Faculty of Electrical Technology and Engineering

FABRICATION AND CHARACTERIZATION OF DYE-SENSITIZED SOLAR CELLS USING NATURAL DYE AS SENSITIZERS.

MUHAMMAD SAFUAN BIN MD ALI

Bachelor of Electrical Engineering Technology with Honours

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DEDICATION

I dedicate this thesis to my beloved mother, Dahliah Binti Abdul Hamid, and father, Md Ali Bin Md Noah, and to dearest siblings, Nabilah Binti Md Ali and Akmal Bin Md Ali. Last and foremost to all of my lecturer and dearest friends who have been my source of encouragement.

ABSTRACT

This report presents an experimental method to a dye-sensitized solar cell (DSSC) utilising a mix of Spinacia oleracea and Plumeria rubra, also known as green spinach and the Frangipani plant. DSSCs have emerged as a viable alternative to conventional solar systems due to their low cost, ease of production, and great light gathering qualities. In this study, the petals of Spinacia oleracea, Curcuma longa, Chukandar, and Plumeria rubra were gathered and tested for their ability to absorb visible light in order to determine which of these two natural dye combinations had a wider spectrum than the others. The dye was extracted from the materials, which was then used in UV-Vis spectroscopy. Additionally, three different co-sensitized dye combinations were produced by mixing Spinacia oleracea and Plumeria rubra with synthetic dye (N719), and their power conversion efficiencies (PCE) were investigated. The study also explored the influence of two different thicknesses of TiO2 and different glass substrates (ITO and FTO) on the PCE and I-V characteristics of the DSSCs. The experiments were conducted under the same parameters for annealing temperature and the co-sensitized dye mixture ratio. The findings revealed that Plumeria rubra co-sensitized with synthetic dye (N719) using FTO as the glass substrate exhibited the highest PCE at 0.032352%, while Spinacia oleracea co-sensitized with Plumeria rubra had the lowest PCE at 0.000014%. UV-Vis spectra and I-V characteristics for these eight samples were investigated using G2001A1 Ossila Optical Spectrometer and Ossila solar simulator. This research contributes to the investigation of natural dyes derived from botanical sources for sustainable and environmentally friendly DSSC manufacture, highlighting the potential of Spinacia oleracea and Plumeria rubra as viable alternatives to synthetic dyes in solar cell technology.

ABSTRAK

Laporan ini membentangkan kaedah eksperimen untuk menghasilkan sel suria peka pewarna (DSSC) menggunakan gabungan Spinacia oleracea dan Plumeria rubra, juga dikenali sebagai bayam hijau dan tumbuhan Frangipani. Oleh kerana kosnya yang rendah, kemudahan pengeluaran dan sifat penuaian cahaya yang sangat baik, DSSC telah muncul sebagai alternatif yang mungkin kepada sistem suria konvensional. Dalam kajian ini, daun Spinacia oleracea, Curcuma longa, Chukandar, dan kelopak bunga Plumeria rubra telah dikumpulkan dan diuji untuk keupayaan mereka untuk menyerap cahaya yang boleh dilihat untuk menentukan mana di antara dua kombinasi pewarna semula jadi ini mempunyai spektrum yang lebih luas daripada yang lain. Pewarna telah diekstrak daripada bahan, yang kemudiannya digunakan dalam spektroskopi UV-Vis. Tambahan pula, tiga kombinasi pewarna sensitif bersama yang berbeza dihasilkan dengan mencampurkan Spinacia oleracea dan Plumeria rubra dengan pewarna sintetik (N719), dan kecekapan penukaran kuasa (PCE) mereka dikaji. Kajian ini juga meneliti pengaruh dua ketebalan TiO2 yang berbeza dan substrat kaca yang berbeza (ITO dan FTO) terhadap PCE dan ciri-ciri I-V. Eksperimen dijalankan di bawah parameter yang sama untuk suhu annealing dan nisbah campuran pewarna sensitif bersama. Penemuan ini mendedahkan bahawa Plumeria rubra yang disensitif bersama dengan pewarna sintetik (N719) menggunakan FTO sebagai substrat kaca menunjukkan PCE tertinggi pada 0.032352%, manakala Spinacia oleracea yang disensitif bersama dengan Plumeria rubra mempunyai PCE terendah pada 0.000014%. Spektra UV-Vis dan ciri-ciri I-V untuk lapan sampel ini dikaji menggunakan Spektrometer Optik G2001A1 Ossila dan simulator solar Ossila. Kajian ini menyumbang kepada penerokaan pewarna semula jadi daripada sumber botani untuk pengeluaran DSSC yang mampan dan mesra alam, menunjukkan kemungkinan Spinacia oleracea dan Plumeria rubra sebagai alternatif yang baik kepada pewarna sintetik dalam teknologi sel suria.

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TABLE OF CONTENTS

		PAGE
DECLARATION		
APPROVAL		
DEDICATIONS		
ABSTRACT		**i**
ABSTRAK		**ii**
ACKNOWLEDGEMENTS		**iii**
TABLE OF CONTENTS		**iv**
LIST OF TABLES		**vii**
LIST OF FIGURES		**viii**
LIST OF ABBREVIATIONS		**x**
CHAPTER 1	**INTRODUCTION**	**11**
1.1	Background	11
1.2	Addressing Global Issue Through Dye-Sensitized Solar Cells.	13
1.3	Problem Statement	14
1.4	Project Objective	15
1.5	Scope of Project	16
CHAPTER 2	**LITERATURE REVIEW**	**17**
2.1	Introduction	17
2.2	Understanding [Global/Current Issue] in the Literature.	20
2.3	Natural Dye	21
	2.3.1 Anthocyanin	21
	2.3.2 Betalain 23	
	2.3.3 Chlorophyll	25
	2.3.4 Flavonoids	26
2.4	Synthetic Dye	28
	2.4.1 Metal organic complex dye	29
	2.4.1.1 Zinc porphyrin	29
	2.4.2 Metal free organic dye	30
2.5	Recent developments of DSSC using natural and synthetic dye	33
2.6	Summary	56
CHAPTER 3	**METHODOLOGY**	**59**
3.1	Introduction	59
3.2	Project flowchart	59
	3.2.1 Natural dye sensitizer design	60

3.2.2 Fabrication and optimization of DSSC 61
3.2.3 Performance analysis of DSSC 63
3.3 Project block diagram 65
3.4 Experimental setup 67
3.4.1 Natural dye solution preparation. 67
3.4.2 Synthetic dye (N719) solution preparation. 68
3.4.3 Preparation of electrolyte solution 68
3.4.4 Preparation of platinum solution for counter electrode 69
3.4.5 Cleaning process for glass, Indium Tin Oxide (ITO) and Fluorine Doped Tin Oxide (FTO). 70
3.4.6 Preparation of photoanode layer 71
3.4.7 Preparation of dye on photoanode layer 72
3.4.8 Preparation of counter electrode layer 73
3.4.9 DSSC fabrication 74
3.5 Material Characterization 75
3.5.1 Ultraviolet-Visible Spectroscopy (UV-Vis) 75
3.5.2 Solar Simulator 76
3.6 Parameters 76
3.7 Equipment & materials 78
3.8 Summary 83

CHAPTER 4 RESULTS AND DISCUSSIONS 84
4.1 Introduction 84
4.2 Preliminary Result. 85
4.2.1 Ultraviolet-visible spectroscopy (UV-Vis) of various natural dye 85
4.2.1.1 Green Spinach 85
4.2.1.2 Turmeric 86
4.2.1.3 Beetroot 87
4.2.1.4 Frangipani 88
4.2.1.5 Overall evaluation 88
4.3 Results and Discussion. 89
4.3.1 Results and Analysis 89
4.3.1.1 Effect on different thicknesses of TiO2 on the performance of the various type of co-sensitizer on the power conversion efficiency (PCE). 89
4.3.1.2 UV-Visible analysis of the three different co-sensitized dye for 1 layer of TiO2 photoanode. 92
4.3.1.3 UV-Visible analysis of the three different co-sensitized for 2 layer of TiO2 photoanode. 95
4.3.1.4 Current-voltage (*IV*) characteristic. 98
4.4 Summary 103

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS 104
5.1 Conclusion 104
5.2 Potential for Commercialization 105
5.3 Future Works 106

REFERENCES 108

APPENDIX **111**

LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1	Natural Dye	33
Table 2.2	Synthetic Dye.	48
Table 3.1	The optimization method based on Design Expert software.	77
Table 3.2	Equipment and materials table.	78
Table 4.1	Effect on different thicknesses of TiO_2 on the performance of the various type of co-sensitizer on the power conversion efficiency (PCE).	91
Table 4.2	The values of Voc, Jsc, PCE, and FF for the different thickness of TiO_2 various types of co-sensitizer.	91
Table 4.3	Efficiency, Voc, FF, and Jsc values for all the samples.	100

LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 2.1	Type of dyes used as photosensitizers in the fabrication of DSSCs	19
Figure 2.2	The UV-VIS absorption spectra of the anthocyanin extract at various pH values [1]	22
Figure 3.1	Natural dye sensitizer design.	60
Figure 3.2	The fabrication and optimization of DSSC flowchart.	61
Figure 3.3	The performance analysis of DSSC flowchart.	63
Figure 3.4	Project block diagram.	65
Figure 3.5	Green Spinach (Spinacia oleracea)	67
Figure 3.6	The dried spinach were crush into fine green paste.	67
Figure 3.7	Plumeria Rubra (Frangipani).	68
Figure 3.8	The dried petals were crushed into a fine red paste.	68
Figure 3.9	Preparation of electrolyte solution.	69
Figure 3.10	Preparation of platinum solution.	69
Figure 3.11	Sonication process to clean the glass substrate beakers.	70
Figure 3.12	Preparation of photoanode layer	71
Figure 3.13	Preparation of dye on photoanode layer	72
Figure 3.14	Preparation of counter electrode layer.	73
Figure 3.15	Complete fabrication of DSSC.	74
Figure 3.16	G2001A1 Ossila Optical Spectrometer.	75
Figure 3.17	Keithley 2450.	76
Figure 4.1	Green spinach asorption wavelength.	85
Figure 4.2	Turmeric absorption wavelength.	86
Figure 4.3	Beetroot absorption wavelength.	87

Figure 4.4 Frangipani absorption wavelength. 88

Figure 4.5 Absorption wavelength of beetroot, frangipani, spinach and turmeric. 89

Figure 4.6 Effect on different thicknesses of TiO2 on the performance of the various type of co-sensitizer on the power conversion efficiency (PCE) .91

Figure 4.7 UV-Vis adsorption spectra of the three type of co-sensitized dye for 1 layer of TiO2. 94

Figure 4.8 Overall bandgap for 1 layer of TiO2 for three different co-sensitized. 95

Figure 4.9 UV-Vis adsorption spectra of the three type of co-sensitized for 2 layer of TiO2. 97

Figure 4.10 : (a) Bandgap of spinach & frangipani for 2 layer of TiO2 (b) Bandgap of spinach & synthetic for 2 layer of TiO2 (c) Bandgap of frangipani & synthetic for 2 layer of TiO2 (d) Bandgap of frangipani & synthetic for 2 layer of TiO2 using FTO as glass substrate 98

Figure 4.11 : (a) J-V characteristic of spinach & frangipani for 1 layer and 2 layer of TiO2 (b) J-V characteristic of spinach & synthetic for 1 layer and 2 layer of (c) J-V characteristic of frangipani & synthetic for 1 layer and 2 layer of TiO2 (d) J-V characteristic of frangipani & synthetic for 1 layer and 2 layer of TiO2 using FTO as glass substrate 102

LIST OF ABBREVIATIONS

V	-	Voltage
I	-	Current
SDGs	-	Sustainable development goals
TiO2	-	Titanium dioxide
DSSCS	-	Dye-sensitized solar cells
UV-Vis	-	Ultraviolet visible spectroscopy
FTO	-	Fluorine doped tin oxide
ITO	-	Indium Tin Oxide
SEM	-	Scanning electron microscope
XRD	-	X-ray powder diffraction

CHAPTER 1

INTRODUCTION

1.1 Background

The dye-sensitized solar cells (DSSCs) technique has become one of the most well-established and well-understood solutions for nanomaterial-based photovoltaics. These photoelectrochemical cells consist of a transparent scaffold built of inorganic material, often a nanoporous sheet of titanium dioxide sensitized with organic dye molecules that absorb light, most commonly ruthenium complexes. Unlike the other methods outlined, which use solid-state semiconductors to create a photocurrent and transport electrons, DSSCs usually use an electrolyte in liquid form for moving ions to a platinum counter electrode. DSSCs are capable of up to 12.3% efficiency (11.9% validated) and may be advantageous due to their use of low-cost materials, ease of assembly, and potential for modular modules. However, DSSCs face significant hurdles because of their limited stability over the long term under light as well as high temperatures, poor near-infrared absorption, and relatively low open-circuit voltages induced by interfacial recombination [1].

The issues outlined above in the advancement of dye-sensitized solar cells (DSSCs) have prompted the investigation of numerous strategies for improving their efficiency and stability. Natural dyes as sensitizers are one of the most promising alternatives, owing to their plentiful availability, low cost, and eco-friendliness. Natural dyes derived from plants and fruits have distinct qualities that make them viable replacements for typical ruthenium-based colours. These dyes possess high extinction coefficients, great visual absorption, and the capacity for injecting electrons into the TiO2 electrode's conduction band [2].

Several studies have reported the successful use of natural dyes in DSSCs, including dyes extracted from pomegranate, beetroot, spinach, and blackberry. However, there is still a need to investigate the potential of other natural dyes and optimize the fabrication process for achieving higher efficiency and stability of DSSCs. Moreover, the use of natural dyes in DSSCs has not been extensively studied for their performance under different environmental conditions, such as high temperatures and prolonged exposure to light.

Therefore, the present project aims to fabricate and characterize DSSCs using natural dyes as sensitizers and evaluate their efficiency and stability under different environmental conditions. The research project will involve the processing of natural dyes from various plant sources, preparation of TiO2 electrodes, sensitization of electrodes with natural dyes, assembly of DSSCs, and characterization of their performance using various techniques, such as current-voltage (IV) curves, electrochemical impedance spectroscopy (EIS), and UV-visible spectroscopy. The project's outcomes will provide insights into the potential of natural dyes as sensitizers in DSSCs and their suitability for practical applications.

1.2 Addressing Global Issue Through Dye-Sensitized Solar Cells.

Climate change is a huge worldwide topic that has gotten a lot of attention recently. Global environmental challenges include global warming, rise in sea levels, acidification of the oceans, and unusual weather occurrences. These issues require immediate action and efforts from all sectors of society to mitigate and adapt to their impacts. One solution that can help address the climate issue is the use of Dye-Sensitized Solar Cells (DSSCs). DSSCs are a type of photovoltaic technology that utilizes a layer of photosensitive dye to absorb sunlight and convert it into electricity. Unlike traditional solar cells, DSSCs are lightweight, flexible, and low-cost, making them a promising alternative energy source. DSSCs have the potential to make a significant impact on reducing carbon emissions and addressing the climate crisis by providing clean, renewable energy. The use of DSSCs can help achieve several Sustainable Development Goals (SDGs), including SDG 7 (affordable and clean energy), SDG 9 (industry, innovation, and infrastructure), and SDG 13 (climate action). By providing clean energy, DSSCs can reduce the reliance on fossil fuels and help meet the energy needs of communities, especially those in developing countries. Moreover, the production of DSSCs can create new employment opportunities, which can contribute to economic growth and poverty reduction. Additionally, DSSCs can be used in a variety of applications, such as portable electronic devices, building-integrated photovoltaics, and solar-powered water desalination systems, which can improve access to essential services. In conclusion, addressing the climate issue is a global challenge that requires collective efforts from all sectors of society. DSSCs are a promising solution that can contribute to mitigating the impacts of climate change by providing clean, renewable energy. By promoting the use of DSSCs, we can help achieve various SDGs, such as clean and inexpensive energy, industry, innovation and infrastructure, and climate action.

1.3 Problem Statement

Dye-sensitized solar cells (DSSCs) have been widely researched as an alternative because of their inexpensive cost of production in comparison to traditional solar cells, simplicity of fabrication, and potential for efficient energy conversion. In recent years, natural dyes have been explored as a potential alternative to synthetic dyes as sensitizers in DSSCs. The current problem with synthetic dyes is that they can be expensive, toxic, and pose environmental hazards. As a result, due to their potential to be inexpensive, ecologically friendly, and sustainable, the development of natural dyes to replace synthetic dyes has attracted attention in recent years. This research involves the fabrication and characterization of DSSCs using natural dyes as sensitizers, with a focus on evaluating their efficiency and stability. However, the fabrication and characterization of dye-sensitized solar cells (DSSCs) using natural dyes as sensitizers presents a number of challenges. One major challenge is the selection of suitable natural dyes that can effectively absorb light and transfer the electrons to semiconductor material. The dye must also be stable and durable under various operating conditions. Another challenge is the optimization of the fabrication process, including the deposition of the dye on the semiconductor surface, the choice of electrolyte, and the design of the cell architecture. Furthermore, the performance of the DSSCs may be affected by various factors such as the purity of the natural dyes, the thickness of the dye layer, and the type and quality of the counter electrode. Moreover, careful characterization of the DSSCs is essential to evaluate their efficiency and stability, as well as to identify areas for further improvement. Therefore, achieving high efficiency and stability in these cells requires overcoming challenges such as poor light absorption, low electron injection efficiency, and degradation of the dye molecules over time. Furthermore, solving these problems is crucial to realizing the full potential of natural dyes in solar cells and to making renewable energy more accessible and sustainable.

1.4 Project Objective

The main aim of this project is to develop a fabrication and characterization methodology for dye-sensitized solar cells using natural dye as sensitizers. Specifically, the objectives are as follows:

a) To investigate and design an efficient and cost-effective natural dye sensitizer for Dye-Sensitized Solar Cells (DSSCs), which can improve their overall efficiency.

b) To fabricate the DSSCs using the natural dye sensitizers and optimize the fabrication process by varying the parameters such as the thickness of the TiO_2 layer, and the combination of the dye.

c) To analyze the performance of the DSSCs under various conditions such as different light intensities, and to evaluate their efficiency and stability. This will help in understanding the working mechanism of DSSCs and identifying the factors that affect their performance, and ultimately lead to the development of more efficient and sustainable solar cells.

1.5 Scope of Project

The scope of this project are as follows:

a) To investigate the suitability of different natural dyes as sensitizers for DSSCs and identify the most effective ones. This scope involves assessing their light absorption capacity, and evaluating their performance in DSSCs. The investigation will also focus on optimizing the structure of the natural dye molecules to improve their efficiency and stability in DSSCs.

b) To fabricate DSSCs using the selected natural dye sensitizers and optimize the fabrication process for improved efficiency and stability. This scope involve optimizing other parameters such as the thickness of the TiO2 layer and the combination of the dye to improve the DSSCs performance.

c) To analyze the performance of the fabricated DSSCs under various operating conditions, including different light intensities. This scope involves characterizing the DSSCs using various techniques such as current-voltage measurements, solar simulator, and UV-visible spectroscopy to evaluate their efficiency, and stability. The analysis will also include identifying the factors that influence DSSC performance and proposing strategies for enhancing their efficiency and stability.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Renewable energy development has received increased attention in recent years as a potential solution to these issues. Due to their excellent efficiency, affordable price, and environmental friendliness, dye-sensitized solar cells (DSSCs) have become known as an attractive option among several forms of renewable energy technology. Natural dyes, in particular, have piqued the interest of researchers because they have several advantages over synthetic dyes, including abundance, low cost, and biodegradability.

In this context, the present project aims to fabricate and characterize DSSCs using natural dyes as sensitizers. The project will explore the potential of natural dyes extracted from various sources, such as fruits, vegetables, and flowers, as sensitizers for DSSCs. The performance of the DSSCs will be evaluated based on various parameters, including the open-circuit voltage, short-circuit current density, fill factor, and overall efficiency.

Several research have been conducted to date on the use of natural dyes in DSSCs, and great progress has been made in this field. However, there is still much to be explored, and the present project aims to contribute to the existing knowledge by providing a comprehensive analysis of DSSC effectiveness utilizing natural dyes as sensitizers as illustrated in Figure 2.1 .The findings of this project will not only enhance our understanding of the potential of natural dyes as sensitizers but also provide significant insights for the creation of efficient and affordable DSSCs. Dye-sensitized solar cells (DSSCs) utilize dyes as photosensitizers to convert light into electricity, with two main categories being natural and synthetic dyes. Natural dyes, sourced from organic materials like plants, offer eco-friendliness but may have limitations in stability and efficiency. On the other hand, synthetic dyes, chemically engineered for specific properties, such as ruthenium-based complexes, often provide higher efficiency and stability. The choice between natural and synthetic dyes involves a trade-off between environmental sustainability and performance, as researchers strive to enhance the efficiency and durability of DSSCs as shown in Figure 2.1 which is the variety type of dye for natural dye and synthetic dye.

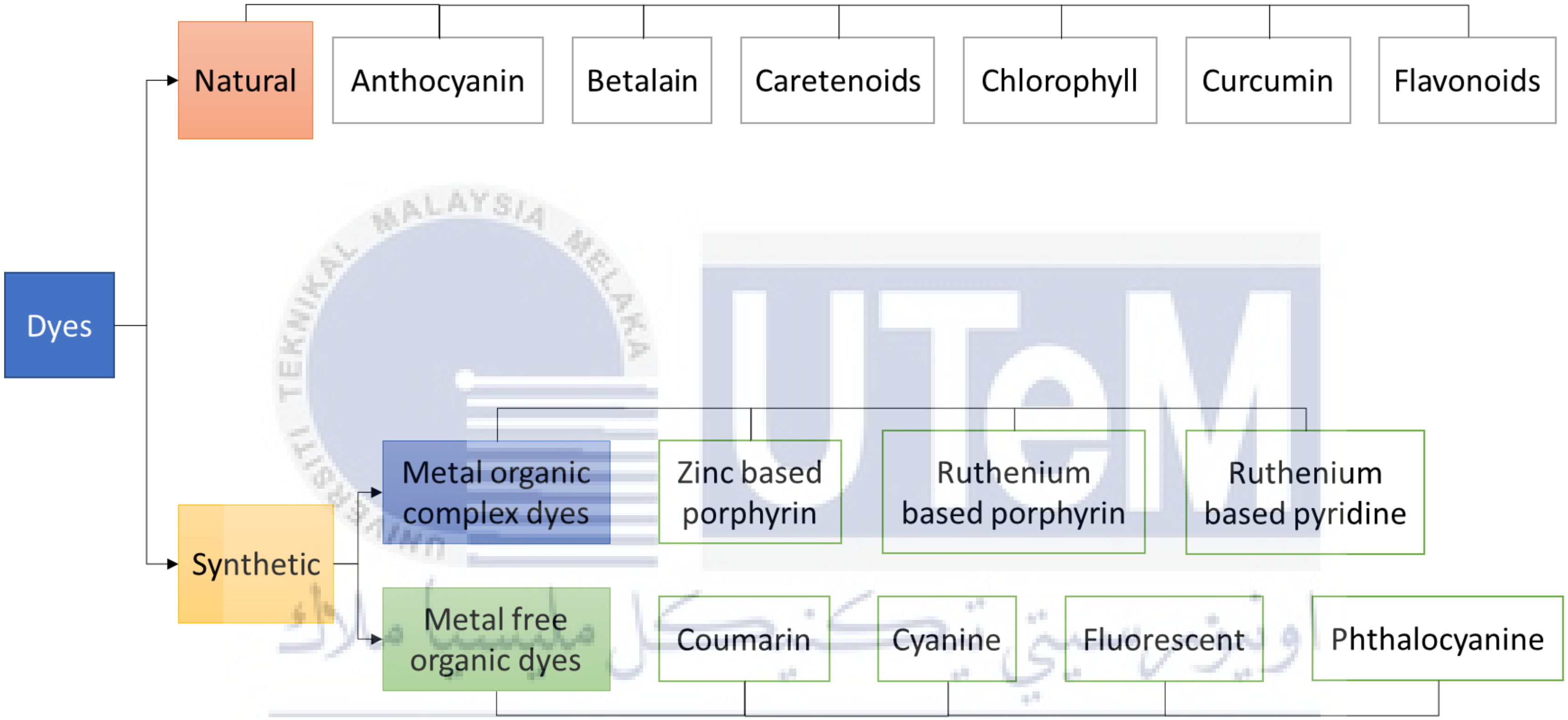


Figure 2.1 Type of dyes used as photosensitizers in the fabrication of DSSCs

2.2 Understanding [Global/Current Issue] in the Literature.

The fabrication and characterization of dye-sensitized solar cells using natural dyes as sensitizers is a current issue in the literature. With the growing demand for renewable energy sources and the necessity for long-term development, dye-sensitized solar cells (DSSCs) have appeared as a possible alternative to traditional silicon-based solar cells. Photosensitive dyes are used in DSSCs to catch sunlight and convert it into electrical energy. While synthetic dyes have been extensively researched and used in DSSCs, natural dyes produced by plants, fruits, and vegetables have gained popularity because to their inexpensiveness, ease of availability, and eco-friendliness.

The use of natural dyes as sensitizers in DSSCs, on the other hand, presents various obstacles, including low efficiency, poor stability, and limited light absorption. Researchers have concentrated on refining the construction and characterization procedures of DSSCs utilizing natural dyes to overcome these difficulties. Studies have explored various approaches such as optimizing the dye extraction process, modifying the electrode surface, and creating new counter electrodes to improve DSSC performance and stability.

Despite advances in this sector, further research is needed to completely understand the mechanisms involved in the operation of natural dye-sensitized solar cells. According to the literature, knowing the electrical and optical properties of natural dyes, as well as their interactions with the electrolyte, can lead to the development of more efficient and stable DSSCs. As such, the current issue in the literature is to explore and develop new strategies for the fabrication and characterization of natural dye-sensitized solar cells, with the aim of enhancing their efficiency, stability, and viability as a renewable energy source.

2.3 Natural Dye

Natural dyes have gained considerable attention as sensitizers in dye-sensitized solar cells (DSSCs) due to their abundance, renewability, and low toxicity. This literature review focuses on the fabrication and characterization of DSSCs using natural dyes as sensitizers. The review highlights the importance of renewable energy sources and the suitability of DSSCs for solar energy conversion. It discusses the characteristics and properties of natural dyes that make them attractive for DSSCs. The review explores fabrication techniques, including sensitization methods and the development of dye adsorption layers. It also examines characterization techniques to evaluate the performance and efficiency of DSSCs with natural dyes. Challenges such as dye stability, degradation, and long-term performance are addressed, along with proposed strategies to enhance efficiency and stability. The review concludes by summarizing key findings, identifying gaps in knowledge, and suggesting future research directions for advancing natural dye-sensitized solar cells.

2.3.1 Anthocyanin

Anthocyanins are sensitive to changes in pH, and their color can vary depending on the acidity or alkalinity of their environment. In acidic conditions, they appear red, while in more alkaline environments, they tend to be blue or purple. Figure 2.2 illustrated the UV–VIS absorption spectra of the anthocyanin extract at various pH values [1]. The authors found that crude extract performs better than further purified anthocyanin. This is attributed to the presence of natural copigments in the crude extract. On the other hand, natural green and red dyes were extracted from Malabar spinach and red spinach, respectively [2]. The researchers found that individual green and red dye sensitized DSSCs had efficiencies of 0.466% and 0.531%, respectively. However, when the dyes were combined at different volume ratios, the efficiency improved significantly. The optimal combination was determined to be 20% green and 80% red dye, resulting in an efficiency of 0.847%, which was 1.82 and 1.6 times higher than the efficiencies obtained with individual green and red dyes.

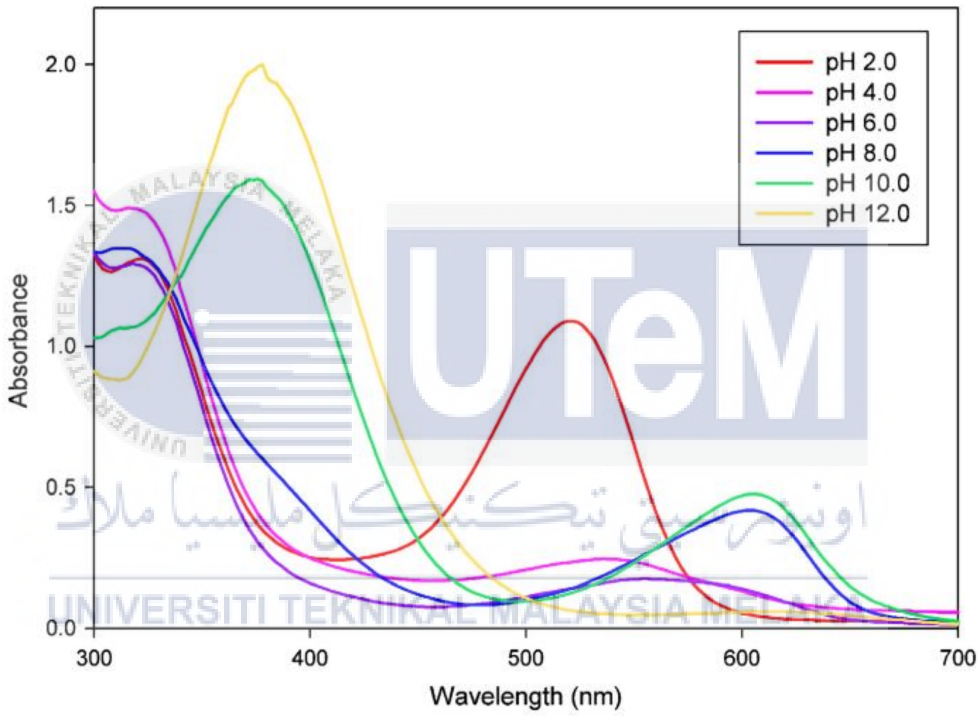


Figure 2.2 The UV-VIS absorption spectra of the anthocyanin extract at various pH values [1]

Alternatively, the utilization of natural dyes extracted from Chrysanthemum flowers was examined [3]. The researchers extracted dyes from flowers of three different colors: violet, green, and blue, which are rich in anthocyanins. They constructed organic photovoltaic cells using a titanium dioxide nanoparticle-based photoanode and platinum electrode-based photocathodes. The highest photovoltaic conversion efficiency was observed in the Chrysanthemum violet (CV) cell, with an efficiency of 1.348%, compared to 1.229% and 0.485% for the Chrysanthemum green (CG) and Chrysanthemum blue (CB) cells, respectively. The study highlights the advantages of natural dyes over synthetic dyes and inorganic materials in terms of abundance, accessibility, and affordability. It suggests that organic solar cells utilizing natural dyes could be a viable option for energy generation and contribute to sustainable development goals.

In summary, both articles explore the use of natural dyes in solar cell technology, but with different sources of natural dyes. The first article [2] focuses on green and red dyes extracted from Malabar spinach and red spinach, while the second article [3] examines dyes extracted from Chrysanthemum flowers of various colors. Both studies demonstrate the potential of natural dyes in improving the efficiency of solar cells and offer sustainable and eco-friendly alternatives to traditional synthetic dyes and inorganic materials.

2.3.2 Betalain

There are two main types of betalains: betacyanins and betaxanthins. Betacyanins are red to violet pigments, while betaxanthins are yellow to orange pigments. The specific color produced by betalains depends on the pH of the environment. Kabir et. Al 2019 focuses on the use of beetroot and curcumin extracts as alternatives to traditional solar cells in dye-sensitized solar cells (DSSC) [4]. The research found that co-sensitizing DSSCs with a mixture of betalain extract from beetroot and curcumin extract from turmeric resulted in improved cell performance. This was attributed to a wider absorption spectrum and higher light absorption compared to using a single dye. The optimized dye mixture achieved a maximum cell efficiency of 0.649%. The article also discusses the incorporation of singlewalled carbon nanotubes (SWCNTs) and post $TiCl_4$ treatment, which further enhanced cell efficiency to 0.903% and 1.108% respectively. The study highlights the importance of natural dyes and the use of SWCNTs to improve electron transport without resistance. Additionally, the post-$TiCl_4$ treatment reduces surface recombination and electron leakage, leading to improved solar cell performance. Overall, the article provides valuable insights into enhancing the efficiency of DSSCs and promoting sustainable energy technologies.

In the second article [5] , the focus is on the use of natural dyes extracted from prickly pear and mulberry fruits in DSSCs. The study extracted the pigments betalain from prickly pear and anthocyanin from mulberry through column chromatographic separation. Various solvent extract methods were tested to obtain the pigments, which were then used as sensitizers in DSSCs. The highest efficiency achieved in this study was 0.82% when a 1:1 cocktail blend of anthocyanin and betalain extracts was used. The combination of the two pigments showed improved photo-stability compared to using betalain alone, indicating a synergistic effect and an advantage of using natural dye combinations in DSSCs. The article highlights the interest in natural dyes due to the emphasis on green chemistry and sustainable energy. Methanol and aqueous methanol were used for improved extraction and adsorption to the TiO_2 semiconductor surface. The study also discusses the challenge of extended illumination and dark aging on the photostability of natural organic dyes. Despite this challenge, the use of natural dyes in DSSCs offers economic and environmental advantages in terms of low manufacturing cost. The study concludes by suggesting the exploration of other fruits as sensitizers and further advancements in the use of natural dyes for sustainable energy production.

Both articles explore the use of natural dyes in DSSCs, but they differ in the specific dyes used. The first article [4] focuses on beetroot and curcumin extracts, while the second article [5] examines prickly pear and mulberry pigments. In terms of pigment and efficiency, both studies demonstrate that the combination of different natural dyes can lead to improved performance in DSSCs. The first article [4] shows that co-sensitizing with betalain and curcumin extracts enhances cell performance by broadening the absorption spectrum and increasing light absorption. Similarly, the second article [5] highlights the synergistic effect and improved photo-stability achieved by combining anthocyanin and betalain extracts from prickly pear and mulberry. Both articles emphasize the potential of natural dye combinations to enhance DSSC efficiency.

In terms of efficiency, the first article [4] achieved a maximum cell efficiency of 1.108% with the use of betalain and curcumin extracts, along with SWCNTs and post-TiCl4 treatment. The second article [5] achieved a slightly higher efficiency of 0.82% with the combination of anthocyanin and betalain extracts from prickly pear and mulberry. Both studies recognize the challenges faced by DSSCs using natural dyes, such as degradation and reduced stability over time. They suggest measures like proper sealing and TiCl4 treatment.

2.3.3 Chlorophyll

Two articles focus on the utilization of natural dyes as photosensitizers in dye-sensitized solar cells (DSSCs), each highlighting a specific plant and its pigment composition. The first article [6] emphasizes the use of Strobilanthes cusia (SC) as a natural dye and its primary pigment composition of chlorophyll-a and chlorophyll-b. It explores alternatives to platinum-based counter electrodes (CEs) and proposes the use of graphite/FTO as a feasible alternative, which demonstrated the highest photoelectric output. The overall efficiency of the SC dye based DSSC was reported to be 0.12%.

In contrast, the second article [7] focuses on the potential of natural pigments extracted from Inthanin bok leaves (Lagerstroemia macrocarpa) in DSSCs. Carotenoids were found to be the predominant pigments in these leaves. The article investigates the parameters affecting DSSC performance, such as layer thickness and temperature, and evaluates the efficiency of the pigments extracted from Inthanin bok leaves, reporting a specific condition efficiency of 1.138%. Additionally, it discusses the potential of natural pigments as eco-friendly alternatives to synthetic dyes.

Both articles share a common goal of exploring sustainable and eco-friendly alternatives for renewable energy sources. They highlight the importance of finding natural alternatives to platinum-based CEs and emphasize the potential of natural pigments in enhancing the performance of DSSCs while reducing the environmental impact of solar cell technology. In summary, these articles contribute to the growing body of research on natural dyes in DSSCs, showcasing different plant sources and their respective pigment compositions, and providing insights into their potential applications in the field of solar energy.

2.3.4 Flavonoids

The first article [8] explores the use of Aloe vera gel as a natural dye source for dye-sensitized solar cells (DSSCs). The study focuses on the influence of different solvents on the performance of DSSCs and highlights the advantages of using natural dyes in large-area applications. It mentions that previous natural dyes led to low efficiencies, but Aloe vera gel extracts contain dyes that have the potential to capture light throughout the entire solar radiation range. The researchers tested various solvents for extracting Aloe vera gel and found that dimethyl sulfoxide (DMSO) resulted in the highest efficiency in the DSSCs. However, the efficiency of the DMSO-extracted Aloe vera gel decreased after 6 days. The study concludes by recommending further testing of extraction methods or the use of other plant-based dyes.

In contrast, the second article [9] focuses on the use of a natural dye extracted from Cassia fistula flowers as a photosensitizer for DSSCs. The article discusses the advantages of using natural dyes, including their cost-effectiveness and environmentally friendly nature. It highlights the good attachment properties of the photoactive molecules in Cassia fistula, making them suitable for DSSCs. The article compares the extracted dye from Cassia fistula with other natural dyes used as sensitizers in DSSCs. It also describes the optimization of chemical constituents and the assembly of DSSCs using Cassia fistula flowers. The study concludes that the anthocyanin pigment found in Cassia fistula flowers has anchoring groups that facilitate bonding with the TiO_2 photoanode surface, leading to higher energy conversion efficiency in DSSCs. The article further discusses the stability and efficiency of the photocurrent generated by the DSSC using the natural dye sensitizer from Cassia fistula flowers, highlighting its stable and promising sensitization ability.

In terms of pigment, both articles highlight the use of natural dyes as pigment sources for dye-sensitized solar cells. Aloe vera gel extracts which are flavonoids contain dyes with a peak in the near-infrared range, while the extracted dye from Cassia fistula flowers is rich in flavonoids pigment. The pigment in Aloe vera gel allows for light capture throughout the solar radiation range, while the flavonoids pigment in Cassia fistula provides better energy conversion efficiency in DSSCs.

Regarding efficiency, the first article [8] acknowledges that Aloe vera gel extracts yielded efficiency of 0.006% with DMSO solvents that were lower than those achieved with anthocyanins. The study recommends further testing of extraction methods or the use of other plant-based dyes to improve efficiency. On the other hand, the second article [9] presents the efficiency of the DSSC using the natural dye sensitizer from Cassia fistula flowers, reporting a maximum power output of 0.71mW/cm2 and an efficiency of 0.213%. It suggests exploring new natural dye sensitizers for DSSCs.

In summary, both articles discuss the use of natural dyes in dye-sensitized solar cells. While the Aloe vera gel extracts show potential in capturing light throughout the solar radiation range, they exhibit lower efficiencies compared to anthocyanins. In contrast, the natural dye sensitizer from Cassia fistula flowers demonstrates stable and promising sensitization ability, leading to higher energy conversion efficiency in DSSCs.

2.4 Synthetic Dye

This literature review focuses on the utilization of synthetic dyes and natural dyes as sensitizers in dye-sensitized solar cells (DSSCs). Synthetic dyes have traditionally been the primary choice for DSSCs due to their tunability and stability, leading to enhanced performance and efficiency. However, the environmental concerns and high production costs associated with synthetic dyes have led researchers to explore natural dyes as greener alternatives. Natural dyes offer benefits such as renewable sourcing, low cost, and potential biodegradability. This review aims to provide a comprehensive analysis of the advancements and limitations of synthetic dyes in DSSCs while highlighting the potential of natural dyes as sensitizers. By comparing their performance, stability, and environmental impact, this review seeks to guide future research towards the development of efficient and sustainable DSSCs.

2.4.1 Metal organic complex dye

2.4.1.1 Zinc porphyrin

In the first article [10], scientists conducted a study to examine the impact of alkyl substituents on the photophysical properties and performance of dye-sensitized solar cells (DSSCs) using a series of A3B-type zinc porphyrin dyes. They found that increasing the length and number of alkyl substituents resulted in higher power conversion efficiency, with a maximum efficiency of 1.29% achieved in solar cells utilizing dodecyloxy-substituted zinc porphyrin. The researchers synthesized and characterized these compounds, providing insights into the effect of alkyl substituents on zinc (II) porphyrin model compounds and their potential application in DSSCs. The article emphasizes the unique properties of porphyrin sensitizers and their potential as candidates for light harvesting systems.

On the other hand, the second article [11] focuses on the design and synthesis of three new porphyrin sensitizers for DSSCs. These sensitizers incorporated a fluorine-substituted benzothiadiazole as an auxiliary acceptor and thiophene as a π bridge to optimize the electronic configuration for efficient charge transfer. The researchers investigated the influence of the fluorine atom and thiophene unit on the photophysical and photochemical properties of the sensitizers. The highest photon to current conversion efficiency (PCE) achieved was 6.98% for the TH-2F-based device. This high efficiency was attributed to the strong electron-withdrawing ability of the fluorine atom and the intramolecular interaction between the auxiliary acceptor and thiophene, facilitating efficient intramolecular charge transfer. The article highlights the potential of porphyrin sensitizers as alternatives to ruthenium-based dyes, particularly for their cost-effectiveness and utilization of inexpensive metals or metal-free designs.

Regarding pigment and efficiency, the first article [10] achieves a maximum efficiency of 1.29% with the dodecyloxy-substituted zinc porphyrin, while the second article [11] attains a higher efficiency of 6.98% with the TH-2F-based device. Although the zinc porphyrin sensitizers exhibit superior efficiency, it's important to note that the two articles focus on different aspects and experimental conditions, making direct comparisons challenging. Both articles emphasize the potential of porphyrin sensitizers in improving the performance of DSSCs, albeit through different modifications and strategies.

2.4.2 Metal free organic dye

The first article [12] focuses on the design and synthesis of four metal-free organic sensitizers with fused azacycle units as donors for dye-sensitized solar cells (DSSCs). The researchers investigate the relationship between the size and conjugation of the donors and the performance of the DSSCs. Sensitizer QL3, with N-phenyl-iminostilbene (ISB) as the donor, exhibits the highest power conversion efficiency (PCE) of 6.22% among all dyes, and up to 7.14% when co-adsorbed with CDCA and 8.26% by cosensitizing with another dye, WL5. The article emphasizes the importance of the ISB unit as a promising donor due to its planar structure and increased conjugation, providing valuable insight for future metal-free organic sensitizers.

In contrast, the second article [13] discusses the design and synthesis of four co-sensitizers based on (N-benzothiazolyl)-cyanoacetamide for DSSCs. The dyes are designed with a donor-π-acceptor architecture for efficient solar energy conversion. Co-sensitization with these dyes enhances the power conversion efficiency (PCE) of DSSCs compared to a popular ruthenium-based sensitizer. Among the co-sensitizers, SA20 exhibits the highest PCE of 8.27%, along with improved short-circuit photocurrent (Jsc) values of 19.25 mA/cm2 and open circuit photovoltage (Voc) of 0.68 V. The article highlights the potential of (N-benzothiazolyl)-cyanoacetamide dyes as promising candidates for efficient DSSCs.

Regarding pigment and efficiency, the first article [12] mentions the use of fused azacycle donors in the D-A-π-A structure, where the size and conjugation of the donors significantly affect the photovoltaic performance of DSSCs. Sensitizer QL3, with the N-phenyl-iminostilbene (ISB) donor, exhibits the highest PCE among all dyes. The article highlights the planar structure and increased conjugation of the ISB unit as promising for efficient organic dyes.

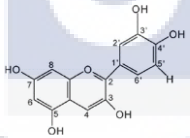
In the second article [13] , the (N-benzothiazolyl)-cyanoacetamide dyes are used as co-sensitizers to enhance the efficiency of DSSCs. The co-sensitizers exhibit improved power conversion efficiency compared to a popular ruthenium-based sensitizer. Among them, SA20 shows the highest PCE, along with enhanced short-circuit photocurrent and open circuit photovoltage values. The compact size of the co-sensitizers, decreased dye aggregation, and filling of empty gaps between dyes contribute to their improved efficiency.

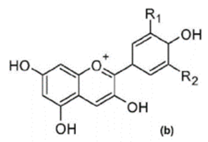
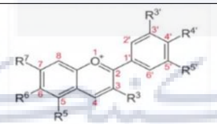
Both articles highlight the importance of optimizing the molecular structure of dyes to improve the efficiency of DSSCs. The first article emphasizes the size and conjugation of the fused azacycle donors, while the second article focuses on the donor-acceptor architecture of (N-benzothiazolyl)-cyanoacetamide dyes. Both studies provide valuable insights into the development and optimization of organic dyes for use in renewable energy technologies.

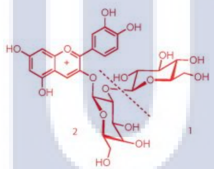
2.5 Recent developments of DSSC using natural and synthetic dye

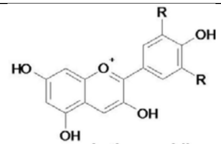
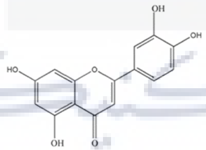
Table 2.1 provides a comprehensive overview of various natural dyes used in dye-sensitized solar cells (DSSCs) based on the previous research. The table includes information on the author(s), pigment, type of plant, chemical structure, power conversion efficiency (PCE), year of the study, and the parameters investigated.

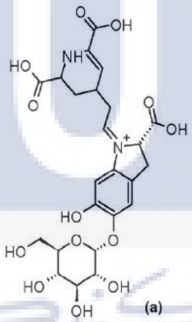
Table 2.1 Natural Dye

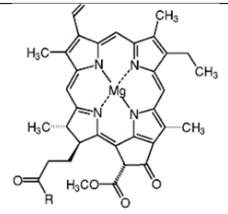
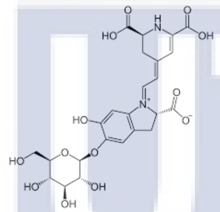
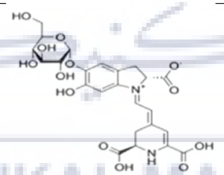
Author(s)	Pigment	Type of plant	Chemical structure	PCE (%)	Year	Parameters investigated
[2]	Anthocyanin	Red spinach		0.531	2019	UV–Vis spectroscopy, FTIR spectroscopy, (I-V) characteristics , Voc, Isc, Fill factor, Efficiency, Combination of dye

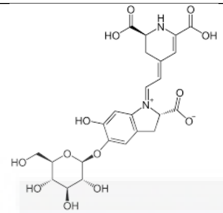
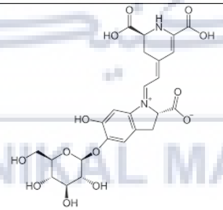
[14]	Anthocyanin	Cranberry		0.066	2023	UV–Vis spectroscopy, FTIR spectroscopy, (I–V) characteristics, (C–V) characteristics, (C-f) characteristics, (Rs-V) characteristics, Voc, Isc, Fill factor, Efficiency, Combination of dye
[3]	Anthocyanin	Chrysanthemum Blue		0.485	2023	UV–Vis spectroscopy, FTIR spectroscopy, (I-V) characteristics , grain size, thickness, uniformity, and

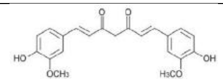
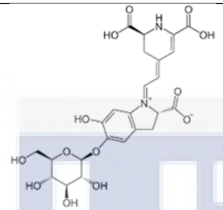
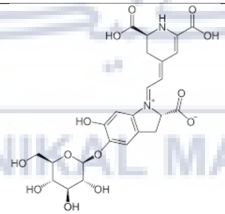
						porosity of the thin film, Photovoltaic characterization, Voc, Isc, Fill factor, Efficiency, Combination of dye
[15]	Anthocyanin	P. rubra flowers		0.038	2020	UV–Vis spectroscopy, FTIR spectroscopy, (I-V) characteristic, (J-V) characteristic, Optical absorption characteristic, SEM analysis, Voc, Jsc, Fill factor, Efficiency

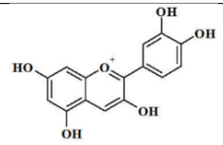
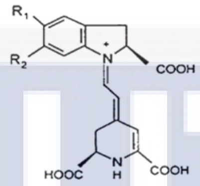
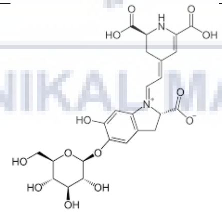
[16]	Anthocyanin	Pomegranate	 Anthocyanidins	0.2	2021	UV–Vis spectroscopy, FTIR spectroscopy, PL spectroscopy, (I-V) characteristics, SEM analysis, Optical absorption characteristic, (XRD) studies, Voc, Isc, Fill factor, Efficiency
[3]	Cyanidin-based anthocyanin	Chrysanthemum Violet		1.35	2023	UV–Vis spectroscopy, FTIR spectroscopy, (I-V) characteristics , grain size, thickness, uniformity, and

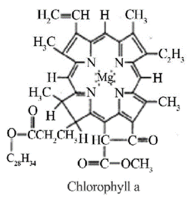
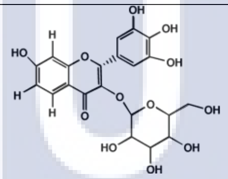
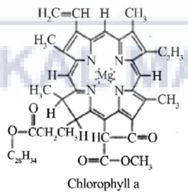
						porosity of the thin film, Photovoltaic characterization, Voc, Isc, Fill factor, Efficiency, Combination of dye
[14]	Betalain	Beetroot		0.014	2023	UV–Vis spectroscopy, FTIR spectroscopy, (I–V) characteristics, (C–V) characteristics, (C-f) characteristics, (Rs-V) characteristics, Voc, Isc, Fill factor, Efficiency, Combination of dye

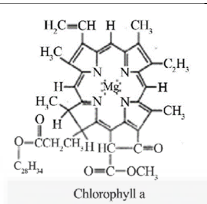
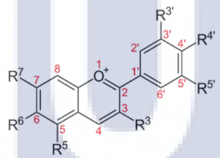
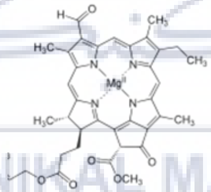
[17]	Betalain mixed with Chlorophyll (1:1 ratio)	Tridax procumbens leaf and beetroot	 Chlorophyll  Betalain	0.11	2022	UV–Vis spectroscopy, FTIR spectroscopy, (I-V) characteristic, (J-V) characteristic, SEM analysis, Voc, Jsc, Fill factor, Efficiency
[18]	Betalain	Basella alba fruits (malabar spinach)		0.466	2023	UV–Vis spectroscopy, FTIR spectroscopy, PL spectroscopy, (I-V) characteristic, (J-V) characteristic, Voc,

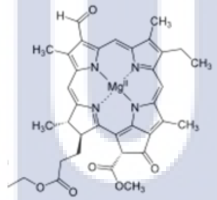
						Jsc, Fill factor, Efficiency
[4]	Betalain	Beetroot		0.220	2019	UV–Vis spectroscopy, (I-V) characteristics, SEM analysis, Voc, Isc, Fill factor, Efficiency, Combination of dye, Degradation of the DSSC
[4]	Betalain & curcumin (1:2 ratio) max efficiency	Beetroot & turmeric	 Betalain	0.649	2019	UV–Vis spectroscopy, (I-V) characteristics, SEM analysis, Voc, Isc, Fill factor, Efficiency,

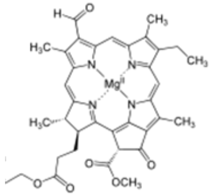
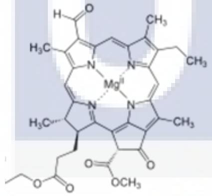
			 Curcumin			Combination of dye, Degradation of the DSSC
[5]	Betalain	Prickly pear (Opuntia phaeacantha)		0.47	2020	UV–Vis spectroscopy, FTIR spectroscopy, (I-V) characteristic, Voc, Jsc, Fill factor, Efficiency, Benefit of column separation/purification
[5]	Betalain & Anthocyanin	Prickly pear (Opuntia phaeacantha) & mulberry	 Betalain	0.82	2020	UV–Vis spectroscopy, (I-V) characteristic, Voc, Jsc, Fill factor, Efficiency, Benefit of

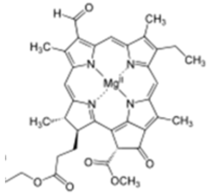
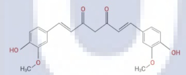
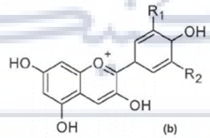
			 Anthocyanin			column separation/purification
[19]	Betanin	Beetroot	 Betacyanins	0.56	2019	UV–Vis spectroscopy, FTIR spectroscopy, (I-V) characteristic, Optical absorption characteristic, Voc, Isc, Fill factor, Efficiency
[19]	Betanin & Chlorophyll (80% : 20%)	Beetroot & Spinach		0.99	2019	UV–Vis spectroscopy, FTIR spectroscopy, (I-V) characteristic, Optical absorption

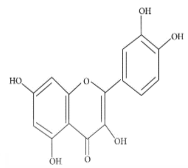
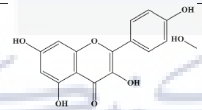
			Betalain  Chlorophyll			characteristic, Voc, Isc, Fill factor, Efficiency
[20]	Chlorophyll	Angsana tree (Pterocarpus Indicus Wild Leaf)		0.035	2019	UV–Vis spectroscopy, FTIR spectroscopy, (I-V) characteristics , Voc, Isc, Fill factor, Efficiency
[2]	Chlorophyll	Malabar spinach		0.466	2019	UV–Vis spectroscopy, SEM characterization, (I-V) characteristics , Voc, Isc, Jsc, Fill

						factor, Efficiency, Combination of dye
[2]	Chlorophyll & Anthocyanin (20% : 80%)	Malabar spinach & Red spinach	 Chlorophyll  Anthocyanin	0.847	2019	UV–Vis spectroscopy, FTIR spectroscopy, (I-V) characteristics , Voc, Isc, Fill factor, Efficiency, Combination of dye
[3]	Chlorophyll	Chrysanthemum Green		1.229	2023	UV–Vis spectroscopy, FTIR spectroscopy, (I-V) characteristics , grain size, thickness, uniformity, and

						porosity of the thin film, Photovoltaic characterization, Voc, Isc, Fill factor, Efficiency, Combination of dye
[6]	Chlorophyll	Strobilanthes cusia (FTO glass counter electrodes)		0.00067	2023	UV–Vis spectroscopy, (I-V) characteristic, SEM analysis, Voc, Jsc, Fill factor, Efficiency, Different counter electrode materials.

[6]	Chlorophyll	Strobilanthes cusia (Graphite counter electrodes)		0.0385	2023	UV–Vis spectroscopy, (I-V) characteristic, SEM analysis, Voc, Jsc, Fill factor, Efficiency, Different counter electrode materials.
[6]	Chlorophyll	Strobilanthes cusia (Pt counter electrodes)		0.0118	2023	UV–Vis spectroscopy, (I-V) characteristic, SEM analysis, Voc, Jsc, Fill factor, Efficiency, Different counter electrode materials.

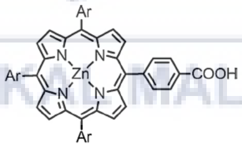
[7]	Chlorophyll and carotenoids	Inthanin bok leaves	 Chlorophyll  Carotenoids	1.138	2023	UV–Vis spectroscopy, FTIR spectroscopy, (I-V) characteristic, SEM analysis, Voc, Fill factor, Efficiency, dye thickness, temperature
[21]	Curcumin and anthocyanin	Turmeric & Red spinach	 Curcumin  Anthocyanin	1.572	2019	UV–Vis spectroscopy, FTIR spectroscopy, (I-V) characteristics , Photovoltaic characterization, Voc, Isc, Fill factor, Efficiency,

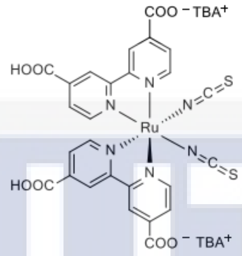
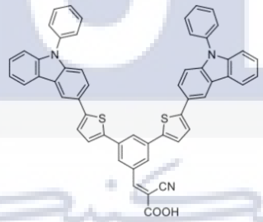
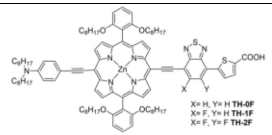
						Combination of dye, TiCl4 treatment
[8]	Flavonoids	Aloe vera		0.006	2019	UV–Vis spectroscopy, (I-V) characteristic, Optical absorption characteristic, Voc, Isc, Fill factor, Efficiency, Different solvents
[9]	Flavonoids	Cassia fistula	 Kaempferol	0.21	2019	UV–Vis spectroscopy, FTIR spectroscopy, (J-V) characteristic, Optical absorption characteristic, Voc,

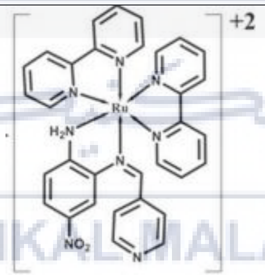
						Jsc, Fill factor, Efficiency

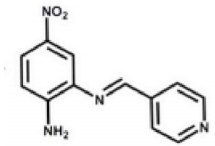
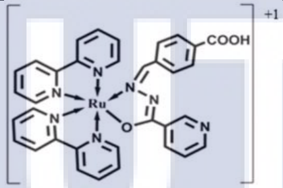
Table 2.2 provides a summary of various synthetic dyes used in the field of solar cells, particularly in the development of sensitizers for dye-sensitized solar cells (DSSCs) based on the previous research paper. The table includes information on the author(s), pigment, type of synthetic, chemical structure, power conversion efficiency (PCE), year of the study, and the parameters investigated in the research paper.

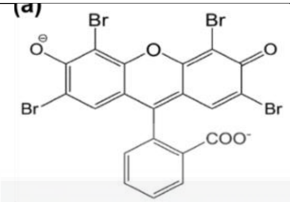
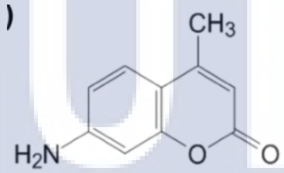
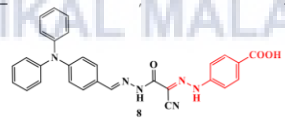
Table 2.2 Synthetic Dye.

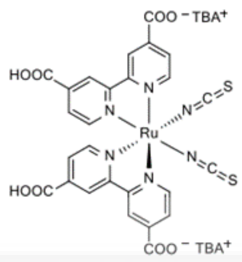
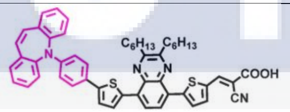
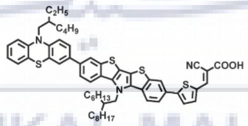
Author(s)	Pigment	Type of synthetic	Chemical structure	PCE (%)	Year	Parameters investigated
[10]	A3B-type Zn (II) porphyrins	Zinc porphyrin		1.29	2020	UV–Vis spectroscopy, (J-V) characteristic, Jsc, Voc, Isc, Fill

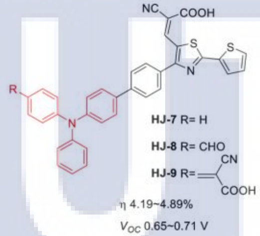
						factor, Efficiency, Different solvents
[22]	N719 + CD2	Ruthenium-based (New Y type organic sensitizers CD1–3 with D2–π–A configuration)	 N719  CD2	7.96	2021	UV–Vis spectroscopy, Electrochemical impedance spectroscopy, (J-V) characteristic, Jsc, Voc, Isc, Fill factor, Efficiency, Different solvents
[11]	TH-2F	Zinc porphyrin (Three ‘donor–		6.98	2020	UV–Vis spectroscopy, (J-

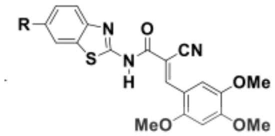
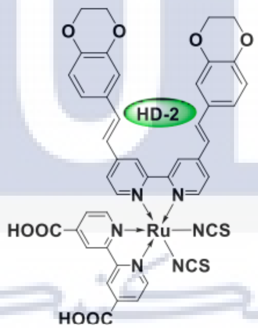
		acceptor–π bridge–acceptor' (D–A–π–A) type zinc porphyrin sensitizers TH-2F with a benzothiadiazole (BTD) unit two fluorine atoms)				V) characteristic, Jsc, Voc, Isc, Fill factor, Efficiency, Different solvents
[23]	RNPDA + NPD-PC	Heteroleptic dual anchored Ruthenium(II) sensitizer synthesized using 4-Nitro-	 RNPDA	3.42	2019	UV–Vis spectroscopy, FTIR spectroscopy, (J-V) characteristic, Photostability,

		phenylene-diamine Schiff base)	 NPD-PC			Nyquist plot, Bode's plot, Voc, Isc, Fill factor, Efficiency, Different solvents
[24]	RNIHFB	Ruthenium(II) sensitizer with anchored hydrazide ligand	 RNIHFB	4.22	2022	UV–Vis spectroscopy, FTIR spectroscopy, (J-V) characteristic, Photostability, Nyquist plot, Bode's plot, Voc, Isc, Fill factor,

						Efficiency, Different solvents
[25]	EY-CM	Eosin Y and Coumarin	 Eosin  Coumarin	6.15	2023	UV–Vis spectroscopy, (J-V) characteristic, SEM analysis, (XRD) studies, Nyquist plot, Voc, Isc, Fill factor, Efficiency, Different solvents
[26]	Compound 8 + N719	Four novel acetohydrazonoyl cyanide	 Compound 8	8.63	2023	UV–Vis spectroscopy, Electrochemical

		compounds (5–8) with a triphenylamine moiety	 N719			impedance spectroscopy, (J-V) characteristic, Voc, Isc, Fill factor, Efficiency, Combination solvents
[12]	QL3 + WL5	Four novel D-A-π-A metal-free organic sensitizers QL1–4 with the fused azacycle units as donors	 QL3  WL5	8.26	2022	UV–Vis spectroscopy, (J-V) characteristic, Electrochemical impedance spectroscopy, Jsc, Voc, Isc, Fill

						factor, Efficiency, Sizes and conjugations of azacycle, Combination dye
[27]	HJ-7	Three triphenylamine dyes were synthesized with 4-phenyl-2-(thiophen-2-yl)thiazole as π-bridge and cyanoa- crylic		4.89	2021	UV–Vis spectroscopy, (J-V) characteristic, Jsc, Voc, Isc, Fill factor, Efficiency, Combination dye

		acid as the acceptor				
[13]	SA20 + HD-2	Four novels (N-benzothiazolyl)-cyanoacetamide-based metal-free dyes SA17–20 with D-π-A architecture	 SA19: R = H SA20: R = OMe 	8.27	2022	UV–Vis spectroscopy, (I-V) characteristic, (J-V) characteristic, Electrochemical impedance spectroscopy, Jsc, Voc, Isc, Fill factor, Efficiency, Combination dye

2.6 Summary

The article presents the fabrication and characterization of dye-sensitized solar cells (DSSCs) using natural dyes as sensitizers. The literature review discusses the importance of DSSCs as a renewable energy source and the use of natural dyes as an alternative to synthetic dyes due to their low cost and eco-friendliness. The review also covers the various natural dyes used in DSSCs, including anthocyanin, chlorophyll, and betalains, and their properties. The significance findings from the studies were highlighted as follows:

- The crude extract performs better than further purified anthocyanin. This is attributed to the presence of natural copigments in the crude extract [1].
- To improve the cell efficiency, the researchers combined the green and red dyes at different volume ratios. They found that the optimum combination was 20% green dye and 80% red dye, which resulted in a co-sensitized DSSC with a maximum cell efficiency of 0.847%. [2]
- The absorption spectrum of the dyes directly influenced the adsorption of the active layer and the generation of photoexcited electrons. Among the dyes tested, Chrysanthemum Violet showed the most promising results, with values of open circuit voltage, short circuit current, fill factor, and efficiency of 0.58 V, 0.845 mA, 0.44, and 1.348%, respectively. [3]
- The combination of betalain extract from beetroot and curcumin extract from turmeric as sensitizer sources for DSSC resulted in enhanced cell performance. The optimized combination of red and yellow dyes (at the 1:2 vol ratio) had the highest cell efficiency of 0.649%, which was 195% and 37% higher than single individual red (η = 0.22%) and yellow (η = 0.473%) dye-sensitized DSSC's cell efficiency,

respectively. The addition of carbon nanotube and post TiCl4 treatment further enhanced the cell performance, resulting in a cell efficiency of 1.108%. [4]

- Betalain from prickly pear and anthocyanin from mulberry, showed promising potential as sensitizers for DSSCs. The study also explored the effects of different extraction solvents, the stability of the natural dyes, and the potential for improved performance through the use of a cocktail blend of the two extracts. The results indicated that the natural dyes from prickly pear and mulberry have the potential to be used as sensitizers in DSSCs, with further optimization and research. [5]
- Aqueous methanol (90% methanol/10% water) was determined to be the optimum extraction solvent for prickly pear betalain, whereas 100% methanol was optimal for mulberry anthocyanin. A 1:1 cocktail combination of anthocyanin and betalain extracts had an overall maximum efficiency of 0.82%, which was ascribed in part to a widened and enhanced absorption spectrum. [6]
- Carotenoids have the largest concentration (10.666.324 g/ml), followed by chlorophyll-a (2.7080.251 g/ml) and chlorophyll-b (2.5000.102 g/ml). The maximum efficiency of the pigments extracted from Inthanin bok leaves is 1.138% 0.018, using a coating of TiO2 nanoparticles and a temperature of 300 °C. [7]
- The UV/Vis spectra of the dye solutions revealed that DMSO extraction produced the greatest visible peak around 550 nm, whereas all solvents except water produced a near infrared (NIR) peak around 1000 nm. Initially, DMSO-extracted Aloe vera gel dyes had the highest efficiency, but after six days, most efficiencies were comparable within measurement error. Only cells removed with water consistently shown reduced efficiency. [8]
- Experiment and density functional theory investigations on a natural dye extract from Cassia fistula and its application in dye-sensitized solar cells.The electron transport

properties between the dye's lowest unoccupied molecular orbital (LUMO) and the TiO2 conduction band were investigated. Under 100 mW/cm2 illumination, the photoelectric values Voc = 0.549 V, Jsc = 0.51 mA/cm2 and = 0.21% were achieved with DSSC manufactured employing C. fistula sensitized TiO2 photo anode. [9]

CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology of this project involves fabricating and characterizing dye-sensitized solar cells (DSSCs) using natural dyes as sensitizers. The approach is experimental, utilizing empirical modeling and statistical analysis. Controlled experiments will be conducted to examine the performance of DSSCs with different natural dyes, focusing on factors such as efficiency and stability. The fabrication process will involve various steps, the characterization will include absorption spectra (UV-Vis Spectroscopy) and Fourier-transform infrared spectroscopy (FTIR) and the measuring parameters will also include the percentage of dye mixture and viscosity of TiO_2 paste. The research design is presented in Figure 3.1, 3.2 and 3.3, outlining the overall framework of the study. The goal is to contribute to renewable energy research and sustainable photovoltaic systems.

3.2 Project flowchart

The purpose of this project work flowchart is to describe the project work system so that readers can better comprehend the project work and the procedures needed to complete this project.

3.2.1 Natural dye sensitizer design

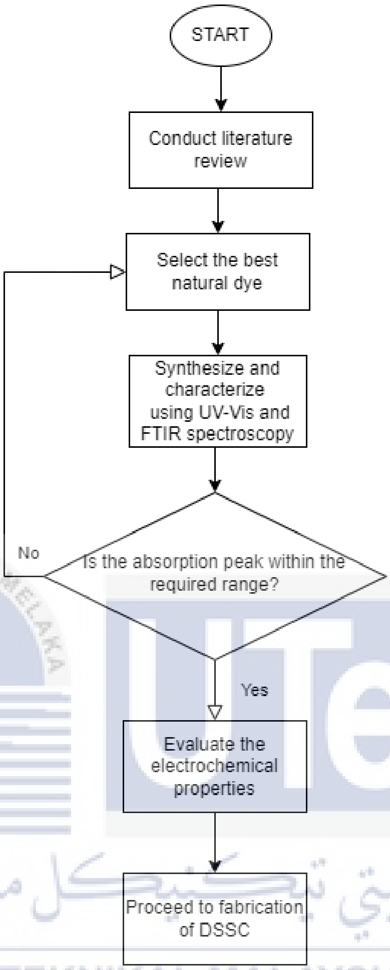


Figure 3.1 Natural dye sensitizer design.

Figure 3.1 appears to depict the process and steps involved in the design of natural dye sensitizers for Dye-Sensitized Solar Cells (DSSCs). The figure outlines a systematic approach, likely part of a research methodology, for developing and optimizing natural dyes to be used as sensitizers in DSSCs. Here's a breakdown of the key steps mentioned:

- Conduct literature review

A literature review was conduct to review natural dye that has a potential as sensitizers for DSSCs.

- Select the best natural dye

Based on the results of the literature review, choose the natural colour or dyes that have the best ability to absorb light and the greatest stability.

- Synthesize and charactrize using UV-Vis and FTIR spectroscopy.

Create the natural dye and analyse them using spectroscopic techniques like UV-Vis and FTIR to determine their absorption range.

- **Evaluate the electrochemical properties.**

Utilise cyclic voltammetry to analyse the electrochemical properties of the natural dyes.

3.2.2 Fabrication and optimization of DSSC

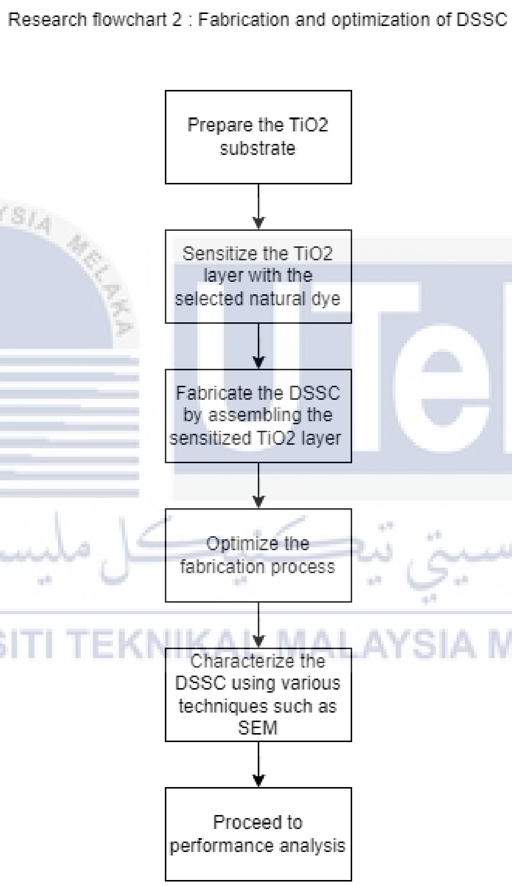


Figure 3.2 The fabrication and optimization of DSSC flowchart.

Figure 3.2 illustrates the step-by-step process involved in the fabrication and optimization of Dye-Sensitized Solar Cells (DSSC). The flowchart outlines key stages in the production of these solar cells, which are known for their potential application in harnessing solar energy. Here's a brief explanation of each step:

- **Prepare the TiO2 substrate.**

Using a conductive glass substrate as a base, create the TiO_2 substrate by thinly filming it.

- **Sensitize the TiO_2 layer with the selected natural dye.**

Sensitize the TiO_2 layer with the chosen natural dye(s) using various TiO_2 paste concentrations and different percentages of the chosen natural dye mixture.

- **Fabricate the DSSC by assembling the sensitized TiO_2 layer.**

Assemble the sensitized TiO_2 layer with a counter electrode, a conductive electrolyte, and a top electrode to fabricate the DSSCs.

- **Optimize the fabrication process.**

Change the parameters of the fabrication process, such as the TiO_2 layer's thickness and the percentage of the chosen natural dye mixture, to achieve the best results.

- **Characterize the DSSC using various techniques such as SEM.**

Analyse the DSSCs using several methods such as SEM.

3.2.3 Performance analysis of DSSC

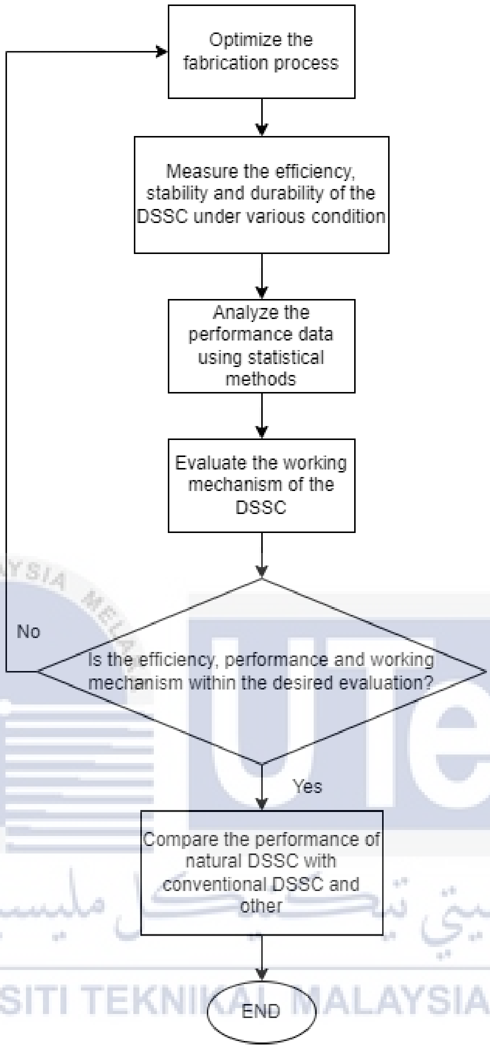


Figure 3.3 The performance analysis of DSSC flowchart.

Figure 3.3 presents a flowchart depicting the performance analysis of Dye-Sensitized Solar Cells (DSSCs). The flowchart outlines a systematic approach to evaluate the efficiency, stability, and durability of DSSCs, considering various environmental conditions such as temperature and light intensities. The key steps in the analysis process are:

- **Measure the efficiency, stability and durability of the DSSC.**

Measure the DSSCs' effectiveness, stability, and durability under a variety of circumstances, including varied temperatures and light intensities.

- **Analyze the performance data.**

Utilise statistical techniques such as ANOVA and regression analysis to analyse the performance data.

- **Evaluate the working mechanism of the DSSC.**

Determine the elements that influence the DSSCs' performance by evaluating the DSSCs' operational design.

- **Compare the performance of natural DSSC with conventional DSSC and other.**

Examine how the natural dye-sensitized DSSCs perform in comparison to more traditional DSSCs and other solar cell types.

3.3 Project block diagram

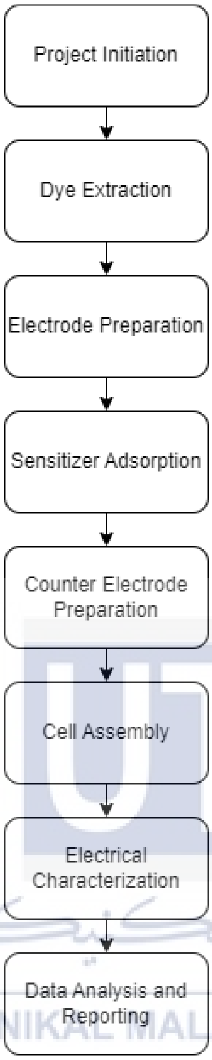


Figure 3.4 Project block diagram.

Figure 3.4 presents a project block diagram outlining the various stages involved in a solar cell fabrication project, particularly focusing on dye-sensitized solar cells (DSSCs). Here's a brief explanation of each step in the diagram:

- **Project Initiation**

Specify the goals and parameters of the project. Assemble the instruments and resources needed.

- **Dye Extraction**

Gather natural dyes from frangipani, turmeric, beetroot, and green spinach. Ethanol solvents are used to extract the dye from the sources. Use filter paper to purify the dye extract by filtering it.

- **Electrode Preparation**

Fluorine-doped tin oxide, or FTO, should be prepared as a transparent conducting substrate. After that, cover the FTO substrate with a thin coating of titanium dioxide, TiO2. TiO2 layer should be heated to improve crystallinity and adherence.

- **Sensitizer Adsorption**

Soak the TiO2-coated substrate for 24 hours to allow the dye molecules in the chosen natural dye solution to adsorb onto the TiO2 surface. The sensitized substrate is then thoroughly cleaned with deionized (DI) water and dried.

- **Counter Electrode Preparation**

Create a counter electrode by covering the conductive glass substrate with a graphite catalyst layer.

- **Cell Assembly**

Putting the graphite-coated counter electrode and the sensitised TiO2 electrode together, sealing the joint to stop leaks, and drilling a small hole for the electrolyte injection. Then, the electrolyte solution is poured into the DSSC, filling the gap between the electrodes with iodide, iodine, and a redox couple.

- **Electrical Characterization**

Check the solar cell's current-voltage (I-V) properties after it has been constructed. Additionally, evaluate important variables including open-circuit voltage (Voc), short-circuit current (Isc), fill factor (FF), and efficiency.

- **Data Analysis and Reporting**

Review the data and compare them to existing benchmarks or other sensitizers. Additionally, make a summary of the results, draw some conclusions, and note any areas that still need work. Prepare a thorough report that includes the fabrication procedure, the findings of the characterisation, and its conclusions.

3.4 Experimental setup

The experimental setup includes the extraction, purification, and characterization of natural dyes derived from plant sources. The construction of DSSCs will resemble a sandwich, and several electrical characterization methods will be used to assess their performance. The DSSCs' stability and long-term performance will also be looked at. The study intends to evaluate the potential of using natural dyes as efficient and sustainable sensitizers in solar cell technology.

3.4.1 Natural dye solution preparation.

In this study, green dye and two red dyes were extracted from Green Spinach and Plumeria Rubra as shown in Figure 3.5 and Figure 3.7 respectively. The components were first cleaned in distilled water to get rid of any contaminants before being allowed to dry for two hours to get rid of moisture. In addition, the dried Green Spinach and Plumeria Rubra were finely ground into green and red pastes as shown in Figure 3.6 and Figure 3.8 and then soaked in ethanol solvent. The mixture of pasted materials and ethanol was 1 g: 10 ml. The extract was filtered and used as a raw sensitizer source.

Figure 3.5 Green Spinach (Spinacia oleracea)

Figure 3.6 The dried spinach were crush into fine green paste.

Figure 3.7 Plumeria Rubra (Frangipani).

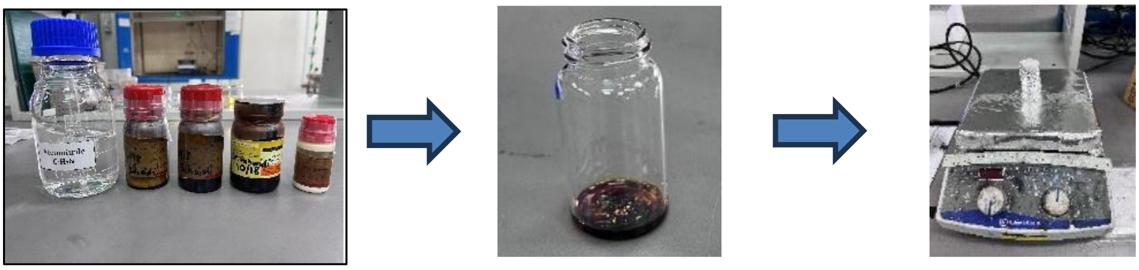
Figure 3.8 The dried petals were crushed into a fine red paste.

3.4.2 Synthetic dye (N719) solution preparation.

N719 dye was made by dissolving 10 mg of N719 in 25 ml of ethanol and stirring the solution for 2 hours at 150 rpm. To avoid contact with light, the dye was prepared in a conical flask covered with aluminium foil.

3.4.3 Preparation of electrolyte solution

The electrolyte was composed of 1.4 g of ethyl-methyl-imidazolium iodine (MPII) and 0.6 g of 4-tert-butylpyridine (TBP), 0.13 g of lithium iodide (LiI), and 0.13 g of iodine inside the vial. Finally, add 10 ml of acetonitrile and thoroughly mix everything using a hot plate. 15 minutes of mixing is sufficient to ensure that the solution is well-combined. The electrolyte is significant in DSSC because it helps the inner charge carriers move between electrodes and keep the dye alive during the DSSC process. The entire process was illustrated in Figure 3.9. The electrolyte solution was then placed in a dark container and the container was tightly shut to keep out direct sunlight. It is crucial to protect the solution from sunshine because it can cause deterioration or unwanted effects.



1.4 g of ethyl methylimidazolium iodine, 0.6 g of 4-tertbutylpyridine, 0.13 g of lithium iodide, 0.13 g of iodine and 10 ml of acetonitrile.

The solution after all the chemical mixed.

The solution stirred on the hot plate for 15 minutes.

Figure 3.9 Preparation of electrolyte solution.

3.4.4 Preparation of platinum solution for counter electrode

The electrolyte solution was prepared by dissolving 10.36 mg Hexachloroplatinic acid hexahydrate in 10 ml Isopropyl Alcohol (IPA). The solution was mixed on hotplate on room temperature for 1 hour. This process is illustrated in Figure 3.10.

10.36 mg of Hexachloroplatinic acid hexahydrate powder.

10 ml of Isopropyl Alcohol (IPA).

The Pt solution was produced after 1 hour of mixing on a hotplate.

Figure 3.10 Preparation of platinum solution.

3.4.5 Cleaning process for glass, Indium Tin Oxide (ITO) and Fluorine Doped Tin Oxide (FTO).

With a thickness of 1850, ITO exhibits strong transmittance and excellent conductivity. Furthermore, the dimensions of ITO glass were 50 mm x 50 mm, with a glass thickness of 1.1 mm and a sheet resistance of 10-15/square. FTO also offers strong transmittance and conductivity qualities. However, the FTO glass arrived from the factory with dimensions of 200 mm x 150 mm and 2.2 mm glass thickness with 6-8 /square of sheet resistance. To begin, the microscope glass substrate and ITO were cut into 1.5 cm × 2 cm rectangles. The substrates were then cleaned with tap water and liquid detergent for 10 minutes using an ultrasonic cleaning machine at 60 degrees Celsius before being sonicated in deionized water (DI) for 10 minutes using a sonicator, as illustrated in Figure 3.11. The substrates were then sonicated for 10 minutes in isopropyl alcohol (IPA). This procedure was also done for the substrate in acetone to remove the organic residuals. Following that, the substrates were cleaned with deionized water (DI) and then dried in an oven at 100°C until the water marks were eliminated.

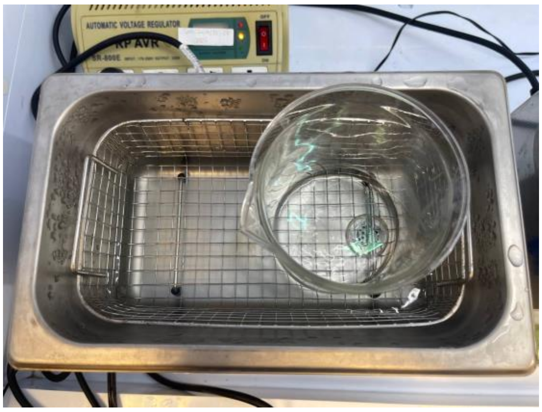


Figure 3.11 Sonication process to clean the glass substrate beakers.

3.4.6 Preparation of photoanode layer

Before beginning the process, blow the grid board. Place the glass on the grid board, ensuring that the ITO layer is on top. Follow the specified positioning shown in the figure, leaving a 1cm x 1cm square area for paste application. Next, position the Kapton film precisely as indicated, covering only the designated 1cm x 1cm area as shown in Figure 3.12. Apply the TiO_2 paste onto the larger glass surface, holding the slide at a 45-degree angle and spreading the paste to the glass's end while ensuring no bubbles as shown in Figure 3.12. It is crucial to confirm the even spread of the paste throughout the 1cm x 1cm square area for optimal results. It is recommended to perform a single attempt during the spreading process. Carefully remove the Kapton tape without touching or damaging the paste area. Finally, bake the photoanode layer thin film using a furnace for 30 minutes at 450 degree celsius.

Kapton film covering 1 cm x 1cm area.

The slide holded at 45 degree angle to spread the paste through the 1 cm x 1 cm area.

The photoanode layer thin film is prepared to be baked in the furnace.

Figure 3.12 Preparation of photoanode layer

3.4.7 Preparation of dye on photoanode layer

To make co-sensitized dye solutions, combine Frangipani and Green spinach in a 50:50 ratio, Green spinach with synthetic dye (N719), and Frangipani with synthetic dye (N719). Submerge the photoanode layer in the dye solutions for adsorption, and wait overnight until a relatively uniform colour is noticed on both the back and front sides of the FTO glass, indicating that dye adsorption has been completed. After that, take the photoanode out of the dye bath solution and rinse it with deionized water. Allow the photoanode layer to dry, either on its own or in a 100° Celsius oven for 10 minutes. The photoanode is now co-sensitized and ready for usage in the chosen application. Figure 3.13 depicts the procedure.

Prepare the dye solution in a container.

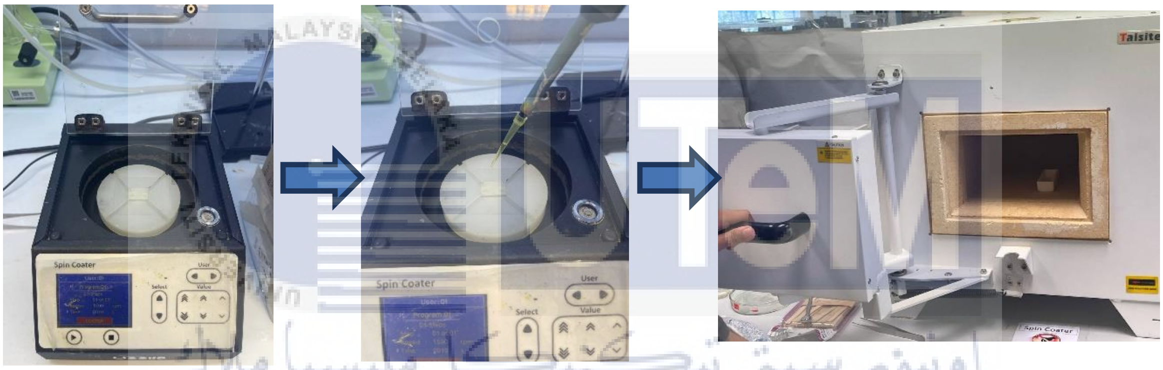
Place the photoanode layer in the dye solution for dye adsorption.

The photoanode layer after drying.

Figure 3.13 Preparation of dye on photoanode layer

3.4.8 Preparation of counter electrode layer

First, place the glass on the spin coater, making sure the FTO layer is facing up; check this orientation with a continuity test. After that, dispense 50uL of the solution into the glass before quickly sealing the lid and spinning at 1500 rpm for 10 seconds. Transfer the glass to a furnace and bake the counter electrode for 30 minutes at 450 degrees Celsius. This thorough technique enables proper alignment and deposition of the FTO layer on the glass substrate, followed by the required spinning and thermal treatment for counter electrode fabrication. Figure 3.14 depicts this entire procedure.



Position the glass in the spin coater. Ensure that the FTO layer is on top.

Pour 50uL of the solution into a glass. Close the lid and spin the machine for 10 seconds at 1500 rpm.

Baking the counter electrode glass in the furnace for 30 minutes at 450 degrees Celsius.

Figure 3.14 Preparation of counter electrode layer.

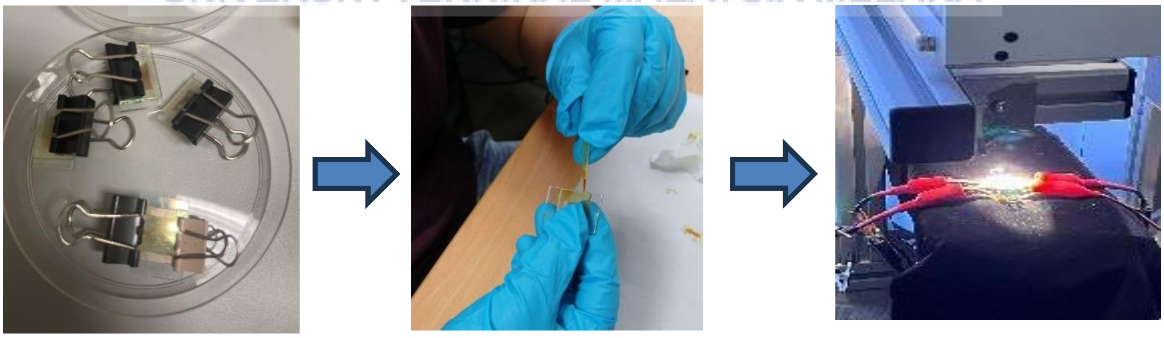
3.4.9 DSSC fabrication

A DSSC structure is made up of a working electrode and a counter electrode sandwiched between two electrolytes. Green Spinach co-sensitized with Frangipani, Green Spinach co-sensitized with Synthetic dye (N719), and Frangipani co-sensitized with Synthetic dye (N719) are the three types of working electrodes, while Pt is coated with ITO glass substrate. As illustrated in Figure 3.15, the fabrication was achieved by combining the working electrode and the counter electrode in a sandwich form. Binder clips hold the two electrodes together while they are in use. As a consequence, the manufacturing and assembly method for a typical DSSC was completed and ready for testing on a solar simulator (Keithley 2450) with simulated AM 1.5G light at 100mW/cm2.

$$\eta = \frac{VocJscFF}{Pin} \times 100 \tag{3.1}$$

$$FF = \frac{Vmax \times Jmax}{Voc \times Isc} \tag{3.2}$$

where FF, Joc, Pin, and Voc represent the fill factor, short circuit current density, incoming light energy (100 mW cm2), and open circuit voltage.



A standard DSSC with a complete sandwich design.

Add electrolyte to the spaces inside the device.

The device is now ready for testing.

Figure 3.15 Complete fabrication of DSSC.

3.5 Material Characterization

This section describes in detail the analytical characterisation approaches used in assessing the three separate co-sensitized of green spinach with frangipani, green spinach with synthetic dye (N719), and frangipani with synthetic dye (N719). First, Ultraviolet-Visible Spectroscopy (UV-Vis) provides information on absorption spectra in the ultraviolet-visible range.Based on light absorption properties, this technology detects chemical alterations and colour differences in materials. The Keithley 2450 solar simulator is next shown, which is an important instrument for analysing the current-voltage properties of Dye-Sensitized Solar Cells (DSSCs). The combination of UV-Vis spectroscopy and solar simulator experimentation, combined with real-time monitoring of parameters such as open-circuit voltage (Voc), short-circuit current density (Isc), fill factor (FF), and power conversion efficiency (PCE), provides a comprehensive approach to understanding both the optical and electrical properties of materials, advancing research in a variety of scientific domains.

3.5.1 Ultraviolet-Visible Spectroscopy (UV-Vis)

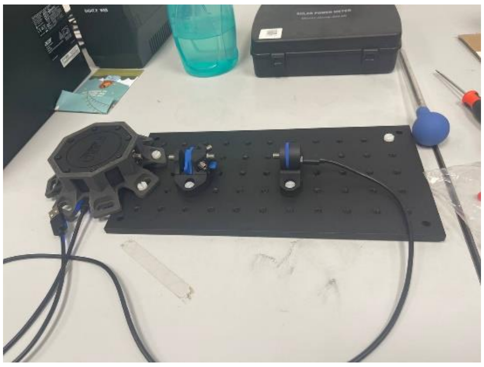


Figure 3.16 G2001A1 Ossila Optical Spectrometer.

Figure 3.16 shows the G2001A1 Ossila Optical Spectrometer used for UV-Vis analysis. UV spectroscopy is an optical spectroscopy that uses light in the visible (VIS), ultraviolet, and near-infrared ranges. UV-Vis spectroscopy (UV- Vis spectroscopy) is the study of absorption spectra in the ultraviolet-visible spectral range. Different substances will appear to be a different colour depending on where light is absorbed in the visible spectrum. Furthermore, molecular changes take place in this area. UV-Vis spectroscopy, unlike fluorescence spectroscopy, measures transitions from excited to ground states.

3.5.2 Solar Simulator

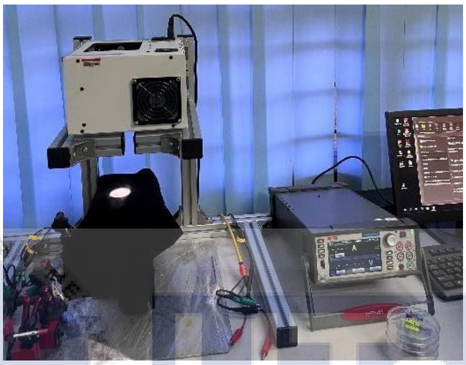


Figure 3.17 Keithley 2450.

To investigate the I-V characteristics of DSSCs, a Ossila solar simulator was used in combination with a computer-controlled source-meter (Keithley 2450). All four parameters are analysed and shown on the computer screen in real time: open-circuit voltage (VOC), short-circuit current density (JSC), fill factor (FF), and power conversion efficiency (PCE).

3.6 Parameters

This study focuses on examining the effects of various percentage ratios of green spinach, frangipani and synthetic dye (N719) mixture on the electrical performances of 8. To simulate and determine the number of samples that would be required if the dye percentage ratio of the two natural dyes that we chose varied, we used Design Expert (response surface method). The thickness of TiO_2 varies at 55000 and 110000 of TiO_2 paste. The percentage ratio indicates how much frangipani, green spinach and synthetic dye (N719) are present in the mixture. The glass substrate of ITO were used to compared the current and voltage for the different of the dye percentage ratio and the thickness of TiO2. The highest PCE of the mixture then will be tested on FTO glass subsrate to compared the results between the glass substrate. We want to identify the relationship between these variables and the electrical behavior of the samples by systematically adjusting the percentage ratio of the green spinach, frangipani and synthetic dye (N719) mixture, the the thickness of TiO2, and different type of glass substrate. With the help of this study, we hope to learn more about the ideal circumstances that can improve the electrical performance of materials dyed with natural substances.

Table 3.1 The optimization method based on Design Expert software.

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Run	A:Green spinach dye	B:Frangipani dye	C : Synthetic dye (N719)	D:TiO2 thickness layer	E:Glass subsrate
	ml	ml	ml	nm	
1	20	20	0	55000	ITO
2	20	20	0	110000	ITO
3	20	0	20	55000	ITO
4	20	0	20	110000	ITO
5	0	20	20	55000	ITO
6	0	20	20	110000	ITO
7	0	20	20	55000	FTO
8	0	20	20	110000	FTO

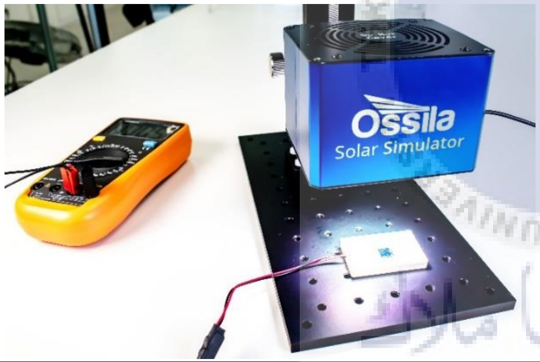
3.7 Equipment & materials

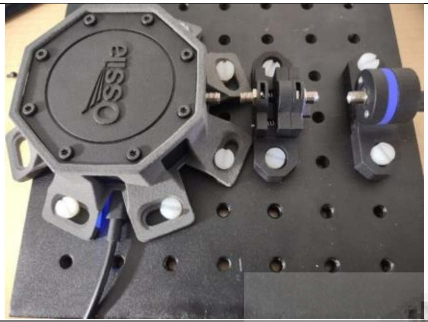
To properly construct and characterize DSSCs for this project, as well as to ensure precise analysis and optimization of the solar cell performance, a variety of specialized equipment is needed. These tools are essential for precisely fabricating and characterizing DSSCs, which enables accurate analysis and optimization of solar cell performance each of the equipment, explanation and the purpose of it is shown in Table 3.2.

Table 3.2 Equipment and materials table.

Equipment	Explanation	Purpose for this project
Glass Substrates FTO 	A transparent conductive metal oxide that can be utilized to create clear electrodes for thin-film photovoltaic systems, including organic photovoltaic systems.	The glass substrate offers structural stability and transparency, enabling light to reach the solar cell's active components. The glass substrate's FTO coating serves as the photoconversion process's working electrode by promoting effective electron travel and collection. The project can make reliable, long-lasting DSSCs that efficiently utilise natural dyes to convert solar energy into electrical energy thanks to the utilization of FTO-coated glass.

Annealing Oven 	Parts made of plastic or metal are heated in an annealing oven chamber to just below their transition temperature for the specified amount of time in order to prevent tensions and cracking during the machining process.	Enabling stability and degradation investigations, aiding dye adsorption onto the semiconductor film, encouraging dye diffusion inside the film, and optimizing the film's characteristics by thermal processing.
Parafilm 	An easily removed adhesive tape that is occasionally used for binding, sealing, or mending as well as temporarily defining margins, shielding surfaces	Used for enclosing the electrolyte solution, masking electrodes, forming patterns and boundaries during dye application, aligning and securing cell components, and sealing edges to stop light leakage.
Platinum as Counter Electrode 	An electrode utilized in a three-electrode electrochemical cell for voltametric analysis or other reactions where an expected flow of electricity is present.	Its major function is to complete the electrical circuit by transporting electrons from the external circuit to the dye-sensitized electrode. Because of its exceptional conductivity and stability, graphite is preferred. It provides effective electron transport and makes it easier to reduce oxidized dye molecules, enabling the regeneration of dye sensitizers for ongoing light absorption.

Multimeter 	A device that measures various electrical characteristics.	In addition to electrical characterization, it also does efficiency calculations, troubleshooting, quality control, and optimization. The multimeter assists in evaluating the effectiveness, performance, and quality of the DSSCs by measuring variables including voltage, current, resistance, and continuity. It assists in identifying electrical issues, comparing various dye sensitizers, and improving the efficiency of the solar cell.
Solar Simulator 	A light source that mimics sunlight and is employed in research to assess the activation or catalysis of processes by visible (or near-visible) light.	By offering a regulated light source that mimics sunlight conditions, it aids in measuring the effectiveness of the DSSCs. The simulator helps researchers improve the functionality of the gadget by enabling them to change variables like temperature, light intensity, and spectrum.
Ultraviolet-visible (UV-Vis) spectrophotometers	Utilize a light source that emits light on a sample that spans the UV to visible spectrum (usually 190 to 900 nm). The instruments then measure how much light at each wavelength is absorbed, transmitted, or reflected by the sample.	Aids in figuring out the dye's absorption spectrum and band gap energy, enable to improve dye selection and DSSC effectiveness. Also measures the amount of dye loaded onto the semiconductor electrode and evaluates the dye's stability under various circumstances.

		
Natural dye extract 	A dye is a colored material that forms a chemical bond with the surface it is applied to. This separates dyes from pigments, which do not chemically bond to the substrate they colour.	Concentrated dye solutions are made by extracting natural dyes from mixture of green spinach and frangipani and dissolving them in ethanol. These solutions are used to coat the titanium dioxide (TiO2) layer on the DSSC photoanode, enabling the dye molecules to adsorb and form a layer that absorbs light.
Titanium Dioxide (TiO2) Paste 	TiO2 is the chemical formula for titanium dioxide, sometimes referred to as titanium (IV) oxide or TiO2.	The paste's TiO2 nanoparticles offer a significant surface area for dye adsorption and effective light absorption. A binder component and a solvent are also included in the paste to help in adhesion and application. After coating, the paste is sintered to get rid of the solvent and binder, leaving a porous TiO2 layer behind. The natural dye is subsequently deposited onto the TiO2 surface, absorbing light energy and starting electron transport within the DSSC.

Electrolyte 	A material that separates into ions when dissolved in water or bodily fluids (particles with electrical charges).	To allow the flow of charge inside the solar cells. The potassium iodide, iodine, and ethylene glycol electrolyte solution functions as a redox pair. It makes it easier for electrons to get from the dye to the semiconductor in the solar cells. When a dye absorbs sunlight, it converts the energy into electrons that are then transferred into a semiconductor. An electric potential is produced when the electrolyte's iodine accepts the dye's electrons and causes a charge separation. Electricity is created as a result of this potential driving the flow of electrons across the external circuit.
Solvents (Ethanol) 	An essential industrial chemical, ethanol is employed in the synthesis of other organic compounds as a solvent.	It has a variety of uses, including the extraction of dye molecules from natural sources and the subsequent purification of the extracted dye solution. Additionally, ethanol is used as a solvent to create the sensitising dye solution and the electrolyte solution necessary for the DSSCs to operate at their best. The DSSC components are also cleaned and treated on the surface with ethanol to create a clean surface for effective dye adsorption and electron transfer.

3.8 Summary

This chapter describes a thorough and systematic technique to fabricating and characterising dye-sensitized solar cells (DSSCs) that use natural dyes as sensitizers. Using an experimental design with empirical modelling and statistical analysis, the project includes essential phases such as literature evaluation, natural dye selection, synthesis, and characterisation, followed by the construction, optimisation, and analysis of DSSCs. Three thorough flowcharts depict the procedures involved in natural dye sensitizer design, DSSC manufacture and optimisation, and DSSC performance evaluation. Furthermore, the chapter includes detailed processes for preparing natural and synthetic dye solutions, electrolyte solutions, platinum solutions for counter electrodes, and glass substrate cleaning. The material characterization section describes analytical approaches for testing DSSC characteristics, including as Ultraviolet-Visible Spectroscopy (UV-Vis) and a solar simulator. The inclusion of an optimisation factors table as well as a list of necessary equipment and supplies ensures a thorough grasp of the project's technique in furthering renewable energy research through sustainable photovoltaic systems.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter examines the fabrication and characterisation of dye-sensitized solar cells (DSSCs) using natural dyes as sensitizers. The absorption properties of Green Spinach, Curcumin, and Beetroot dyes were examined using UV-Vis spectroscopy to determine their potential for solar cell applications. The data revealed different absorption peaks for each natural dye, highlighting the unique light absorption capacity of various materials. The findings support the potential of natural dyes as effective sensitizers for DSSCs, offering a sustainable strategy to increase solar cell efficiency. Various combinations of natural dyes were investigated, including frangipani co-sensitized with spinach, spinach co-sensitized with synthetic dye N719, frangipani co-sensitized with synthetic dye N719 using FTO glass, and frangipani co-sensitized with synthetic dye N719 using FTO glass. The analysis examined the effect of different co-sensitizers, changes in TiO2 paste thickness, and various glass substrate types on DSSC performance. The findings provide an in-depth understanding of the combinations between natural dyes, co-sensitizers, and fabrication parameters, allowing for improved DSSC performance through informed optimization tactics.

4.2 Preliminary Result.

4.2.1 Ultraviolet-visible spectroscopy (UV-Vis) of various natural dye

4.2.1.1 Green Spinach

To verify the produced dyes' capacity to absorb visible light, UV-Vis spectroscopy was used. The investigation was carried out using the UV-2450 instrument, which has a wavelength range of 200 to 800 nm. A spectrum that results, called an absorption spectrum, reveals how much light was absorbed by the sample at each wavelength. Chlorophylls are a group of diverse organic substances found in green spinach dye the wavelength for green spinach is shown in Figure 4.1.

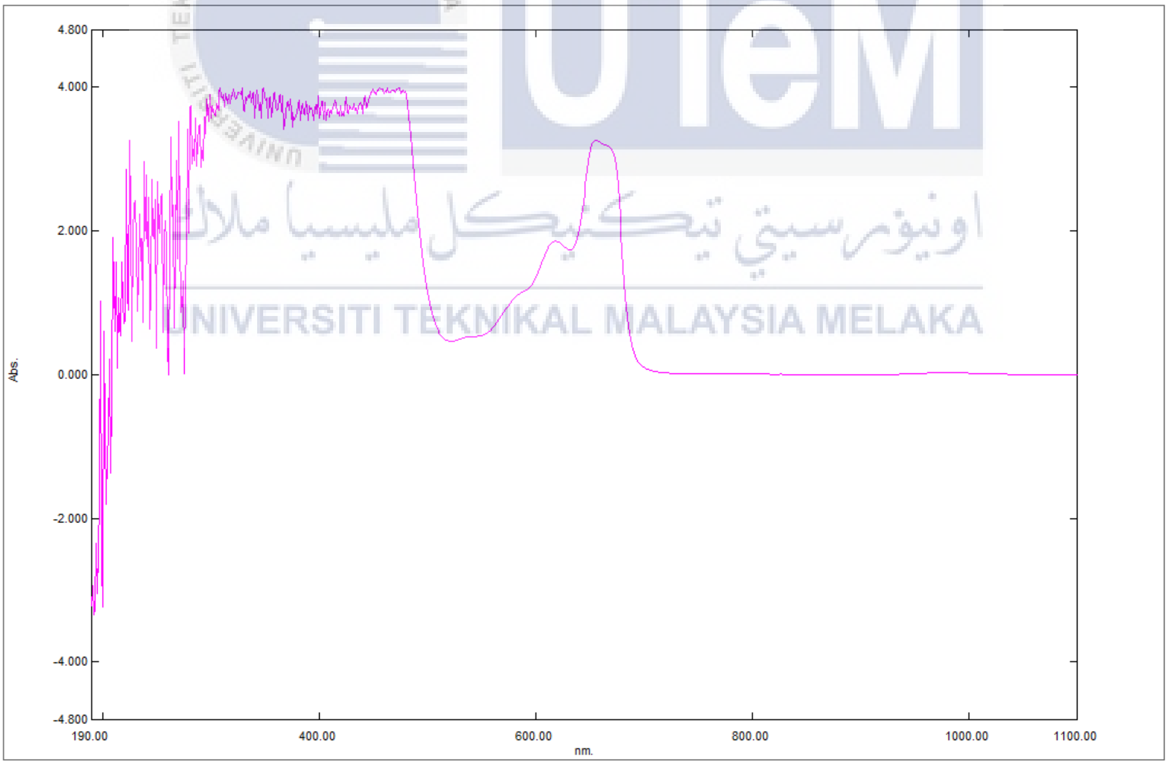


Figure 4.1 Green spinach asorption wavelength.

4.2.1.2 Turmeric

Using UV-Vis spectroscopy, the dyes' ability to absorb visible light was confirmed. The UV-2450 instrument, which has a wavelength range of 200 to 800 nm, was used for the experiment. An absorption spectrum, which is what emerges, shows how much light was absorbed by the sample at each wavelength as shown in Figure 4.2. Turmeric colour contains a variety of chemical compounds referred to as curcumin.

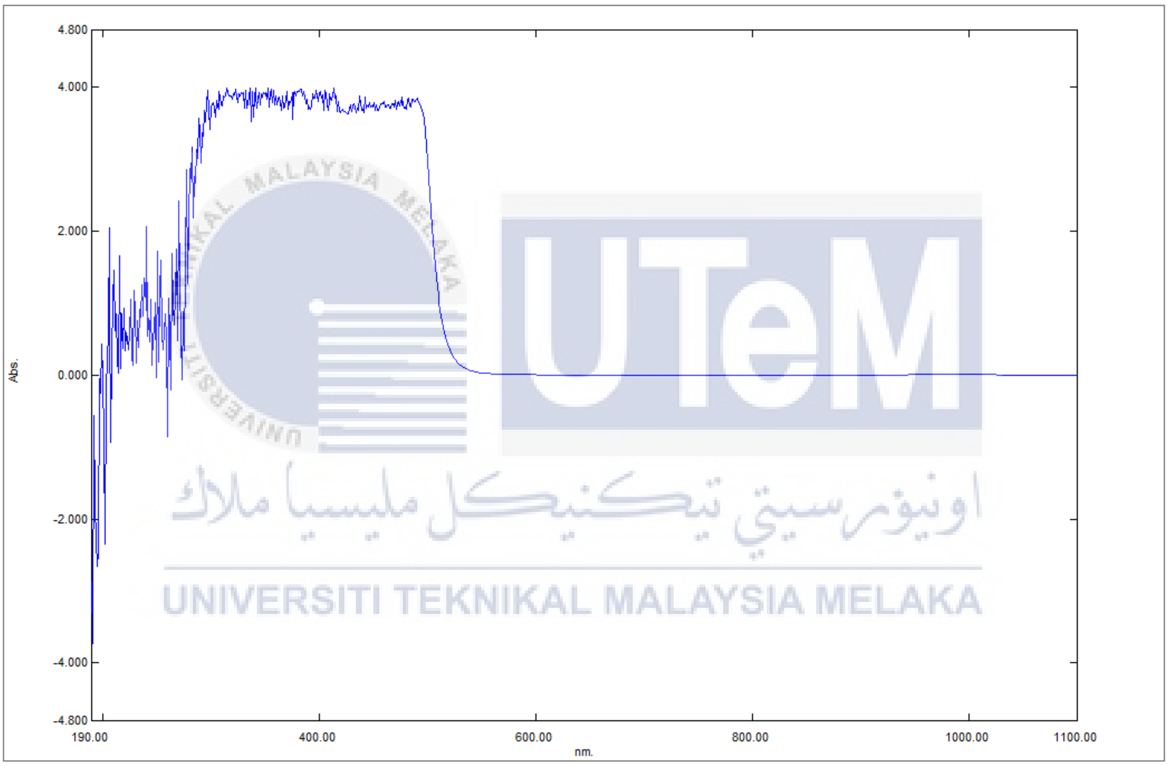


Figure 4.2 Turmeric absorption wavelength.

4.2.1.3 Beetroot

The dyes' capacity to absorb visible light was verified using UV-Vis spectroscopy. What appears is an absorption spectrum, which reveals the amount of light that was absorbed by the sample at each wavelength as shown in Figure 4.3.Betacyanins are a class of chemical molecules that give beetroot its distinctive coloration.

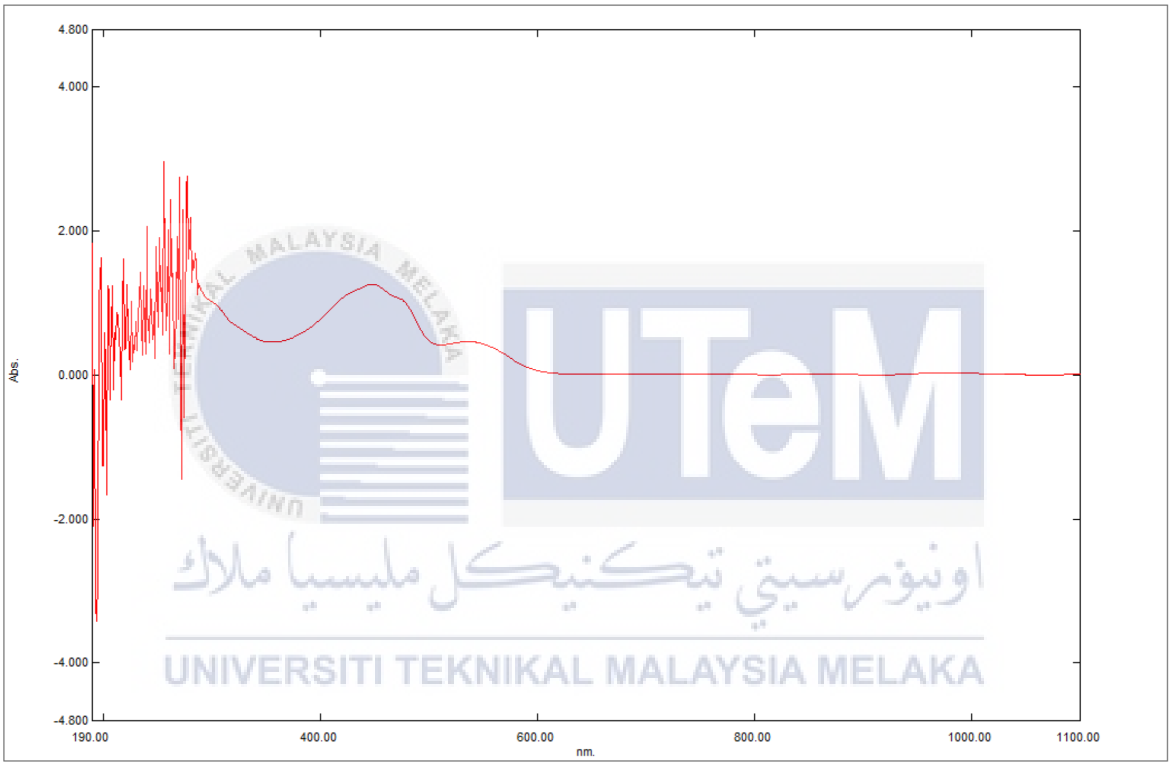


Figure 4.3 Beetroot absorption wavelength.

4.2.1.4 Frangipani

Using UV-Vis spectroscopy, the dyes' ability to absorb visible light was confirmed. An absorption spectrum, which displays the amount of light absorbed by the sample at each wavelength, is what is seen. The class of chemical compounds known as chromophores is responsible for the characteristic colour of frangipani as shown in Figure 4.4.

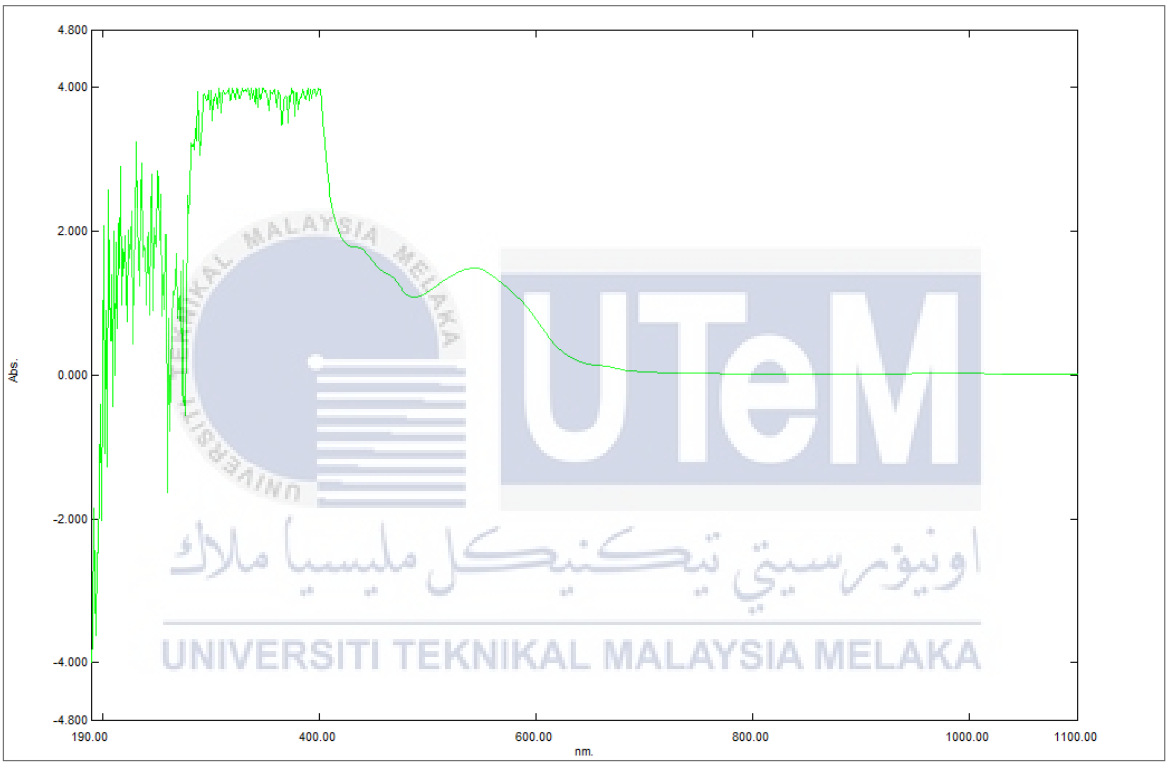


Figure 4.4 Frangipani absorption wavelength.

4.2.1.5 Overall evaluation

To verify their capacity to absorb visible light, the produced dyes were put via UV-Vis spectroscopy. Based on the absorption wavelength, we choose which of these four dyes will be used for the combination of two natural dyes to sensitize using UV-Vis spectroscopy. Various chemical substances collectively referred to as chlorophylls, curcumin or curcuminoid, betacyanins and chromophores respectively are found in the dyes Spinacia oleracea, Curcuma longa, Chukandar and Plumeria Rubra. The dye's vivid colour and absorption characteristics are due to these chlorophylls, curcumin or curcuminoid, betacyanins and chromophores.

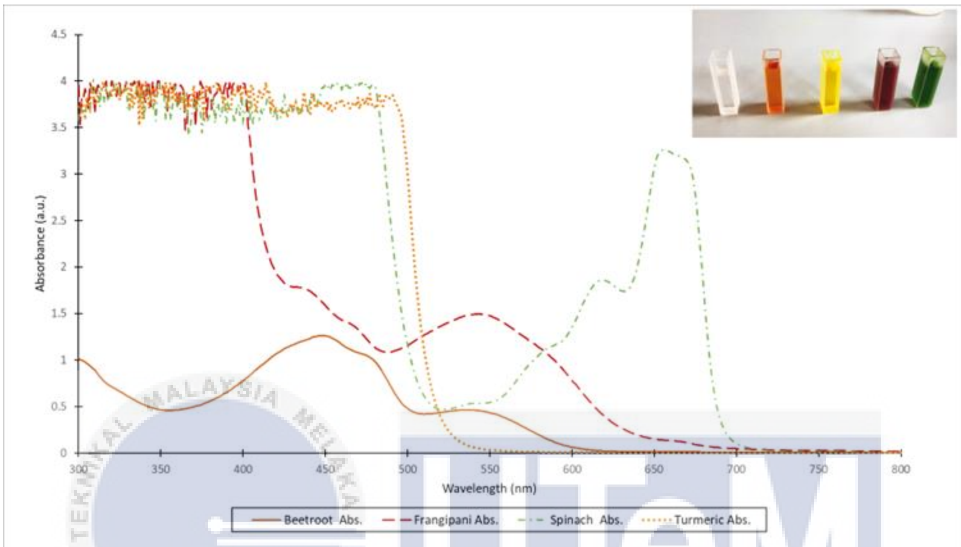


Figure 4.5 Absorption wavelength of beetroot, frangipani, spinach and turmeric.

Because the two dyes had different levels of absorption capacity, spinach and frangipani were chosen based on the UV-Vis spectroscopy results in Figure 4.5. The combination of these two dyes will absorb light over a wider spectrum than the others.

4.3 Results and Discussion.

4.3.1 Results and Analysis

4.3.1.1 Effect on different thicknesses of TiO2 on the performance of the various type of co-sensitizer on the power conversion efficiency (PCE).

Table 4.1 shows the influence of varying TiO2 thicknesses on the performance of several types of co-sensitizers on the PCE. The thickness was varied between 55000 and

110000 nm to see how it affected the DSSC's Voc, Jsc, FF, and PCE. As can be seen in this Table 4.1, N719 co-sensitized with plumeria rubra using FTO (110000 nm thickness of TiO2) has the highest PCE with 0.032352%, followed by N719 co-sensitized with plumeria rubra (110000 nm thickness of TiO2) with 0.011096%, frangipani co-sensitized with green spinach (110000 nm thickness of TiO2) with 0.004451%, N719 co-sensitized with frangipani using FTO with 0.002781, N719 co-sensitized with green spinach (110000 nm thickness of TiO2) with 0.002173%, N719 co-sensitized with frangipani (55000 nm thickness of TiO2) with 0.00154%, N719 co-sensitized with green spinach (55000 nm thickness of TiO2) with 0.000178% and lastly, frangipani co-sensitized with green spinach (55000 nm thickness of TiO2) with 0.0000139%. Figure 4.6 depicts the PCE of N719 co-sensitized with frangipani, frangipani co-sensitized with green spinach, and N719 co-sensitized with green spinach, with the highest PCE for the three occurring at the same thickness of 110000nm and decreasing at 55000nm.

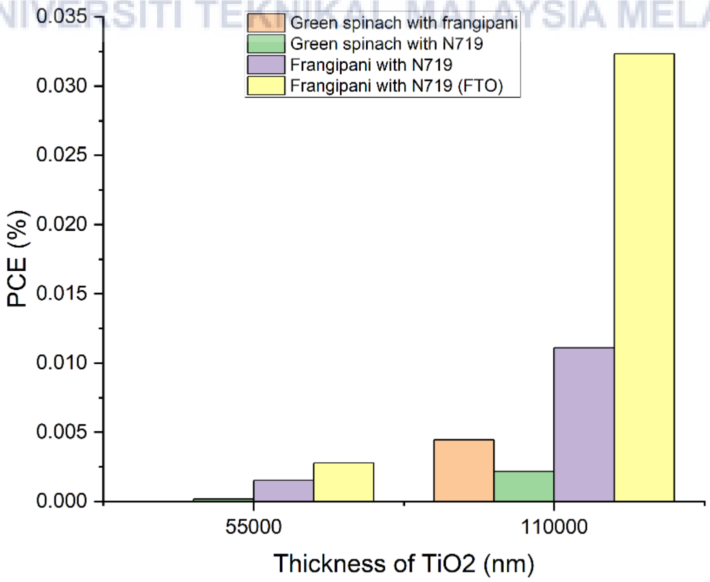


Figure 4.6 Effect on different thicknesses of TiO2 on the performance of the various type of co-sensitizer on the power conversion efficiency (PCE) .

Table 4.1 Effect on different thicknesses of TiO2 on the performance of the various type of co-sensitizer on the power conversion efficiency (PCE).

Type of co-sensitizer	Thickness of TiO2 (nm)	PCE (%)
frangipani co-sensitized with green spinach	55000	0.000014
	110000	0.004451
N719 co-sensitized with green spinach	55000	0.000178
	110000	0.002173
N719 co-sensitized with frangipani	55000	0.00154
	110000	0.011096
N719 co-sensitized with frangipani (FTO)	55000	0.002781
	110000	0.032352

Now, we calculated the Voc, Jsc, and fill factor values based on the co-sensitizer data with the greatest PCE. The relevance of Voc, Jsc, fill factor, and PCE influence on the two distinct thicknesses is shown in Table 4.2. According to Table 4.2, all configurations exhibited very low open circuit voltages (Voc) of not greater than 0.4 V. Table 4.2 reveals that the N719 with frangipani using FTO as glass substrate has the greatest PCE of 0.032352% at 110000nm which is higher than the efficiency of the previous research for natural frangipani dye [28]. The lowest PCE, on the other hand, is frangipani with green spinach with 0.0000139% at 55000nm.

Table 4.2 The values of Voc, Jsc, PCE, and FF for the different thickness of TiO2 various types of co-sensitizer.

Type of co-sensitizer	Thickness of TiO2 (nm)	Jsc (A/m^2)	Voc (V)	FF(%)	PCE (%)
Spinach with frangipani	55000	0.000519	0.2	0.133752	0.000014
	110000	0.002236	0.1	19.90415	0.004451
Spinach with synthetic dye (N719)	55000	0.00028	0.2	3.187251	0.000178
	110000	0.027002	0.1	0.804802	0.002173
	55000	0.025101	0.1	0.613337	0.00154

Frangipani with synthetic dye (N719)	110000	0.14412	0.1	0.76987	0.011096
Frangipani with synthetic dye (N719) using FTO as glass substrate	55000	0.03023	0.2	0.46001	0.002781
	110000	0.10501	0.4	0.77022	0.032352

In conclusion, based on the results in table 4.1 and figure 4.6, the PCE for 2 layers of TiO2 with a thickness of 110000 nm was considerably more than the PCE for 1 layer of TiO2 with a thickness of 55000. However, based on my observations during this laboratory analysis, the surface of a single layer of TiO2 photoanode layer was much more uniform after being baked for 30 minutes at 450 degrees Celsius, whereas the surface layer of a double layer of TiO2 photoanode layer was not uniformly dry after being baked for the same parameter in an annealing oven. As a result, when the two layers of TiO2 photoanode layer were soaked in the co-sensitized dye solution and dried, the surface of the ITO or FTO glass was substantially peeled off. This can be avoided if the baking time is extended or the temperature is significantly greater than the specifications that have been specified. And perhaps if the two layers of TiO2 photoanode layer were more equally dried, the PCE would be significantly greater than the data gathered.

4.3.1.2 UV-Visible analysis of the three different co-sensitized dye for 1 layer of TiO2 photoanode.

The UV-Vis absorption spectra shown in figure 4.7 demonstrate the absorbance patterns of three different co-sensitized dye attached to a single layer of TiO2. The x-axis shows light wavelength in nanometers, while the y-axis represents absorbance in arbitrary units (a.u.). Each peak in the spectrum corresponds to an electronic transition within the dye molecule, and the height of the peak represents the intensity of the transition.

Looking at the four spectra, the first comprises frangipani and spinach (1 layer of TiO2) and has a strong peak at 392 nm as well as a lesser peak at 416. The second spectrum, spinach & synthetic (1 layer of TiO2), shows a visible peak at 391 nm and a smaller peak at 404 nm. The third spectrum, frangipani & synthetic (1 layer of TiO2), contains a strong peak at 391 nm that is a combination of pigments in the frangipani flower and synthetic dye, as well as a lesser peak at 417 nm. The fourth spectrum, frangipani & synthetic (FTO 1 layer of TiO2), includes a big peak at 393 nm and a smaller peak at 409 nm, which are caused by pigments found in frangipani flowers and synthetic dye, respectively. After 423 nm, all four spectra steadily decreased.

These spectral variances are due to changes in the chemical structures of the dyes. Notably, as compared to natural dyes, the synthetic dye has a shorter absorption spectrum, implying higher selectivity in the wavelengths it can absorb. This property might be beneficial in solar cell applications, perhaps leading to improved efficiency.

Next, , the optical band gap was extracted from UV-Vis analysis of the 1 layer of TiO2 with the three different co-sensitized dye. The optical band gaps (Eg) of the three co-sensitized can be approximated using the following Tauc's equation:

$$(ahv)^n = A(hv - Eg) \tag{4.1}$$

$$E = \frac{1024}{\lambda} \tag{4.2}$$

$$\alpha = \frac{2.303A}{l} \tag{4.3}$$

where hv signifies photon energy, absorption coefficient, and n equal to 2 implies indirect bandgap material. The optical band gap for the absorption peak was calculated using Equation 4.1. Equation 4.2 was used to calculate the energy, where lambda is the absorption wavelength. The absorption coefficient was calculated using equation 4.3, where A is the absorbance and l is the sample thickness. Figure 4.8 depicts plots of (hv)2 vs. hv for three distinct co-sensitized spinach with frangipani, spinach with synthetic dye, frangipani with synthetic dye, and frangipani with synthetic dye (FTO). The optical bandgap of the three distinct co-sensitized was found using Tauc's relation, and it has bandgap of 2.76 eV for spinach with frangipani, frangipani with synthetic, and frangipani with synthetic (FTO), and 2.81 eV for spinach with synthetic solely which is the same bandgap as the previous work for a single spinach dye [29] .It demonstrates that frangipani play an important part in the bandgap without frangipani, the bandgap would be greater. A lower bandgap allows for easier electron movement, which improves conductivity. In contrast, a higher bandgap results in insulator-like behaviour. An ideal bandgap in solar cells combines light absorption efficiency with charge carrier separation.

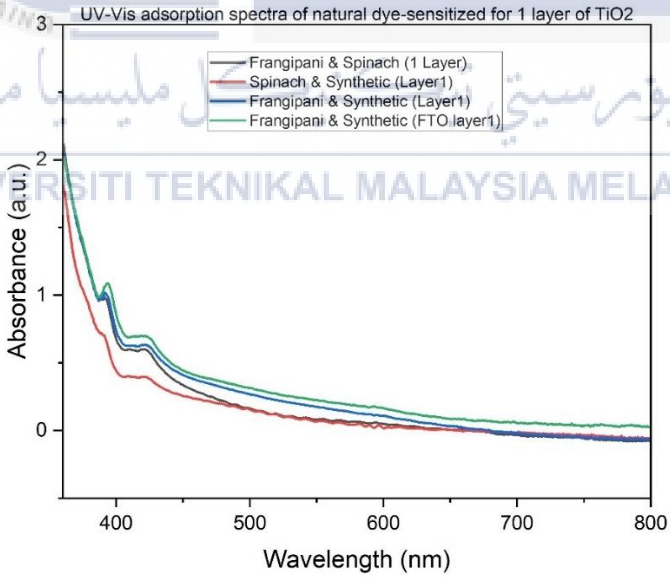


Figure 4.7 UV-Vis adsorption spectra of the three type of co-sensitized dye for 1 layer of TiO2.

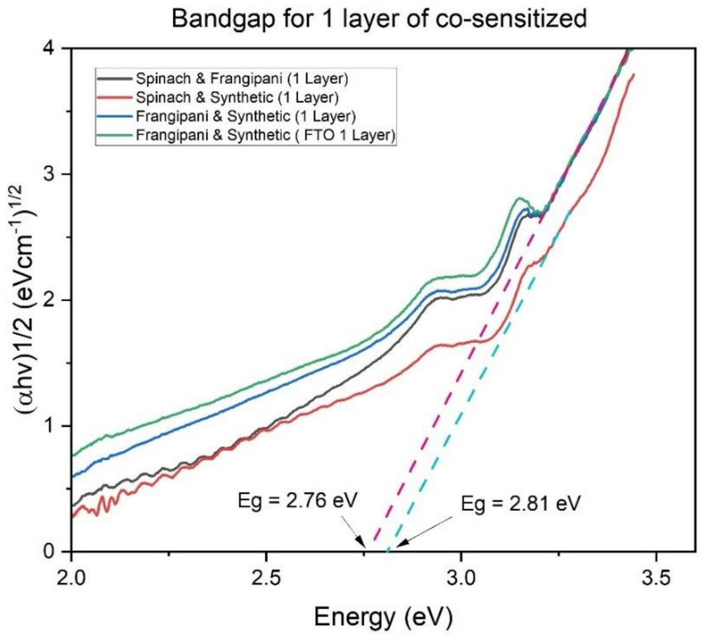


Figure 4.8 Overall bandgap for 1 layer of TiO2 for three different co-sensitized.

4.3.1.3 UV-Visible analysis of the three different co-sensitized for 2 layer of TiO2 photoanode.

UV-Visible analysis was performed to explore the optical absorption spectra of two layers of TiO2 thickness with three various types of co-sensitized and can analyse the energy bandgap, Eg, of the corresponding co-sensitized. The wavelength relationship of absorption in the spectral area 295-800 nm for the three types of co-sensitized is shown in Figure 4.9. The energy gap created by the three types of co-sensitized caused a significant drop in absorbance at short wavelengths. For the first spectrum, which consists of frangipani and spinach (2 layers of TiO2), there is a big peak at 355 nm and a smaller peak at 400. The second spectrum, spinach & synthetic (2 layer TiO2), reveals a noticeable peak at 360 nm and a lesser peak at 406 nm. The third spectrum, frangipani & synthetic (2 layer TiO2), has a prominent peak at 355 nm, which is a mix of pigments in the frangipani flower and synthetic dye, as well as a smaller peak at 388 nm. The fourth spectrum, frangipani & synthetic (FTO 2 layer of TiO2), has a large peak at 365 nm and a lesser peak at 404 nm created by pigments present in frangipani flowers and synthetic dye, respectively. The variations in absorption spectra can be related to the dyes' unique chemical structures. A conjugated structure of double bonds in the spinach dye absorbs light in the blue and green portions of the spectrum. The conjugated structure of frangipani dye absorbs light in the green and yellow parts of the spectrum. The synthetic dye has a complicated structure that allows it to absorb light at a broader variety of wavelengths.

A dye-sensitized photoelectrode's absorption qualities are critical for its efficiency in converting light to energy. A dye that absorbs light at several wavelengths will be able to collect more energy from the sun. However, in order to create electricity, the dye must be able to efficiently transport this energy to the TiO2 semiconductor. According to my observations, the adsorption spectra for 2 layer TiO2 thickness were not as uniform as for 1 layer TiO2 thickness. This is most likely due to the TiO2 surface not being properly dried during the annealing process because the duration and temperature were not appropriate for the thickness of 2 layer TiO2.

The optical energy band gap (Eg) is derived using Equation 4.1's classical connection. Regarding permitted indirect optical transitions, the value of n in the formula is equal to 2. The indirect bandgap was found in this study by constructing a graph between (hv)2 and (hv) in eV, as shown in Figure 4.10. The band gap values for as deposited, frangipani and spinach (2 layer of TiO2), spinach & synthetic (2 layer of TiO2), frangipani & synthetic (2 layer of TiO2), and frangipani & synthetic (FTO 2 layer of TiO2) are 3.17 eV, 3.05 eV, 3.37 eV, and 3.07 eV, respectively.

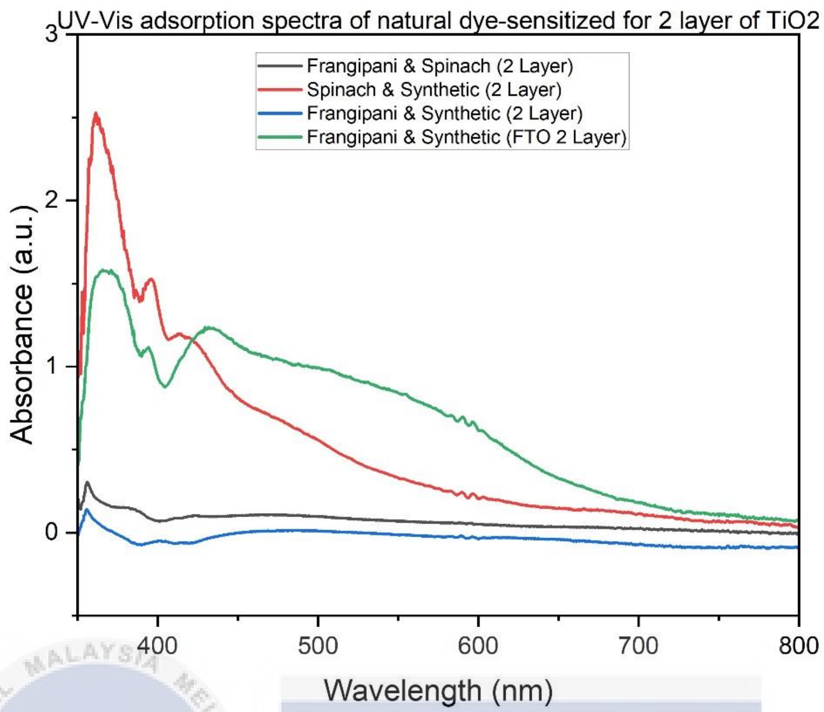


Figure 4.9 UV-Vis adsorption spectra of the three type of co-sensitized for 2 layer of TiO2.

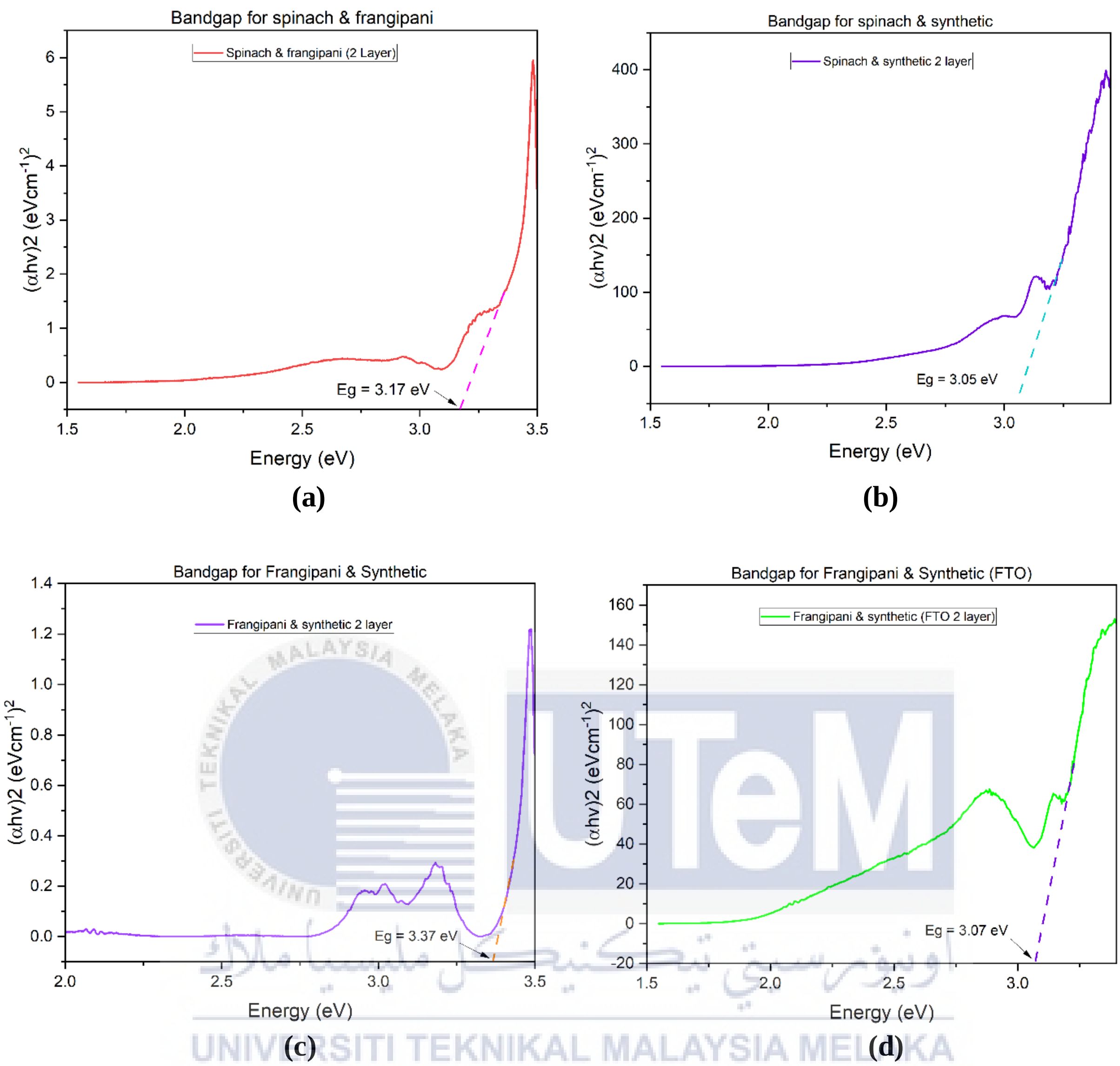


Figure 4.10 : (a) Bandgap of spinach & frangipani for 2 layer of TiO2 (b) Bandgap of spinach & synthetic for 2 layer of TiO2 (c) Bandgap of frangipani & synthetic for 2 layer of TiO2 (d) Bandgap of frangipani & synthetic for 2 layer of TiO2 using FTO as glass substrate

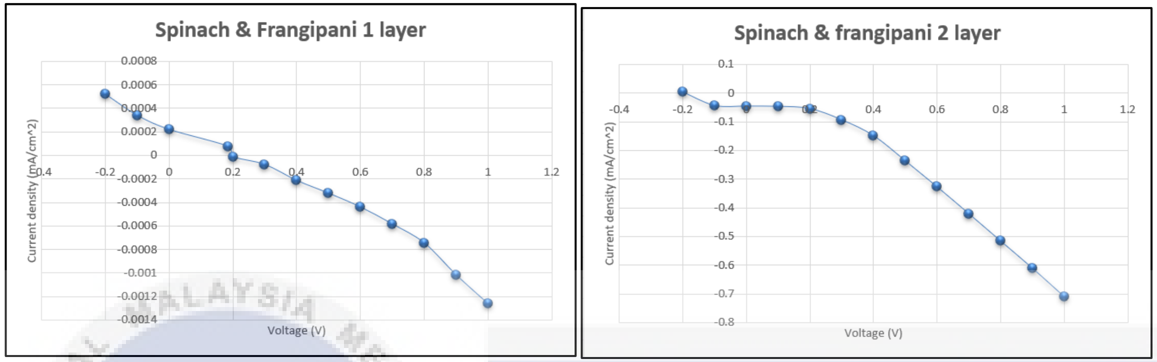
4.3.1.4 Current-voltage (*IV*) characteristic.

In this part, the I-V properties of dye-sensitized solar cells were thoroughly explored. The working electrode and counter electrode were sandwiched together to form the DSSC. An ossila solar simulator (Keithley 2450) was used to do the experiment under simulated AM 1.5G light with a power density of 100 mW/cm2. There were eight samples to be prepared, which included spinach co-sensitized with frangipani, spinach co-sensitized with synthetic (N719), frangipani co-sensitized with synthetic (N719), and frangipani co-sensitized with synthetic (N719) using FTO as glass substrate, all four samples had two different TiO2 thicknesses, single layer TiO2 and double layer TiO2, for a total of eight samples. Following that, Figure 4.11 (a) depicts the J-V curve of spinach and frangipani for 1 layer and 2 layers of TiO2. The pattern of the J-V curve shows that the J-V curve of spinach and frangipani for 1 layer performed better than the J-V curve of spinach and frangipani for 2 layer. This is because the optimal curve should be as shown in the J-V curve of spinach and frangipani for 2 layer of TiO2. However, the greatest results are obtained when the curve begins with a positive current density, remains steady, and then progressively decreases. The J-V curve for two layers of TiO2 thickness is considerably superior than the J-V curve for one layer of TiO2 thickness in Figures 4.11 (b) and 4.11 (c). Finally, for Figure 4.11 (d), the J-V curve of frangipani & synthetic for 1 layer of TiO2 thickness utilising FTO as glass substrate, the graph is nearly same for the case of 2 layer of TiO2 thickness.

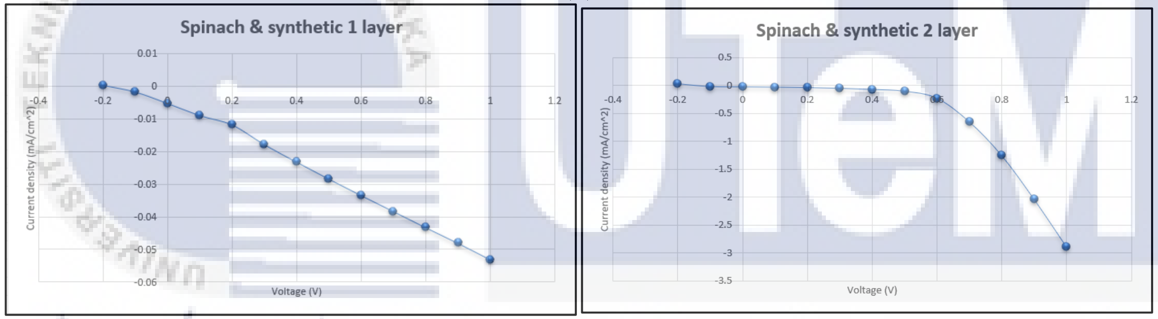
Using equations 3.1 and 3.2, the I-V characteristics measurement may provide FF values, efficiency, Jsc, and Voc. Table 4.2 summarises the efficiency, Voc, FF, and Jsc values for all the samples, where frangipani with synthetic dye (N719) utilising FTO as glass substrate with double layer of TiO2 thickness produced the greatest efficiency at 0.032352%. On the other hand, the lowest efficiency of 0.000014% was achieved with spinach and frangipani with single thickness of TiO2.

Table 4.3 Efficiency, Voc, FF, and Jsc values for all the samples.

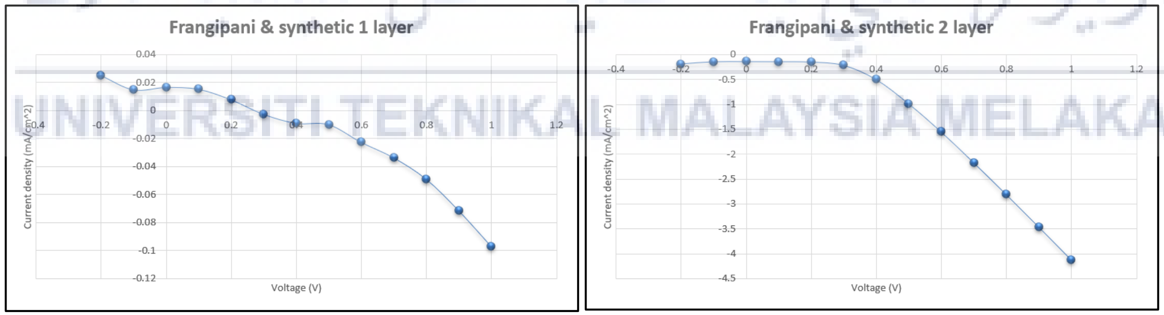
Type of co-sensitizer	Thickness of TiO2 (nm)	Efficiency (η%)	Fill factor (FF)	Open current voltage (V_{oc}) (V)	Short circuit current density (J_{sc}) (mA/cm^2)
Spinach with frangipani	55000	0.000014	0.133752	0.2	0.000519
	110000	0.004451	19.90415	0.1	0.002236
Spinach with synthetic dye (N719)	55000	0.000178	3.187251	0.2	0.000280
	110000	0.002173	0.804802	0.1	0.027002
Frangipani with synthetic dye (N719)	55000	0.00154	0.613337	0.1	0.025101
	110000	0.011096	0.76987	0.1	0.144120
Frangipani with synthetic dye (N719) using FTO as glass substrate	55000	0.002781	0.46001	0.2	0.030230
	11000	0.032352	0.77022	0.4	0.105010


Spinach & Frangipani 1 layer
Current density (mA/cm^2)
Voltage (V)
Spinach & frangipani 2 layer
Current density (mA/cm^2)
Voltage (V)

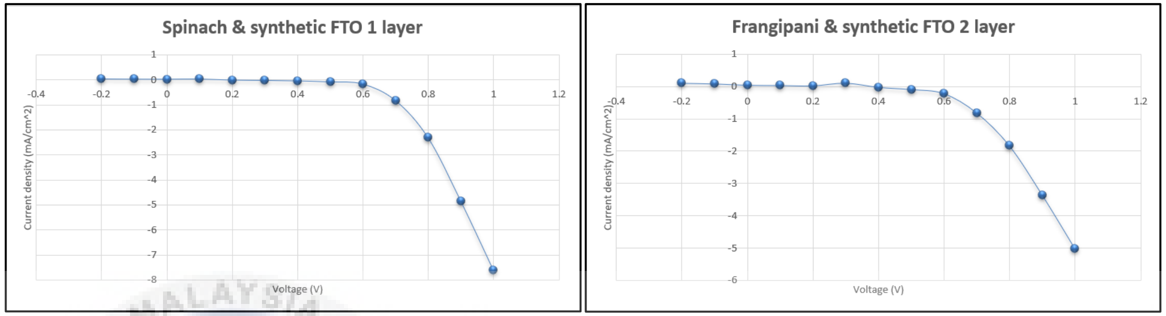
(a)


Spinach & synthetic 1 layer
Current density (mA/cm^2)
Voltage (V)
Spinach & synthetic 2 layer
Current density (mA/cm^2)
Voltage (V)

(b)


Frangipani & synthetic 1 layer
Current density (mA/cm^2)
Voltage (V)
Frangipani & synthetic 2 layer
Current density (mA/cm^2)
Voltage (V)

(c)



(d)

Figure 4.11 : (a) J-V characteristic of spinach & frangipani for 1 layer and 2 layer of TiO2 (b) J-V characteristic of spinach & synthetic for 1 layer and 2 layer of (c) J-V characteristic of frangipani & synthetic for 1 layer and 2 layer of TiO2 (d) J-V characteristic of frangipani & synthetic for 1 layer and 2 layer of TiO2 using FTO as glass substrate

4.4 Summary

This chapter investigates the fabrication and characterisation of dye-sensitized solar cells (DSSCs) with a focus on sustainable photovoltaic systems, especially using natural dyes such as Green Spinach, Curcumin, and Beetroot. The inquiry starts with UV-Vis spectroscopy, which is used to examine the absorption characteristics of various dyes, displaying unique peaks that indicate their potential for solar cell applications. Beyond individual sensitizers, the study digs into the synergy of diverse combinations, revealing detailed insights on the co-sensitization of colours like frangipani with spinach and synthetic dye N719. Importantly, the chapter examines the effect of various TiO2 paste thicknesses on DSSC performance, providing a detailed review of power conversion efficiency (PCE) under varied situations. The extensive investigation extends to UV-Vis absorption spectra for various layers of TiO2, unravelling the complicated interplay between sensitizers and their impact on optical band gaps. Furthermore, the investigation of current-voltage (IV) characteristics emphasises the research's practical applications, emphasising the importance of fabrication parameters in reaching optimal efficiency. The chapter not only contains empirical data, but also synthesises them into a cohesive narrative, establishing the framework for informed methods to improve the performance of DSSCs in the field of renewable energy research.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, this project intends to investigate the potential of natural dyes as sensitizers in order to address the difficulties encountered in the development of dye-sensitized solar cells (DSSCs). Although DSSCs have advantages such low cost, simple assembly, and possible flexibility, they have drawbacks like instability, absorption effectiveness, and interfacial recombination. Due to their availability, affordability, and environmental friendliness, natural dyes present a possible replacement for synthetic dyes.

The project's goals include examining effective and affordable natural dye sensitizers, enhancing the use of natural dyes in the DSSC fabrication process, and assessing how well the DSSCs work in diverse environmental settings. The results of the experiment will offer further insight into the potential of natural dyes as sensitizers in DSSCs and their suitability for real-world uses.

The use of DSSCs, notably those that use natural dyes, can help deal with the world's problem of climate change. In order to fulfil sustainable development objectives including access to inexpensive and clean energy, industry and innovation, and climate action, DSSCs provide clean and renewable energy, lowering dependency on fossil fuels. Additionally, DSSCs can give communities access to energy, generate employment opportunities, and be used in a variety of ways.

The review of the literature emphasizes the importance of natural dyes in DSSCs and the continuous research in this area. Studies on the characteristics of several natural dyes, including anthocyanin, chlorophyll, and betalains, have revealed elements that can improve the efficiency and long-term reliability of DSSCs, such as the use of crude extracts and the best dye combinations.

The methodology section outlines the experimental approach of the project, including the fabrication and characterization of DSSCs using natural dyes. Controlled experiments will be conducted, and parameters such as dye mixture ratios and TiO2 paste viscosity will be varied to optimize the performance of DSSCs. Specialized tools and techniques, such as UV-Visible spectroscopy and solar simulator, will be used for characterization.

Overall, this project aims to contribute to renewable energy research and sustainable photovoltaic systems by harnessing the potential of natural dyes in DSSCs. By paving the way for the creation of effective and affordable DSSCs, the study's results and insights can encourage the use of clean and renewable energy sources.

5.2 Potential for Commercialization

The fabrication and characterization of dye-sensitized solar cells (DSSCs) employing natural dyes as sensitizers hold tremendous commercialization potential. In comparison to conventional solar cells, this technology has a number of benefits, including lower cost, simple construction, and the use of sustainable and eco-friendly natural dyes. Natural dyes offer DSSCs a more affordable and eco-friendlier alternative by resolving the problems with synthetic dyes, such as their high cost, toxicity, and environmental dangers. Natural dye-sensitized solar cells are a desirable choice for mass production and wide adoption due to their availability and low cost. Flexible substrates can be used to build DSSCs, opening the door to the creation of thin, flexible solar panels. Due to their adaptability, DSSCs that use natural dyes as sensitizers provide potential for commercialization in a variety of markets and industries. Natural dye-sensitized solar cells can raise their total efficiency and compete with other photovoltaic technologies by improving their ability to harvest light, electron injection efficiency, and stability. Natural dyes are used as sensitizers in DSSCs, which offer a renewable energy option that helps achieve sustainable development goals and lessens the environmental impact of using conventional energy sources. This includes optimizing the fabrication process, enhancing the stability and durability of DSSCs under various environmental conditions, and investigating novel natural dye sources. Their low cost, abundance, eco-friendliness, and possibility for modular module fabrication make them appealing for large-scale manufacture and integration into a variety of applications. This technology can help accomplish sustainable development goals and create jobs by addressing the global need for inexpensive and clean energy.

5.3 Future Works

For future improvements, the fabrication and characterization of dye-sensitized solar cells (DSSCs) using natural dyes as sensitizers can be enhanced as follows:

i) Characterize the DSSC using various techniques such as SEM: Analyze the morphology and surface characteristics of the fabricated DSSCs using techniques like scanning electron microscopy (SEM). This helps to understand the structural properties and potential improvements in the device architecture.

ii) Analyze the performance data: Utilize statistical techniques such as analysis of variance (ANOVA) and regression analysis to analyze the performance data. This helps identify significant factors affecting the DSSCs' performance and establish correlations between fabrication parameters and device characteristics.

iii) Compare the performance of natural DSSCs with conventional DSSCs and other solar cell types: Conduct comparative studies to assess how natural dye-sensitized DSSCs perform in comparison to conventional DSSCs and other types of solar cells. Evaluate their efficiency, stability, and other key parameters to understand the advantages and limitations of natural dye-based systems.

iv) By implementing these future improvements, the fabrication and characterization of dye-sensitized solar cells using natural dyes as sensitizers can be enhanced, leading to more efficient and sustainable solar energy conversion.

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APPENDIX

No.	Task	PSM1														PSM2													
	Weeks	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1	Briefing for PSM1 by JK PSM FTKEE																												
2	Project Title Conformation and Registration																												
3	Briefing with Supervisor																												
4	Study the Project Background																												
5	Drafting Chapter 1: Introduction																												
6	Task progress evaluation 1																												
7	Drafting Chapter 2: Literature Review																												

8	Table of Summary Literature Review																												
9	Drafting Chapter 3: Methodology																												
10	Work on the Software/Hardware																												
11	First Draft submission to Supervisor																												
12	Task progress evaluation 2																												
13	Submission Report to the Panel																												
14	Presentation of BDP1																												
15	Drafting Chapter 4: Analysis Data and Result																												
16	Data Analysis and Result																												
17	Record the Result																												

18	Drafting Chapter 5: Conclusion and Recommendation																												
19	Compiling Chapter 4 and Chapter 5																												
20	Submit Latest Report to Supervisor																												
21	Finalize the Report																												
22	Presentation of BDP2																												