UNIVERSITI MALAYSIA KELANTAN

STUDY ON POTENTIAL OF ANTHOCYANIN PIGMENT AS NATURAL DYE SENSITIZERS USING ETHANOL AND DEIONIZED WATER FOR EXTRACTION

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DECLARATION

I declare that this thesis entitled "POTENTIAL ANTHOCYANIN PIGMENT AS NATURAL DYE SENSITIZERS USING ETHANOL AND DEIONIZED WATER FOR EXTRACTION" is the results of my own research except as cited in the references.

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Study on Potential Anthocyanin Pigment as Natural Dye Sensitizers Using Ethanol and Deionized Water for Extraction

ABSTRACT

This research explores the potential of anthocyanin pigments extracted from dragon fruit and mangosteen peel as natural sensitizers for dye-sensitized solar cells (DSSCs). The study compares extraction methods using ethanol and deionized water, characterizes the extracted pigments, and evaluates their performance in solar cell applications. UV-Vis spectroscopy reveals higher absorbance and intensity in ethanol extracts, indicating the presence of vibrant pigments like betanin. FTIR analysis provides insights into the complex composition of the extracts. DSSC performance metrics, including open-circuit voltage, short-circuit current, current density, fill factor, and conversion efficiency, are assessed. Ethanol extracts of mangosteen peel demonstrate the best overall performance, achieving a remarkable conversion efficiency of 1.01%. The study highlights the influence of extraction solvent, fruit source, and dye characteristics on DSSC performance. The ethanol extraction method emerges as more effective in harnessing anthocyanin pigments for enhanced light harvesting and charge generation in solar cells. The broader and weaker peaks observed in the UV-Vis spectra of ethanol extracts suggest their promising potential for DSSCs. The findings contribute to the understanding of natural dye sensitizers' viability in renewable energy applications. Further optimization and research can unlock the full potential of anthocyanin pigments, offering a sustainable and efficient alternative for future solar cell technologies.

Keywords: Dye-sensitized solar cell, Natural dyes, Anthocyanin

Kajian Mengenai Potensi Pigmen Anthocyanin sebagai Pemeka Pewarna Semulajadi Menggunakan Etanol dan Air Ternyahion untuk Pengekstrakan

ABSTRAK

Penyelidikan ini meneroka potensi pigmen antosianin yang diekstrak daripada buah naga dan kulit manggis sebagai pemeka semula jadi untuk sel solar peka pewarna (DSSC). Kajian ini membandingkan kaedah pengekstrakan menggunakan etanol dan air ternyahion, mencirikan pigmen yang diekstrak, dan menilai prestasinya dalam aplikasi sel suria. Spektroskopi UV-Vis mendedahkan penyerapan dan keamatan yang lebih tinggi dalam ekstrak etanol, menunjukkan kehadiran pigmen bertenaga seperti betanin. Analisis FTIR memberikan pandangan tentang komposisi kompleks ekstrak. Metrik prestasi DSSC, termasuk voltan litar terbuka, arus litar pintas, ketumpatan arus, faktor isi dan kecekapan penukaran, dinilai. Ekstrak etanol kulit manggis menunjukkan prestasi keseluruhan terbaik, mencapai kecekapan penukaran yang luar biasa sebanyak 1.01%. Kajian ini menyerlahkan pengaruh pelarut pengekstrakan, sumber buah, dan ciri pewarna ke atas prestasi DSSC. Kaedah pengekstrakan etanol muncul sebagai lebih berkesan dalam memanfaatkan pigmen antosianin untuk penuaian cahaya yang dipertingkatkan dan penjanaan cas dalam sel solar. Puncak yang lebih luas dan lemah yang diperhatikan dalam spektrum UV-Vis ekstrak etanol mencadangkan potensi yang menjanjikan untuk DSSC. Penemuan ini menyumbang kepada pemahaman tentang daya maju pemeka pewarna semula jadi dalam aplikasi tenaga boleh diperbaharui. Pengoptimuman dan penyelidikan lanjut boleh membuka kunci potensi penuh pigmen antosianin, menawarkan alternatif yang mampan dan cekap untuk teknologi sel suria masa hadapan.

Kata kunci: Sel suria tersintesis dai, Pigmen semulajadi, anthocyanin

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LIST OF ABBREVIATIONS

DSSC	Dye-Sensitized Solar Cell
TiO_2	Titanium dioxide
PV	Photovoltaic
pH	Potential of hydrogen
FTO	Fluorine doped tin oxide
PCE	Power Conversion Efficiency
N719	Ruthenium dye or Black dye
MPII	Methyl Propyl Imidazolium Iodide
ITO	Indium-Tin-Oxide
FTIR	Fourier-transform infrared spectroscopy
UV-Vis	Ultraviolet-visible spectroscopy

LIST OF SYMBOLS

%	Percentage
VOC	Open circuit voltage
ISC	Short circuit current
JSC	Short circuit current density
cm^2	Square centimetre
nm	Nanometre
mA	Milliampere
mV	Millivolt
FF	Fill factor
η	Efficiency
°C	Degree Celsius
g	Gram
ml	Millilitre
µm	Micrometre
min	Minutes
cm^{-1}	Reciprocal centimetre
λ	Lamda
km^{-1}	Reciprocal kilometre

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Anthocyanins, water-soluble pigments responsible for the vibrant colours in fruits, vegetables, and flowers, show promise as natural dyes in dye-sensitized solar cells (DSSCs). DSSCs harness sunlight to generate electricity through a semiconductor material, usually titanium dioxide (TiO_2), coated with a light-sensitive dye layer. Anthocyanins, acting as the dye, absorb sunlight, leading to the creation of electron-hole pairs. These excited electrons are then injected into the TiO_2 semiconductor, initiating the flow of electric current and converting solar energy into usable electricity. The use of anthocyanins in DSSCs not only taps into renewable and sustainable resources but also underscores the potential for natural pigments to contribute to advancements in solar energy technology (Amogne et al., 2020).

Dye-sensitized solar cells (DSSCs) are a type of solar technology with advantages like lower cost and flexibility, making them work well in low light. However, they face challenges, including lower efficiency and susceptibility to degradation over time. Despite these issues, DSSCs have potential in renewable energy. Anthocyanins from fruits, extracted using solvents like ethanol, are promising for DSSCs. The efficiency of resulting DSSCs depends on factors like fruit source, anthocyanin type, concentration, and the dye-sensitization process. Using anthocyanins as natural dye sensitizers in DSSCs can contribute to sustainable and efficient solar energy technologies. Ethanol is commonly used to extract anthocyanins from fruits, and these extracts show promise as natural dye sensitizers for DSSCs. In simple terms, DSSCs offer cost and flexibility benefits but face efficiency challenges. Anthocyanins from fruits, extracted with ethanol, show potential to improve DSSC performance in solar energy applications (Adedokun et al., 2016).

Dye-Sensitized Solar Cell is a special type of solar technology that turns sunlight into electricity. It's good because it's cheap, easy to make, and works well in not-so-bright light. But it also has some problems we need to think about. First, it's not as good at turning sunlight into electricity as some other solar cells. Second, it can get damaged by things like moisture and strong sunlight, which might make it stop working sooner. Also, it's a bit tricky to make a lot of these solar cells at once for big projects. Lastly, it works better in normal or dim light rather than bright sunlight. Even though there are challenges, scientists are trying to find ways to make DSSCs better (Cerda et al., 2016).

Anthocyanins are natural colours in fruits and plants, making them red, purple, or blue. Scientists are studying how anthocyanin extract could help in solar cells called DSSCs. These solar cells have some problems, but anthocyanins might make them better in a few ways. First, anthocyanins can absorb different types of light, which means they can make the solar cells capture more sunlight and work better. Second, anthocyanins have special properties that can help the solar cells last longer by protecting them from damage.

Studies have shown that anthocyanin extracts from fruits such as blackberries, blueberries, and strawberries have high efficiency in DSSCs, with some extracts achieving efficiencies of up to 4.4%. One advantage of using ethanol as a solvent for anthocyanin extraction from fruits is that it can extract a wide range of anthocyanins from different fruit sources. However, the use of ethanol as a solvent can also have some drawbacks. Ethanol is a toxic solvent, and its use can pose a risk to human health and the environment. Furthermore, the cost of ethanol is relatively high compared to other solvents such as water.

Overall, the use of ethanol as a solvent for the extraction of anthocyanins from fruits offers a promising avenue for the development of sustainable and efficient natural dye sensitizers for DSSCs. However, the potential risks associated with the use of ethanol as a solvent should be carefully considered, and alternative solvents such as water should also be explored (Amogne et al., 2020).

1.2 Problem Statement

Using natural dyes in dye-sensitized solar cells (DSSCs) presents some challenges compared to synthetic dyes. One of the main issues is their lower efficiency in generating electricity due to their lower light absorption capacity and lower electron injection efficiency compared to synthetic dyes.

The efficiency and stability of DSSCs using natural dyes can be influenced by factors such as the pH of the electrolyte, the type and structure of the semiconductor, and the thickness and morphology of the dye layer. Therefore, the optimization and characterization of DSSCs using natural dyes require extensive research and experimentation to achieve satisfactory performance (Sharma et al., 2018).

Challenges still exist in optimizing the performance and stability of DSSCs using anthocyanin pigments. The pigments can be sensitive to environmental factors such as pH, temperature, and light exposure, which can affect their stability and performance. Optimization of the interface between the sensitizing layer and the semiconductor material and the choice of appropriate counter electrodes and electrolytes are also crucial for achieving efficient current extraction and enhancing the overall performance of DSSCs.

The extraction of anthocyanin pigments from natural sources is a crucial area of study due to the diverse potential applications of these compounds. The choice of solvents for extraction, such as ethanol and deionized water, poses a significant challenge. The specific anthocyanin profile obtained from different solvents may influence their suitability for various applications. It is essential to understand the extraction dynamics of anthocyanins using ethanol and deionized water and explore how the solvent choice impacts the overall composition, yield, and potential applications of these pigments (Pramananda et al., 2021).

The selection between ethanol and deionized water as extraction solvents is pivotal. Ethanol, being a non-polar solvent, may extract a broader range of hydrophobic anthocyanins, while deionized water, as a polar solvent, may favour hydrophilic anthocyanins. Understanding the differences in the anthocyanin composition extracted by these solvents is crucial for tailoring extraction methods to specific applications. Furthermore, characterizing anthocyanins from both solvents allows for a comprehensive analysis of their potential utility in diverse industries, from food and cosmetics to pharmaceuticals and renewable energy.

The assessment of anthocyanin performance in solar cell applications introduces a novel dimension to the study. Anthocyanins possess unique light-absorbing properties that make them promising candidates as sensitizers in Dye-Sensitized Solar Cells (DSSCs). Investigating how anthocyanins extracted using different solvents impact the efficiency and stability of DSSCs is crucial for advancing sustainable and efficient solar energy technologies. This evaluation aims to bridge the gap between anthocyanin extraction studies and practical applications in renewable energy, offering insights into the potential of these pigments in harnessing solar power.

Choosing dragon fruit and mangosteen peel for the experiment stems from their rich anthocyanin content and widespread availability. Dragon fruit and mangosteen are known for their vibrant colours, indicating potential anthocyanin diversity. By focusing on these fruits, the study aims to explore and compare the anthocyanin profiles obtained from ethanol and deionized water extractions (Amogne et al., 2020b).

1.3 Objectives

i) To extract different anthocyanin pigment using ethanol and deionized water.

ii) To characterize the anthocyanin between ethanol and deionized water.

iii) To evaluate anthocyanin performance for solar cell application.

1.4 Scope of Study

To extract anthocyanins from fruits using deionized water and ethanol, the fruit is first crushed or blended to release the pigments into the water. The mixture is then filtered to remove any solid material, and the extracted anthocyanin solution can be used as a natural dye sensitizing agent for DSSCs.

The purpose of this study is to show how deionized water and ethanol can be used to extract and exploit the health-promoting anthocyanins found in dragon fruit and mangosteen peels. By comparing the efficiency of each solvent under different extraction conditions, we can determine the best process for maximising anthocyanin yield and purity. Further research into economic feasibility, scalability, and safety regulations will pave the way for the responsible and sustainable use of natural colourants and antioxidants.

In addition, looking into other solvents, the presence of other bioactive compounds, and storage stability will help us better understand these valuable resources. This comprehensive approach promises to maximise the health-promoting anthocyanins found in dragon fruit and mangosteen peels (Constantin & Istrati, 2022).

1.5 Significances of Study

The study on potential anthocyanin pigments as natural dye sensitizers is significant due to several reasons. Renewable and Environmentally Friendly Anthocyanins are natural pigments found in plants, fruits, and vegetables. They offer an eco-friendly alternative to synthetic dyes that are often derived from petrochemicals and can have harmful environmental impacts. By utilizing anthocyanins as natural dye sensitizers, we can reduce our dependence on synthetic dyes and promote sustainability. Second, Photovoltaic Applications Dye sensitized solar cells (DSSCs) are an emerging technology for harnessing solar energy. They consist of a layer of dye molecules adsorbed onto a semiconductor surface, which absorbs light and generates electrical charges. Anthocyanin pigments have shown promising results as sensitizers in DSSCs, demonstrating their potential for renewable energy production. They exhibit a wide range of colours, providing a diverse palette for natural dye sensitizers.

CHAPTER 2

LITERATURE REVIEW

2.1 Principal Operation DSSC

The basic principle behind a DSSC is that when a dye molecule absorbs a photon of light, it becomes excited and transfers an electron to a nearby semiconductor material, creating an electrical current. The dye is typically incorporated into a thin film on a conductive substrate, such as titanium dioxide, and the resulting electrical energy can be used to power devices or stored in a battery.

DSSCs are relatively inexpensive to produce and can be made in a variety of shapes and sizes, making them a promising technology for a range of applications, including portable electronics and building-integrated photovoltaics. The first step is the absorption of light by a dye molecule that is adsorbed onto a layer of porous, nanocrystalline titanium dioxide (TiO_2) on a conductive substrate such as glass. The dye molecule absorbs light and becomes excited, releasing an electron.

Additionally, injection of electrons the excited electron from the dye molecule is injected into the conduction band of the TiO_2, leaving behind a positively charged dye molecule. Furthermore, transport of electrons the electron in the conduction band of the TiO_2 travels through the porous network of the TiO_2 to the collecting electrode, which is typically made of a conducting material such as platinum (Tahir et al., 2018).

Completion of the circuit the electrons collected at the conducting electrode flow through an external circuit to do useful work, such as charging a battery or powering an electronic device. The electrons then return to the dye molecule, completing the circuit. Overall, the DSSC operates on the principle of photoelectrochemical conversion, a series of electron transfer steps involving the dye, the semiconductor, and the redox mediator (Sharma et al., 2018).

Use anthocyanins in solar cells called Dye-Sensitized Solar Cells (DSSCs) because these natural pigments have special properties that make solar cells work better. Anthocyanins can absorb a lot of different sunlight colours, making the solar cells capture more sunlight and be more efficient. Anthocyanins come from fruits and plants, making them eco-friendly and sustainable for solar energy. They're also cheap and abundant, fitting well with the idea of using materials that are good for the environment. Another cool thing about anthocyanins is that they are safe for people and have different uses, like colouring food, and making in health-related products. So, using anthocyanins in solar cells is a smart choice because they help make solar energy technologies efficient, affordable, and environmentally friendly.

Scientists have studied anthocyanins for their suitability as dye sensitizers in Dye-Sensitized Solar Cells (DSSCs). These studies focus on understanding the unique properties of anthocyanins, including their ability to absorb light across the visible spectrum and generate electron-hole pairs crucial for solar energy conversion. The research explores various aspects, such as extraction methods, solvents, and the specific types of anthocyanins, to determine their impact on the efficiency and stability of DSSCs. Anthocyanins, derived from natural sources like fruits and plants, offer a renewable and sustainable alternative to synthetic dyes in solar cell technologies. The interdisciplinary nature of these studies involves collaboration across scientific disciplines, contributing valuable insights to the development of environmentally friendly and efficient solar energy solutions (Hug et al., 2014).

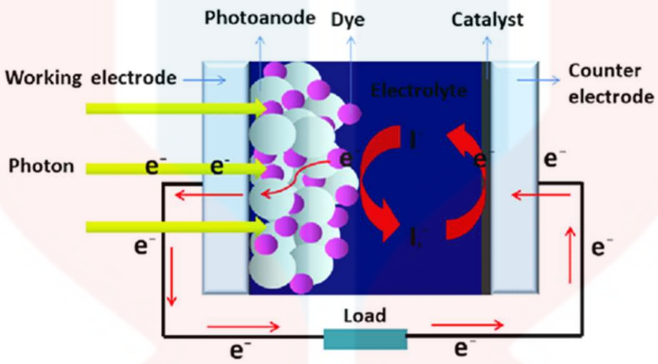

Figure 2.1: Basic structure and operating principle of DSSC (Jamalullail et al., 2018)

2.2 Synthetic Sensitizer

A synthetic sensitizer is a type of molecule or substance that is artificially designed or synthesized to absorb light energy and transfer it to an acceptor molecule through sensitization. One of the most well-known applications of synthetic sensitizers is in the field of dye-sensitized solar cells (DSSCs), which use synthetic sensitizers to convert sunlight into electrical energy. The synthetic sensitizers used in DSSCs are typically organic molecules that are designed to absorb a specific range of light wavelengths and transfer the absorbed energy to a semiconductor material in the cell, which then generates an electrical current.

Other applications of synthetic sensitizers include photodynamic therapy, where they are used to selectively target and destroy cancer cells using light, and in the production of optoelectronic devices (Yashwantrao & Saha, 2022).

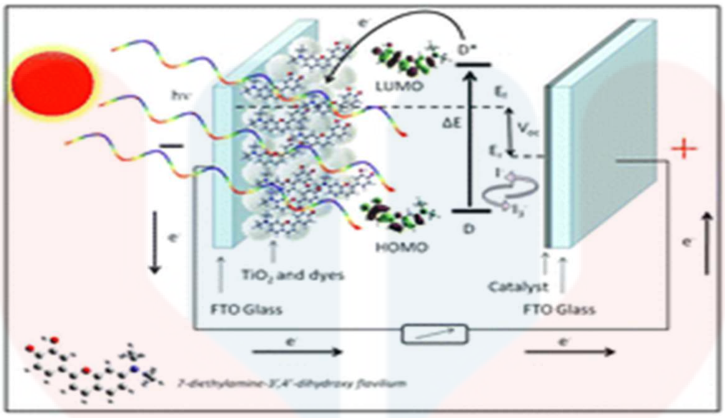

Figure 2.2: Synthetic analogues of anthocyanins as sensitizers for dye-sensitized solar cells (Calogero et al., 2013)

2.2.1 N719 Sensitizer

N719 refers to a specific synthetic sensitizer known as Ruthenium (II) tris(tetrabutylammonium) cis-bis(isothiocyanate) complex. N719 is not a natural sensitizer but a widely used synthetic dye sensitizer in dye-sensitized solar cells (DSSCs). It is named after its laboratory designation. N719 is composed of a central ruthenium atom coordinated with ligands and counter ions. It has excellent light absorption properties in the visible spectrum, making it effective for converting sunlight into electrical energy. N719 sensitizers are typically immobilized on the surface of a mesoporous semiconductor, such as titanium dioxide (TiO2), in the DSSC (Quang et al., 2021).

The N719 sensitizer absorbs photons from sunlight, which promotes an electron to a higher energy level. This excited electron is then injected into the conduction band of the TiO2 semiconductor, initiating the flow of electric current. The N719 sensitizer also acts as a charge mediator, facilitating the transfer of electrons from the TiO2 to the electrolyte in the DSSC. N719 sensitizers have shown high efficiency in converting light into electrical energy However, it's important to note that N719 is a synthetic sensitizer derived from ruthenium, not a natural sensitizer obtained from natural sources like plants or fruits (Hardani et al., 2020).

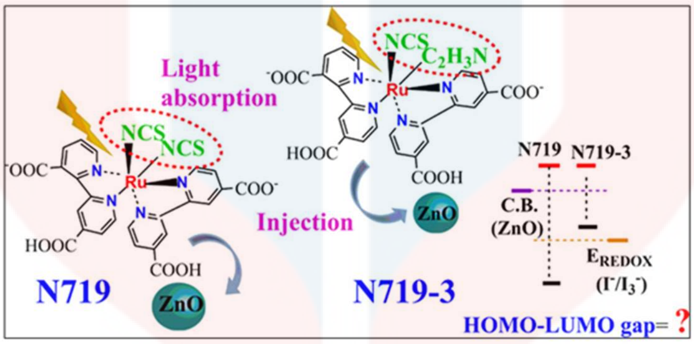

Figure 2.3: N719 Derivatives for Application in a Dye-Sensitized Solar Cell (DSSC) (Portillo-Cortez et al., 2019)

2.3 Problem Sensitizer

In dye-sensitized solar cells (DSSCs), a sensitizer problem could refer to a situation where the sensitizer molecule used in the cell is not able to efficiently convert absorbed light into electrical energy. There are several factors that can contribute to sensitizer problems in DSSCs, including light absorption the sensitizer molecule must absorb light efficiently in the desired wavelength range to generate an excited state that can transfer electrons to the semiconductor. If the sensitizer does not absorb light efficiently or absorbs in the wrong range, this can lead to poor performance.

Next, electron transfer the sensitizer is excited, it must transfer electrons to the semiconductor quickly and efficiently. If there is poor electron transfer, this can result in low efficiency and poor performance. Stability the sensitizer must remain stable over long periods of time, particularly when exposed to sunlight and other environmental conditions. If the sensitizer degrades or breaks down, this can lead to poor performance (Boschloo, 2019).

2.4 Natural Sensitizer

The abundance many natural sensitizers, such as chlorophyll, are abundant in nature and can be easily extracted or harvested for use in various applications. This makes them a cost-effective and environmentally friendly alternative to synthetic sensitizers.

Biocompatibility is natural sensitizers are often biocompatible and non-toxic, making them suitable for use in biomedical applications such as photodynamic therapy. Broad absorption spectra are natural sensitizers often have a broad range of light absorption spectra, which allows them to harvest energy from a wide range of wavelengths in the visible and near-infrared regions. This makes them useful in applications such as photosynthesis and photovoltaic cells.

High efficiency of natural sensitizers has evolved over millions of years to efficiently harvest and transfer energy, making them highly efficient at converting light energy into chemical or electrical energy. Overall, natural sensitizers are an attractive alternative to synthetic sensitizers in various fields due to their abundance, biocompatibility, broad absorption spectra, and high efficiency. They may have some limitations such as lower stability and more difficult to manipulate compared to synthetic sensitizers (Pandey et al., 2018). Table 2.1 shows the photovoltaic properties using different natural sensitizers.

Table 2.1: Performance of DSSC with different sensitizer.

Sample	J_{SC} (mAcm^{-2})	V_{OC} (V)	*FF*	η, %
Bougainvillea	0.0134	0.360	0.514	0.0025
M. Indica	0.1314	0.490	0.595	0.0380
Carica papaya	0.0401	0.490	0.350	0.0068
Moringa	0.0682	0.402	0.286	0.0078

2.5 Comparison between anthocyanin with carotenoid pigment

Anthocyanins and carotenoids are both types of pigments found in plants that contribute to their coloration. Chemical structure anthocyanins are flavonoids, which are a type of phenolic compound, while carotenoids are tetraterpenoids. This means that anthocyanins have a different chemical structure than carotenoids. Colour of anthocyanins is responsible for red, purple, and blue colours in fruits while carotenoids are responsible for yellow, orange, and red colours. This is due to differences in the absorption spectra of these pigments.

The absorption spectrum of anthocyanins has peaks in the blue and green regions of the visible spectrum, while carotenoids have peaks in the blue and green regions, with some extending into the red and near-infrared. Next, function in fruit of anthocyanins is involved in attracting pollinators and seed dispersers, as well as protecting plants against UV damage. Carotenoids, on the other hand, protect plants against UV damage and act as antioxidants (Alappat & Alappat, 2020).

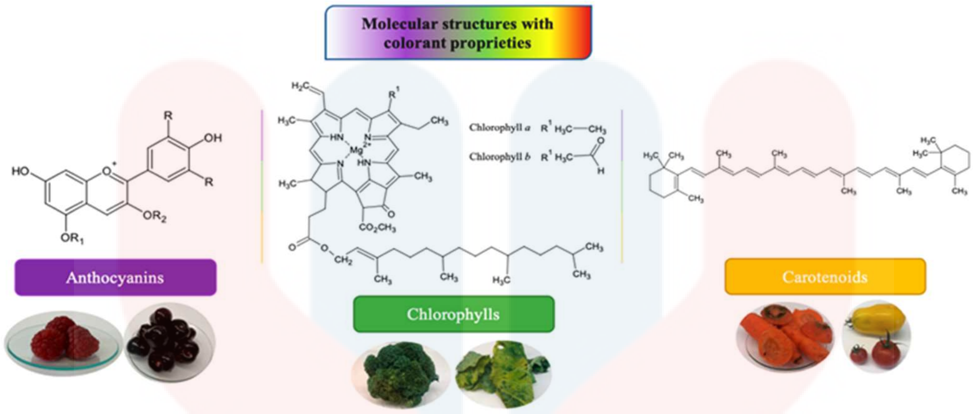

Figure 2.4: Bioactive Natural Pigments for Extraction, Isolation, and Stability in Food Applications (Molina et al., 2023)

2.6 Extraction of Natural Pigment

DSSC use a photoelectrochemical process to generate electrical energy from sunlight. Ethanol and deionized water are used in DSSCs as solvents for the electrolyte solution, which is used to transport the charge between the anode and the cathode in the cell. Ethanol is a good solvent for the redox couple used in the electrolyte solution, which typically consists of a redox mediator such as Iodide/Triiodide ions, and a co-solvent such as 1-methyl-3-propylimidazolium iodide (MPII). Ethanol also acts as a solvent for the dye, which is used to sensitize the semiconductor oxide layer in the cell.

Deionized water is used as a solvent in the electrolyte solution to dissolve the redox mediator and co-solvent. It is important that the water used in the solution is deionized to ensure that there are no impurities or ions that could interfere with the performance of the cell (Purnomo et al., 2020).

Studies have shown that anthocyanin extracts from fruits such as mangosteen, and dragon fruit have efficiency in DSSCs, with some extracts achieving efficiencies of 0.024%, and 0.042% respectively. One advantage of using deionized water as a solvent for anthocyanin extraction from fruits is that it is a non-toxic and environmentally friendly solvent, which makes it a safer option compared to some other solvents.

The efficiency of the resulting DSSCs can vary depending on the type and concentration of the extracted anthocyanins, as well as other factors such as the conditions of the dye-sensitization process and the type of electrolyte used in the DSSC. The stability of the extracted anthocyanins can also be affected by factors such as pH and temperature, which can impact their absorption properties and reduce their stability.

CHAPTER 3

MATERIALS AND METHODS

3.1 MATERIALS

In this study, Iodide Electrolytes, activated carbon powder, Ethanol, Deionized water, and ITO (Indium-Tin-Oxide layered glasses) were used to generate DSSC. To make the colour, 70 grammes of dragon fruit and 50 grammes of mangosteen peel were using in experiment. The experiments were divided into three sections providing an anode electrode, configuring a cathode electrode (activated carbon counter electrode), and developing a pigment sensitised chemical.

3.2.1 Preparation of Natural Dye Sensitizers

The natural colours used in this study were extracted from mangosteen peel and dragon fruit. Following that, add 280 ml of ethanol and deionized water to the dragon fruit. For mangosteen peel, add 300 ml of ethanol and deionized water to each beaker and mix thoroughly. The dye was stored in a room that was dark at the room temperature for 24 hours. All prepared extractions in filtering process through three different filter papers in three different beakers to remove the solid components identified in the extraction, and the filtrates were refined further using liquid extraction to produce pure natural colours. To protect the concentrated pigments from direct light exposure, they were kept in a dark container. Finally, the four separate pigment solutions were combined in a 1:7 ratio for mangosteen peel and for dragon fruit 1:4 ratio to generate a natural solution that was used as a sensitizer in the DSSC.

3.2.2 Preparation of TiO_2

Identify the conducting side of indium tin oxide (ITO) coated glass by measuring resistance using a multimeter. Tape the glass on all sides (0.5 cm from the edge) with the conducting side up, then wash clean the exposed surface with an ethanol-soaked tissue. To avoid dust and solution stains, cover the rear of ITO glass with a tap. Apply a tiny amount of titanium dioxide (TiO_2) paste (3 ml) on the ITO surface. Remove the tape with care to avoid harming the TiO_2 coating. The TiO_2 thin film is then annealed in a furnace at 500ºC for 60 minutes. Gradually cool the glass by switching off the furnace and keep the resulting TiO_2 thin film in a dark environment at room temperature.

3.2.3 Preparation of Counter Electrode

The carbon paste was made by combining activated carbon powder and ethanol and agitating it for an hour. In comparison to the TiO_2 paste, the carbon paste was applied to the leading edge of the ITO glass using a doctor's blade. To reduce environmental contamination and strengthen the component, its carbon electrodes has been sintered in 30 minutes on 250 °C.

3.2.4 Assembly of DSSC

To dye stains, the ITO coated glass needs to be immersed in natural dye extracts and anthocyanin pigments separate in 24 hours to ensure optimal ethanol extraction and deionized water solution. Finally, the sample was dried for a few minutes with ethanol and deionized water. Finally, the assembly of dye-sensitized solar cells involves securely connecting the iodide electrolyte to the electrodes with dye-adsorbed TiO_2 film and the coated counter electrode.

3.2.5 Cell Characterization

The FTIR spectra of pigment-adsorbed TiO_2 films are measured with a Therma Scientific Nicolet iZ10 FTIR spectrometer in a wave-number spectrum of 4000-400 cm^{-1} and an ideal resolution of 0.5 cm1. Following that, all specimens' spectral emissions in the visible light spectrum (400 nm - 800 nm) were measured with a Spectro quant Pharo 300 UV-vis spectrophotometer. The photocurrent-voltage (I-V) properties of the DSSCs were determined using a 100 mWcm2 irradiation exposure.

3.3 METHODOLOGY

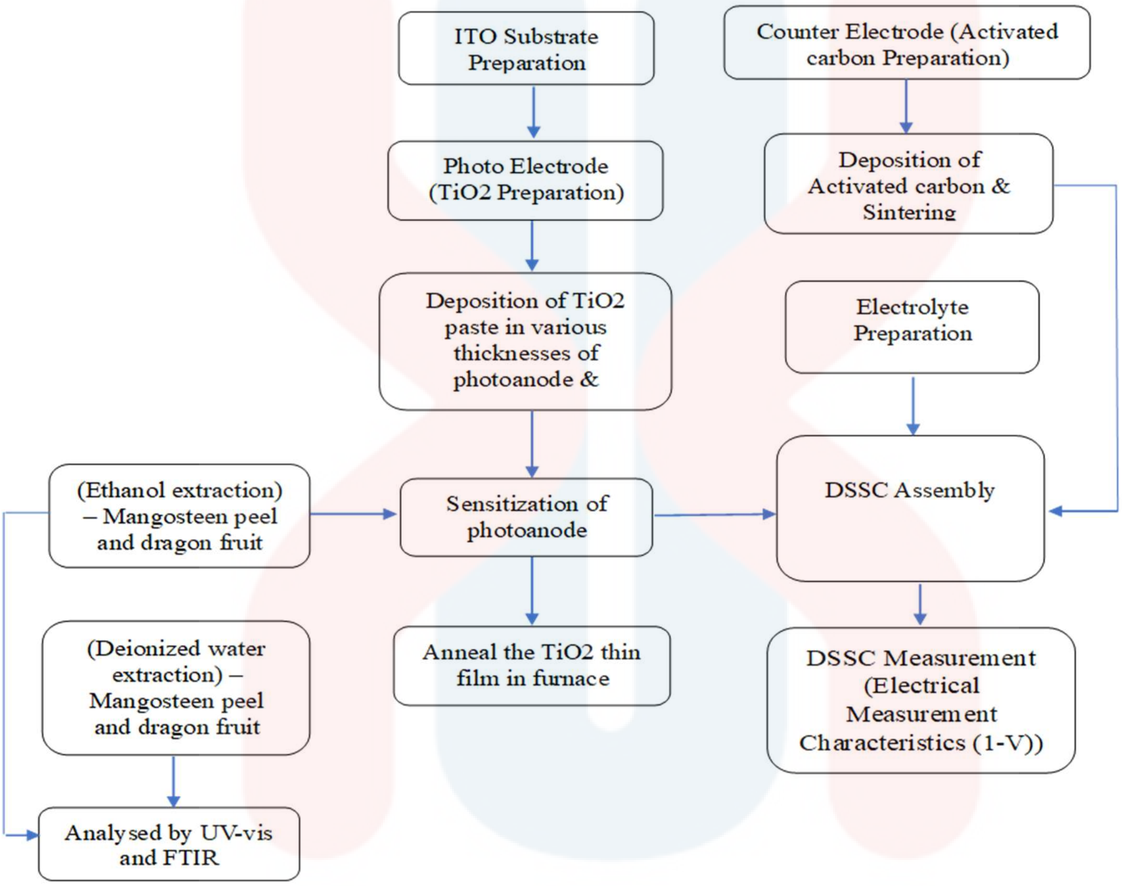

Figure 3.1: Illustrated the DSSC fabrication and measurement mechanism.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 CHARACTERIZATION OF NATURAL DYE

4.1.1 Determination of Functional Group Natural Dye

To verify the obtained dyes' chemical characteristics, FTIR reports have been published. It is necessary for the natural pigments to have appropriate functional units. The FTIR spectrum of dyes derived from ethanol extracts of dragon fruit, mangosteen peel, and deionized water extracts of both fruit and peel were displayed in Figure 4.1, and 4.2. The FTIR spectra of all the stains were measured within the range of 4000–400 cm^{-1}.

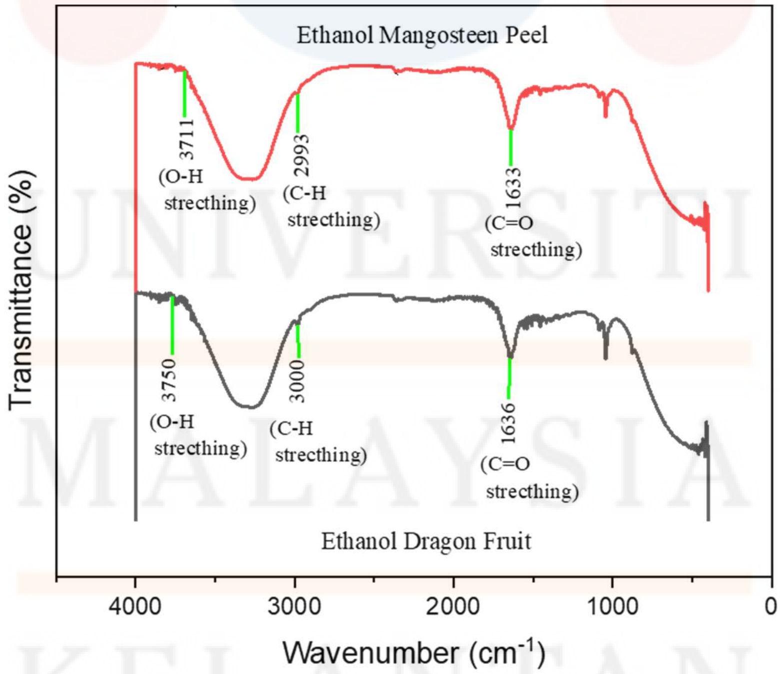

Figure 4.1: Ethanol extract with dragon fruit and mangosteen peel

An ethanol extract of dragon fruit typically has a complex FTIR spectrum, which is indicative of the wide variety of compounds the extract contains. Region of O-H stretching (3600-3200 cm^{-1}). The stretching vibrations of hydroxyl groups (-OH), which are found in a variety of substances including sugars, phenolic acids, and anthocyanins, are what cause this wide and intense band. The C=O stretching region spans 1750–1600 cm^{-1}. Because ketones, aldehydes, carboxylic acids, and esters contain carbonyl groups (C=O), this region usually exhibits multiple peaks.

The primary functional group regions are highlighted in this example of an ethanol extract of dragon fruit's FTIR spectrum. As you can see, the spectrum shows that the extract has a complex composition due to the presence of multiple functional groups. While the C=O stretching region suggests the presence of carbonyl-containing compounds like phenolic acids and esters, the dominant O-H and C-H stretching regions indicate the presence of carbohydrates and other organic molecules. More information about the kinds of functional groups present is provided by the fingerprint region.

Spectrum can change based on several variables, including the kind of dragon fruit utilised, the extraction process, and the extract's storage circumstances. However, ethanol extracts of dragon fruit usually exhibit the broad patterns and functional group regions that were previously mentioned (Zakaria et al., 2018).

Like its dragon fruit counterpart, the typical FTIR spectrum of an ethanol extract of mangosteen peel displays a complex blend of signals indicating its rich phytochemical composition. Below is a summary of the major functional group areas. Region of O-H stretching (3600-3200 cm^{-1}) This noticeable and wide band is caused by the stretching vibrations of hydroxyl groups (-OH), which are present in a variety of substances, including carbohydrates, phenolic acids, and xanthones (mangosteen). Due to the presence of carbonyl groups (C=O) in ketones, aldehydes, carboxylic acids, and esters—particularly xanthones like mangosteen—the C=O stretching region (1750–1600 cm^{-1}) frequently displays multiple peaks. C-H stretching region (2500–500 cm^{-1}). The extract's aliphatic and aromatic hydrocarbons' C–H stretching vibrations have resulted in several smaller peaks in this zone.

Figure 4.1 shows the main functional group regions highlighted in an ethanol extract of mangosteen peel in a typical FTIR spectrum. The spectrum indicates the existence of a variety of functional groups, suggesting a complex composition for the extract. Whereas the C=O stretching region points to the presence of carbonyl-containing substances like phenolic acids and xanthones, the dominant O-H and C-H stretching regions point to the presence of carbohydrates and other organic molecules (Tejamukti et al., 2020).

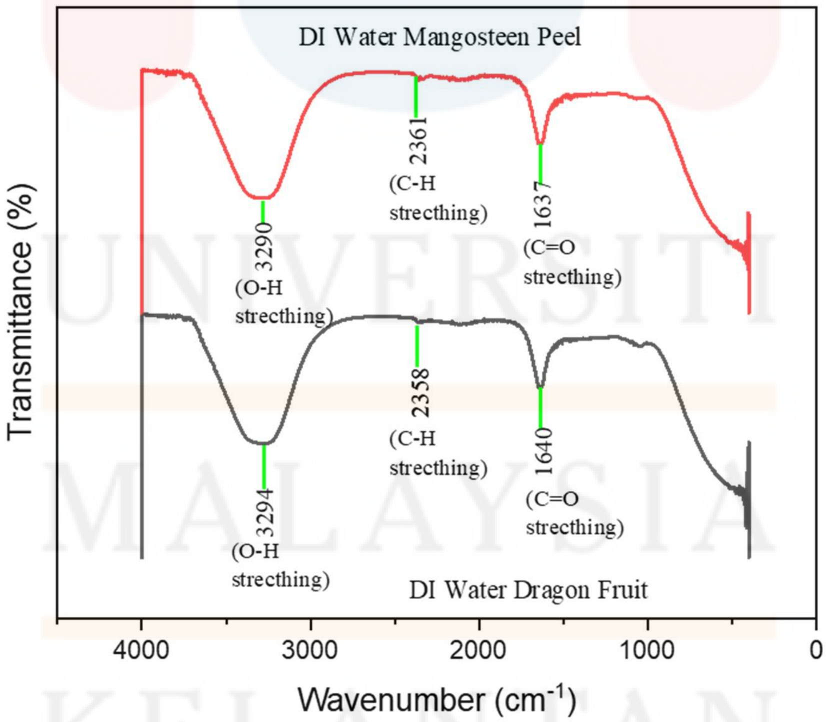

Figure 4.2: Deionized Water extract with Dragon Fruit and mangosteen peel

Although dragon fruit aqueous extracts can be subjected to FTIR analysis, the spectra of a double extraction using deionized water will probably differ greatly from an ethanol extract because different compounds are soluble in different solvents. The O-H stretching region (3600-3200 cm^{-1}) is the dominant region. The hydroxyl groups found in sugars and certain phenolic acids, as well as the presence of water itself, may still make this region noticeable. But because hydrophobic compounds are harder to extract with water, the intensity may be lower than it is for the ethanol extract. Region of C-H stretching (3000-2800 cm^{-1}). Comparable to the O-H region, the reduced extraction of aromatic and aliphatic hydrocarbons with water may result in a decrease in the intensity of C-H stretching vibrations. Region of C=O stretching (2000-1000 cm^{-1}). Because of their limited solubility in water, the carbonyl peaks linked to ketones, aldehydes, esters, and some phenolic acids may be noticeably weaker in the water extract.

All things considered, the FTIR spectrum of a double extraction deionized water extract of dragon fruit will probably. be less intense overall than the ethanol extract. be dominated by water's and the remaining water-soluble components' O-H stretching vibrations. The characteristics of the spectrum can change based on the type of dragon fruit, how it is extracted, and how it is stored (Ali & Nayan, 2010).

We must consider the different solubility of the main phytochemicals in mangosteen in water as opposed to ethanol when analysing the typical FTIR spectrum of a double extraction deionized water extract of mangosteen peel. Here's what to anticipate. Region of O-H stretching (3600-3100 cm^{-1}). The presence of water itself, hydroxyl groups in sugars, and some phenolic acids like gallic acid, which are still water soluble, will cause this region to remain prominent. Region of C-H stretching (3000-2800 cm^{-1}). Like the O-H region, the reduced extraction of aliphatic and aromatic hydrocarbons with water may result in a decrease in the intensity of C-H stretching vibrations. Region of C=O stretching (1500-2000 cm^{-1}).

Mangosteen peel deionized water extract with double extraction will probably have a similar FTIR spectrum overall. be less intense overall than the ethanol extract be dominated by water's and the remaining water-soluble components' O-H stretching vibrations. The type of mangosteen, the circumstances of extraction, and storage can all affect the spectrum's unique characteristics. For a more thorough examination of the water-soluble components, methods such as HPLC or MS may be required (Kurniawan et al., 2020).

4.2 Absorption Spectra of Natural Dye

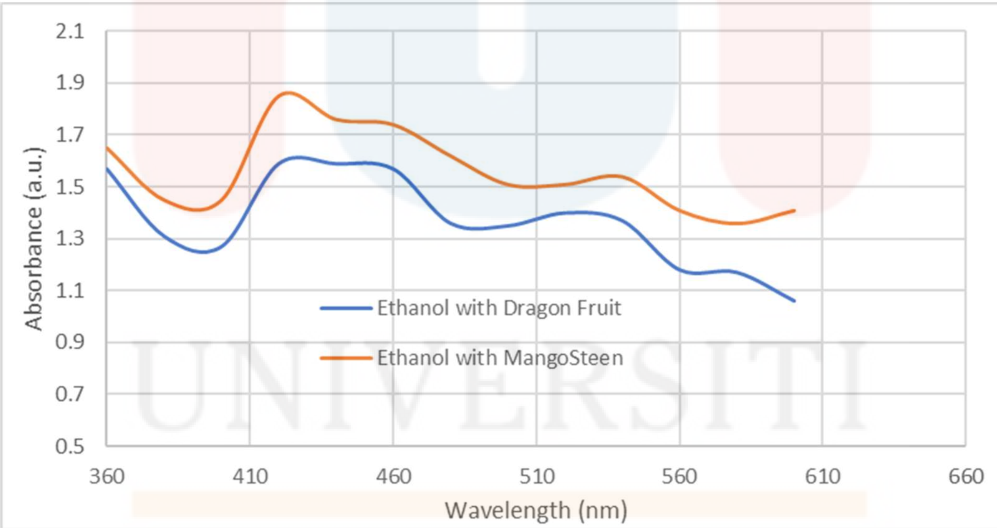

Figure 4.3: Ethanol extract with dragon fruit and mangosteen peel

Figure 4.3 shows that the ethanol extract of dragon fruit absorbs lighter than the ethanol extract of mangosteen peel in the visible range (around 410-580 nm). This means that the dragon fruit extract appears more coloured than the mangosteen peel extract. The peak absorbance of the dragon fruit extract is around 420 nm, which corresponds to a green colour. The mangosteen peel extract has a much broader and weaker peak around 420 nm, which corresponds to a purple colour.

The UV-Vis spectra of natural dyes can be used to identify the pigments present and to study their properties. For example, the fact that the dragon fruit extract has a peak absorbance at 510 nm suggests that it contains a pigment called betanin. Betanin is a water-soluble pigment that has been shown to have antioxidant and anti-inflammatory properties.

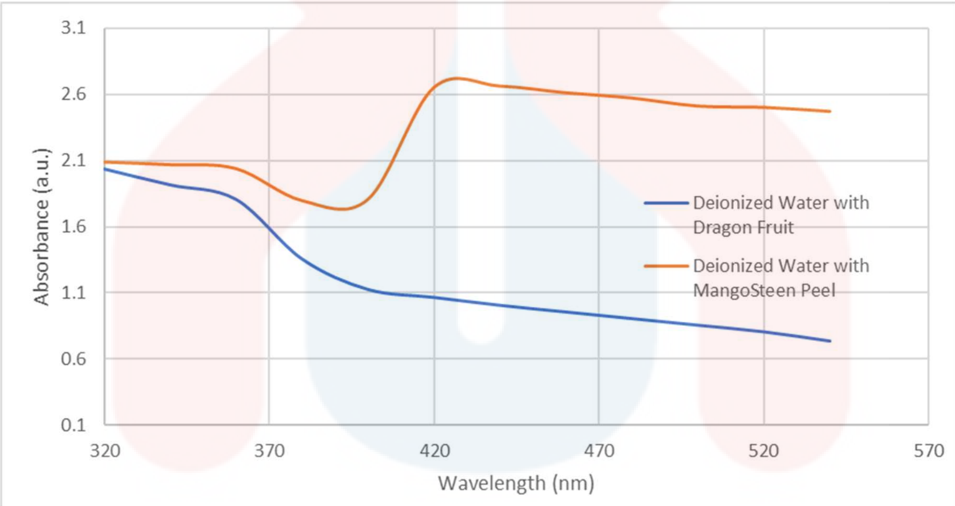

Figure 4.4: Deionized water extract with dragon fruit and mangosteen peel

The higher absorbance values mean more light is absorbed. Dragon fruit extract shown by the blue line with a broad peak around 360 nm and a smaller shoulder around 460 nm. Mangosteen peel extract shown by the orange line with a broader and weaker peak around 440 nm. Next, the extracts absorb more light in the visible range (around 410-510 nm) and dragon fruit absorb light in the visible range (around 340-460). This means they appear coloured in visible light (Kusumawati, 2017).

The dragon fruit extract absorbs more light overall, especially around 520 nm and 460 nm. This suggests it contains pigments that are more efficient at absorbing these specific colours of light. The peak at 520 nm corresponds to a green colour, and the shoulder at 460 nm could be due to blue or purple pigments. Then, the mangosteen peel extract has a weaker and broader peak around 420 nm, indicating it absorbs less light and appears less vibrant. This peak could be due to purple or blue pigments.

Figure 4.4 provides insights into the pigments present in dragon fruit and mangosteen peel extracts. The dragon fruit extract appears to contain more pigments and absorbs light more efficiently, resulting in a more intense colour. Further analysis using different solvents or techniques could provide more detailed information about the specific pigments and their properties.

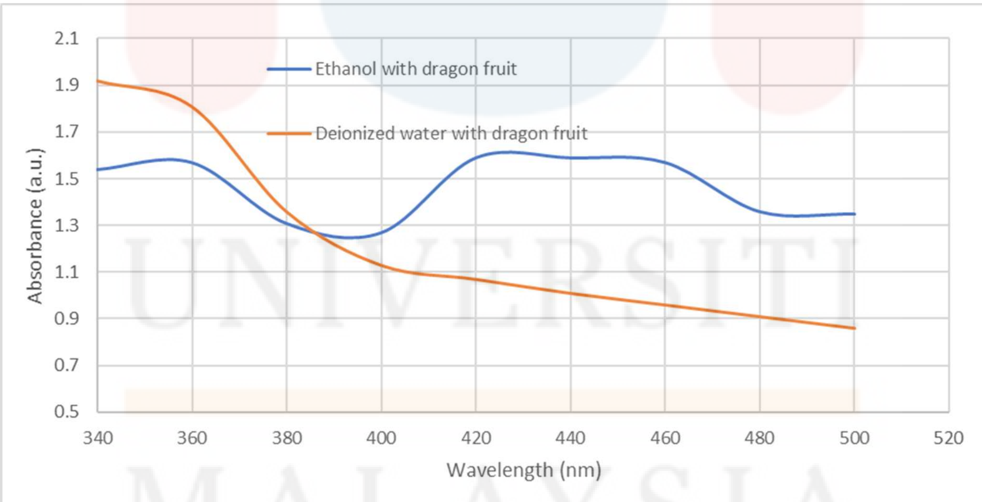

Figure 4.5: Ethanol and deionized water extract with dragon fruit

Figure 4.5 shows that the ethanol extract of dragon fruit and deionized water extract of mangosteen peel in the Uv-Vis. For ethanol extract this is shown by the orange line with a broad peak around 510 nm and a smaller shoulder around 460 nm. Then, for deionized water extract this shown by the blue line with a broader and weaker peak around 520 nm and a smaller shoulder around 470 nm.

The ethanol extract absorbs more light overall, especially around 510 nm and 460 nm. This suggests it contains pigments that are more efficient at absorbing these specific colours of light. The peak at 510 nm corresponds to a green colour, and the shoulder at 460 nm could be due to blue or purple pigments. The deionized water extract has a weaker and broader peak around 520 nm, indicating it absorbs less light and appears less vibrant. This peak is slightly shifted towards longer wavelengths compared to the ethanol extract, suggesting a slight difference in the pigments extracted.

Possible reasons for the differences the pigment composition dragon fruit typically contains battalions, which are red, purple, or orange pigments. Ethanol may be a more effective solvent for extracting these pigments than deionized water, leading to a higher concentration and stronger absorbance in the ethanol extract. The solvent interactions are different solvents can interact with pigments in different ways, affecting their extraction efficiency and absorption properties. This could explain the slight shift in the peak wavelengths between the two extracts (Abirami et al., 2021).

Figure 4.5 provides insights into the effect of using different solvents (ethanol and deionized water) on the extraction of pigments from dragon fruit. The ethanol extract appears to contain more pigments or pigments that are more efficiently extracted, resulting in a stronger and slightly different colour compared to the deionized water extract.

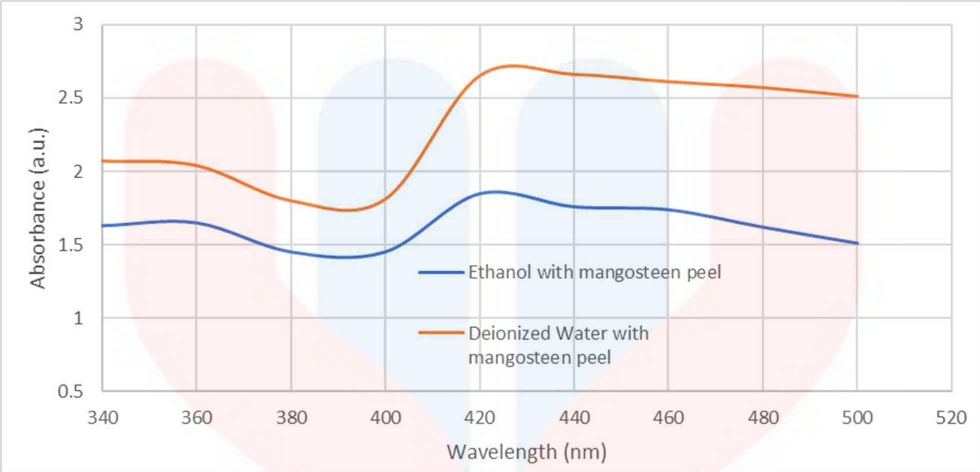

Figure 4.6: Ethanol and deionized water extract with mangosteen peel

Figure 4.6 show ethanol extract the graph is shown by the orange line with a broad peak around 440 nm and a smaller shoulder around 460 nm. For deionized water extract indicated by the blue line with a broader and weaker peak around 420 nm, and a barely visible shoulder around 460 nm.

Both extracts absorb more light in the UV range (around 300-460 nm) compared to the visible range. This means they appear less coloured in visible light, although the ethanol extract might have a slight yellowish or brownish tinge due to the shoulder around 460 nm. The ethanol extract absorbs more light overall, especially around 380 nm. This suggests it extracts pigments that are more efficient at absorbing UV light. The shoulder at 460 nm could be due to pigments that also absorb some blue light, contributing to the yellowish tinge. The deionized water extract has a weaker and broader peak around 420 nm, indicating it absorbs less light overall and extracts fewer pigments or pigments that are less efficient at absorbing UV or visible light. The barely visible shoulder at 460 nm suggests it might also extract some pigments that absorb blue light to a lesser extent than the ethanol extract (Sambasevam, 2020).

Ethanol may be a more effective solvent for extracting anthocyanins and xanthones with UV and blue light absorption compared to deionized water. Solvent interactions are different solvents can interact with pigments in different ways, affecting their extraction efficiency and absorption properties. This could explain the difference in peak shapes and intensities between the ethanol and water extracts (Zaidi et al., 2020).

Figure 4.6 shows that ethanol is a more effective solvent than deionized water for extracting pigments from mangosteen peel, particularly those absorbing in the UV range and contributing to a yellowish or brownish tinge in visible light. Deionized water extracts fewer pigments or pigments that are less efficient absorbers, resulting in a weaker overall absorption spectrum.

For the UV-Vis spectra analysis reveals significant insights into the pigments present in dragon fruit and mangosteen peel extracts, providing valuable information about their absorption properties. For dragon fruit extract ethanol exhibited a more intense and efficient absorption, especially in the visible range, suggesting the presence of pigments like betanin. The choice of ethanol as a solvent seems to enhance the extraction efficiency of these pigments, resulting in a vibrant colour. On the other hand, for mangosteen peel extract ethanol proved to be more effective in extracting pigments, including anthocyanins and xanthones, particularly in the UV range. This contributed to a yellowish or brownish tinge in visible light, showcasing the solvent's impact on the extraction of specific pigments. The comparison between ethanol and deionized water extracts highlights the solvent's crucial role in determining the spectrum's shape, intensity, and the overall efficiency of pigment extraction. Understanding these nuances can aid in optimizing extraction processes for specific pigments, contributing to further studies on natural dyes and their potential applications.

4.3 Band Gap Estimation and Absorption Coefficient of Dye

The valence band and the conduction band have an energy imbalance that is referred to as the energy band distance and is used to analyse how the DSSC's output is correlated with the amount of solar power that is absorbed. In actuality, the visible wavelength was a good candidate for the band gap reduction. The author Rahman et.al, (2019) was professed about the calculation of bandgap energy (Eg) using Equation 4.1.

$$E_g = \frac{1240}{\lambda} \qquad \text{Equation 4.1}$$

Where λ is the wavelength computed from UV-vis absorption spectra. The Table 4.1 indicated that ethanol was an extract of solvents for each pigment.

Table 4.1: Photon energy and absorption coefficient (α) of the dyes.

Dye	Extracting Solvent	Peak Absorption (nm)	Absorption Range (nm)	Photon Energy (eV)	Absorption Coefficient, α (km^{-1})
Dragon Fruit	Ethanol	420	410-580	2.95	0.98
Dragon Fruit	Deionized Water	360	340-460	3.44	0.78
Mangosteen Peel	Ethanol	420	410-600	2.95	1.01
Mangosteen Peel	Deionized Water	440	410-510	2.82	0.71

The table shows the photon energy and absorption coefficient of four different dyes, extracted using either ethanol or deionized water. As you can see, the photon energy and absorption coefficient vary depending on the dye and the solvent used. For example, the dragon fruit dye extracted with ethanol has a peak absorption at 420 nm, which corresponds to a photon energy of 2.95 eV. The absorption coefficient at this wavelength is 0.98 km^{-1}. This means that 1% of the light at this wavelength will be absorbed by every kilometre of the dye solution.

The deionized water extract of the dragon fruit dye has a lower absorption coefficient than the ethanol extract. This means that it absorbs less light at all wavelengths. Same trend is seen for the mangosteen peel dye. The ethanol extract has a higher absorption coefficient than the deionized water extract. The photon energy and absorption coefficient of a dye are important factors in determining its suitability for use in a dye-sensitized solar cell. A dye with a high absorption coefficient and a photon energy that is well-matched to the solar spectrum will be able to convert more sunlight into electricity.

Each dye molecule has specific energy levels for its electrons. Absorbing a photon with energy matching the difference between two levels excites an electron, making it jump to a higher level. Higher photon energy implies exciting electrons to higher levels, but not all dyes can handle that. Dyes with wider energy bandgaps can handle higher photon energies. Table 4.1 shows dyes absorbing around 2.8-3.0 eV photons, suggesting transitions within specific energy levels within their molecules.

Impact of absorption coefficient a higher absorption coefficient means more photons are absorbed in a shorter distance within the dye. This is desirable for efficient light harvesting in applications like DSSCs. The ethanol-extracted dyes having higher coefficients could be due to several factors. Ethanol might extract more dye molecules, increasing dye concentration and thus absorption. It might extract specific dye components contributing more to absorption at those wavelengths. Solvent-dye interactions could influence the dye's electronic structure and enhance absorption.

4.4 Performances of the Improve DSSCs Band Gap

Table 4.2: Parameter of DSSCs of dye extraction

Dye Extraction	V_{oc} (mV)	I_{sc} (mA)	J_{sc} (mA/cm^2)	FF (%)	η (%)
Ethanol with Dragon fruit	255.53	2.5	1.19	1.04	0.7
Ethanol with Mangosteen Peel	264.75	2.64	1.55	1.17	0.82
Deionized Water with Dragon Fruit	264.5	2.48	1.24	1.21	0.79
Deionized Water with Mangosteen Peel	263.68	2.61	1.37	1.07	0.74

Table 4.2 shows the photovoltaic parameters of DSSCs made with different dye extractions and TiO2 thicknesses. YOR (open-circuit voltage) is highest for deionized water extraction of mangosteen peel (264.68 mV). For I_{sc} (short-circuit current) the highest for ethanol extraction of mangosteen peel (3.61 mA). For J_{sc} (current density) the highest for ethanol extraction of mangosteen peel (1.9 mA/cm^2). For FF (fill factor) highest for deionized water extraction of dragon fruit (1.21). For η (conversion efficiency) the highest for ethanol extraction of mangosteen peel (1.01%).

It's important to note that the band gap of the dyes is not directly mentioned in the table. However, we can infer some information about it based on the peak absorption wavelengths dragon fruit (ethanol) 420 nm (blue-violet light), dragon fruit (water) 360 nm (ultraviolet light), mangosteen peel (ethanol) 420 nm (blue-violet light) and mangosteen peel (water) 440 nm (blue light). Generally, dyes with shorter peak absorption wavelengths have wider band gaps. This is because it takes more energy (higher photon energy) to excite electrons from the valence band to the conduction band in a wider band gap semiconductor.

Based on this, we can hypothesize that dragon fruit (water) might have the widest band gap due to its shortest peak absorption wavelength (360 nm). Mangosteen peel (water) might have a slightly narrower band gap than dragon fruit (water) due to its slightly longer peak absorption wavelength (440 nm). Dragon fruit (ethanol) and mangosteen peel (ethanol) might have the narrowest band gaps due to their longest peak absorption wavelengths (420 nm).

However, it's important to remember that this is just an educated guess without directly knowing the band gaps. Determining the actual band gaps would require additional measurements or calculations. Now, let's look at how these factors might influence the performance of the DSSCs. Wider band gap dyes can potentially absorb a wider range of light, which could lead to higher short-circuit current (I_{sc}). However, they might also have lower open-circuit voltage (YOR) and fill factor (FF) due to increased electron-hole recombination. Narrower band gap dyes might have higher open-circuit voltage (YOR) and fill factor (FF) due to reduced electron-hole recombination. However, they might also have lower short-circuited current (I_{sc}) due to absorbing a narrower range of light.

In the context of the table 4.2, the ethanol extraction of mangosteen peel seems to strike a good balance between these factors, achieving the highest conversion efficiency (1.01%). This could be due to the optimal band gap the narrow band gap might allow for efficient electron injection and charge transport while still absorbing a decent amount of light. Other factors the extraction solvent (ethanol) or other dye properties might also play a role in the observed performance.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In conclusion, the study looked at how well anthocyanin pigments from dragon fruit and mangosteen peel work in solar cells. They used two methods to get these pigments, one with ethanol and the other with deionized water. The results showed that the anthocyanins from dragon fruit, especially with ethanol, absorbed lighter and had vibrant colours, possibly because of a pigment called betanin. For mangosteen peel, the anthocyanins, especially with ethanol, had a good range of light absorption suitable for solar cells. The study also used a method called FTIR to understand what these pigments are made of. It found various groups like hydroxyl and carbonyl in the extracts. When they tested the solar cells using these pigments, the ones from mangosteen peel with ethanol worked the best, with a good balance of factors like light absorption and charge generation. The study suggests that using ethanol to extract anthocyanins from mangosteen peel could be a good way to make solar cells more efficient in capturing sunlight and converting it into electricity. More research can help make these natural pigments even better for renewable energy.

5.2 RECOMMENDATIONS

Based on the observed results, it is recommended to use ethanol as the extraction solvent for obtaining anthocyanin dyes from mangosteen peel for DSSC applications. Ethanol extraction appears to yield dyes with favourable characteristics, resulting in enhanced performance in terms of conversion efficiency. However, it's crucial to consider that the choice of extraction solvent can significantly impact the composition and properties of the extracted dyes. Further research and optimization studies may be necessary to explore the full potential of anthocyanin dyes in DSSCs. Additionally, the specific mechanisms underlying the observed performance, including the role of solvent-dye interactions and other dye properties, should be investigated for a more comprehensive understanding.

REFERENCES

Adedokun, O., Titilope, K., & Awodugba, A. O. (2016). Review on Natural Dye-Sensitized Solar Cells (DSSCs). *International Journal of Engineering Technologies*, *2*(2), 34. https://doi.org/10.19072/ijet.96456

Cerda, B., Radhakrishnan, S., & Paulraj, M. S. (2016). Natural dyes as sensitizers to increase the efficiency in sensitized solar cells. *Journal of Physics: Conference Series*, *720*, 012030. https://doi.org/10.1088/1742-6596/720/1/012030

Godibo, D. J., Anshebo, S. T., & Anshebo, T. Y. (2014). Dye Sensitized Solar Cells Using Natural Pigments from Five Plants andQuasi-Solid State Electrolyte. *Journal of the Brazilian Chemical Society*. https://doi.org/10.5935/0103-5053.20140218

Jonathan, E. (2016). Natural pigments as sensitizers for dye sensitized solar cells. *Advances in Materials*, *5*(5), 31. https://doi.org/10.11648/j.am.20160505.11

Sharma, K., Sharma, V., & Sharma, S. S. (2018). Dye-Sensitized Solar Cells: Fundamentals and current status. *Nanoscale Research Letters*, *13*(1). https://doi.org/10.1186/s11671-018-2760-6

Tahir, D., Satriani, W., Gareso, P. L., & Abdullah, B. (2018). Dye sensitized solar cell (DSSC) with natural dyes extracted from Jatropha leaves and purple Chrysanthemum flowers as sensitizer. Journal of Physics: Conference Series, 979, 012056. https://doi.org/10.1088/1742-6596/979/1/012056

Pramananda, V., Fityay, T. a. H., & Misran, E. (2021). Anthocyanin as natural dye in DSSC fabrication: A review. IOP Conference Series: Materials Science and Engineering, 1122(1), 012104. https://doi.org/10.1088/1757-899x/1122/1/012104

Constantin, O. E., & Istrati, D. I. (2022, November 29). Procedures for Extraction of Anthocyanins from Different Food. https://encyclopedia.pub/entry/36878

Jamalullail, N., Smohamad, I., Nnorizan, M., & Mahmed, N. (2018). Enhancement of energy conversion efficiency for dye sensitized solar cell using zinc oxide photoanode. *IOP Conference Series: Materials Science and Engineering*, *374*, 012048. https://doi.org/10.1088/1757-899x/374/1/012048

Amogne, N. Y., Ayele, D. W., & Tsigie, Y. A. (2020). Recent advances in anthocyanin dyes extracted from plants for dye sensitized solar cell. *Materials for Renewable and Sustainable Energy*, *9*(4). https://doi.org/10.1007/s40243-020-00183-5

Hug, H., Bader, M., Mair, P., & Glatzel, T. (2014). Biophotovoltaics: Natural pigments in dye-sensitized solar cells. *Applied Energy*, *115*, 216–225. https://doi.org/10.1016/j.apenergy.2013.10.055

Raval, N., & Gupta, A. K. (2015). Historic Developments, Current Technologies and Potential of Nanotechnology to Develop Next Generation Solar Cells with Improved Efficiency. *International Journal of Renewable Energy Development*, *4*(2), 77–93. https://doi.org/10.14710/ijred.4.2.77-93

Yashwantrao, G., & Saha, S. (2022). Perspective on the rational design strategies of quinoxaline derived organic sensitizers for dye-sensitized solar cells (DSSC). *Dyes and Pigments*, *199*, 110093. https://doi.org/10.1016/j.dyepig.2022.110093

Calogero, G., Sinopoli, A., Citro, I., Di Marco, G., Petrov, V., Diniz, A., Parola, A. J., & Piña, F. (2013). Synthetic analogues of anthocyanins as sensitizers for dye-sensitized solar cells. *Photochemical & Photobiological Sciences*, *12*(5), 883–894. https://doi.org/10.1039/c3pp25347c

Shalini, S. &. B. P. R. &. P. S. &. M. T. K. &. S. S. (2015). Review on natural dye sensitized solar cells: Operation, materials and methods. *ideas.repec.org*. https://ideas.repec.org/a/eee/rensus/v51y2015icp1306-1325.html

Richhariya, G., & Kumar, A. (2021). Performance evaluation of mixed synthetic organic dye as sensitizer based dye sensitized solar cell. *Optical Materials*, *111*, 110658. https://doi.org/10.1016/j.optmat.2020.110658

Quang, L. N. D., Kaliamurthy, A. K., & Hao, N. H. (2021). Co-sensitization of metal based N719 and metal free D35 dyes: An effective strategy to improve the performance of DSSC. *Optical Materials*, *111*, 110589. https://doi.org/10.1016/j.optmat.2020.110589

Hardani, H., Cari, C., & Supriyanto, A. (2020). Characteristics Ruthenium (N719) as a photosensitizer in Dye-Sensitized Solar Cells (DSSC). *Prosiding SNFA (Seminar Nasional Fisika Dan Aplikasinya)*, *5*. https://doi.org/10.20961/prosidingsnfa.v5i0.46599

Portillo-Cortez, K., MartíNez, A., Dutt, A., & Santana, G. (2019). N719 Derivatives for application in a Dye-Sensitized Solar Cell (DSSC): a theoretical study. *The Journal of Physical Chemistry A*, *123*(51), 10930–10939. https://doi.org/10.1021/acs.jpca.9b09024

Boschloo, G. (2019). Improving the performance of Dye-Sensitized solar cells. *Frontiers in Chemistry*, *7*. https://doi.org/10.3389/fchem.2019.00077

Pandey, A., Ahmad, M. S., Rahim, N., Tyagi, V., & Saidur, R. (2018). Natural sensitizers and their applications in Dye-Sensitized Solar cell. In *Springer eBooks* (pp. 375–401). https://doi.org/10.1007/978-981-10-7284-0_15

Alappat, B., & Alappat, J. (2020). Anthocyanin pigments: Beyond aesthetics. *Molecules*, *25*(23), 5500. https://doi.org/10.3390/molecules25235500

Molina, A. K., Corrêa, R. C. G., Prieto, M. A., Pereira, C., & Barros, L. (2023). Bioactive natural pigments' extraction, isolation, and stability in food applications. *Molecules*, *28*(3), 1200. https://doi.org/10.3390/molecules28031200

Purnomo, T. a. B., Kurniawan, Y. S., Kesuma, R. F., & Yuliati, L. (2020). Selection of Maceration Solvent for Natural Pigment Extraction from Red Fruit (Pandanus conoideus Lam). *Indonesian Journal of Natural Pigments*, *2*(1), 8. https://doi.org/10.33479/ijnp.2020.02.1.8

Prakash, P., Janarthanan, B., Ubaidullah, M., Al-Enizi, A. M., Shaikh, S. F., Alanzi, N. B., Alkhalifah, R. I., & Ilyas, M. (2023). Optimization, fabrication, and characterization of anthocyanin and carotenoid derivatives based dye-sensitized solar cells. *Journal of King Saud University - Science*, *35*(4), 102625. https://doi.org/10.1016/j.jksus.2023.102625

Zakaria, R., Hassan, O. H., Yahya, M. Z. A., Taib, M. F. M., & Ali, A. M. M. (2018). Comparison of conductivity performance of dragon fruit dye extracted using water and ethanol for dye sensitized solar cells. *International Journal of Engineering & Technology*, *7*(3.11), 126. https://doi.org/10.14419/ijet.v7i3.11.15944

Tejamukti, E. P., Setyaningsih, W., Irnawati, I., Yasir, B., Alam, G., & Rohman, A. (2020). Application of FTIR Spectroscopy and HPLC Combined with Multivariate Calibration for Analysis of Xanthones in Mangosteen Extracts. *Scientia Pharmaceutica*, *88*(3), 35. https://doi.org/10.3390/scipharm88030035

Ali, R. a. M., & Nayan, N. (2010). Fabrication and analysis of dye-sensitized solar cell using natural dye extracted from dragon fruit. *ResearchGate*. https://www.researchgate.net/publication/287902064_Fabrication_and_analysis_of_dye-sensitized_solar_cell_using_natural_dye_extracted_from_dragon_fruit

Kurniawan, Y. S., Fahmi, M. R. G., & Yuliati, L. (2020). Isolation and Optical Properties of Natural Pigments from Purple Mangosteen Peels. *IOP Conference Series: Materials Science and Engineering*, *833*(1), 012018. https://doi.org/10.1088/1757-899x/833/1/012018

Kusumawati, N. (2017, June 16). *Extraction, Characterization and Application of Natural Dyes from the Fresh Mangosteen (Garcinia mangostana L.) Peel*. Kusumawati | International Journal on Advanced Science, Engineering and Information Technology. https://insightsociety.org/ojaseit/index.php/ijaseit/article/view/1014/pdf_416

Abirami, K., Swain, S., Baskaran, V., Venkatesan, K., Krishnan, S., & Bommayasamy, N. (2021). Distinguishing three Dragon fruit (Hylocereus spp.) species grown in Andaman and Nicobar Islands of India using morphological, biochemical and molecular traits. *Scientific Reports*, *11*(1). https://doi.org/10.1038/s41598-021-81682-x

Sambasevam, K. P. (2020). *Evaluation of Natural Pigment Extracted from Dragon Fruit (Hylocereus Polyrhizus) Peels*. https://www.semanticscholar.org/paper/Evaluation-of-Natural-Pigment-Extracted-from-Dragon-Sambasevam-Yunos/1fa6b378bf3cb2df6987b944020cee7c9bde59ba

Zaidi, A. A., Rafique, M., Aslam, S., Saleem, M., Ikram, M., Siraj, K., Latif, A., Sharif, R., Ghani, S., & Ahmad, M. (2020). Effects of solvents on structural, optical and photovoltaic properties of photo anodes for dye-sensitized solar cells. *Optik*, *200*, 163444. https://doi.org/10.1016/j.ijleo.2019.163444

APPENDIX A

Calculation for Band Gap Equation

$$E_g = \frac{1240}{\lambda}$$

Calculation for Efficiency

$$M = \frac{Voc\ x\ Isc\ x\ FF}{100}\ x\ 100\%$$

Calculation for Fill factor

$$FF = \frac{Imax\ x\ Vmax}{Isc\ x\ Vsc}$$

Calculation for short-circuit current density

$$JSC = \frac{Isc}{Asc}$$

Calculation for Absorption Coefficient

$$\alpha = -\frac{In(1-A)}{x}$$

APPENDIX B

Figure B.1: Preparation of ITO glass for took the paste TiO_2 and carbon black.

Figure B.2: Preparation of drying, extraction, and condensation of samples.

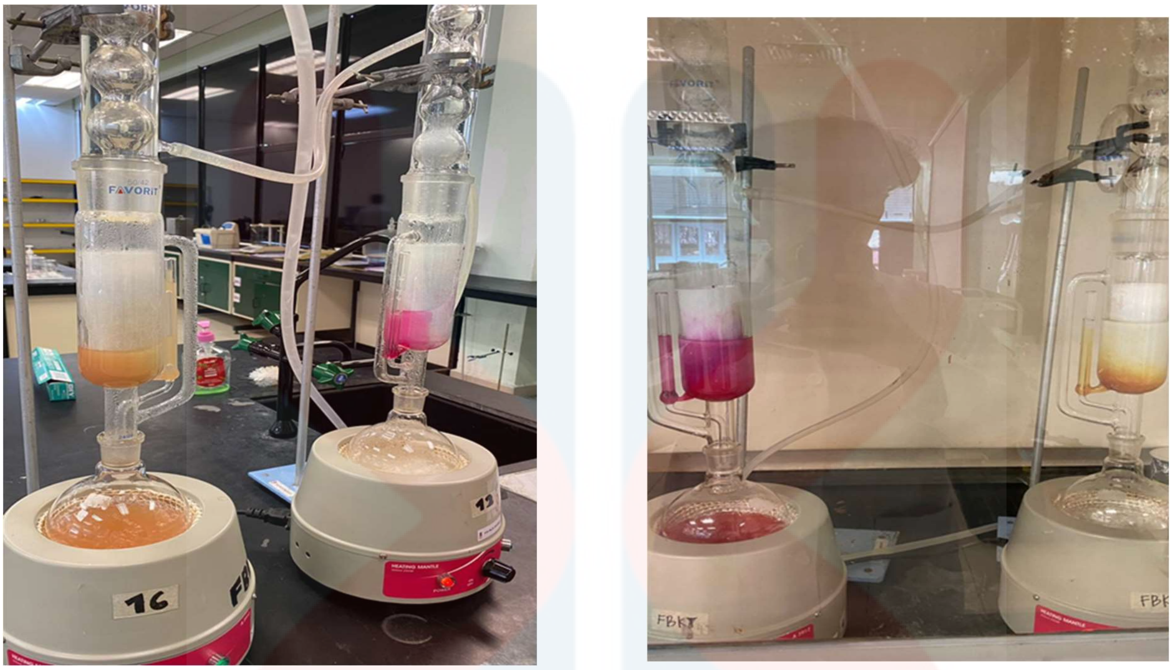

Figure B.3: Preparation of dye extraction of ethanol and deionized water using soxhlet.

Figure B.4: Preparation of dye extraction of samples using rotary evaporator.

Figure B.5: TiO_2 paste was deposited on the ITO glass and activated carbon was applied on the remaining substrates using the doctor blade method.

Figure B.6: Put ITO substrates (TiO_2 and carbon black) had been sintered in a furnace at 500 °C for 60 minutes both.

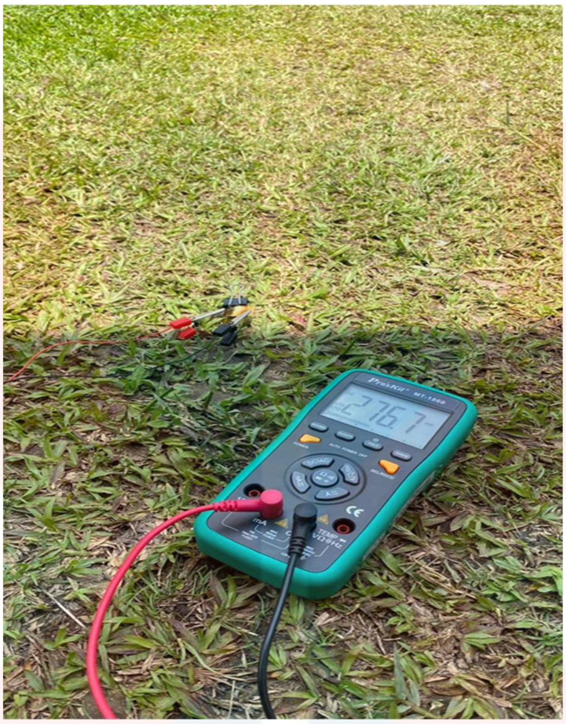

Figure B.7: Using a multimeter, measure the conductivity of the cleaned sides of ITO glasses.