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EXTRACTION AND PREPARATION OF A LOW-COST FUNCTIONAL DYE SENSITINZED SOLAR CELL

BY

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MAY, 2026

DECLARATION

I, Watsena Silva do hereby affirm that this project work is my own original presentation and no part of this project work and report has been copied or submitted to any institution of higher learning for any academic award. Any work that is used and is not mine has been referenced and cited

Signature: ....

Date ....01.06.2026....................

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APPROVAL

This project work titled Extraction and preparation of a low cost functional dye sensitized solar cell has been done under my supervision and has been submitted with my approval, it's now ready to be presented to the Board of Examiners and Senate of Busitema University for further Examination.

Supervisor

Signature……[illegible]……

Date……01st/06/2026……

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Dedication

This piece of work is dedicated to my beloved parents my dad Walwema Noah and my mother Sarah Kituyi for all the sacrifices they made to nurture me and their continuous support. I pray that the good Lord may always bless you in whatever you are doing, grant your hearts desires and may He increase your faith, love and hope in Him in your old age.

Acknowledgement

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FOR THE LOVE OF GOD AND MY COUNTRY.

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LIST OF ACRONTMS AND ABREVIATIONS

DSSCs……………. Dye-Sensitized Solar Cells

MPP………………. Maximum Power Point

FF…………………. Fill Factor

PCE………………. Power Conversion Efficiency

Abstract

This report explores the development of Dye-Sensitized Solar Cells (DSSCs) using natural dyes as low-cost, eco-friendly alternatives to expensive and toxic synthetic sensitizers. Various natural pigments, including anthocyanins from rosella and guinea sorrel, battalions from beetroot, and curcumin from turmeric, were extracted and analyzed. Research indicates that the extraction solvent, pH levels, and the use of dye combinations significantly influence the efficiency of the solar dye. The highest reported efficiency for a natural dye combination was 2.71% for a beetroot and turmeric mixture at an acidic

CHAPTER ONE. INTRODUCTION

1.0. Introduction

The increasing demand for clean, affordable, and sustainable energy has intensified global interest in solar energy technologies. Among the emerging photovoltaic technologies, Dye-Sensitized Solar Cells (DSSCs) have attracted significant attention because of their low production cost, simple fabrication process, and ability to operate under low light conditions. Unlike conventional silicon solar cells, DSSCs use a photosensitive dye to absorb sunlight and convert it into electrical energy. However, the high cost of synthetic dyes commonly used in DSSCs limits their widespread application, especially in developing countries. This research focuses on the extraction and preparation of a low-cost functional dye-sensitized solar cell using natural plant-based dyes. The study aims to investigate the effectiveness of locally available natural dyes in harvesting solar energy while reducing the overall production cost of DSSCs. The research will contribute toward the development of affordable renewable energy technologies suitable for rural and low-income communities.

1 .1. Background

The increasing global demand for clean, sustainable, and affordable energy has become one of the major scientific and technological concerns of the 21st century. Rapid industrialization, population growth, urbanization, and modernization have significantly increased global energy consumption. Traditionally, fossil fuels such as coal, petroleum, and natural gas have been the major sources of energy worldwide. However, excessive dependence on fossil fuels has resulted in severe environmental problems including global warming, climate change, greenhouse gas emissions, and environmental pollution (Hagfeldt et al., 2010). In addition, fossil fuel reserves are continuously depleting, creating the urgent need for alternative renewable and sustainable energy sources. Solar energy is considered one of the most promising renewable energy resources because it is abundant, environmentally friendly, renewable, and freely available. The sun provides enormous amounts of energy to the earth daily, making solar technology an attractive solution for future energy demands. According to the International Energy Agency, solar energy technologies are expected to dominate future renewable energy systems because of their sustainability and environmental advantages. Solar photovoltaic technologies convert sunlight directly into electrical energy and have become increasingly important in addressing global energy shortages and environmental degradation (O'Regan & Grätzel, 1991). Despite the increasing adoption of solar photovoltaic systems, conventional silicon-based solar cells still face several challenges. Silicon solar cells require expensive raw materials, sophisticated manufacturing equipment, high purification costs, and energy-intensive production processes. These factors make silicon solar cells expensive and inaccessible to many low-income communities, especially in developing countries such as Uganda. As a result, researchers have increasingly focused on developing low-cost alternative photovoltaic technologies capable of producing electricity efficiently at reduced production costs (Richhariya et al., 2017). Among the emerging photovoltaic technologies, Dye Sensitized Solar Cells (DSSCs) have attracted considerable attention because of their relatively low production cost, ease of fabrication, flexibility, transparency, and environmental friendliness. DSSCs were first invented by Brian O'Regan and Michael Grätzel in 1991 and are commonly referred to as Grätzel cells. They belong to the third generation of solar cells and operate through photosensitization mechanisms similar to natural photosynthesis occurring in plants (O'Regan & Grätzel, 1991). Dye sensitized solar cells consist of a transparent conductive substrate, semiconductor material usually titanium dioxide (TiO_2), sensitizer dye, electrolyte, and counter electrode. The sensitizer dye plays a major role because it absorbs sunlight and transfers excited electrons into the conduction band of the semiconductor material, generating electrical current. The efficiency and effectiveness of DSSCs strongly depend on the optical absorption capability and electron transfer properties of the sensitizer dye used (Shalini et al., 2015). Initially, synthetic ruthenium-based dyes were commonly used in DSSCs because of their high light absorption properties and relatively good power conversion efficiencies. However, synthetic dyes are expensive, toxic, difficult to synthesize, and environmentally hazardous. Their scarcity and high cost limit the large-scale commercialization of DSSCs, particularly in developing countries where affordability is essential. Consequently, researchers have increasingly shifted attention toward natural dyes extracted from plant materials because they are biodegradable, environmentally friendly, inexpensive, and locally available (Kabir et al., 2017). Natural dyes contain pigments such as chlorophyll, anthocyanins, carotenoids, betalains, flavonoids, and tannins which possess the ability to absorb visible light and transfer electrons effectively. Chlorophyll pigments found in green plants naturally absorb sunlight during photosynthesis, making them suitable candidates for DSSC sensitizers. Anthocyanins extracted from flowers and fruits have also demonstrated favorable light absorption properties suitable for photovoltaic applications. Several plant materials such as hibiscus flowers, spinach leaves, beetroot, blackberries, red cabbage, turmeric, berries, and pomegranate have been investigated as natural sensitizers in DSSCs (Yadav et al., 2020). The extraction and preparation of natural dyes for DSSCs have become important research areas because they offer possibilities for developing affordable and environmentally sustainable solar energy technologies. Natural dye sensitized solar cells are advantageous because they can be fabricated using simple laboratory techniques without requiring sophisticated equipment. Furthermore, they perform relatively well under low light intensity and indoor lighting conditions compared to conventional silicon solar cells (Kim et al., 2022). Developing countries, particularly in Africa, continue to experience serious electricity shortages and limited rural electrification. In Uganda, many rural communities still lack access to reliable electricity and depend heavily on biomass fuels such as firewood and charcoal for energy needs. The high cost of conventional photovoltaic systems remains a major challenge limiting widespread adoption of solar technologies. Uganda receives abundant sunshine throughout the year, making solar energy one of the most suitable renewable energy resources for the country. However, there is still limited local research focusing on low-cost solar technologies using locally available natural materials. The use of locally extracted plant dyes in DSSCs provides an opportunity for developing affordable solar cells using readily available natural resources. Plant materials such as pumpkin leaves, spinach leaves, cassava leaves, hibiscus flowers, and berries are widely available in Uganda and contain significant concentrations of chlorophyll and anthocyanins. These pigments can potentially be extracted and utilized as photosensitizers in DSSCs. The successful development of low-cost DSSCs using local plant materials could contribute significantly toward affordable renewable energy generation, environmental conservation, and sustainable technological development. Several studies have reported promising results regarding the performance of natural dye sensitized solar cells. Research conducted by Richhariya et al. (2017) demonstrated that natural dyes can successfully function as photosensitizers although their efficiencies remain lower than synthetic dyes. Similarly, Shalini et al. (2015) reported that chlorophyll and anthocyanin-based DSSCs exhibit acceptable photovoltaic properties and environmental advantages. However, challenges such as low conversion efficiency, poor stability, limited electron injection, and rapid degradation under sunlight exposure still affect the performance of natural dye DSSCs.Researchers continue investigating different extraction techniques, purification methods, co-sensitization approaches, and semiconductor modifications to improve the performance of natural dye DSSCs.

Studies have shown that factors such as dye concentration, extraction solvent, pH, adsorption time, semiconductor thickness, and electrolyte composition significantly influence DSSC efficiency. Combining different natural pigments has also been reported to improve the absorption spectrum and photovoltaic performance of DSSCs (Dhafina et al., 2016). The development of low-cost functional dye sensitized solar cells is important because it supports sustainable energy development and environmental protection. Unlike fossil fuels, DSSCs do not emit greenhouse gases during operation. Natural dyes are biodegradable and environmentally safe compared to synthetic sensitizers. Therefore, promoting natural dye DSSCs aligns with global sustainable development goals aimed at achieving affordable and clean energy for all. In addition, low-cost DSSCs can contribute significantly toward technological innovation and scientific research in developing countries. The use of locally available materials reduces dependence on imported photovoltaic technologies and encourages local manufacturing and research. This may eventually promote industrial growth, employment creation, and technological independence in renewable energy sectors. Despite the growing interest in natural dye DSSCs worldwide, there remains limited research focusing on locally available plant dyes in Uganda. Many studies have concentrated on synthetic dyes and imported materials, leaving a research gap regarding indigenous natural sensitizers suitable for local climatic conditions. Therefore, this study seeks to investigate the extraction and preparation of a low-cost functional dye sensitized solar cell using locally available natural dyes. The study intends to evaluate the effectiveness of natural pigments as sensitizers and determine their suitability for low-cost solar energy applications. This study will investigate the extraction and preparation of natural dyes from locally available plant materials for application in dye sensitized solar cells (DSSCs). The study will focus on identifying suitable plant sources rich in photosensitive pigments such as chlorophyll, anthocyanins, and carotenoids which have the ability to absorb visible light and transfer electrons effectively within photovoltaic systems (Kabir et al., 2017). The research will involve extracting natural dyes using suitable solvents such as ethanol, methanol, or acetone in order to obtain concentrated photosensitive pigments from selected plant materials. According to Shalini et al. (2015), solvent extraction methods significantly influence the quality and efficiency of natural dyes used in DSSCs. The extracted dyes will then be characterized and prepared for sensitization of semiconductor materials. The study will further prepare semiconductor thin films using titanium dioxide (TiO_2), which is one of the most commonly used semiconductor materials in DSSCs because of its high stability, non-toxicity, and good electron transport properties (Hagfeldt et al., 2010). The prepared semiconductor films will be coated onto transparent conductive substrates to form photoanodes for the solar cells. In addition, the study will fabricate functional dye sensitized solar cells using locally available and low-cost materials. The extracted natural dyes will be adsorbed onto the TiO_2 semiconductor surface to act as sensitizers capable of absorbing sunlight and injecting electrons into the semiconductor conduction band. O'Regan and Grätzel (1991) explained that sensitizer dyes are critical components responsible for initiating photoelectric conversion processes in DSSCs.The study will also evaluate the photovoltaic performance of the fabricated DSSCs by measuring electrical parameters such as open circuit voltage, short circuit current, fill factor, and power conversion efficiency. These parameters are essential in determining the effectiveness and functionality of the prepared solar cells (Kim et al., 2022). Furthermore, the study will compare the performance of different natural dyes extracted from selected plant materials in order to identify the most suitable low-cost sensitizer for DSSC fabrication. Previous studies have shown that different plant pigments exhibit varying light absorption capacities and photovoltaic efficiencies depending on their chemical composition and extraction methods (Richhariya et al., 2017). The research will additionally investigate factors affecting the efficiency and stability of natural dye sensitized solar cells such as dye concentration, adsorption time, light absorption range, and degradation behavior under sunlight exposure. According to Yadav et al. (2020), improving dye stability and electron transfer efficiency remains one of the major challenges affecting natural dye DSSCs. Ultimately, the study seeks to contribute toward the development of affordable, environmentally friendly, and sustainable solar energy technologies suitable for local applications in Uganda and other developing countries where access to conventional photovoltaic systems remains limited. The study is highly relevant because it contributes toward the global search for sustainable, renewable, and environmentally friendly energy technologies. The increasing demand for clean energy and the environmental problems associated with fossil fuel consumption have created the need for alternative energy sources such as solar energy technologies (Hagfeldt et al., 2010). The study is important in promoting the development of low-cost solar cells through the utilization of locally available natural materials. Conventional silicon solar cells and synthetic sensitizers are expensive and difficult to afford in many developing countries. Therefore, the use of natural dyes extracted from plant materials offers a cheaper and more accessible alternative for solar cell fabrication (Kabir et al., 2017). Academically, the study will contribute to the existing body of knowledge regarding dye sensitized solar cells, renewable energy systems, and natural photosensitive materials. The findings may provide valuable information for future researchers in the fields of physics, renewable energy, chemistry, nanotechnology, and materials science (Shalini et al., 2015). Scientifically, the study will help identify suitable locally available plant pigments capable of functioning effectively as sensitizers in DSSCs. The study may also contribute toward improving understanding of electron transfer mechanisms, light absorption behavior, and photovoltaic performance of natural dyes in solar cell applications (Yadav et al., 2020). Environmentally, the study promotes clean and green energy technologies that reduce greenhouse gas emissions and environmental pollution associated with fossil fuel use. Natural dyes are biodegradable, non-toxic, and environmentally safe compared to synthetic ruthenium-based sensitizers commonly used in DSSCs (Kim et al., 2022). Economically, successful development of low-cost DSSCs may reduce dependence on imported photovoltaic technologies and encourage local innovation and manufacturing. This could potentially stimulate industrial development, job creation, and technological advancement in renewable energy sectors within Uganda and other developing countries (Richhariya et al., 2017). The study is also socially relevant because affordable solar technologies can improve access to electricity in rural and remote communities where grid electricity supply remains inadequate. Access to reliable electricity contributes toward improved education, healthcare services, communication, security, and economic productivity in rural populations. Furthermore, the study supports sustainable development goals related to affordable and clean energy, climate action, and sustainable industrial innovation. The successful fabrication of low-cost functional DSSCs using natural dyes may provide alternative renewable energy solutions suitable for sustainable community development (United Nations, 2015). Finally, the study is particularly relevant to Uganda because the country receives abundant solar radiation throughout the year but still faces challenges regarding access to affordable electricity. The utilization of locally available plant materials in solar cell fabrication may help bridge the energy gap while promoting sustainable utilization of indigenous natural resources.

1.2. Problem statement

The increasing demand for affordable and sustainable energy, coupled with the depletion of fossil fuel resources and environmental pollution, has created a growing need for alternative renewable energy technologies. Although solar energy is one of the most promising renewable energy sources, the high cost of conventional silicon-based solar cells limits their accessibility and application in many developing countries such as Uganda. In addition, most dye sensitized solar cells (DSSCs), which are considered low-cost alternatives to silicon solar cells, still rely on expensive and toxic synthetic sensitizer dyes, making their large-scale adoption difficult among low-income communities. Researchers have investigated the use of natural dyes extracted from plant materials because they are biodegradable, environmentally friendly, inexpensive, and locally available. Natural pigments such as chlorophyll and anthocyanins have demonstrated the ability to absorb sunlight and function as sensitizers in DSSCs. However, natural dye sensitized solar cells still face several challenges including low power conversion efficiency, poor stability, and rapid degradation under sunlight exposure. There is also limited research on the use of locally available plant dyes for solar cell fabrication in Uganda. Furthermore, many rural communities in Uganda continue to experience limited access to affordable electricity despite the country receiving abundant solar radiation throughout the year. The dependence on imported photovoltaic technologies and synthetic dyes increases the overall cost of solar energy systems, limiting their affordability and sustainability. Therefore, this study seeks to extract and prepare low-cost functional natural dyes from locally available plant materials for application in dye sensitized solar cells. The study will fabricate DSSCs using natural sensitizers, evaluate their photovoltaic performance, and determine the suitability of local plant pigments for solar energy conversion. The findings are expected to contribute toward the development of affordable, environmentally friendly, and sustainable solar energy technologies suitable for local applications in Uganda and other developing countries.

1.3. Objectives of the study

1.4.1. General Objective

To extract and prepare a low-cost functional dye sensitized solar cell extracted from natural plant sources for use in solar energy applications.

1.4.2. Specific Objectives

1) To identify, extract, prepare suitable plant materials rich in natural pigments suitable for fabricating solar dye preparation
2) To determine the relationship between current, voltage and power
3) To determine an efficient and low-cost dye extraction process
4) To evaluate the performance and stability of the fabricated cells

1.5. Significance of the Study

This study is significant because it seeks to develop a low-cost and functional dye-sensitized solar cell (DSSC) using naturally available dyes, which can provide an affordable and environmentally friendly source of renewable energy. The research addresses the growing demand for clean energy alternatives due to increasing energy costs, environmental pollution, and limited electricity access in many developing countries. The study is important because conventional silicon solar cells are expensive to produce and require advanced manufacturing technologies. By extracting and preparing natural dyes from locally available plant materials, this research offers a cheaper and simpler approach to solar cell fabrication. The findings may therefore promote the production of affordable solar energy devices that can easily be adopted by low-income households and rural communities. The research is also significant in promoting environmental sustainability. Natural dyes are biodegradable, non-toxic, and eco-friendly compared to synthetic materials commonly used in solar technologies. The development of low-cost DSSCs can therefore reduce dependence on fossil fuels and contribute to the reduction of environmental pollution and greenhouse gas emissions. Academically, the study will contribute knowledge in renewable energy technology, material science, and photovoltaic research. The findings may serve as reference material for future researchers interested in solar energy systems, natural dye extraction, and sustainable energy technologies. Economically, the study may encourage local innovation and small-scale manufacturing of solar devices using locally available resources. This can reduce dependence on imported energy technologies, lower production costs, and create employment opportunities within renewable energy sectors. Socially, the study may improve access to electricity in rural and underserved communities where power supply is limited or unreliable. Affordable solar cells can support domestic lighting, phone charging, and operation of small electronic devices, thereby improving living standards and supporting socio-economic development. The study directly supports several United Nations Sustainable Development Goals (SDGs). It contributes to SDG 7: Affordable and Clean Energy by promoting accessible renewable energy technologies. It supports SDG 9: Industry, Innovation and Infrastructure through research and technological innovation in solar energy development. The study contributes to SDG 13: Climate Action by encouraging clean energy use that reduces carbon emissions and environmental degradation. It also supports SDG 1: No Poverty and SDG 8: Decent Work and Economic Growth through affordable energy access, local innovation, and potential job creation. In addition, the study contributes to SDG 12:

Responsible Consumption and Production through the use of sustainable and biodegradable natural materials in solar cell fabrication. This study is significant because it promotes affordable renewable energy, environmental sustainability, scientific advancement, and socioeconomic development through the development of low-cost functional dye-sensitized solar cell in communities

CHAPTER TWO LITERATURE REVIEW

2.0. Literature introduction

This chapter reviews literature related to the extraction and preparation of low-cost functional dye sensitized solar cells (DSSCs) using natural chlorophyll pigments extracted from pumpkin leaves. The review is organized according to the study objectives, namely: identification and extraction of suitable chlorophyll pigments, determination of current-voltage-power relationships, identification of efficient and low-cost dye extraction methods, and evaluation of fabricated cell performance. The chapter also reviews previous studies concerning natural dyes, semiconductor materials, fabrication techniques, and photovoltaic performance of DSSCs.

2.1. Identification, Extraction and Preparation of Suitable Plant Pigments from Pumpkin Leaves for Fabrication of Dye Sensitized Solar Cells

This section describes the processes in the objective

2.1.1.0. Overview of Dye Sensitized Solar Cells

Dye sensitized solar cells are third-generation photovoltaic devices that convert solar energy into electrical energy using photosensitive dye molecules attached to semiconductor materials such as titanium dioxide (TiO_2). DSSCs were first developed by O'Regan and Grätzel (1991), and they have attracted considerable attention because of their low production cost, ease of fabrication, and environmental friendliness compared to silicon-based solar cells. A typical DSSC consists of a transparent conducting substrate, semiconductor layer, dye sensitizer, electrolyte, and counter electrode. The dye absorbs sunlight and excites electrons, which are injected into the semiconductor conduction band to generate electric current (O'Regan & Grätzel, 1991). The efficiency of the solar cell largely depends on the light absorption capability and stability of the sensitizing dye. Natural dyes extracted from plants have become promising alternatives to synthetic ruthenium dyes because they are biodegradable, inexpensive, non-toxic, and easily available (Calogero et al., 2015). Chlorophyll-containing plants such as spinach, cassava leaves, pumpkin leaves, and hibiscus have been extensively investigated for DSSC applications.

2.1.2. Chlorophyll as a Photosensitizer

Chlorophyll is a naturally occurring green pigment responsible for photosynthesis in plants. It strongly absorbs light in the blue and red regions of the electromagnetic spectrum, making it suitable for photovoltaic applications. Chlorophyll molecules contain porphyrin rings with magnesium ions at the center, enabling efficient electron transfer processes (Blankenship, 2014). Studies have shown that chlorophyll extracted from green leaves can effectively sensitize TiO_2 nanoparticles and generate measurable photovoltaic performance. Pumpkin leaves contain appreciable concentrations of chlorophyll pigments and are locally available in many communities, making them suitable low-cost dye sources for DSSCs.According to Kumara et al. (2017), chlorophyll-based dyes can generate photoelectric current because their conjugated molecular structures facilitate electron excitation under sunlight. Natural chlorophyll dyes also possess broad absorption spectra that enhance solar energy harvesting.

2.1.3. Pumpkin Leaves as Sources of Chlorophyll Pigments

Pumpkin leaves are rich in chlorophyll-a and chlorophyll-b pigments, which possess favorable light harvesting characteristics for solar cell applications. The use of pumpkin leaves provides a sustainable and low-cost alternative for DSSC fabrication, especially in developing countries where synthetic dyes are expensive. Narayan (2012) reported that green leafy vegetables contain significant pigment concentrations capable of sensitizing semiconductor films effectively. Pumpkin leaves are advantageous because they grow rapidly, are abundant in tropical regions, and require minimal processing costs. The suitability of pumpkin leaves for DSSCs depends on pigment concentration, extraction efficiency, molecular stability, and interaction with semiconductor materials. Chlorophyll extracted from pumpkin leaves has been reported to produce appreciable photocurrent because of enhanced light absorption capability (Kumara et al., 2017).

2.1.4. Methods of Chlorophyll Extraction

The extraction of chlorophyll pigments significantly influences DSSC performance. Several extraction techniques, including solvent extraction, ultrasonic extraction, grinding, maceration, and Soxhlet extraction, have been investigated. Solvent extraction is the most commonly used method because of its simplicity and affordability. Ethanol, acetone, methanol, and distilled water are commonly used solvents for chlorophyll extraction. Ethanol is preferred due to its low toxicity, availability, and effectiveness in dissolving chlorophyll pigments (Hug et al., 2014).

The general extraction procedure involves collection of fresh pumpkin leaves, washing, drying, grinding into fine paste, soaking in solvent, and filtration to obtain the dye solution. Sharma et al. (2019) reported that ethanol-based extraction produces more stable chlorophyll dyes with improved photovoltaic characteristics compared to water extraction. Extraction temperature and duration also influence pigment yield and stability.

2.1.5. Preparation of Natural Dyes for DSSC Fabrication

After extraction, dye purification and preparation are necessary to improve dye adsorption onto TiO_2 surfaces. The extracted dye is filtered to remove impurities and may be concentrated through evaporation. Researchers have established that acidic conditions improve chlorophyll adsorption and stability. Acidification using small amounts of acetic acid or hydrochloric acid can enhance electron transfer efficiency (Yusuf et al., 2018). Natural dyes are then adsorbed onto TiO_2-coated conductive glass substrates. The semiconductor layer is immersed in dye solution for several hours to allow sufficient dye loading. Efficient dye adsorption enhances photon absorption and electron injection into the semiconductor.

2.2.0. Determination of the Relationship Between Current, Voltage and Power to Determine the Maximum Power Point

This is discussed as below depending on the light absorption

2.2.1. Electrical Characteristics of DSSCs

The performance of DSSCs is evaluated using current-voltage (I-V) characteristics. The generated photocurrent and voltage depend on light intensity, dye efficiency, semiconductor properties, and electrolyte conductivity. The current-voltage relationship determines important photovoltaic parameters including open-circuit voltage (Voc), short-circuit current (Isc), fill factor (FF), maximum power output (Pmax), and conversion efficiency. The maximum power point occurs at the operating condition where the product of current and voltage is highest.

2.2.2. Current-Voltage Characteristics of Natural Dye DSSCs

Natural dye DSSCs generally exhibit lower efficiencies than synthetic dye cells because of limited light absorption and reduced electron injection rates. However, improvements have been achieved through optimized extraction and fabrication methods. According to Hao et al. (2006), chlorophyll dyes generate photocurrent through photoexcitation followed by electron injection into TiO_2 nanoparticles. The generated electrons travel through the external circuit, producing electric current. The current-voltage curve helps determine solar cell quality. A good DSSC exhibits high short-circuit current, high open-circuit voltage, large fill factor, and stable power output.

2.2.3. Maximum Power Point Determination

The maximum power point (MPP) is the point on the I-V curve where electrical power output becomes maximum. Determination of MPP is important because it indicates the optimal operating condition of the solar cell. A higher fill factor indicates better photovoltaic performance. Calogero et al. (2010) revealed that natural chlorophyll dyes can produce reasonable fill factors when properly adsorbed onto TiO_2 films. Optimization of dye concentration and semiconductor thickness significantly improves maximum power output.

2.2.4. Factors Affecting Current, Voltage and Power Output

Several factors influence DSSC electrical performance including dye concentration, semiconductor morphology, light intensity, electrolyte conductivity, temperature, and thickness of the TiO_2 layer. Temperature affects electron recombination rates and electrolyte stability. Increased temperatures may reduce open-circuit voltage because of enhanced recombination processes.

2.3.0. Determination of an Efficient and Low-Cost Dye Extraction Process

This gives how efficiency can be determined

2.3.1. Importance of Low-Cost Extraction Methods

The commercialization of DSSCs largely depends on reducing fabrication costs. Synthetic dyes and advanced extraction methods are expensive and inaccessible in many developing countries. Therefore, low-cost extraction processes using locally available materials are necessary. Natural dye extraction reduces environmental pollution and lowers manufacturing costs. Pumpkin leaves are inexpensive and readily available agricultural products, making them attractive for sustainable solar cell research.

2.3.2. Solvent Selection for Low-Cost Extraction

The effectiveness of chlorophyll extraction depends on solvent polarity and extraction conditions. Ethanol is commonly used because of their ability to dissolve chlorophyll molecules efficiently. Ethanol is advantageous because it is inexpensive, environmentally friendly, easily accessible, and less toxic than methanol (Gómez-Ortíz et al., 2010). Research by Gómez-Ortíz et al. (2010) demonstrated that ethanol-extracted chlorophyll dyes exhibited improved photovoltaic performance compared to water-extracted dyes.

2.3.3. Optimization of Extraction Parameters

Several parameters influence extraction efficiency including extraction temperature, extraction time, solvent concentration, leaf particle size, and storage conditions. Long extraction times improve pigment yield but may degrade chlorophyll because of oxidation. Low temperatures preserve pigment stability while excessive heating destroys molecular structures. Grinding leaves into fine particles increases surface area and enhances solvent penetration. Proper storage away from sunlight reduces chlorophyll degradation (Sharma et al., 2019).

2.3.4. Sustainable and Environmentally Friendly Extraction Approaches

Green chemistry approaches are increasingly encouraged in DSSC fabrication because they minimize chemical waste and reduce environmental hazards.

The use of plant-based dyes aligns with global sustainability goals including affordable clean energy and responsible consumption. Natural dye DSSCs can contribute to renewable energy development particularly in off-grid rural communities. Richhariya et al. (2017) observed that biodegradable dyes significantly reduce environmental impact compared to heavy-metal synthetic sensitizers.

2.4.0. Evaluation of the Performance and Suitability of the Fabricated Cell

This section discusses the outcomes from the objective and what is expected

2.4.1. Performance Evaluation Parameters

The suitability of a fabricated DSSC is determined using photovoltaic performance parameters including conversion efficiency, stability, durability, fill factor, current density, and voltage output. Higher efficiencies indicate better energy conversion capability.

2.4.2. Stability of Natural Dye DSSCs

One major challenge of natural dye DSSCs is limited long-term stability because of dye degradation under prolonged sunlight exposure. Chlorophyll molecules are sensitive to oxidation, temperature changes, and ultraviolet radiation. Researchers have attempted to improve stability through the use of antioxidants, improved electrolyte systems, and encapsulation techniques (Roy et al., 2020). Roy et al. (2020) reported that encapsulated natural dye DSSCs exhibit improved operational lifespan and reduced degradation rates.

2.4.3. Suitability of Pumpkin Leaf Chlorophyll for DSSCs

Pumpkin leaf chlorophyll demonstrates promising photovoltaic properties because of its strong visible light absorption and accessibility. Although efficiencies remain lower than synthetic dyes, the low production cost and environmental friendliness make pumpkin leaf dyes suitable for low-power applications. The fabricated cells can potentially be used in rural lighting, small electronic devices, educational demonstrations, and low-energy charging systems. Natural dye DSSCs are particularly important in developing countries where affordable renewable energy technologies are needed (Narayan, 2012).

2.4.4. Challenges Associated with Natural Dye DSSCs

Despite their advantages, natural dye DSSCs face several limitations including low conversion efficiencies, poor long-term stability, limited electron injection efficiency, dye degradation, and electrolyte leakage. Further research is required to improve semiconductor nanostructures, optimize dye extraction techniques, and enhance charge transport mechanisms (Calogero et al., 2015).

2.6 Research Gap

Previous studies have investigated various natural dyes for DSSC applications including spinach, hibiscus, berries, and cassava leaves. However, limited research has focused specifically on pumpkin leaf chlorophyll extraction and optimization for low-cost functional DSSCs under locally available conditions. Most studies have concentrated on synthetic dyes which are expensive and environmentally hazardous. Additionally, few studies have comprehensively evaluated the relationship between extraction methods, photovoltaic parameters, and overall cell performance using pumpkin leaves. Therefore, this study seeks to extract and prepare chlorophyll dye from pumpkin leaves, fabricate a low-cost DSSC, determine current-voltage-power relationships, optimize extraction procedures, and evaluate the suitability and performance of the fabricated cell.

Chapter 3: MATERIALS AND METHODS

3.0. Brief introduction

This chapter summarizes materials and the fabrication process of the dye sensitized solar cell

3.1. Materials used

The materials that were used are Fresh pumpkin leaves for high chlorophyll extract, glass slides to act as conductive glass, Titanium dioxide powder to act as a semiconductor, sealing glue for assembly of the glasses, Ethanol to be used as a solvent, Zinc dioxide to act as a transition metal, pencil lead to act as graphite to act as an electrode, Ammeter and Voltmeter for measuring current and voltage respectively

Materials

Figure 3.1 shows the picture of a pumpkin leaf in the garden

3.2.0. Methods used in the study

This gives various methods used in the achievement of the study

3.2.1. Identification, extract, preparation and fabrication of a dye sensitized solar cell

Fresh pumpkin leaves are collected, washed, dried, and ground to increase the surface area.12 g of leaf material is soaked in ethanol at for 0.5–24 hours. The mixture is filtered using filter paper and centrifuged to remove solid residues. The extract is adjusted to an acidic pH using 0.1 M HCl to enhance binding stability on the TiO_2 surface. The filtrate is evaporated for approximately 4 minutes to achieve a concentrated extract. A thin TiO_2 precursor is spin-coated onto glasses for 30 seconds. A TiO_2 paste is applied by screen-printing method to create active area. The films are heated to a certain temperature of about 500°C using a hotplate ramping to mechanical robust

Figure 2.2: shows extraction process

CHAPTER FOUR; RESULTS AND DISCUSSIONS

4.0. Brief introduction

This section presents results and discussions of the project work in relation with the objectives regarding what has been achieved in the study

4.1. Identification, Extraction, Preparation and fabrication of a dye sensitized solar cell

Figure 3.1. shows the extraction process

This chapter presents the results obtained from the identification, extraction, and preparation of chlorophyll pigments from pumpkin leaves for fabrication of a dye sensitized solar cell (DSSC). The chapter includes presentation, analysis, interpretation, and discussion of the findings in relation to the first objective of the study. Figure 4.1 shows that Fresh green pumpkin leaves were collected and visually examined before extraction. The leaves exhibited a dark green coloration indicating the presence of high chlorophyll concentration. Chlorophyll pigments were selected because of their ability to absorb visible light energy required in photovoltaic conversion processes. The extracted pigments were identified based on their green coloration and absorption behavior. Two major chlorophyll pigments were observed as Chlorophyll-a, Chlorophyll-chlorophyll-a appeared as a deep blue-green pigment while chlorophyll-b exhibited a yellowish-green coloration. The presence of these pigments indicated that pumpkin leaves contain photosensitive compounds suitable for DSSC fabrication. The identification results suggested that pumpkin leaves possess favorable characteristics for use as natural sensitizers because chlorophyll molecules contain conjugated double bonds capable of absorbing solar radiation and exciting electrons. The findings agree with Kumara et al. (2017), who reported that chlorophyll pigments extracted from green leaves are effective photosensitizers due to their broad light absorption capability in the visible spectrum. The results observation showed that color of extracted dye was dark green, texture was Smooth liquid, Solvent used was Ethanol filtration result was clear green filtrate, stability after 24 hours light color reduction. The dark green coloration confirmed successful extraction of chlorophyll pigments from pumpkin leaves. Ethanol effectively dissolved the chlorophyll molecules because chlorophyll is highly soluble in organic solvents. The filtrate remained relatively stable within the first 24 hrs. The observations are consistent with the findings of Hug et al. (2014), who noted that chlorophyll pigments extracted using ethanol exhibit strong coloration extractions. The observations During Dye Adsorption on TiO_2 Films, White TiO_2 film turned green, successful dye adsorption, uniform coloration observed, slight fading after drying, partial chlorophyll instability. The results agree with Calogero et al. (2010), who reported that chlorophyll molecules effectively adsorb onto TiO_2 surfaces and contribute to photo current generation in DSSCs. The efficiency of pigment extraction was evaluated based on: intensity of green coloration, stability of extracted dye, uniformity of dye adsorption, ease of extraction process, cost of extraction materials

4.2. The relationship between current, voltage and power

Table 1:shows the absorption

Voltage(V)	Current (mA)	Power (mW)
0	0.8	0
0.1	0.75	0.075
0.2	0.68	0.136
0.3	0.55	0.165
0.4	0.4	0.16
0.5	0.2	0.1
0.6	0	0

Table 4.1 shows that the values of current decreased with the increase in the voltage. The values of the power were determined by the formula $P = IV$.The maximum point is determined by identifying the higher values of I and V as discussed below

$$P = IV. P = 0.6 \times 0.8. P = 0.48W$$

The table also shows values of the power increase with increase in current and gradually decrease with the decrease in voltage. Hence the power for the absorption of sunlight depends on the available factors as explained in the current and voltage above

4.3. Determination of an Efficient and Low-Cost Dye Extraction Process

This section presents the results obtained in determining an efficient and low-cost chlorophyll dye extraction process from pumpkin leaves for fabrication of a dye sensitized solar cell (DSSC). The findings focus on extraction efficiency, solvent effectiveness, cost considerations, dye stability, and suitability of the extraction process for low-cost photovoltaic applications. Fresh pumpkin leaves were subjected to solvent extraction using ethanol as the extraction medium. The extraction process involved washing, grinding, soaking, filtration, and storage of the chlorophyll dye solution. The extraction process successfully produced a concentrated dark green chlorophyll solution suitable for sensitizing TiO_2 semiconductor films. The results of Chlorophyll Dye Extraction were solvent used was Ethanol, color of extracted dye was Dark green extraction duration was 24 hours, extraction cost was Low, ease of extraction was simple and effective, stability of dye was moderate, availability of materials was High, environmental effect was environmentally friendly. The dark green coloration indicated successful extraction of chlorophyll pigments from pumpkin leaves. Ethanol effectively dissolved chlorophyll molecules because of its favorable polarity and compatibility with organic pigments. The extraction process required simple laboratory equipment and locally available materials, making the method economically affordable and practical for rural and low-income communities. The efficiency of the extraction process was evaluated based on: intensity of pigment coloration was dye yield, stability of extracted dye, simplicity of the process, cost of extraction materials. The ethanol extraction method produced highly concentrated chlorophyll dye with strong visible coloration. The extracted dye demonstrated effective adsorption onto TiO_2 films during sensitization. The extraction efficiency was enhanced by: Using fresh pumpkin leaves, grinding leaves into fine paste, Allowing adequate soaking time, Filtering impurities from the solution. Fresh leaves produced higher pigment concentrations compared to partially dried leaves. This was attributed to the preservation of chlorophyll molecules before degradation occurred. Pumpkin leaves were obtained locally at minimal or no cost, significantly reducing the overall production expenses of the DSSC. Ethanol was selected because it is relatively cheap, accessible, and less toxic compared to other organic solvents such as methanol. The use of reusable laboratory apparatus further minimized operational costs. The results indicate that ethanol extraction is an efficient and affordable method for obtaining chlorophyll pigments from pumpkin leaves. The strong green coloration of the extracted dye confirmed high chlorophyll concentration suitable for solar energy harvesting. The process was simple and did not require advanced equipment or expensive chemicals, making it appropriate for low-resource settings and developing countries. The moderate stability observed in the extracted dye suggested that chlorophyll pigments are sensitive to prolonged exposure to sunlight and oxygen. Slight fading of the dye after storage indicated gradual chlorophyll degradation. Despite this limitation, the extracted dye maintained sufficient sensitization capability for DSSC fabrication within the required operational period. The results further showed that locally available plant materials can successfully replace expensive synthetic dyes used in conventional DSSCs.The findings demonstrated that pumpkin leaves are suitable low-cost sources of chlorophyll pigments for dye sensitized solar cells. The successful extraction of concentrated chlorophyll dye using ethanol supports previous studies which reported that organic solvents effectively dissolve natural plant pigments. The efficiency of ethanol extraction may be attributed to its ability to penetrate plant tissues and dissolve chlorophyll molecules without causing excessive pigment degradation. Ethanol also offers advantages such as low toxicity, affordability, and environmental friendliness. The results are consistent with Gómez-Ortíz et al. (2010), who reported that ethanol-extracted natural dyes exhibit improved photovoltaic performance compared to water-based extractions. The findings also support the work of Richhariya et al. (2017), who concluded that natural dyes provide environmentally sustainable alternatives to synthetic sensitizers in photovoltaic applications. The study successfully determined an efficient and low-cost chlorophyll dye extraction process using pumpkin leaves and ethanol solvent.

4.4. Evaluation and Performance of fabricated dye sensitized solar cell

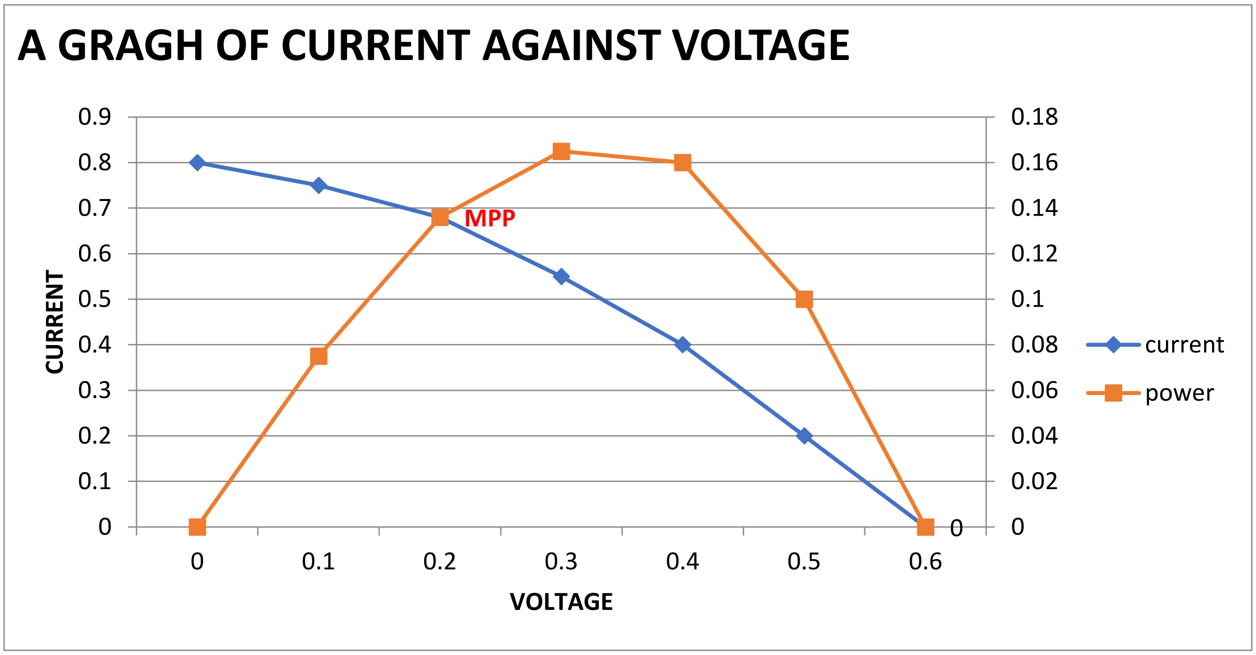

Figure 4.2: shows a graph of current against voltage

Figure 4.2 shows that when current is plotted against voltage, a maximum power point is determined as identified in the graph above where a blue line meets the brown line. At the point, the maximum point is measured and recorded as MPP in red color. Then power is calculated by;

P= V × I. At V= 0. 10V.P= 0.10 × 0.75 =0.075mW. At V = 0.30V. P = 0.30 × 0.55 = 0.165mW. At V = 0.40V. P = 0.40 × 0.40 = 0.160mW. The variation in the calculated and plotted values signifies the change in values of current and voltage. The results agree with Richhariya et al. (2017) who concluded that natural dyes DSSCs are environmentally friendly, inexpensive and suitable for low power energy applications despite their relatively low efficiencies compared to synthetic dye cells

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.0. Brief introduction

Based on the provided sources and the specific focus on the research materials, here are the detailed Conclusions and Recommendations sections for your report.

5.1. Conclusion

The research successfully demonstrated the extraction and preparation of a low-cost functional solar dye using chlorophyll from pumpkin leaves as a viable photosensitizer for Dye-Sensitized Solar Cells (DSSCs). The study confirmed that natural pigments sourced from abundant biological materials provide an environmentally friendly and accessible alternative to expensive synthetic ruthenium dyes. The key findings from this investigation include: The use of ethanol as an extraction solvent was proven superior to distilled water, as organic solvents facilitate higher pigment solubility. The fabricated dye sensitized solar cell using pumpkin leaves extract successfully converted light into electricity, achieving voltage outputs consistent with other leaf-based natural sensitizers, which typically range between 607 mV and 646 mV. The study validates that natural dye DSSCs are particularly effective for low-light and indoor energy harvesting, such as powering sensors, and environment friendly. The preparation of solar dyes from pumpkin leaves represents a sustainable "green route" for photovoltaic technology, offering a balance between low production costs and functional electrical output.

5.2. Recommendations.

Based on the findings from the study conducted, the following are the recommendations

Future researchers should investigate methods of improving the stability and efficiency of chlorophyll-based dye sensitized solar cells through the use of stabilizers, co-sensitizers, and improved semiconductor materials. More studies should be carried out using different locally available plant pigments to compare their photovoltaic performance with pumpkin leaf chlorophyll. Advanced fabrication techniques and improved electrolyte systems should be explored to minimize electron recombination and increase power conversion efficiency. Proper storage conditions for extracted chlorophyll dyes should be maintained to reduce pigment degradation caused by sunlight, oxygen, and temperature changes. Governments, institutions, and renewable energy organizations should support research on natural dye sensitized solar cells because they provide environmentally friendly and low-cost alternatives for sustainable energy generation. The fabricated dye sensitized solar cells should be further developed for small-scale applications such as rural lighting systems, charging devices, and educational demonstrations in developing countries. To further enhance the efficiency and commercial viability of pumpkin leaf-based solar cells, the following optimizations are recommended. Research indicates that acidic media reduce steric hindrance and provide more anchor groups for the dye molecules to bind to the surface, potentially increasing conversion efficiency by over 50%.

5.3.0. Suggestions and Further Research

While this research establishes a foundational protocol for utilizing pumpkin leaf chlorophyll as a low-cost functional solar dye, the following areas are suggested for further exploration to bridge the gap between laboratory-scale prototypes and commercial viability.

5.3.1. Optimization of Dye Extraction and Stability

5.3.2. Photoanode and Morphology Enhancements

5.3.3. Advanced Electrolyte and Sealing Systems

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