include semiconductor materials, typically silicon, which absorbs photons from sunlight, liberating electrons and creating an electric current. The electrical energy generated can then be utilized for various applications.

### **Materials and Methods**

The materials used are high grade chemicals obtained from Sigma-Aldrich without further mixing. The materials used include:

#### **Materials**

Indium Tin Oxide glass substrates, Acetone, Isopropyl alcohol (IPA), Deionized water, Cleanroom wipes or lint-free wipes, Ultrasonic bath (optional), Compressed, nitrogen gas (optional), moringa, distilled water, ethanol, Glass conducting substrate, Titanium dioxide, Nitric acid (redox electrolyte).

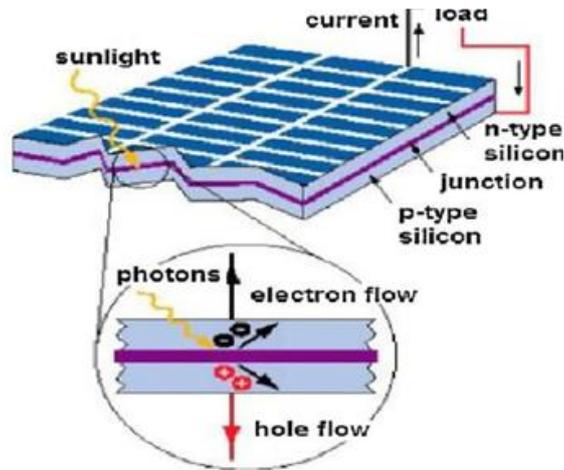


Figure 1: Schematic of the working of a solar cell (Brew-Hammond, 2010)

## Method

### Substrate Cleaning

Indium Tin Oxide (ITO) glass is commonly used as a transparent conducting electrode in the fabrication of solar cells, including dye-sensitized solar cells. Proper cleaning of ITO glass is crucial to ensure the removal of contaminants and to achieve good adhesion of subsequent layers. Before cleaning, the ITO was visually inspected for any visible particles or defects. The substrate glass was handled with clean gloves to avoid introducing new contaminants. Dust or particles were blown or gently brushed away using compressed air or a clean, soft brush. ITO glass was immersed in a container of acetone for a few minutes. An ultrasonic bath was used for more effective cleaning. This helps to remove organic contaminants and residues. The ITO substrate was rinsed with deionized water to remove the acetone and any remaining residues. A gentle stream of water was used and also, the glass substrate was dipped into a container of deionized water.

The ITO glass was immersed in a container of isopropyl alcohol (IPA) for a few minutes. Again, an ultrasonic bath was used to enhance the cleaning process. IPA helps to remove any remaining contaminants and ensures a clean surface. The ITO glass was rinsed again with deionized water to remove the IPA and any remaining impurities. It was ensured that the water used is of high purity to avoid introducing new contaminants.

The ITO glass was allowed to air-dry in a clean environment. A stream of clean, dry nitrogen gas to aid was also used in the drying. Thereafter, the ITO glass was inspected under appropriate lighting conditions to ensure that it is free from particles, streaks, or watermarks. The process was repeated until a perfect clean and drying was achieved. Store the cleaned ITO glass in a dust-free environment until it is ready for further processing in the solar cell fabrication.

### Dye Extraction and Characterization

Fresh moringa leaves were harvested, washed and cleaned to remove any impurities.



Plate 1: Harvested Moringa leaves

The moringa leaves were air-dried for 3 days, and were hand pulverized for a period of time.

After this phase, it was pulverized using the pulverizer at Engineering Materials Development Institute, Akure

The sieve shaker was used to sort them into desired sizes before converting it to Moringa paste. Moringa dye was extracted from Moringa leaves using standardized procedure. The paste was converted to the Moringa dye as seen in the syringe ready for application.



Plate 2: Particles of the hand pulverized Moringa leaves



Plate 3: A finer particle of Moringa leaves



Plate 4: The Moringa paste ready for application

The next phase is the preparation of Titania paste. A paste was made using the titanium dioxide to act as the conductor for the electrons. The paste was made by diluting the titania with nitric acid. The acid was added in drop wise and stirred until a smooth paste with no lumps.

#### **Dye Sensitization Process**

The glass and Indium Tin Oxide substrates were cleaned using standard process which are; Initial rinse with distilled water, Acetone cleaning which sonicate for 10 minutes, Isopropyl Alcohol cleaning for 10 minutes further sonicate, Nitrite Acid Etching of Indium Tin Oxide substrate, final rinse with deionized water, drying the substrate with nitrogen gas and final visual inspection of substrate. This was to remove impurity prior to usage. The Moringa dye was used to sensitize the solar cells with Moringa dye using a consistent and standardized procedure.

The Moringa dye was optimized, that is to improve dye's performance as a photo sensitizer, enhancing its ability to absorb sunlight and transfer electrons to titanium oxide layer for the sensitization process to ensure uniform and effective coating on the semiconductor surface.

#### **Solar Cell Fabrication**

The DSSC fabrications involves two sides for the solar cells viz the anode and the cathode. The anode is the working side of the solar cells and the cathode is the counter electrode.

The anode side is fabricated in the following ways. The paste of the titanium was applied to the conducting Indium Tin Oxide glass. The conducting side of the ITO was ascertain using a multimeter. The resistance of the multimeter goes to zero when the multimeter touches the conducting part. A duct tape is used to tape the four side of the ITO and a space is left in the middle of the ITO

glass.

The titania paste is applied on the surface of the ITO glass evenly. The paste is allowed to dry for about 10 minutes.

Thereafter, it is placed on a hot a plate to heat it up. It should heat for about 10 minutes to anneal it. After that phase is completed, the next is dyeing the cells. The moringa dye is used to perform this. The moringa dye is applied on top the annealed titania paste to form a greenish colour. Distilled water is used to rinse the dye off the surface of the cells. A final rinse is made using isopropanol which acts the drying agent. This forms the anode side of the cells which is the working side of the solar cells. Plate 5. shows the anode aspect of the Moringa DSSC.

The cathode is formed in the following ways. The conducting glass is coated with graphite. Pencil or any form of graphite can be used. They are used to cover a large part of the conducting glass. The graphite acts as the catalyst to keep the reaction going. The graphite coated cathode side is used to cover the anode side of the solar cells. They are binded together using binder clips. This forms the solar cells except that a redox electrolyte is still needed. The redox electrolyte is iodine and potassium iodide. They are added in drop of 2 or 3. Thereafter, the anode and cathode and squeeze until there is uniform mixing. Plate 6. shows the fabricated devices with the anode and the cathode

Since 80% more than transparency is needed of the substrate because the more purity the substrate, the more optimum permission of the sunlight passage to the effective cell area and for the efficient transfer of charges and for the reduction of energy loss in the Dye – sensitized solar cell, (DSSCs),



Plate 5: Anode component of the Moringa DSSC

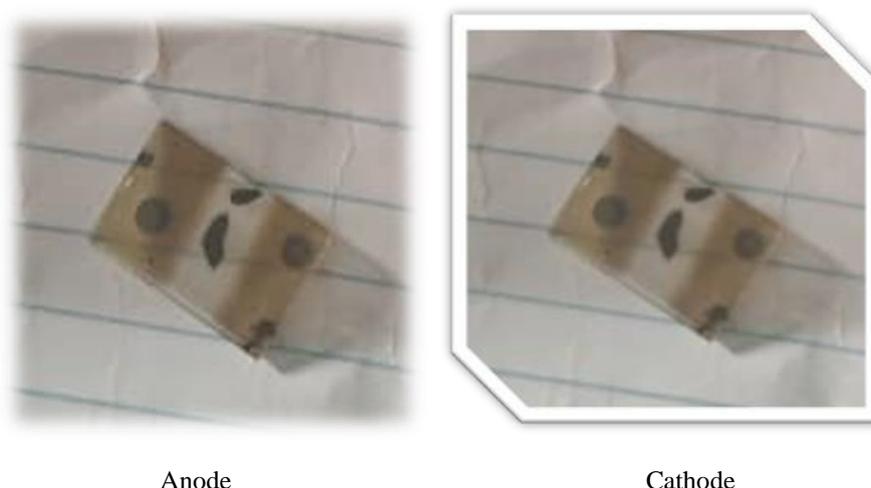


Plate 6: The fabricated Moringa Dye sensitized solar cells showing Anode and Cathode

The fluorine – doped Tin oxide, and indium Tin oxide, are the applied conductive substrate for the dye – sensitized solar cell.

The substrates contain soda lime glass coated with layers of indium – doped Tin oxide and fluorine – doped Tin oxide.

The films of ITO consist of more than 80% transmittance capacity and  $18 \Omega/\text{cm}^2$  resistance, and that of FTO films have a lower transmittance of less than 75% in the visible region and resistance of  $8.5\Omega/\text{cm}^2$ ,

The electrodes were made by depositing a thin layer of the oxide semiconducting materials, ( $\text{TiO}_2$ ), anode and NiO cathode on a transparent conducting glass plate of FTO /ITO, these oxides have a wide energy band gap generating 3-3.2eV.

The  $\text{TiO}_2$  was used as a semiconducting layer mostly, yet the conducting layers only absorb a small fraction of light in ultraviolet visible, UV, region of the Device.

Then the working electrodes are immersed in a mixture of photosensitive sensitizer and solvent. After soaking the film into the solution, the dye become covalently bond to the  $\text{TiO}_2$  surface, a number of dye molecules are attached on the nanocrystalline  $\text{TiO}_2$  surface due to porous structure and large surface area of the electrode, and as a result of this, light absorption at the semiconductor surface is increased.

### The Working Device Principle of The Design

These involve four stages:

1. Light absorption
2. Injection of electron

3. Transportation of carrier, and
4. Collection of current.

The continuous complete cycle of these steps keeps converting photons into current, and as long as the Device keeps receiving sunlight, the electricity is up there for powering our appliances.

### Results and Discussion

X-ray diffraction analysis (Rigaku Miniflex) were used in the  $2\theta$  values between 100-800 degree. Specific surface area and pore size distribution analysis of the  $\text{TiO}_2$  nanopowder were accomplished by using the  $\text{N}_2$  adsorption-Bruenur-Emmet-Teller (BET, Micromeritics, ASAP 2020) isotherm method.

The XRD pattern of  $\text{TiO}_2$  nanoparticles produced is shown in Figure 4.1. Reflection peaks in the XRD pattern validate the anatase phase and excellent crystalline structure of  $\text{TiO}_2$ . Furthermore, the anatase phase and 141:141/amd unit cell symmetry of  $\text{TiO}_2$  nanoparticles match card number DB 5000223. The Williamson-Hall formula given in Equation 1 was used to determine the average crystal sizes of the produced  $\text{TiO}_2$  nanoparticles (Sethy et al., 2023).

$$\beta \cos \theta = \frac{0.9\lambda}{D} + 4\varepsilon \sin \theta \quad (1)$$

The symbols " $\lambda$ ", " $\varepsilon$ ", "D", and " $\theta$ " in this formula indicate the peak's reflection angle, crystal size, lattice strain, and X-ray wavelength, respectively. FWHM, or the full width at half the peak height, is denoted by the symbol  $\beta$ s. The average particle size of the synthesized  $\text{TiO}_2$  nanopowders was calculated as 13.54 nm. This calculated value is compatible with the average particle sizes of  $\text{TiO}_2$  previously used in DSSC applications (Moazami et al., 2015).

Surface photographs of the synthesized  $\text{TiO}_2$  were examined with FE-SEM. The SEM photograph given in Figure 2. reflected close-contact spherical particles with an average diameter of 100 nm. Such close contact facilitates electron transport at the interface and allows greater dye absorption at the surface (Nelson and Chandler, 2004).

When it comes to redox cycles and dye loading of DSSCs, the surface area and porosity of  $\text{TiO}_2$  nanopowders are crucial. The study examined the pore size and specific surface area of the produced  $\text{TiO}_2$  nanoparticles using the BET technique. The isotherm curve of  $\text{N}_2$  gas based on the principle of adsorption and desorption was as showed in Figure 4.

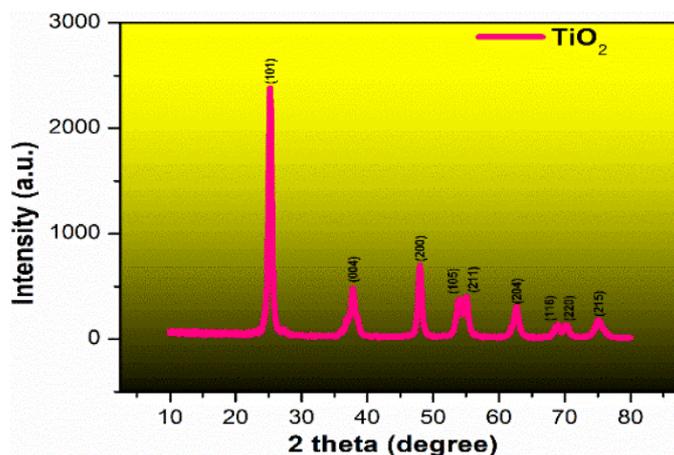


Figure 2: XRD diffraction pattern of produced  $\text{TiO}_2$  nanopowder

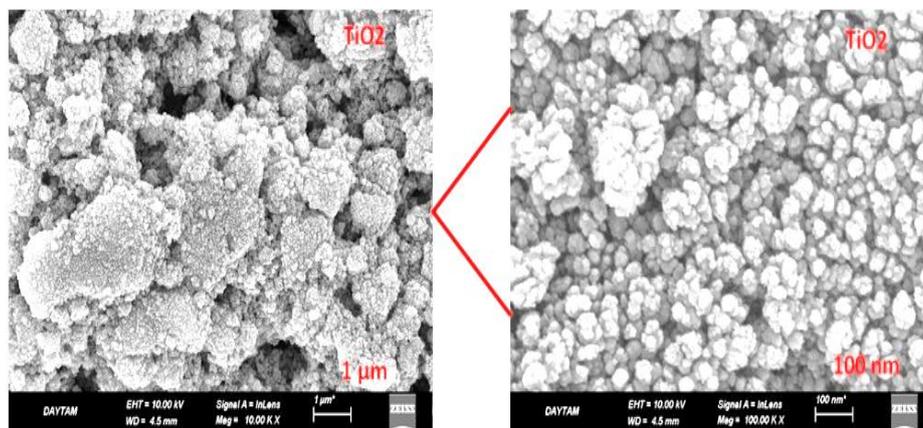


Figure 3: SEM images of  $\text{TiO}_2$  particles at different scanning

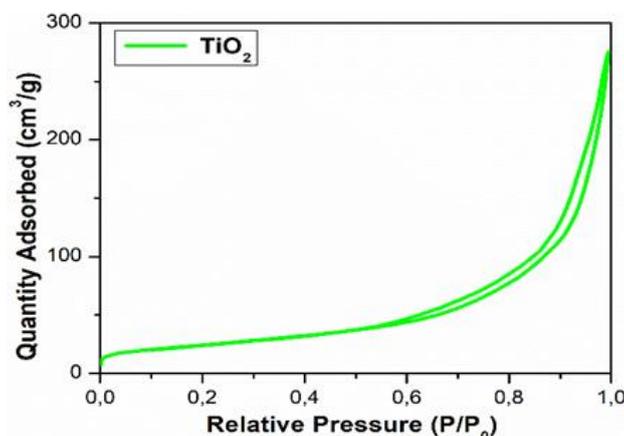


Figure 4: Plots showing the  $\text{N}_2$  adsorption/desorption of generated  $\text{TiO}_2$  nanoparticles

The generated TiO<sub>2</sub> nanoparticles demonstrated the presence of mesoporous structure and represented isotherm type IV by the Brunauer Deming DemingTeller (BDDT) classification (Xu et al., 2015). The produced TiO<sub>2</sub> particles were found to have a specific surface area of 6.36 m<sup>2</sup>/g. The porosity of the TiO<sub>2</sub>-based photoanode was determined by the BJH (Barret-Joyner-Halenda) method. The TiO<sub>2</sub> thin film's mean pore radius and pore volume were determined to be 61.95 nm and 0.189 cm<sup>3</sup>/g, respectively. Large surface area and pore size photoanodes were known to enhance electrolyte transport pathways and dye loading in DSSCs (Wali et al., 2016). BET studies showed that the obtained parameters are suitable for high-performance DSSCs (Sayahi et al., 2021, Anitha et al., 2015).

“AZTEC OXFORD DETECTOR”). The element present in the Moringa Dye Sensitize Solar cells is measure using Scanning Electron Microscope fitted with EDX. The EDX is shown in Figure 5.

As can be seen, this shows the presence of Ti, O and Ni for the TiO<sub>2</sub>, respectively and the in representing the ITO substrate. This confirms the presence of the semiconducting and redox electrolyte needed for the DSSC. Table 1 showed the percentage compositions of the elements.

**Performance Evaluation**

The readings of the solar cells volts and current are read using either multimeter or four-point probe to obtain the voltage and current readings. The key parameters of the dye-sensitized solar cells are

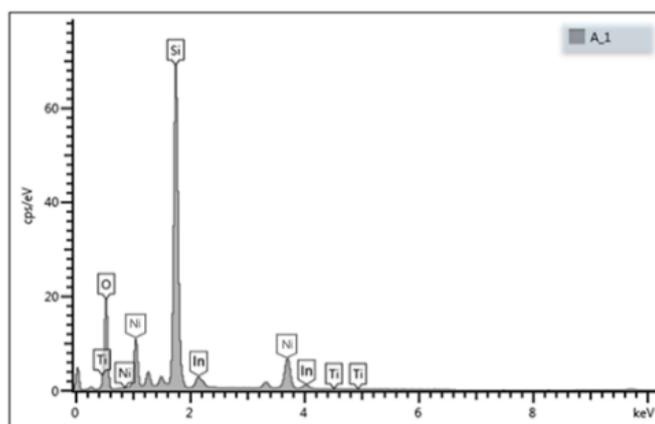


Figure 5: EDX of the fabricated Moringa DSSC

Table 1: A comparison table showing elemental and percentage composition of imported solar panel from (China, Canada, and Germany) and Moringa fabricated solar cell

S/N	Elements	Compositions			Moringa Fabricated Solar	
		China%	Canada (%)	Germany (%)	Cell	
1	Si	45	50.43	50.42	Si	64.8
2	O	34.3	39.9	39.9	O	20
3	Na	16.2	NA	NA	Ni	9.8
4	Al	4.5	4.87	4.85	Ti	2.4
5	Zn	NA	4.8	NA	In	3
6	Ni	NA	NA	4.83		
	Total	100%	100%	100%		100%

**Elemental Composition:** The microstructural analysis of the fabricated DSSC was performed using ZEISS ULTRA PLUS Field Emission Gun Scanning Electron Microscope (FEGSEM). Elemental composition was done with Energy Dispersive X-ray Spectrometer (EDS or EDX:

measured, including:

- i. Conversion Efficiency
- ii. The current-voltage characteristics of the fabricated solar cells is evaluated to obtain

the Short-Circuit Current ( $J_{sc}$ ), Open-Circuit Voltage ( $V_{oc}$ ), and Fill Factor (FF)

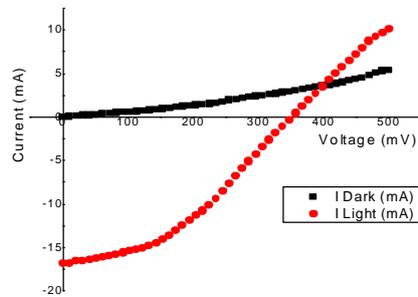
**Characterization**

The Keithley four-point probe was used for the electrical properties. Typical I-V characteristic of the moringa dye sensitized solar cell under illumination and in the dark is depicted in Fig. 6. The J-V characteristic at room temperature in the dark shows that the forward current of the cells increases slowly with increasing voltage. The solar cell has rectification properties since the dark J-V plots were similar to the Shockley diode characteristics which can be expressed by the standard diode equation shown in Equation (2).

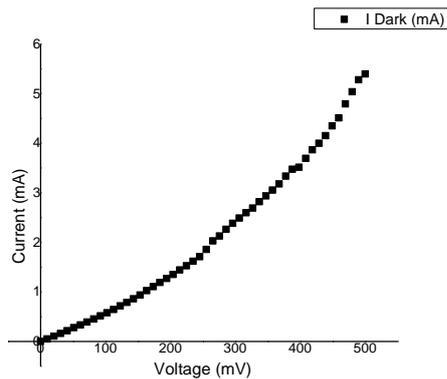
$$J = J_o \left[ \exp\left(\frac{qV}{AkT}\right) - 1 \right] \quad (2)$$

where  $q$  is the electronic charge,  $A$  is the diode quality factor (ideality factor),  $k$  is Boltzmann’s constant,  $T$  is the absolute temperature and  $I_o$  is the reverse saturation current.

The J-V characteristic of the cell under illumination and in the dark ( $100\text{mW}/\text{cm}^2$ ) are shown in Figures 6-7. The solar cell parameters evaluated from the J-V curve are presented in Table 2. The fabricated solar cells exhibit the short circuit current ( $J_{sc}$ ) 16.8 mA, the open circuit voltage ( $V_{oc}$ ) 350 mV, fill factor (FF) 0.39 and conversion efficiency ( $\eta$ ) 2.30 %. This is a marked improvement on values of 0.33 V and 0.29 recorded by Georgieva and Tanusevski (2010) for the open circuit voltage and fill factor respectively. It also showed improvement on the fill factor of 0.28 reported by Noda, Shima and Akinaga (2013).



**Figure 6:** The I-V curve for fabricated Moringa DSSC under illumination and in the dark



**Figure 7:** The I-V curve for fabricated Moringa DSSC under illumination and in the dark

Table 2: Solar Cell Parameters for Fabricated Moringa DSSC

Sample	$J_{sc}$ (mA)	$V_{oc}$ (mV)	$J_{max}$ (mV)	$V_{max}$ (mV)	FF	$\eta$ (%)
Moringa DSSC	16.8	350.0	13.10	173.57	39 %	2.30

### Solar Cell Parameters

The primary parameters that describe the performance of a photovoltaic device are here discussed.

#### i) Open-circuit voltage ( $V_{oc}$ )

Open-circuit voltage is the applied voltage relative to an open circuit where no current flows through the device (that is voltage across the device at zero current).  $V_{oc}$  is obtained at the point of intersection of the I-V curve under illumination at the voltage axis. Under open-circuit conditions, the structure has to bias itself to some voltage  $V_{oc}$  in order to counter the light current caused. The open-circuit voltage  $V_{oc}$  arises as a result of the built-in electric field present in the materials system and can be expressed as shown in Equation (3)

$$V_{oc} = \frac{AkT}{q} \ln \left( \frac{J_L}{J_0} + 1 \right) \quad (3)$$

This quantity is left unaffected by series resistance losses in the cell, but is sensitive to shunt losses.

#### ii) Short-circuit current density ( $J_{sc}$ )

$J_{sc}$  is the current that flows through the junction under illumination at zero applied voltage. i.e  $J_{sc} = J(V=0)$ . In the ideal case it equals the photo generated current density ( $J_L$ ) and is proportional to the incident number of photons, or alternatively the intensity of illumination.

$J_{sc}$  is represented as the intersection of the J-V curve under illumination, at the current axis. For an ideal solar cell ( $R_S = 0$  and  $R_{SH} = \infty$ ) the short-circuit current is given by Equation (4).

$$J_{sc} = J_0 \left[ \exp \left( \frac{q(0)}{AkT} \right) - 1 \right] - J_L, V=0 \quad (4)$$

#### iii) Fill factor (FF)

The fill factor is defined as the inverse of the ratio of the ideal power to the maximum power in operating conditions. It can be defined also as the area of the maximum power rectangle to the product of the short-circuit current and the open-circuit voltage. This is shown in Equation (5).

$$FF = \frac{V_{max} J_{max}}{V_{oc} J_{sc}} \quad (5)$$

#### iv) Efficiency

The most important parameter of a solar cell in terms of its ultimate function is the photovoltaic conversion efficiency. This is defined as the ratio of the output power (electricity) to input power (light) and can be calculated also as shown in Equation (6).

$$\eta = \frac{P_{max}}{P_{in}} = \frac{FF (V_{oc} J_{sc})}{P_{in}} \quad (6)$$

### Conclusion

The development of solar cells using adaptable, locally sourced materials presents a promising opportunity for the future of renewable energy, especially in regions with limited access to conventional materials. In this research article, Moringa leaves were successfully utilized as a dye for the sensitization of solar cells, alongside other essential materials such as titanium dioxide ( $TiO_2$ ), redox electrolytes, and Indium Tin Oxide, (ITO) glass substrate. The synthesized  $TiO_2$  nanopowder exhibited favorable characteristics, with an average particle size of 13.45 nm, as determined by X-ray diffraction analysis, and spherical morphology observed with an average diameter of 100 nm, confirmed by focused electron scanning electronic microscopy, FE-SEM imaging. Elemental analysis through energy dispersive X-ray spectroscopy (EDX) indicated the presence of essential elements like Si, O, Ni, Ti, and In, contributing to the efficiency of the fabricated solar cells. The solar cell parameters demonstrated satisfactory performance with a short-circuit current density ( $J_{sc}$ ) of 16.8 mA, open-circuit voltage ( $V_{oc}$ ) of 350 mV, a fill factor (FF) of 39%, and an energy conversion efficiency of 2.30%. While these results are lower than those of conventional solar cells, they signify that locally sourced materials like Moringa leaves can be effectively utilized to produce functional dye-sensitized solar cells (DSSCs). The findings of this research article underscore the potential for further optimization of the materials and processes used in developing solar cells. With improvements in the synthesis of  $TiO_2$  and the refinement of the dye extraction process, it is possible to increase the overall efficiency and performance of the solar cells. This research article demonstrates that alternative, sustainable materials can play a vital role in the production of solar cells, making renewable energy more accessible and affordable, particularly in developing regions.

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