2A07 STUDY ON CHLOROPHYLL'S CONCENTRATION DEPENDENCY TOWARDSELECTRICAL CHARACTERISTICS OF BANANA MIDRIB-BASED DYE-SENSITIZED SOLAR CELL FOR WASTE MANAGEMENT SOLUTION

RAHAYU BINTI RAHMAD

B.ENG (HONS.) ELECTRICAL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS AND COPYRIGHT

Author's Full Name	: RAHAYU BINTI RAHMAD
Date of Birth	: 29 JULY 1997
Title	:STUDY ON CHLOROPHYLL'S CONCENTRATION DEPENDENCY TOWARDS ELECTRICAL CHARACTERISTICS OF BANANA MIDRIB-BASED DYE-SENSITIZED SOLAR CELL FOR WASTE MANAGEMENT SOLUTION
Academic Session	: SEMESTER 2 2021/2022

I declare that this thesis is classified as:

☐	CONFIDENTIAL	(Contains confidential information under the Official Secret Act 1997)*
☐	RESTRICTED	(Contains restricted information as specified by the organization where research was done)*
☑	OPEN ACCESS	I agree that my thesis to be published as online open access (Full Text)

I acknowledge that Universiti Malaysia Pahang reserves the following rights:

1. The Thesis is the Property of Universiti Malaysia Pahang
2. The Library of Universiti Malaysia Pahang has the right to make copies of the thesis for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by:

RAHAYU

____
(Student's Signature)

970729015918
____
New IC/Passport Number
Date: 17 JUNE 2022

____
(Supervisor's Signature)

DR. AHMAD SYAHIMAN MOHD SHAH
____
Name of Supervisor
Date: 17 JUNE 2022

NOTE: * If the thesis is CONFIDENTIAL or RESTRICTED, please attach a thesis declaration letter.

THESIS DECLARATION LETTER (OPTIONAL)

Librarian,
Perpustakaan Universiti Malaysia Pahang,
Universiti Malaysia Pahang,
Lebuhraya Tun Razak,
26300, Gambang, Kuantan.

Dear Sir,

CLASSIFICATION OF THESIS AS RESTRICTED

Please be informed that the following thesis is classified as RESTRICTED for a period of three (3) years from the date of this letter. The reasons for this classification are as listed below.

Author's Name	RAHAYU BINTI RAHMAD
Thesis Title	STUDY ON CHLOROPHYLL'S CONCENTRATION DEPENDENCY TOWARDS ELECTRICAL CHARACTERISTICS OF BANANA MIDRIB-BASED DYE-SENSITIZED SOLAR CELL FOR WASTE MANAGEMENT SOLUTION
Reasons	(i)
	(ii)
	(iii)

Thank you.

Yours faithfully,

____
(Supervisor's Signature)

Date:

Stamp:

Note: This letter should be written by the supervisor, addressed to the Librarian, *Perpustakaan Universiti Malaysia Pahang* with its copy attached to the thesis.

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Electrical Engineering (Power System).

____

(Supervisor's Signature)

Full Name : Dr. Ahmad Syahiman bin Mohd Shah

Position : Senior Lecturer

Date : 22 June 2022

____

(Co-supervisor's Signature)

Full Name :

Position :

Date :

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

RAHAYU

____

(Student's Signature)

Full Name : RAHAYU BINTI RAHMAD

ID Number : EC18033

Date : 17 JUNE 2022

STUDY ON CHLOROPHYLL'S CONCENTRATION DEPENDENCY TOWARDS ELECTRICAL CHARACTERISTICS OF BANANA MIDRIB-BASED DYE-SENSITIZED SOLAR CELL FOR WASTE MANAGEMENT SOLUTION

RAHAYU BINTI RAHMAD

Thesis submitted in fulfillment of the requirements
for the award of the
B.Eng (Hons.) Electrical Engineering

College of Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2022

ACKNOWLEDGEMENTS

First of all, thanks to Allah S.W.T for his mercy and guidance in giving full strength to me in complete this project. Even I faced with some difficulties in completing this project. But, I still manage to complete it. Also, thanks to Allah S.W.T for giving a good health condition for me to have ability and strength in completing the project during the given time by a lecturer.

I would like to express the appreciation feeling to all lecturers that give me guidance and support throughout in completing this project. Moreover, the lecturer subject which is BEE4724 Engineering Project 2 lecturer who are Dr. Nur Huda Binti Ramlan and Dr. Zetty Adibah Binti Kamaruzzaman. Then, I would like to express my deepest appreciation to a special gratitude I give to my supervisor, Dr. Ahmad Syahiman Bin Mohd Shah who's supported my project under his guidance, gave me a great opportunity to involve in the project fabrication of dye-sensitized solar cells (DSSC).

Aside from that, I am grateful to my senior colleague who provides suggestions and advice on a regular basis. Thank you for always taking the time to share a knowledge about my project and for providing the best answers to all of my questions. Also, I would like to thank my fellow friends for their challenges and constructive criticism, especially on the part where I am weak and need to come up with a new way to do the work. Last but not least, I would like to express my gratitude to my family for their unending support and unconditional love. Thanks to my parents for their love and guidance in whatever I pursue. They are the ultimate role model.

ABSTRAK

Penggunaan klorofil sisa pelepah pisang sebagai pewarna semula jadi alternatif dalam Dye Sensitized Solar Cell (DSSC) boleh memberi manfaat. DSSC ialah teknologi yang menyumbang kepada sumber tenaga boleh diperbaharui, yang mesra alam dan kos rendah. Kesan kepekatan pewarna yang berbeza terhadap prestasi Sel Suria Peka Pewarna (DSSC) telah dikaji. Warna semula jadi yang digunakan dalam kajian ini diperoleh daripada klorofil pelepah pisang. TiO_2, klorofil dan KI masing-masing berfungsi sebagai elektrod kerja, fotosensitizer dan elektrolit dalam DSSC. Teknik *Doctor Blade* digunakan untuk membuat elektrod berfungsi. Selain itu, Sel Suria Peka Pewarna (DSSC) ialah sel solar generasi ketiga yang memanipulasi konsep fotosintesis tumbuhan untuk menuai tenaga daripada cahaya matahari dalam apa jua keadaan walaupun semasa penyinaran rendah atau intensiti cahaya. Klorofil, yang boleh diekstrak daripada kebanyakan tumbuhan hijau, adalah salah satu bahan penting dalam menyerap cahaya untuk penuaian tenaga. Memandangkan tahap kepekatan klorofil tertunda untuk setiap jenis, umur atau bahagian tumbuhan, banyak kajian yang berkaitan dengan skop ini telah dilakukan secara aktif. Dalam kajian ini, pelepah pisang yang kebanyakannya menjadi sisa biasa yang ditinggalkan kerana daun pisang dijadikan sebagai aroma dalam pembungkusan nasi lemak, lemang, tapai dan makanan tradisional. Dengan ini, akan mendapat manfaat untuk mengekstrak tahap kepekatan klorofil yang berbeza untuk fabrikasi tujuan DSSC. Hubungan antara tahap kepekatan klorofil dan keluaran sifat elektrik akan dianalisis dengan lebih lanjut

ABSTRACT

The application of banana midrib waste chlorophyll as an alternative natural dye in Dye Sensitized Solar Cell (DSSC) could be advantageous. DSSC is a technology that contributes to a renewable energy source, which is environmental-friendly and low in cost. The effect of different dye concentrations on the performance of Dye-Sensitized Solar Cells (DSSC) has been studied. The natural colours utilised in this study were derived from the chlorophyll of the banana midrib. TiO_2, chlorophyll and KI serve as a working electrode, photosensitizer and electrolyte in the DSSC respectively. Doctor Blade techniques were employed to make the functional electrode. Besides that, Dye-Sensitized Solar Cell (DSSC) is the third-generation solar cell that manipulates the concept of plant's photosynthesis in order to harvest the energy from the sunlight in whatever condition though during the low irradiance or light intensity. Chlorophyll, which can be extracted from majority of greeny plants, is one of the important substances in absorbing the light for energy harvesting. Since the concentration level of chlorophyll defers for each type, age or part of the plants, numerous studies related to these scopes have been actively performed. In this study, banana midrib that are mostly common waste are left because banana leaves are used as aroma in the packaging of Nasi Lemak, Lemang, Tapai and traditional foods. Hereby, will be benefited to extract different concentration levels of chlorophyll for the fabrication of DSSCs' purpose. The relationship between the chlorophyl's concentration level and the output of electrical properties will be further analyzed.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

η	Efficiency
%	Percentage
°C	Degree celcius
mg/L	milligram per litre

LIST OF ABBREVIATIONS

DSSC	Dye Sensitized Solar Cell
MPT	Maximum Power Point Tracking
UV-VIS	Ultraviolet- Visible Spectrophotometer
TiO_2	Titanium Dioxide
TCO	Conductive oxide
PE	Photoelectrode
FTO	Fluorine-doped tin oxide
ITO	Indium Tin Oxide
Pt	Platinum
CE	Counter electrode
C	Carbon
MPN	3-methoxy propionitrile
ZnO	Zinc oxide
I-	Iodide
I3-	Triiodide
In	Indium
Chl a	Chlorophyll a
Chl b	Chlorophyll b
TC	Total Chlorophyll
HOMO	Highest Inhabited Molecular Orbit
LUMO	Lowest Inhabited Molecular Orbit
I-V	Current-Voltage
Voc	Open Circuit Voltage
Jsc	Short Circuit Current Density
FF	Fill Factor
Rsh	Shunt Resistance
Rs	Series Resistance

CHAPTER 1

INTRODUCTION

1.1 Project background

The dye-sensitized solar cell is a type of photovoltaic technology that converts solar energy into electricity, and it was invented by Gratzel for the first time. DSCC is a type of solar cell that is both inexpensive and environmental- friendly (Sowmya et al., 2021). A dye as a photosensitizer, an electrolyte to supply electrons to the dye, catalysts to draw electrons into the electrolyte (counter electrode), and a layer of semiconductor, often TiO^2, as the dye adsorption and electron transport (working electrode) make up the DSSC structure.

Dye sensitized solar cells (DSSCs) have emerged as one of the most promising technological advancements in renewable energy. The dye, as a sensitizer, is critical in determining the performance of DSSC. Because of their ease of preparation, feasible extraction processes, cost-effectiveness, and environmental friendliness, metal-free natural dyes have proven to be a convenient substitute for rare and expensive Ruthenium-based dyes. Natural dye extraction uses leaves, flowers, petals, barks, and roots that contain chlorophyll, carotenoid, betalains, anthocyanin, and flavonoid pigments. (Iqbal et al., 2019).

The stability, efficiency, and cost of dye sensitized solar cells (DSSC) are not solely determined by the materials used. Fabrication procedures are critical for improving the performance of DSSCs since these qualities are linked to the manner of layer preparation and deposition. Doctor blade method, the blade moves over the substrate at a constant velocity with a specific contact angle and height. The displacement of the blade uniformly distributes the paste onto the substrate, resulting in a fixed thick film. The layer thickness achieved by this method is in the 10–500m range. This technology is less expensive and reduces particle loss by about 5% when compared to spin-coating (Agrawal et al., 2021).

There are various criteria for selecting carbon-based composite materials with the appropriate qualities for DSSC counter electrodes, including high surface area, great conductivity, and outstanding mechanical and thermal stability, all of which allow for improved electrolyte interaction (Jiang et al., 2018). Due to its superior electric conductivity and thermal stability, FTO conducting glass is often utilised in DSSC. However, because the fluorine-doped tin oxide thin film has a greater refractive index than the glass basis, FTO glass has a low transmittance. Meanwhile, TiO_2 compact film is always coated on FTO to improve connectivity between the porous TiO_2 film and the FTO and to reduce electron recombination in the DSSC (Li et al., 2019).

The photoanode, active material (absorbing layer), electrolyte, and counter electrode are the components of DSSCs (López-Covarrubias et al., 2019). The active materials (dye) absorb light passing through the photoanode, and electrons migrate from the dye's highest occupied molecular orbital (HOMO) to the dye's lowest unoccupied molecular orbital (LUMO). The excited electrons are then injected into a TiO_2 or ZnO photoanode, which carries them to an external circuit and to the counter electrode, as described elsewhere (IK, 2018). The counter electrode transports electrons to an electrolyte intermediate, which replaces the photoanode's lost electrons. "Chlorophyll a" and "chlorophyll b" are two types of chlorophyll found primarily in green plants. Every photosynthetic plant has "chlorophyll a," while higher plants and algae have "chlorophyll b." The porphyrin structure of chlorophyll contains pyrrole rings. Chlorophyll (wormwood) dyes were used as photo-sensitizers in DSSCs, with power conversion efficiency of 0.90 %. (Ezike et al., 2021).

The photoelectrochemical properties of DSSC were measured under 1.5 AM illumination. Under visible light (400-700nm) irradiation, dyes with carboxyl and hydroxyl functional groups displayed mild to significant absorption. With open circuit voltages ranging from 0.28 to 0.45 V and short-circuit photocurrent densities ranging from 0.26 to 1.69 mA.cm-1, the photo-electrochemical performance of the different cells was as high as 0.18 percent. By optimising the DSSC constructional characteristics, better efficiencies can be achieved. (Chemistry International, 2021).

1.2 Problem statement

Renewable energy technologies have been popular recently among researchers and developers. The availability of fossil fuel will eventually run out with escalating population rate in near future has triggered the researcher and developer to invent technologies from renewable sources (Chintagunta et al., 2017). For the problem statement is silicone-based solar module has difficulties in capturing direct energy from the sunlight when the solar irradiance is very low (during the rainy, early morning, late evening. Banana midrid become common waste left after the consumption of banana leaves as food packaging as well as traditional *kuih muih*. Waste is typically disposed of by burning or decomposing and contributes to environmental problems (Omar et al., 2020). To overcome this problem, the application of DSSC introduced to make the renewable source energy supply as alternative technologies able to control the pollutant and reduce the waste (Phadtare et al., 2019).

1.3 Objective

The following are the objectives of this research:

1. To investigate the effect of applied external factors to the chlorophyll concentration.

2. To analyze the significance of chlorophyll concentration towards the overall electrical performance of the DSSC.

1.4 Scope of Study

The scopes of this research using chlorophyll-based as dye sensitizer. Besides, Fluorine-doped tin oxide (FTO) (2.5cm x 2.5cm) is used as a conductive glass. It is an important parameter for determining the overall capacity of a solar cell. It describes the quality and suitability of solar cells compared to other glass. Meanwhile, the size of the FTO solar cell (active area) is approximately (1.5 cm x 1.5 cm). Then, during DSSC operation, the electrolyte using potassium iodide (KI) is responsible for the inner charge carrier transit between electrodes and continuously regenerates the dye and itself. For chlorophyll the expected value 150-500mV/sample.

CHAPTER 2

LITERATURE REVIEW

2.1 Conventional uses of banana by-products and waste

Banana is a one-of-a-kind single-harvest perennial crop. The pseudostem and leaves, which are visible, die after it bears fruit, allowing the rhizome to rebuild the freshly emerging plant. Fruit plucking on a plantation needs the decapitation of the entire plant so that young suckers can take its place, and this cycle can go on indefinitely. The pseudostem, leaves, inflorescence, fruit stalk (floral stalk/rachis), rhizome, and peels are all banana by-products. The majority of these by-products can be viewed of as a low-cost commodity with limited commercial value and application, as well as agricultural waste in some situations. In farms, the pseudostem and leaves are typically allowed to degrade in order to replenish some of the nutrients in the soil. Banana inflorescences have a relatively low value due to fluctuating demand and limited acceptability. Banana leaves are still used to wrap traditional dishes in Southeast Asia, however only for a few ethnic foods (Mengstu et al., 2021).

Burning banana wastes could cause serious environmental problems in some areas where "open fire burning" is still practised. Furthermore, the accumulation of banana waste in farms is an eyesore, preventing farmers from collecting mature and ripe bananas. Banana flower stalks and peels are not sold directly from the farm, but they can be found in processing plants where the fruit is packaged or the fleshy pulp is extracted from the peels. Trash from a single banana plant can account for up to 80% of the plant's total mass. 220 tonnes of by-products are produced per hectare each year, necessitating a novel approach to converting these freely available resources into value-added goods (Kerubo Oyaro et al., 2020).

2.1.1 Banana by-products as potential renewable resource in promoting “green” technology

Renewable resources, also known as biomass, are a naturally abundant resource that includes any biologically generated materials such as plants and animals, agricultural products, and biological residues or wastes. These resources can be converted into recyclable and rapidly biodegradable raw materials or products, resulting in environmental acceptability or a "green label" as well as commercial viability. Renewable resources have paved the way for industry for decades, replacing non-renewable resources such as petroleum and gas products, precious metals, and minerals. To ensure the long-term growth of technology, it is critical to promote the use of low-cost agricultural by-products and biological wastes to all imaginable enterprises (Vijayan et al., 2021).

Green technology is a type of ecologically friendly technology that focuses on conserving natural resources while offering the fewest risks to existing species on the planet, including humans. Because reliance on agro-food commodities such as maize to drive green technology will eventually result in food insecurity, ethical concerns, and unsustainable energy returns, the technology should be self-contained from the current agro-food commodity market. Banana by-products are widely available as a source of raw materials for the green technology industry due to their availability of biomass. The fact that bananas have been consumed by humans for a long time with no major negative consequences provides some assurance that these by-products are free of potentially harmful phytochemicals. By-product harvesting, handling, and storage may require less attention than harvesting, handling, and storing other plants with potent and harmful chemical contents. Because it is not dependent on the current agro-food oriented market, the use of banana by-products for industrial applications could boost "green technology." Furthermore, it does not necessitate additional planting space in addition to the current banana plantation for fruit (Ahmed, 2020).

2.2 Organic solar cells

The third generation of solar cell types is the result of research to reduce the cost of solar cells even more. This solar cell is a form of polymer solar cell that is also known as organic solar cells and photo solar cells. Materials such as polyphenylene vinylene and fullerene are used to make organic solar cells. In contrast to the first and second generation solar cell types, which rely on the arrival of photons from sunlight to generate electron pairs and holes as their primary mechanism, third-generation solar cells rely on these incoming photons to produce an awakened exciton instead of a charge pair. Exciton diffuses on two surfaces of the conductor material (typically at glue with semiconductor organics in between two pieces of conductor) to form a pair charge and subsequently a photo current effect (photocurrent) (Hiramoto, 2020).

A photochemical solar cell is a form of solar cell exciton that is made up of a layer of nanoparticles (typically titanium dioxide) that has been coated in a dye. Professor Graetzel was the first to introduce this form of solar cell in 1991, hence it's also known as Graetzel cells or dye-sensitized solar cells (DSSC). This Graetzel cell contains a redox pair that is immersed in an electrolyte (solid or liquid). The use of solar cell composers like this allows the Graetzel cell maker's raw material to be more versatile, and it may be created using a method as easy as screen printing. Despite the fact that this third generation solar still has significant efficiency issues, and the active age of the cells is still too high. In summary, this form of solar cell will be able to have a significant impact in the next 10 years due to its low cost and simple manufacturing procedure (Chemistry International, 2021).

2.3 Fabrication of DSSC

2.3.1 Fluorine-doped Tin Oxide (FTO)

In order to fabricate dye-sensitized solar panels, a variety of conductive glass can be employed. Fluorine-doped tin oxide (FTO) conductive glass is one of the most promising materials for dye-sensitized solar cell fabrication. The FTO conductive glass was chosen for this study because it has a higher heat resistance than other conductive glasses such as ITO. Because of its transparent and conductive nature, FTO is an excellent choice. Furthermore, FTO outperformed ITO in terms of high- temperature processing capability and stability. Thermal stability was shown to be higher in FTO than in ITO. (Korjenic & Raja, 2019).

2.3.2 Photoelectrode and Counter electrode

In this project, carbon as graphite is used in pencils will be used as counter electrode. The counter electrode is usually made up of a conductive catalytic layer, which is a crucial component of DSSCs. Counter electrode make complete the circuit and allow DSSC charge to flow. The counter electrode can be prepared using a variety of techniques, including sputtering, spin coating, dipped coating, electrochemical procedures, and so on. The structural, morphological, and electrical properties of Pt counter electrodes with various textures were studied (Oktariza et al., 2018).

FTO as conducting glass and then coated with another layer which made out of from combination dye (banana midrib) and TiO_2. The name for this glass is photoelectrode. A sensitised semiconductor (photoelectrode) is placed between a catalytic electrode (counter electrode) and an electrolyte in a DSSC. In DSSCs, the photoanode plays a significant role in electron separation and transportation (Mursal et al., 2021).

2.4 The Application of Chlorophyll to make DSSC

Chlorophylls are the most common pigments used in DSSCs as it can be found in all plants. Chlorophyll can absorb red, blue, and violet wavelengths of light and then reflect the green wavelength. These pigments are also in charge of converting light energy into chemical energy. The strong absorption peaks in the visible regions were presented at 420nm and 660nm wavelength in the chlorophyll has attracted many researchers in many fields including photochemical fields. Nowadays, fossil fuels resources such as natural gas, coals and crude oil were considered the important world energy resources (Richhariya et al., 2017). However, due to limited sources and expenses, sustainable and renewable technologies from biomass was introduced. Hence, application of chlorophyll in replacing synthetic dyes in solar cell was chosen because of solar energy is the largest exploitable resource among renewable energy, it gives the globe with more energy in an hour than the entire planet consumes in a year (Panda et al., 2018).

2.4.1 Characteristics of DSSC

Sunlight is the most abundant and sustainable energy source, therefore the approach of device for the effective capture and storage of solar energy become interest of studies by worldwide researchers. Researchers decided to develop dye-sensitized solar cells based on a similar working mechanism in order to mimic the photosynthesis process of absorbing and converting solar energy into chemical energy. The mechanism of DSSC mimics photosynthesis of plants has attracted researcher to investigate the ability of chlorophyll in plants. Chlorophyll was the plant component responsible for absorbing light and converting it into chemical energy. Meanwhile, in DSSC, sensitizer is the component which react like chlorophyll, trap visible light, and transform it into electricity (Okoye et al., 2021).

The electrode film layer (TiO_2) the conductive transparent conductive oxide layer, the counter electrode layer and the redox electrolyte layer are the four main components of DSSC (Yang et al., 2014). Electrode film layer commonly used titanium dioxide (TiO_2) was covered by a monolayer of dye molecules is functioned as light absorber to generate electricity. Titanium dioxide (TiO_2) is one of the popular semiconductors used in DSSC since it is nontoxic, cheap and possesses a large bandgap. TiO_2 is deposited on the TCO substrate in the form of dioxide TiO_2 nano porous particle network to increase the coverage and consequently more sunlight can penetrate into the semiconductor layer. DSSC consists of two transparent conductive oxide (TCO) layers covered with glasses or plastic substrates working as electrodes which are known as Photoelectrode (PE) and Counter electrode (CE) (Maharjan, 2020). TCO becomes a common substrate used in solar cell by researchers because of the high efficiency and high transparency. Photoelectrode (PE) is deposited with mesoporous TiO_2 film covered with dye molecules while Counter electrode deposited with platinum (Pt) and Carbon (C) catalyst for redox reduction process. The fluorine-doped tin oxide (FTO) was used as semiconductor, dye assembly and highly transparent for absorption of sunlight was referred as photoanode in DSSC. A good semiconductor should have high porosity, high surface area and fits with the characteristics of sensitizer to increase the efficiency of the cell (Kusuma, 2017). The Indium-doped tin oxide (ITO) and FTO are two common TCOs used as semiconductor in DSSC. However, due to low availability of Indium (In) and brittle nature, FTO substrate glass coated was more preferable.

Sensitizer is functioned as absorber of solar radiation and main part of the conductivity of the cell. A sensitizer should have hydroxyl group and carbonyl group that required for a good binding with the semiconductor. It should not easily degrade and can absorb a maximum absorbance from visible to near infra-red region of solar radiation to make a good sensitizer (Jaafar et al., 2022). The metal complex sensitizer, natural sensitizer and metal free organic sensitizer are the three types of sensitizers. The metal complex sensitizers were expensive and toxic for nature while for metal free organic sensitizer gives a less efficiency of cell and has complicated synthetic route. Therefore, natural dyes sensitizer becomes latest research by researchers as it employs more simple extraction process and more environmental compared to other types (Richhariya et al., 2017).

Other remaining components in DSSC an electrolyte with reduction-oxidation (redox) mediator and cathode. The main function of electrolyte is to regenerate the dye in the solar . Electrolyte should have these criteria's which are low viscosity, high boiling point, negligible vapor pressure and have high dielectric properties (Ndeze et al., 2021). According to Cahaya et al., 2019, I-/I3- is the commonly used electrolyte as it provides high efficiency to the solar cell. The cathode in DSSC was made up of another TCO on top where the platinum is deposited. The interface between two electrodes is filled with organic electrolyte containing a redox pair like tri-iodide (I3-) or iodide (I-) in an organic solvent like 3-methoxy propionitrile (MPN) function as to reduce the amount of energy provided by the dye molecule. The edge of both electrodes is sealed together with a thermoplastic polymer film that also known as surlyn.

This device offers a physically and economically effective alternative concept to existing p-n junction photovoltaic equipment. It has been identified as one of the attractive sources of renewable energy for the eco-friendly and cost-effective conversion of solar energy into electricity, due to the use of cheap materials, easy manufacturing processes and low environmental impact, especially those sensitized by natural dyes (Hardani et al., 2020). Unlike conventional solar cells, dye-sensitized cells can perform well in low-light environments and are less prone to energy heat loss (Sathishkumar Chinnasamy & Sivasubramanian Ramanathan, 2020).

2.4.2 Operating principle of DSSCs

The operating principle for components of dye sensitized cell. When sunlight strikes the semiconducting oxide (TiO_2) on photo electrode, dye adsorbed on TiO_2 absorb a photon from sunlight. The electrons excite from low to high energy state with the presence of energy from photons. The excited electrons then injected to the conduction band of TiO_2, and oxidized dye is regenerated by capturing electron from the redox electrolyte. Conventionally, the cathode is composed of platinum while anode is an optically transparent electrode like ITO or fluorine tine oxide (FTO) (Kutlu, 2020). To achieve a high energy conversion efficiency, the interface between two electrodes is filled with organic electrolyte containing a redox pair like tri-iodide (I3-) or iodide (I-) (Mehmood et al., 2022). Then the electron from TiO_2 were transported to the conducting substrate of photo electrode using diffusion process.

In counter electrode, electron was transferred from photo electrode to substrate of counter electrode by the help of external electrical circuit. Platinum used as electrode helps in enhancing the transfer of electron between counter electrode and electrolyte and helps in reducing charge transfer resistance counter electrode from 106 to 0.8 to 11 Ω/cm2 (Chandra, 2022). Electrolyte one of the main parts that helps in completing circuit of DSSC and helps in minimize the electron transport problem between photo and counter electrode using ionic transport of redox pair. It should be chemically stable, a good solvent of redox and additives for redox couple components and have low viscosity to provide the best performance of DSSC (Revathi & Jeyakumari, 2021).

As these technologies typically rely on a TiO_2, the challenge encounter during increasing the efficiency of DSSCs has consequently reduce the recombination between the injected electron in TiO_2 and the electrolyte (Gong & Krishnan, 2019). More recombination takes place at the grain boundaries between the TiO_2 nanoparticles (Andualem & Demiss, 2018). For this reason, more experiment conducted to increase the shuttling efficiency of electrons within the TiO_2 network toward the anode. Other than that, usage of platinum as electrode also a great challenge for DSSC. The platinum counter electrode is highly cost and corrosive liquid electrolyte. Hence, to overcome this problem, the performance of counter electrode was fabricated with conducting polymer and using of polyelectrolyte to eliminate the usage of liquid electrolyte that might leaked out in the cell.

The performance of DSSC is generally evaluated based on the parameters of the cell such as power conversion efficiency (η), short circuit current density (Jsc), fill factor (FF) and open circuit voltage (Voc) obtained from its current density versus cell voltage (J-V) characteristics curve (Govindarasu et al., 2021). Open circuit voltage (Voc) is the maximum voltage that can attained from a solar cell when the terminals open. As the light generated current, Voc corresponds to the amount of forward bias on the solar cell. The voltage of an open circuit can be read even though no current connected in the solar. The total open-circuit voltage decreases with increasing cell temperature. The Voc of the cell was expressed as below (Eq. 2.1):

$$Voc = Vt \ln (Jsc/Io) + 1) \qquad (.2.1)$$

Short circuit current (Jsc) can be found at the short circuit terminals of the cell. It happened when the current through the solar cell with the zero voltage across the solar cell. This was due to excessive current flow in the power source that make the solar short circuited. Different from Voc, Jsc is directly proportional with the temperature of solar cell. The expression for short circuit was shown in Eq 2.2.

$$Jsc = I + Io \{\exp (V/Vt) -1\} \qquad (2.2)$$

Fill factor (FF) of solar cell is an important parameter in measuring the quality of the solar cell that determine the power conversion efficiency of solar cell. It compares the maximum power (actual power) to the theoretical power of output at both the open circuit voltage and short circuit current together. When the shunt resistance (Rsh) increases and the series resistance (Rs) decreases, it leads to a higher fill factor, thus the greater efficiency can be achieved and bringing the cell’s output power close to its theoretical maximum. Typical range of fill factors is from 50% to 80% ("Difference between nominal voltage, VOC, Vmp, Isc and imp”, 2020).

$$FF = Vm\ Im/Voc\ Jsc \qquad (2.3)$$

$$N= FF.\ Voc.\ Jsc/ \text{Incident optical power} \qquad (2.4)$$

Vm stands for maximum voltage can be defined as the availability of voltage when the panel connected to a load and operating at maximum capacity under standard test condition. Common value of Vmp was around 70% to 80 % of the Voc. Meanwhile for Imp is when the power output at greatest. The actual amperage reading can be seen when connected to Maximum power point tracking (MPPT). Last but not least, the efficiency of solar cell. It can define as ratio of electrical power to the optical power incident in the cell as shown in Eq 4. Scientist found that the capability of converting electricity from direct sunlight only achieved 44.5 % efficiency (Ward, T. 2017). While for common solar cell, the maximum efficiency is about 25%.

2.4.3 DSSC using chlorophyll

The photoelectric conversion efficiency based on chlorophyll pigment as a natural sensitizer in DSSC was carried out using various kind of plants to determine the performance of chlorophyll sensitized DSSCs. The majority of research in chlorophyll DSSC has been done using an extraction process from natural pigments. Natural sensitizer derived from spinach chlorophyll exhibits photoelectrical performance with an open circuit voltage (Voc) of up to 550 mV, a current short circuit (Isc) of about 0.46 mA, and a fill factor (FF) of about 51% (Zanjanchi & Beheshtian, 2018). Wormwood as a chlorophyll dye for DSSC produced an open circuit voltage of 0.585V and a current short circuit of approximately 1.96 mA, the conversion efficiency is 0.538 % and fill factor of the cell (FF) was about 47%. The efficiency using wormwood plants as sensitizer is 0.9% compared to bamboo and maple which only has 0.7% and 0.4%, respectively. The DSSC device performance from the chlorophyll in leaves of Syngonium Podophyllum Schott shows the 0.308% efficiency, 0.86V of open circuit, 0.6 mA in a current short circuit and fill factor (FF) was about 44.69 (Pratiwi et al., 2017).

2.5 Methods of Extraction Chlorophyll

Extraction is a process of separating desirous solutes from samples by using the effective extraction method. Extraction process plays an important role to get the contents of bioactive compounds for utilization purposes including chlorophyll. This is possible by using a variety of chemical, biochemical, and mechanical techniques to maximise yields while minimising product quality changes. In this research, chlorophyll extraction from banana midrib waste is the main product to get highly efficient chlorophyll to make as a sensitizer in the solar cell. The best method of extraction needs to be chosen by considering other factors as well such as the extraction must be less time consuming, low cost, environmentally friendly and importantly, it can produce high volume of chlorophyll content. This is due to the fact that the extraction process will have an impact on the performance of chlorophyll in DSSC later on (Al-Alwani et al., 2018).

2.5.1 Mechanical extraction

Mechanical extraction is one of the oldest and most widely used methods for separating bioactive compounds. Cell disruption technique followed by mechanical method was found as the most efficient device to increase the extraction yield of chlorophyll from the sample. Mechanical extraction for large scale disruption commonly employs mechanical pressing, bead milling, and homogenization. Generally, extraction using these methods can be accomplished by exerting a sufficient force on the sample. Under this condition, with some pressure is high enough to rupture the cells and produce juice extracted from the sample. This operation can be done in either a batch or continuous process (Ahmed & Anwar, 2022).

Bead milling, also known as bead homogenization, is one of the mechanical cell disruption processes used in the extraction of bioactive components such as chlorophyll. The process of cell disruption will induce through shear forces produced during the rotary movement of the cell and the beads. The collision between beads and cells implicates the mechanism of bead milling disrupt cells as cell grinding between beads. Observations using confocal microscopy after 30 minutes of grinding show that significant damage to the cell wall has occurred, and it is hypothesized that the large contact surface between the cells and the beads made bead milling highly efficient in this case. In the research paper of bead milling has offered a great potential for large scale cell disruption for microalgae. This method was found to be highly efficient at causing cell wall damage and enabled the release of chlorophylls and carotenoids of C.vulgaris. The studies also found the highest yield and overall violacein purity was obtained when using bead milling method (Nemer et al., 2021).

Next, the sugarcane press machine which is another mechanical extraction type available in the laboratory and small-scale level extraction. The sugar cane pressing machine is a well-established processing machinery used to extract juice from the fruits in the processing of plant material. Sugarcane press machine operated by loading the fruit sample into a hopper and then pressing against the grating surface. It is then directed to the compression chamber, where a presser lever is located, and extraction juice is produced. The extracted juice can be gathered using the tap. The efficiency of this extraction to crush and expel juice from plant fibre was measured by its effect on the complete collapse of the cell wall that entraps the juice. As a result, the sample size and operating speed must be considered. The extraction of ferulic acid from a banana stem was used in a sugarcane press machine at 15,000rpm for 15 min. A high yield of extraction volume of juice was produced, and the process only took a least time than other extraction was reported in the experiment. Additionally, this method is very easy to handle because it does not include any chemical substance and is cheaper than solvent extraction (Diantoro et al., 2019).

2.5.2 Chemical extraction

Chemical extraction is a technique that uses selected chemicals to separate hazardous contaminants from soils, sludges, and sediments, minimising the amount of hazardous material that must be treated. Eventhough this method uses chemical solvent, it does not destroy the content in the wastes. Acid extraction and solvent extraction are the two types of chemical extraction processes used. Most common form of chemical extraction used for extraction of bioactive components including chlorophyll is solvent extraction by using organic solvent such as ethanol, acetone, and dimethyl sulfoxide (DMSO). The selection of solvent for the extraction process is a critical step in this technique because it affects the extraction's efficiency later on (Jassim, 2020).

Many experiments have been conducted to achieve a better result of extraction and reduce the interference of the product especially for recovering crucial bioactive compounds like phytochemicals from plants. The extraction of chlorophyll from A. sessilis using 80% (v/v) of acetone was found increasing up to a ratio of 8 ml/g. Meanwhile, the extraction of chlorophyll from spinach, the highest yield of chlorophylls obtained from spinach using methanol solvent was reported. This is because methanol is less polar than ethanol, so it is easier to soluble into chlorophyll (Jinasena et al., 2016).

The ratio of solvent and material must be considered as well in this method to achieve high efficiency of extraction. The studies have been conducted with 90% acetone with different ratio and from the result, it was found the ratio of 5 % and 10% gave the highest extraction efficiency with 0.341 and 0.340 %, respectively. Chla ratio for both ratios also gave a highest value with 63.3% for 5% ratio and 60.7% for 10%. When the material increasing, the extraction efficiency would decrease gradually due to the insufficiency of solvent for full dissolution and extraction of chlorophyll from mulberry leaves cell (Tran et al., 2019).

Even though these experiments prove that this method is less time consuming, it was found that this method gives several drawbacks especially for obtain active components. Such as low extraction efficiency and low selectivity. Furthermore, some of chemical usage is not environmental-friendly and may affect human health. These extractions also require a large quantity of solvent (Sagar et al., 2018). Hence, mechanical extraction is considering a preferable method compared with chemical extraction due to no limitation of extraction and high-rate extraction contents can achieve as well.

2.5.3 Enzymatic extraction

Enzymatic extraction is a biological extraction method that ensures the pigments remain in their natural form. This plant treatment method could be used to extract pigment compounds such as chlorophyll. In nature, chlorophyll is a stable pigment with a green colourant; however, after extraction from plant tissue, the colour may degrade and a derivative of chlorophyll, such as pheophytin and pyropheophorbide, will form. This is due to enzymes and other factors as well such as acid, pH, light, and heat. The main reason for the loss of green colour of chlorophyll of olive green is because of the pH changes and resulted changes of the characteristics of olive green to brown colour of pheophytin. Enzymatic extraction, which uses enzyme to act as an excellent catalyst to assist in the extraction, modification, or synthesis of complex bioactive compounds without affecting the pigment's natural origin, has thus proven to be an effective extraction method for controlling chlorophyll degradation. Enzyme extraction was predicated on the enzyme's intrinsic capacity to catalyse reactions with fine selectivity and the ability to work in aqueous solutions under mild processing conditions. (Siddick et al., 2018).

Many researchers have proposed enzyme treatment as an alternative method of conducting the solvent extraction process. This is because of the limitation of chemical extraction to yield a high concentration of active components due to presence of polysaccharides in plant cell walls and the negative environmental effects when using a large amount of toxic organic solvents, enzymatic extraction was considering a good technique to replace solvent extraction method. Enzymatic extraction of Zn-chlorophyll from pandan leaf produces greater green colour values and more chlorophyll pigments than nonenzymatic extraction. The capacity to suppress the synthesis of lipid hydroperoxide from thiocyanate and ferric nitrilotriacetate was improved by changing the porphyrin structure in chlorophyll molecules, but also increase the colour value of chlorophyll (Madnasri et al., 2019).

Enzyme extraction is more environmentally friendly than chemical extraction since it uses water as a solvent instead of organic chemicals. This method significantly suitable to extract bound compound without loss the origin nature of the pigments and offered high extraction rate as well. However, there also a limitation in using this method. Due to the sensitivity of enzyme behaviour, using enzyme in the extraction was not possible at an industrial level. This method also costly especially in usage of high enzyme in the large volume of sample (Sagar et al., 2018). Hence, it can conclude that, mechanical extraction is a better choice to extraction of chlorophyll compared with these two methods, chemical and enzymatic extraction.

2.6 Factor Affecting Chlorophyll Extraction

The stability of chlorophyll contents in plants is known to be affected by several factors such as extraction time, heat pre-treatment and storage time. Many experiments have been conducted to minimize the chlorophyll degradation that can affect the functionality of chlorophyll later. Analysis of how those factors affect the sample will be explained in detail in the next subtopic

2.6.1 Extraction time on chlorophyll contents

The number of extractions one of the factors that has significant influence on the extraction of both types of chlorophylls. The number of extractions done was dependent on type of sample used and the extraction method used to extract chlorophyll from the sample, either chemically or mechanical method. Generally, multiple extraction is better than single extraction in getting the number of chlorophyll content from the sample. As the number of extractions is increased, the extraction efficiency will increase as well.

Most of experiment conducted by researcher were use chemical extraction According to Ernest Z., (2016) several extractions with smaller volume of solvents are consider more effective than a single extraction with a large volume of solvent used. With the multiple extractions done, the amount of material left on the residue will lower and the extraction will be more complete (Menner, 2019). It can be proven from the experiment conducted on 0.1g of fresh leaves (evergreen type) using 95% ethanol with four replicates and the result shows the higher yield of contents chlorophyll a and chlorophyll b with 11.72 (mg/g) and 5.03 mg/g, respectively (Ying et al., 2018). According to Castle et al., (2018) extraction using methanol shows at least three extractions were necessary to capture more than 75% of chlorophyll a from the sample. Extraction efficiency of the first two extraction recovered is ranged from 79 to 82% and 87% for DMSO and ethanol, respectively. The result indicates that long extraction times needed to get a highly efficient extraction of chlorophylls.

Total chlorophyll content with different solvent has been conducted to determine the number of extractions to get higher yield of chlorophyll a content using different type of crust. The crust type used were dark, intermediate, and light type. The result obtained shows the recovery of chlorophyll using ethanol for dark type is 13.79 μg chlorophyll/ g soil (ISO,1992) and 12.37 μg chlorophyll/ g soil with 31% recovery with extraction time is five times. Same as well for the extraction chlorophyll using 90% acetone, 7.67 μg chlorophyll/ g soil and 9.25 μg chlorophyll/ g soil. While using DMSO, it was found that using 4 times extraction can give 10.85 μg chlorophyll/ g soil by considering the degradation of chlorophyll a to phaeophytin. However, studies also found that when more numbers of extraction time were done especially for chemical extraction method has resulted in the degradation of chlorophyll content (Castle et al., 2018). Hence, we can conclude the selection of solvent used for extraction depend on the sample used should be considered as it influenced the time of chlorophyll extraction.

2.6.2 Time and condition of storage

To avoid degradation of chlorophyll, the effective method of storage for extracted chlorophyll has been conducted in various storage conditions. Extracted chlorophyll was stored in a closed container in the freezer section, open air, closed dark container, dried in the oven for six hours and cooler in the refrigerator. The loss of chlorophyll is low in refrigeration compared to other storage conditions. The researcher also found that drying chlorophyll extract can reduce the loss of chlorophyll especially in long term storage. The possibility to lose chlorophyll is high in ambient conditions at temperature 40°C with

84% of chlorophyll loss. Better preservation chlorophyll for A. sessilis after drying at 70°C compared to drying at 40°C. According to J. H. Wu et 38 al., (2019) chlorophyll in moso bamboo (Phyllostachys pubescence) can be preserved in a dark environment at 4°C for 8 days and 30 days with a selected solvent.

Strong chlorophyll degradation happened in high temperature and recommended to be kept in a low temperature (Park et al., 2018). Only 30 % of chlorophyll was retained in the leaves dried at 98°C. Quick freezing has improved the recovery of chlorophyll a compared when it freezes at -20°C. 5-10% of chlorophyll degraded was found by researchers when it kept at -20°C within six weeks due to enzymatic reactions (Wang et al., 2021). Prevention of chlorophyll loss in low storage temperatures is not effective for soybean and nasturtium leaves but freezing it with dry ice has retained all their chlorophylls. Willsatter (2018) stated that the optimum temperature for the action of chlorophyllase is about 20°C. The loss of chlorophyll contents at room temperatures (18°C to 24°C) only lost 20 to 30 %. Increasing or decreasing drying temperature of dried leaves can stop the enzyme activities and eventually, retain the amount of chlorophyll.

2.6.3 Temperature and heat pre-treatment on chlorophyll concentration

Chlorophyll extraction can be improved by increasing the temperature of extraction. However, strong degradation of chlorophyll can be prominent at high temperatures during the extraction process thus, the selection of suitable temperatures has been conducted in many experiments. Researcher finds that the optimum temperature of chlorophyll extraction is at 50°C on chlorophyll of A. sessillis with the time extraction not exceeding 2 hours. The chlorophyll content in mulberry is decreasing when the temperature exceeds 35°C. Only 48.87% of chlorophyll retained at 40°C compared to the temperature at 25°C with 63.37%. In addition, increasing temperature also converted chlorophyll into new compounds such as pheophytin (dark olive) in mulberry leaves (Tran et al., 2019).

Pre- treatment is a process after extraction of chlorophyll done. This method can be done by cell disruption, enzyme treatment, blanching or dried samples in certain temperatures. Studies found that using a method of cell disruption as pre-treatment of chlorophyll extraction has given the highest yield of chlorophyll contents. Cell disruption by mechanical grinding with the sample cut into small pieces is better than using mortar and pestle (Nemer et al., 2021). Degradation of chlorophyll in pre- processing was found more significant with blanching (cooking the sample in boiling water) and dried in oven for six hours at temperature 40°C. Recently, enzyme treatment as pre-process under optimum condition has been proposed. Normally, this application is used in the extraction to get the flavors and colorants from the sample. However, it is reported that enzyme pre-treatment is not suitable for recovery of chlorophyll (Sowbhagya & Chitra, 2018).

2.7 DSSC Fabrication Categorization

The table below shows the journals/papers that have been reviewed and summarized in several columns.

No.	Title	Glass	Photoelectrode	Dyes	Evaluated parameters	Jsc / Isc	Voc	Finding
1	Fruit peels pigment extracts as a photosensitizer in ZnO-based Dye-Sensitized Solar Cells	FTO	TiO_2 /ZnO	Fruit peels pigment (Musa paradisiaca, Mangifera indica, Punica granatum, and Ananas comosus)	1. Fourier transform-infrared (FT-IR) analysis of natural pigments 2. X-ray diffraction (XRD) analysis of ZnO powder	0.033 to 0.265 $mAcm^{-2}$	0.214 to 0.288 V	The higher conversion efficiency noticed from DSSCs with Mangifera indica peels can be linked to better dye molecules adsorption accessible to ZnO film and transfer of charge in the ZnO-dye-electrolyte interface
2	Chlorophyll Pigments as Nature Based Dye for Dye-Sensitized Solar Cell (DSSC)	ITO	TiO_2	Spinach	1. Photoelectrical properties of DSCs sensitized with chlorophyll pigment 2. Bandgap estimation and absorption coefficient of the dyes	0.32 to 0.35 mA	0.384 to 0.44V	Chlorophyll pigments can be used as a dye sensitizer in DSSC because of its ability in absorbing photon from sunlight and having light harvesting invisible light spectrum and it was proven by testing its observed rate using UV-Vis spectrophotometer
3	Application of dyes extracted from Alternanthera dentata leaves and Musa acuminata bracts as natural sensitizers for dye-sensitized solar cells	FTO	TiO_2	1. Alternanthera dentata leaves 2. Musa acuminata bracts	Photoelectrochemical parameters of the DSSC using the natural extracts of A. dentata leave and M. acuminata bracts	0.5 to 0.9 $mAcm^{-2}$	0.58 to 0.54 V	Under the same extraction, preparation, and irradiation conditions, the performance parameters of the DSSC sensitized with anthocyanin from M. acuminata leaves was higher than those of the DSSC sensitized with chlorophyll from A. dentata leaves
4	Review on the development of natural dye photosensitizer for dye-sensitized solar cells	FTO	TiO_2 / ZnO	Natural dyes	Photoelectrochemical parameters of natural dyes based DSSC.	0.305 $mAcm^{-2}$	0.426 V	Recent developments on different kinds of sensitizers for DSSC devices have led to the use of natural dyes that absorb sunlight within the visible spectrum with higher efficiencies.
5	Performance of Pterocarpus Indicus Willd Leaf Extract as Natural Dye TiO_2-Dye/ITO DSSC	ITO	TiO_2	Pterocarpus Indicus Willd leaves	The solar cell parameters extracted from I-V measurements	0.370817 mA/cm^2	0.400197 V	The dye immersion duration affected the DSSC efficiency. Longer immersion duration results in a decrease in the DSSC efficiency

No.	Author	Title	Glass	Photoelectrode	Dyes	Evaluated parameters	Finding
6	Siddick, S.Z., Lai, C.W., Juan, J.C.	An investigation of the dye-sensitized solar cell performance using graphene-titania (TrGO) photoanode with conventional dye and natural green chlorophyll dye	Fluorine-doped Tin Oxide (FTO) Glass	TiO2/rGO photoanode	1. N719 commercialize dye 2. Natural green chlorophyll dye.	1. Dye absorption spectra 2. Photovoltaic performances of DSSCs 3.EIS analysis of DSSCs 4. Characterization of TrGO photoanode	HRTEM and FESEM images also revealed the growth of the TiO2 on the RGO surface giving rise to an increase in the light absorption ability of DSSCs
7	Madnasri, S., Hadi, S., Wulandari, R.D.A., Yulianti, I., Edi, S.S., Prastiyanto, D.	Performance Stability and Optical Properties of Musa Acuminata bracts-based Dye-Sensitized Solar Cell	ITO	TiO2 / Spray coating of zinc oxide (ZnO)	musa acuminata bracts	The absorbance of Musa acuminata bracts at different volume fraction.	The best fraction of the extraction of banana is 0.3. ZnO coating used the spray coating method is best performed 10 times spraying.
8	Błaszczyk, A., Joachimiak-Lechman, K., Sady, S., Tański, T., Szindler, M., Drygała, A.	Environmental performance of dye-sensitized solar cells based on natural dyes	FTO	TiO2	Juice, pomace, leaves of black chokeberry and N719 dyes	1.Photovoltaic parameters of fabricated DSSCs 2. Environmental impact assessment of analyzed DSSCs expressed as cumulative eco-indicators (Single Scores).	The production of synthetic N719 dye as a single inventory element has higher environmental impact than the production of natural dyes from black chokeberry.
9	Ruba, N., Sowmya, S., Prakash, P., Janarthanan, B., Inbarajan, K.	A novel idea of using dyes extracted from the leaves of Prosopis juliflora in dye – Sensitized solar cells	FTO	TiO2	Prosopis juliflora leaves	Evaluation parameters of the DSSCs constructed using the sensitizers extracted from the leaves of Prosopis juliflora.	Using dyes from Prosopis leaves with different solvents turned to a partial success, because the photoconversion efficiency is higher than few DSSCs made with natural dyes extracted from leaves.
10	Ndeze, U.I., Aidan, J., Ezike, S.C., Wansah, J.F.	Comparative performances of nature-based dyes extracted from Baobab and Shea leaves photo-sensitizers for dye-sensitized solar cells (DSSCs)	FTO	Spin-coating of titanium dioxide (TiO2)	Baobab and Shea dye extracts.	1. Photoelectrochemical parameters of the cells sensitized with natural extracts 2. Optical Parameters for the extracted dyes.	Shea-based DSSCs (SDSSCs) have better power conversion efficiency (PCE) of (0.25 ± 0.13) % due high short-circuit current density compared to Baobab-based DSSCs (BDSSCs) with PCE of (0.11 ± 0.028) %

No.	Title	Journal	Glass	Photoelectrode	Dyes	Jsc / Isc	Voc	Wavelength	Finding
11	The Effect of Photo electrode Ti02 Layer Thickness to The Output Power of Chlorophyll-Based Dye Sensitized Solar Cell (DSSC)	IEEE Journal of 2015 International Seminar on Intelligent Technology and Its Applications	TCO-ITO	TiO2	Jatropha leaves.	15.2 μA	0.321 V	200-800 nm	The fabricated-DSSC based on chlorophyll dye using different thickness layer has been produced with different output power.
12	Short Review: Natural Pigments Photosensitizer for Dye-Sensitized Solar Cell (DSSC)	IEEE Journal of 2017 IEEE 15th Student Conference on Research and Development (SCOReD)	FTO	TiO2	Zadirachta indica leaves	0.43 mA/cm²	0.40 V	471 nm and 662 nm.	This paper emphasizes the most commonly used natural pigments; anthocyanin, chlorophyll and betalain extracted from leaves, fruits and flowers of several plants that had proven that it is the main factor affecting the energy conversion efficiency of DSSC

13	Natural dye extracted from Pandannus amaryllifolius leaves as sensitizer in fabrication of dye-sensitized solar cells	Int. J. Electrochem. Sci., 12 (2017) 747 – 761, doi: 10.20964/2017.01.56	FTO	TiO_2	Pandan leaves	0.4 mA/cm²	0.55 V	400–800 nm	Dyes extracted from pandan leaves (P. amaryllifolius) were found to be highly soluble in ethanol and soluble in acetonitrile, chloroform, ethyl ether, and methanol. The extract obtained using ethanol performed slightly better than extracts derived using the four other solvents
14	Extraction, preparation and application of pigments from Cordyline fruticosa and Hylocereus polyrhizus as sensitizers for dye-sensitized solar cells	Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, VOL. 179, 15 May 2017, Pages 23-31	FTO	TiO_2	Cordyline fruticosa	1.3 mA/cm²	0.616 V	658 nm and 412 nm	The Cordyline fruticosa leaves and Hylocereus polyrhizus fruit's extracts were studied as natural dyes for DSSCs. The UV–Vis absorption spectra of the mixed of chlorophyll-anthocyanin from C. fruticosa leaves and betalains from H. polyrhizus dyes have been studied with different solvents and temperature to determine the optimum parameters due to pigments extracted.
15	Comparative photo-response performances of dye sensitized solar cells using dyes from selected plants	Surfaces and Interfaces, VOL. 20, September 2020, 100619	FTO	TiO_2	Lonchorcarpus cyanescens leaves	6.23 $mAcm^{-2}$	0.384 V	700 nm	Less expensive and more environmentally friendly solar cells can be fabricated using readily available natural dyes in contrast to the highly expensive and less environmentally friendly synthetic dyes such as the Ruthenium dyes

CHAPTER 3

METHODOLOGY

3.1 Flow of Methodology

A flow chart of the whole process has been constructed in Figure 3.1. Firstly, banana midrib were collected as the sample. Then, the sample was extracted by mechanical extraction using an electrical sugarcane press machine to get the juice. After that, the analysis of chlorophyll contents in the extracted sample is using Ultraviolet-Visible Spectrophotometer (UV-VIS). Then, fabrication of photoelectrode (TiO^2)

Next step which is preparation of counter electrode using graphite element (pencil). Then, assembling both counter electrode and photoelectrode (TiO_2) facing each other. After that, for electrical part, measurement of open circuit voltage (Voc) under direct sunlight and measurement of I-V characteristics which is open-circuit voltage (Voc), current density (Jsc), Fill factor (FF) and Efficiency (η) under a solar simulator. Lastly, can evaluation and analysis of obtained results.

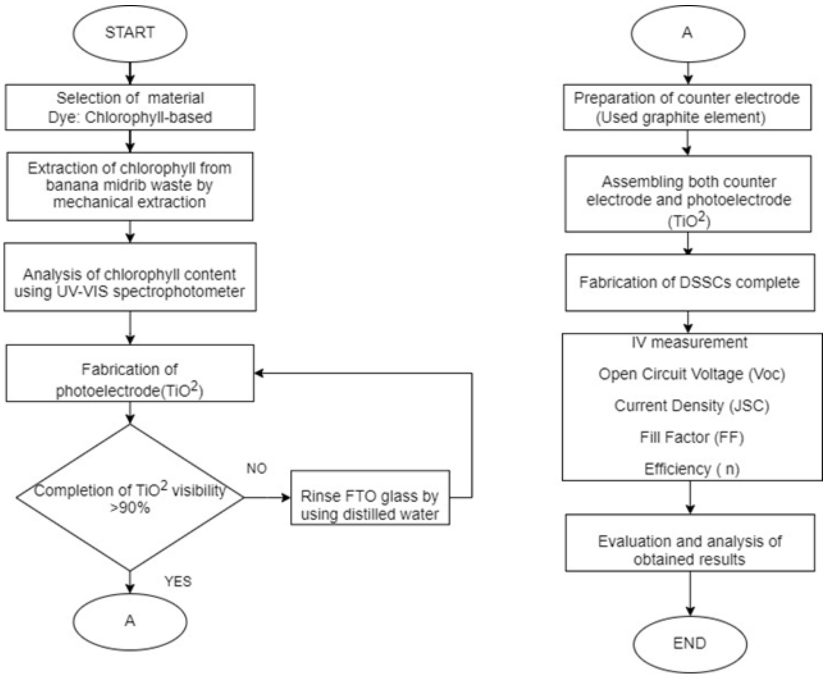


Figure 3. 1: Process flowchart of experiment.

3.2 Material and Equipment List

The material and equipment are listed in the Table 3.1 and Table 3.2 based on the factor need to be examine in this research.

Table 3. 1: The material and equipment need to be used for the extraction of chlorophyll

Factor	Material	Equipment/tool
Extraction time	16 banana midrib of the same size Tap water	Sugarcane machine Knife Basin Centrifuge tube Aluminium foil Pen/marker Sticker label Paper towel
Storage time	Juice of sample	Storage sample Pen/marker Sticker label refrigerator

Heat pre-treatment	Juice of sample	Hot plate beaker Paper towel Sticker label Aluminium foil

Table 3. 2: The material and equipment need to be used for analysis the content of chlorophyll

Material	Equipment/tool
Juice banana midrib sample Water (blank)	UV-VIS Spectrophotometer Cuvette Kim wipes Tissue Dropper

3.3 Preparation of the sample

For the preparation of the sample, cut into small pieces with constant length by using a knife, Next, the banana midrib waste were cleaned first using tap water to remove any contaminant and soil that might have affected the extraction later. Next, dry the samples by using a paper towel. The sample was then ready to be extracted with a sugarcane machine and analyze the chlorophyll contained by using UV-VIS Spectrophotometer.

3.4 Extraction of chlorophyll from banana midrib by mechanical extraction

The prepared samples of banana midrib were extracted by using a sugarcane press machine in the FTKKP laboratory. The juice extracted from the extracted samples was filtered and collected from the pipe. The chlorophyll juice was then collected and placed into a centrifuge tube, ready for analysis of chlorophyll contents using UV-VIS spectrophotometer.

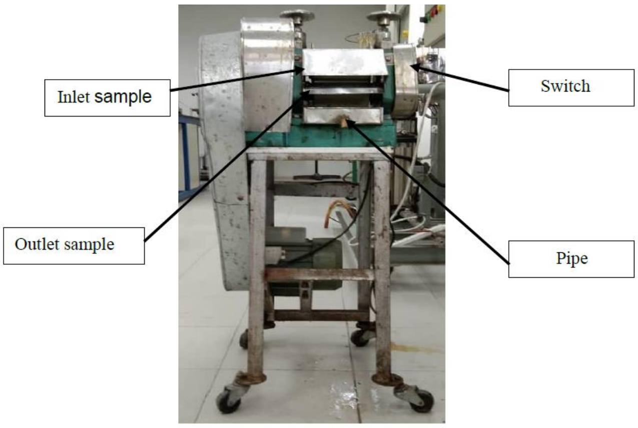


Figure 3. 2: Sugarcane press machine

3.5 Analysis of chlorophyll contents using UV-VIS spectrophotometer

The analysis of chlorophyll contents in the banana midrib juice can be done by using the UV-VIS Spectrophotometer. The juice will help to identify the chlorophyll content in the sample. The total chlorophyll contents divided into 2 which are chlorophyll a and chlorophyll b. According to the calibration graph of standard chlorophyll, the wavelength set for chlorophyll a was 662 nm, while chlorophyll b was 646 nm. The equation for the chlorophyll a and b calculates as shown in Eq. 3.1 to 3.3

$$chl\ a\ (mg/L) = \frac{A662 - 0.0014}{0.0922} \qquad \text{Equation 3.1}$$

$$chl\ b\ (mg/L) = \frac{A646 - 0.0011}{0.043} \qquad \text{Equation 3.2}$$

$$\text{Total of chlorophyll} = \text{Chlorophyll a} + \text{Chlorophyll b} \qquad \text{Equation 3.3}$$

Where: A_{662} = absorbance at a wavelength 662nm;
A_{646} = absorbance at a wavelength 646nm

Figure 3. 3: UV-VIS Spectrophotometer

3.5.1 Measurement of Absorbance

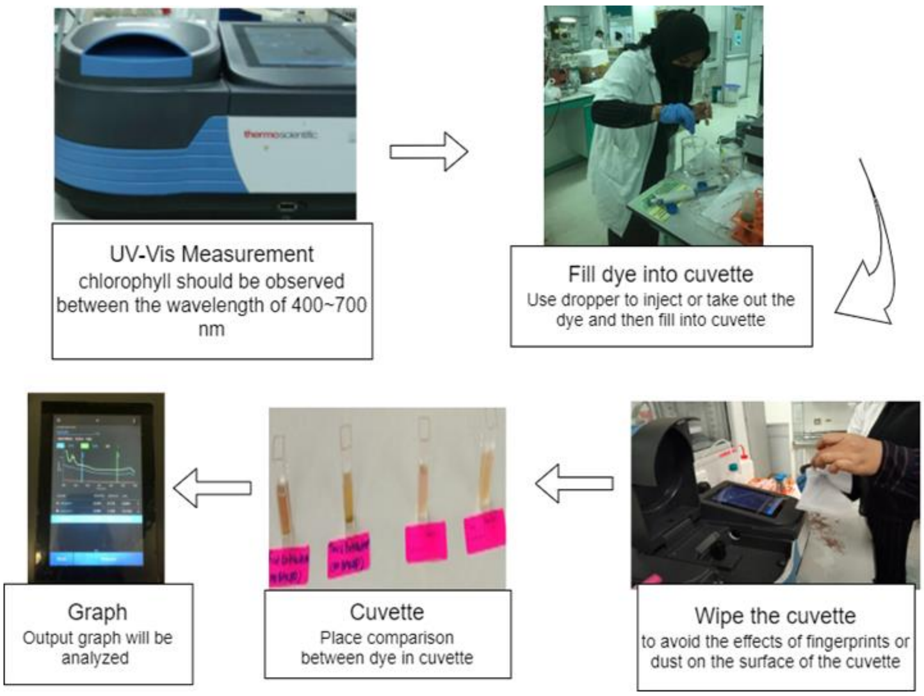


Figure 3. 4: How to measure of chlorophyll content using UV-Vis

3.6 External Factors

There were 3 selected factors in this study. The factors were extraction time, storage time and heat pre-treatment. Table 3.3 shows the factors and conditions examined in this study.

Table 3. 3: Selected factors and their conditions

Factors	Conditions
Extraction time	1-3 times
Storage Time	8-24 hours
Heat pre-treatment	Yes/No

Based on all the factors, The extraction time was done by a using sugarcane machine. The extraction time refers to the amount of waste that was pressed into the sugarcane machine. Then, the sample was stored in the refrigerator in the range of 8 hours to 24 hours. Lastly, the heat pre-treatment was applied by heating juice above the hot plate at 100°C. Figure 3.5 shows the process for the extraction of chlorophyll. The first extraction means the banana midrib rolling in sugarcane machine for the first time. The second extraction means used the same midrib that has been rolled for the first time, rolled again all the midrib. The third extraction also used the same midrib that has been rolled for the second time, rolled again in sugarcane machine.

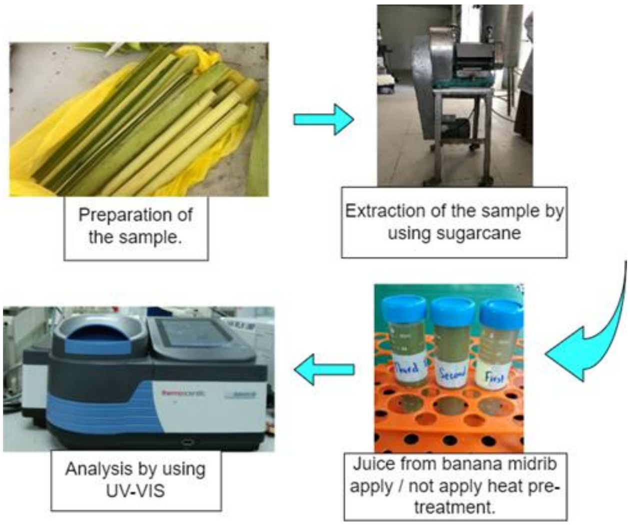


Figure 3. 5: Process for the extraction of chlorophyll

3.7 DSSCs fabrication process

3.7.1 Preparation of TiO_2 layers

Titanium Oxide (TiO_2) was used as a photo electrode on Fluorine Doped Tin Oxide (FTO) as a conductive glass. The FTO conductive glasses used in this project are (2.5cm×2.5cm) in size. Preparation of TiO_2 layers process is Titanium Dioxide (TiO_2) powder is weighted approximately 2g by using analytical balance and placed into a beaker. The beaker is then gradually filled with 4ml of ethanol and 2ml of acetic acid. For 15 minutes, the mixture is stirred with a glass rod until it forms a paste. The beaker is covered by using aluminium foil and let it in fume hood for a while to let the particles equilibrium. The FTO conductive glass was cleaned by using ethanol because to remove any dust or material.

A multimeter was used to measure the conductivity of Fluorine Doped Tin Oxide (FTO) glass. Using the doctor blade method, TiO_2 paste is applied to the FTO glass. Then, the uses of the tape to tape one side of the dye-sensitized solar cell is to make the FTO glass not moving and stay at that placed. Before heating, allow the paste to dry naturally in a fume hood at room temperature. FTO glass is heated by using a Hot Plate for 45 minutes at temperature 450 °C.

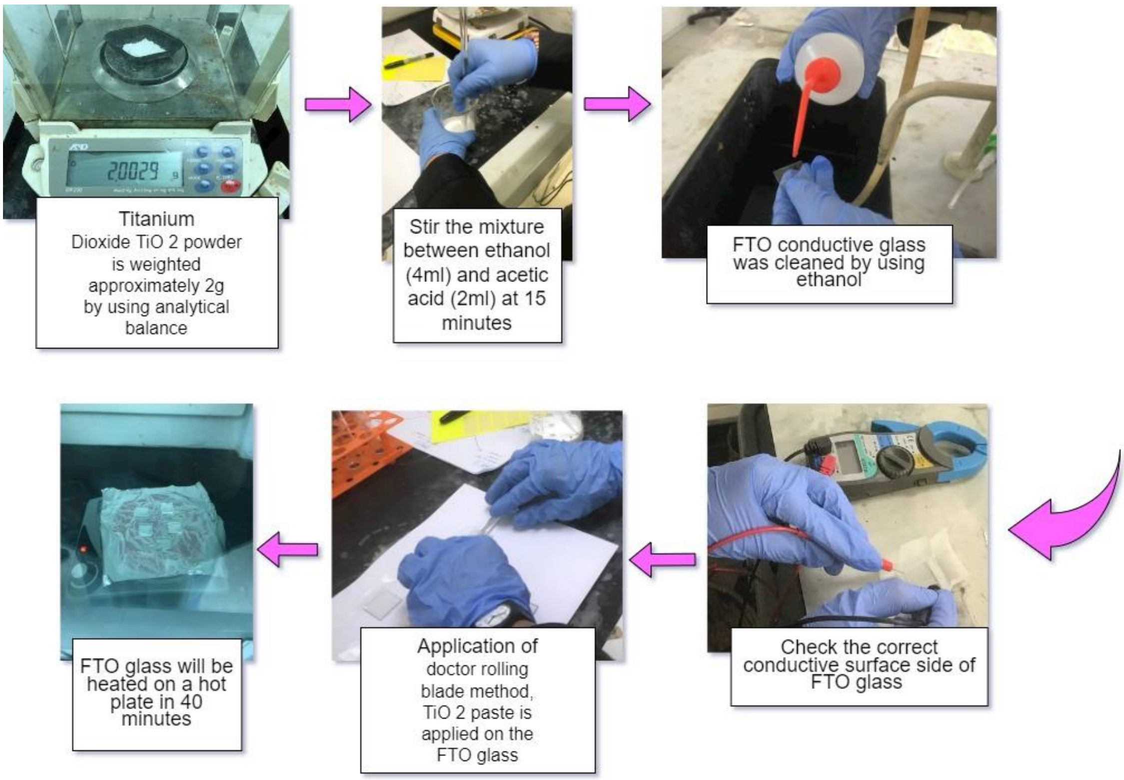


Figure 3. 6: Preparation of TiO_2 layers

3.7.2 Preparation of photoelectrode and counter electrode

Preparation of photoelectrode and counter electrode process is need to immerse the TiO_2 glass in a petri dish with three different dye extraction after done heating process. Next, wrapped using aluminium foil to prevent exposure from air and store it in a dark place for 24 hours. Following that, rinse the FTO glass with distilled water to remove the juice that remains on the FTO glass during immerse process. Then, the other FTO glass is shaded to serve as a counter electrode. After that, clip between working electrode glass and counter electrode glass together to form a sandwich. Drop KI that react as electrolyte before measurement. This fabrication of dye-sensitized needed in order to investigate the output electrical performance of solar cells under sunlight condition and under a solar simulator.

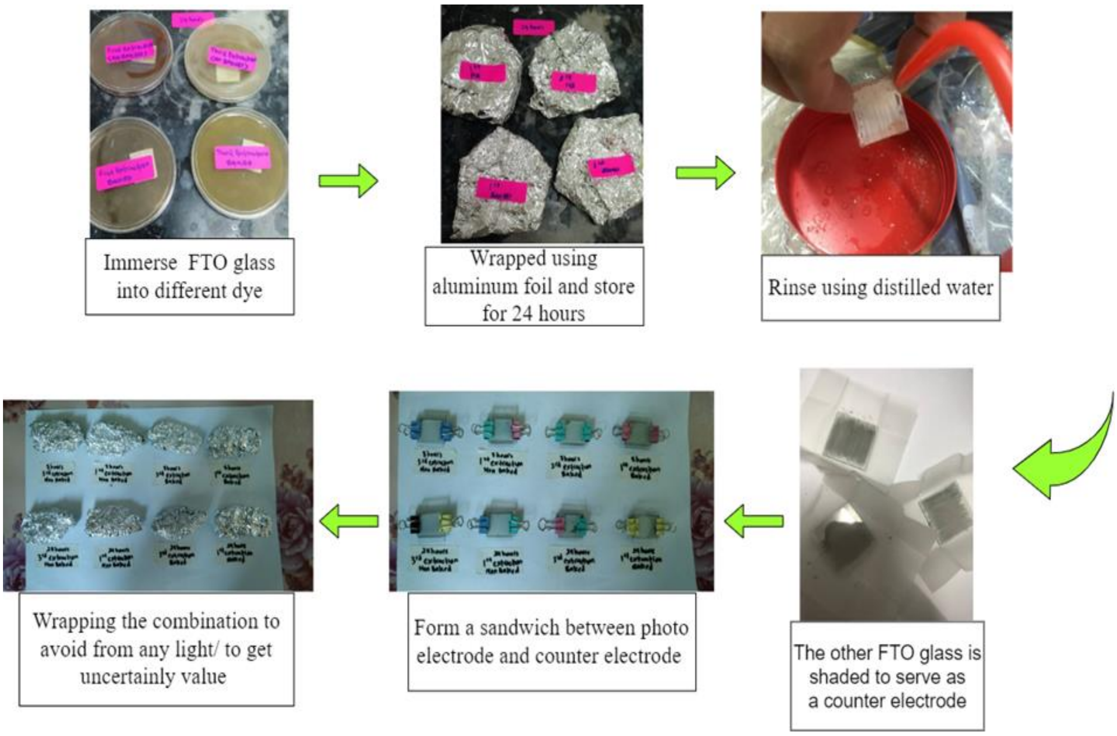
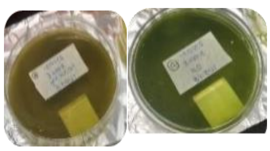
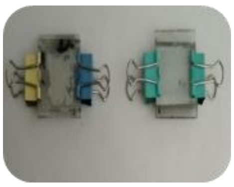
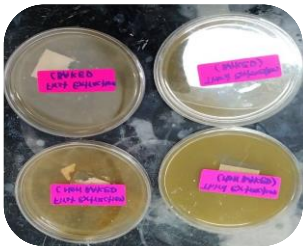


Figure 3. 7: Preparation of photoelectrode and counter electrode

3.8 Sample of fabricated

Table 3. 4: The 10 sample has been done fabricated

10 sample of dye solution	**TiO_2 immersion in dye**	**DSSC**
First Batch ✓ 2 times extraction, pre-heated, 8 hours storage ✓ 2 times extraction, non pre-heated, 8 hours storage		
Second Batch (8 hours) ✓ 3 times extraction, pre-		

heated, 8 hours storage ✓ 1 time extraction, pre-heated, 8 hours storage ✓ 3 times extraction, non pre-heated, 8 hours storage ✓ 1 time extraction, non pre-heated, 8 hours storage		
Second Batch (24 hours) ✓ 3 times extraction, pre-heated, 24 hours storage ✓ 1 time extraction, pre-heated, 24 hours storage ✓ 3 times extraction, non pre-heated, 24 hours storage ✓ 1 time extraction, non pre-heated, 24 hours storage		

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Absorption characteristics by Ultraviolet-Visible Spectrophotometer

In this section analysis of chlorophyll content was performed using UV-Vis Spectrophotometer. Analysis has been completed on 10 DSSC samples which are divided into 2 batches where the first batch is only 2 samples while the second batch is 8 samples. Below shows the results that have been recorded.

4.1.1 Absorption characteristics for First Batch Sample

- 8 hours storage time

Table 4. 1: Absorption for second extraction non pre-heated and pre-heated (8 hours)

Wavelength(nm)	Second Extraction (NB)	Second Extraction (B)
400	3.901	2.9
420	2.999	2.912
440	2.8	2.549
460	2.78	2.577
480	2.522	2.214
500	2.646	2.009
520	2.521	1.99
540	2.479	1.632
560	2.599	1.502
580	2.189	1.477
600	2.099	1.319
620	2.014	1.319
640	1.978	1.187
660	1.789	1.082
680	1.527	1.012
700	1.385	0.77

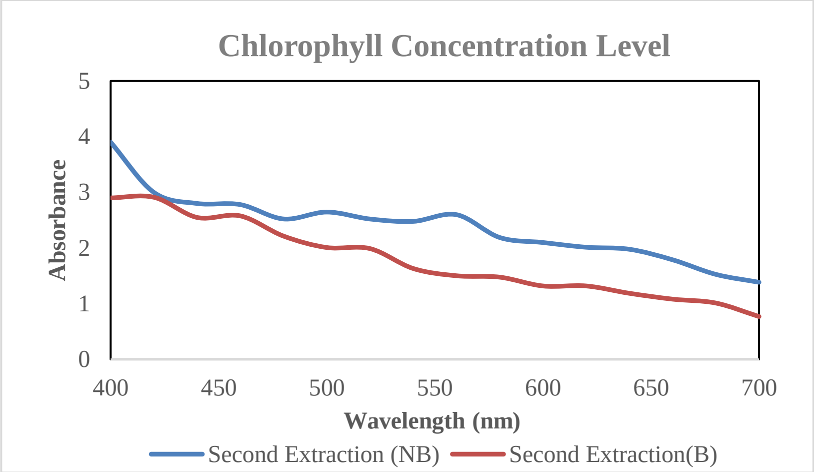


Figure 4. 1: Absorption curve for second extraction non pre-heated and pre-heated

Figure 4.1 shows the measure of absorption is only for the second extraction, it is because for the juice from the first extraction is no longer natural it has been mixed with water during mechanical extraction using sugarcane machine. Then, for the juice from the third extraction it is not enough to make the TiO_2 glass soaking process.

4.1.2 Absorption characteristics for Second Batch Sample

- 8 hours storage time (non pre-heated)

Table 4. 2: Absorption for first & third extraction non pre-heated (8hours)

Wavelength(nm)	First Extraction (NB)	Third Extraction (NB)
400	4.5	3.901
420	2.612	3.999
440	2.549	3.5
460	2.277	2.98
480	2.214	2.922
500	2.001	2.746
520	1.79	2.621
540	1.632	2.679
560	1.502	2.899
580	1.477	2.189
600	1.319	3.899
620	1.319	3.914
640	1.187	4.178
660	1.082	1.789
680	1.012	1.527

700	0.77	1.385

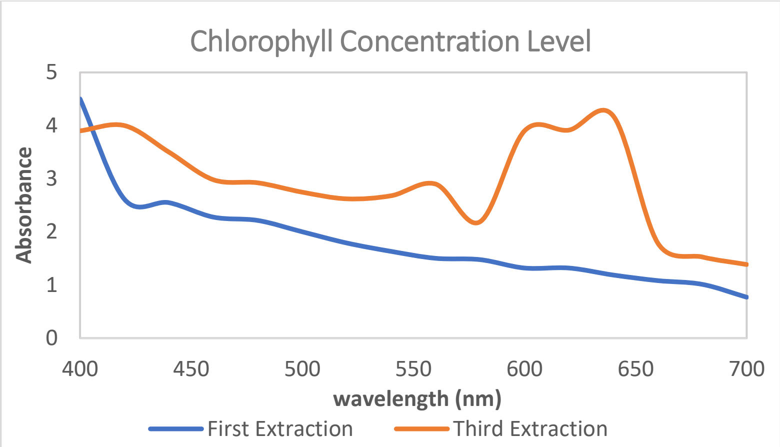


Figure 4. 2: Absorption curve for first & third extraction non pre-heated (8hours)

Figure 4.2 shows the third extraction have a highest peak value of absorption at wavelength 640nm. It is because this sample is the best chlorophyll concentration level in the dye solution among the other sample.

- 8 hours storage time (pre-heated)

Table 4. 3: Absorption for first & third extraction pre-heated (8hours)

Wavelength(nm)	First Extraction (B)	Third Extraction (B)
400	4.5	3.901
420	2.612	3.999
440	2.549	3.5
460	2.277	2.98
480	2.214	2.922
500	2.001	2.746
520	1.79	2.621
540	1.632	2.679
560	1.502	2.899
580	1.477	2.189
600	1.319	3.899
620	1.319	3.914
640	1.187	4.178
660	1.082	1.789
680	1.012	1.527

700	0.77	1.385

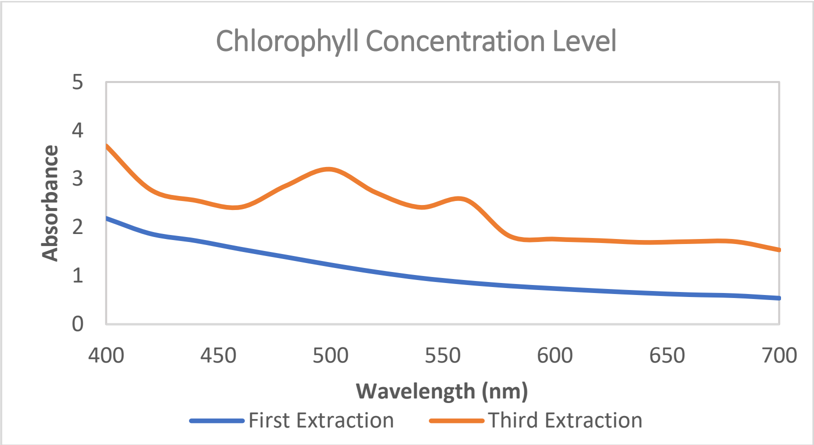


Figure 4. 3: Absorption curve for first & third extraction pre-heated (8hours)

Figure 4.3 shows the third extraction have a higher peak value of absorption at wavelength 500nm. This is because when used pre-heated the chlorophyll content will decrease quickly and a lot. The difference range between wavelength at Figure 4.2 (third extraction non pre-heated) is 140nm.

- 24 hours storage time (non pre-heated)

Table 4. 4: Absorption for first & third extraction non pre-heated (24hours)

Wavelength(nm)	First Extraction (NB)	Third Extraction (NB)
400	2.127	3.42
420	2.245	3.316
440	2.119	3.314
460	1.857	3.264
480	1.414	3.56
500	1.168	3.287
520	1.333	2.826
540	1.222	2.595
560	0.939	2.731
580	0.876	2.715
600	0.824	3.81
620	0.781	2.768
640	0.741	2.697

660	0.71	2.877
680	0.693	3.013
700	0.638	2.304

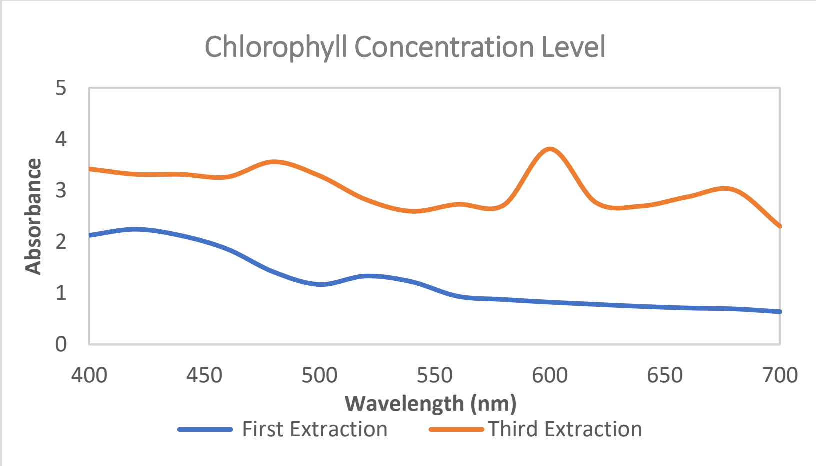


Figure 4. 4: Absorption curve for first & third extraction non pre-heated (24hours)

From the graph the third extraction have a highest peak value of absorption at wavelength 600nm. From that, the Figure 4.4 shows the content of chlorophyll slightly reduced compared to Figure 4.3 (third extraction pre-heated 8 hour). Storage time was found to lower chlorophyll levels not much compared to pre-heated.

- 24 hours storage time (pre-heated)

Table 4. 5: Absorption for first & third extraction pre-heated (24hours)

Wavelength(nm)	First Extraction (B)	Third Extraction (B)
400	1.391	2.367
420	1.239	2.452
440	1.123	2.115
460	1.014	2.614
480	0.925	2.6884
500	0.846	1.944
520	0.768	1.597
540	0.7	1.691
560	0.643	1.309
580	0.594	1.244
600	0.549	1.181

620	0.507	1.132
640	0.471	1.085
660	0.441	1.063
680	0.418	1.057
700	0.387	0.958

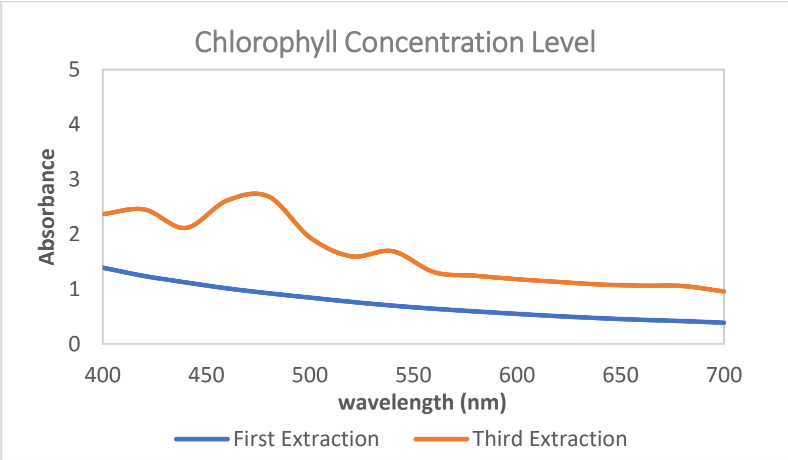


Figure 4. 5: Absorption curve for first & third extraction pre-heated (24hours)

Figure 4.5 shows the third extraction have a highest peak value of absorption at wavelength 480nm. From that, when applied pre-heated showed when used pre-heated chlorophyll reduction occurs rapidly. The difference range between wavelength at figure 4.4 (third extraction non pre-heated) is 120nm.

4.1.3 Summary of Measurement Absorbance

Table 4. 6: The data for overall measurement absorbance

Sample	Result	
	Wavelength	Wavelength at peak absorbance
2nd extraction 8 hours (baked) First Batch	400nm to 700nm	460nm
2nd extraction 8 hours (non baked) First Batch	400nm to 700nm	560nm
3rd extraction 8 hours (baked) Second Batch	400nm to 700nm	500nm
3rd extraction 8 hours (non baked)	400nm to 700nm	640nm

Second Batch		
3rd extraction 24 hours (baked) Second Batch	400nm to 700nm	480nm
3rd extraction 24 hours (non baked) Second Batch	400nm to 700nm	600nm

Table 4.6 shows the third extraction 8 hours non pre-heated have a highest peak value of absorption. This is because this sample are the best chlorophyll concentration level in dye solution among the other sample.

4.2 Measurement of Chlorophyll a & Chlorophyll b

The total chlorophyll contents divided into 2 which are chlorophyll a and chlorophyll b. According to the calibration graph of standard chlorophyll, the wavelength set for chlorophyll a was 662nm, while chlorophyll b was 646nm.

4.2.1 Measurement of absorbance for chlorophyll a & chlorophyll b

- 8 hours storage time

Table 4. 7: The data of chlorophyll content for non pre-heated (8 hours)

Wavelength(nm)	Chl a (NB)	Chl b (NB)
400	5	5
420	3.741	3.007
440	4.236	2.889
460	3.035	2.596
480	3.064	2.534
500	2.832	2.414
520	2.467	2.202
540	2.33	2.072
560	2.27	2.035
580	2.234	1.98
600	2.266	1.926
620	2.262	1.881
640	2.305	1.861
646	2.305	3.12
660	2.515	1.848

662	4.566	1.848
680	2.566	1.883
700	1.936	1.665
720	1.903	1.671

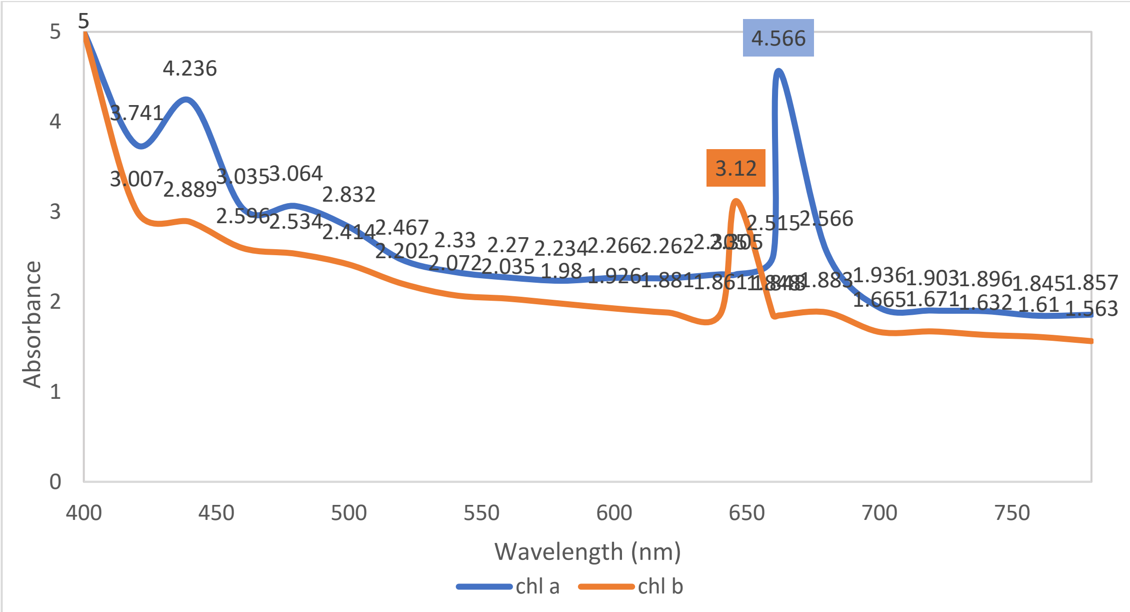


Figure 4. 6: The graph of chlorophyll content for non pre-heated (8 hours)

Based on Figure 4.6 shows the chlorophyll a get the value is 4.566 *mg/L*. Then chlorophyll b get the value is 3.12 *mg/L*. This is the best sample have a higher chlorophyll a and chlorophyll b compared to the other sample.

Table 4. 8: The data of chlorophyll content for pre-heated (8 hours)

Wavelength(nm)	Chl a (B)	Chl b (B)
400	3.065	2.855
420	2.425	2.549
440	2.469	2.132
460	2.287	1.936
480	2.217	1.625
500	2.151	1.513
520	1.341	1.581
540	1.461	1.38
560	1.413	1.404
580	1.474	1.238

600	1.338	1.183
620	1.328	1.132
640	1.394	1.081
646	1.294	1.478
660	1.279	1.051
662	2.501	1.051
680	1.896	1.044
700	1.223	0.941
720	1.467	0.904

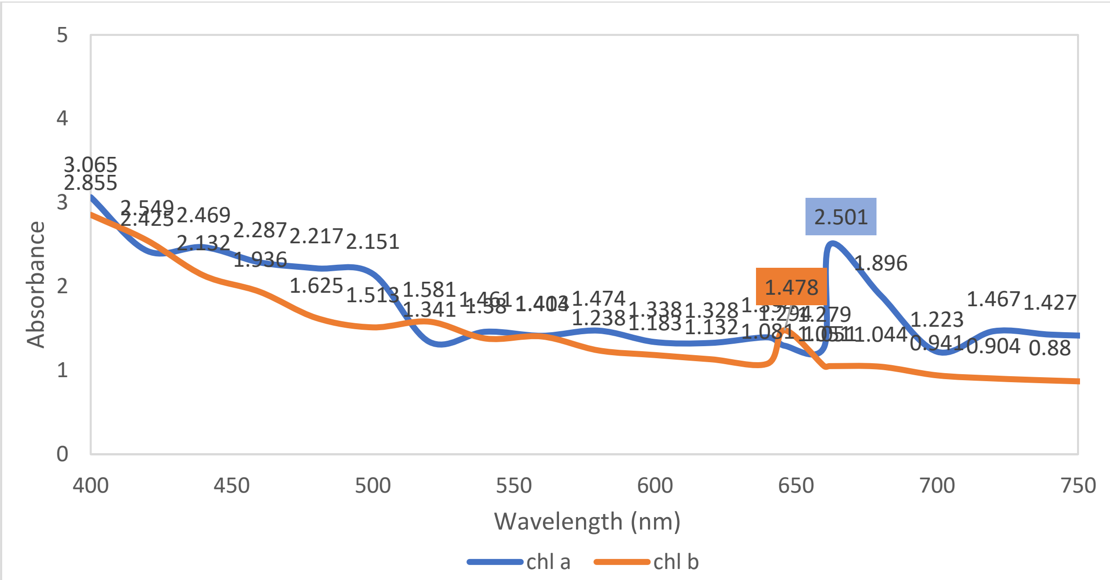


Figure 4. 7: The graph of chlorophyll content for pre-heated (8 hours)

Based on Figure 4.7 the chlorophyll a get the value is 2.501 *mg/L*. Then the chlorophyll b get the value is 1.478 *mg/L*. From that, the heat pre-treatment causing a significant decrease in chlorophyll a and chlorophyll b.

- 24 hours storage time

Table 4. 9: The data of chlorophyll content for non pre-heated (24 hours)

Wavelength(nm)	Chl a (NB)	Chl b (NB)
400	3.526	1.995
420	3.01	1.902
440	2.488	1.966
460	2.301	1.941

480	2.353	1.875
500	2.385	2.284
520	2.135	1.169
540	1.599	1.088
560	1.909	1.927
580	1.966	0.979
600	1.836	0.948
620	1.846	0.925
640	1.825	0.901
646	1.825	2.569
660	1.931	0.911
662	3.501	0.911
680	2.048	0.956
700	1.631	0.82
720	1.573	0.782

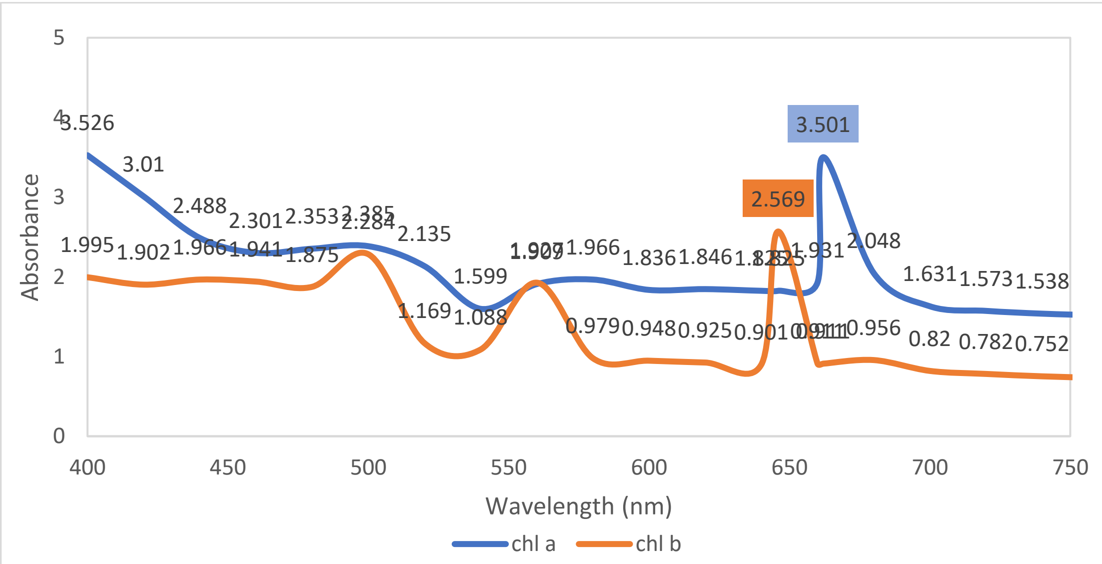


Figure 4. 8: The graph of chlorophyll content for non pre-heated (24 hours)

Based on Figure 4.8 the chlorophyll a get the value is 3.501 *mg/L*. Then chlorophyll b get the value is 2.569 *mg/L*. From that, the storage time shows the content of chlorophyll a and chlorophyll b slightly reduced compared to heat pre-treatment at Figure 4.8 to the value of chlorophyll content at Figure 4.7.

Table 4. 10: The data of chlorophyll content for pre-heated (24 hours)

Wavelength(nm)	Chl a (B)	Chl b (B)
400	2.394	1.999
420	2.559	1.632
440	2.327	1.635
460	2.102	1.511
480	2.022	1.122
500	1.394	1.038
520	1.125	0.946
540	1.145	1.572
560	1.193	0.809
580	1.152	1.056
600	1.525	0.714
620	1.405	0.679
640	1.082	0.65
646	1.099	1.308
660	1.541	0.635
662	2.209	0.635
680	1.623	0.933
700	1.333	0.579
720	1.279	0.555

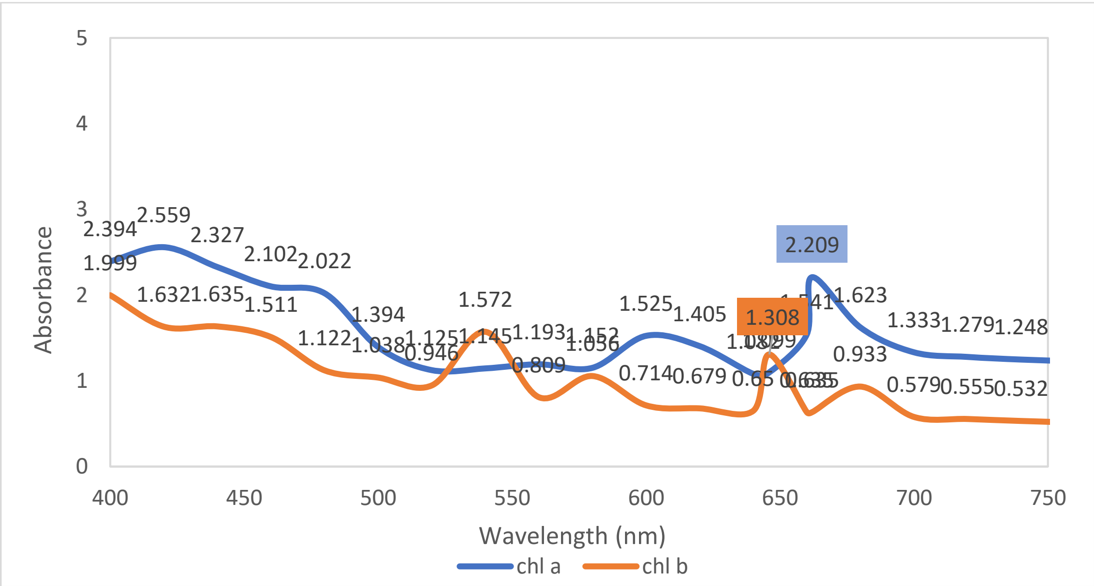


Figure 4. 9: The graph of chlorophyll content for pre-heated (24 hours)

Based on Figure 4.9 the chlorophyll a get the value is 2.209 *mg/L*. Then chlorophyll b get the value is 1.308 *mg/L*. From that, when applied external factor causing a decrease in the original chlorophyll.

4.2.2 Calculation of chlorophyll a & chlorophyll b

Table 4. 11: The calculation of chlorophyll a & chlorophyll b for third extraction at 4 different of dye

Chlorophyll	8 hours storage (Non Baked)	8 hours storage (Baked)	Total difference Chlorophyll (8 hours)	24 hours storage (Non Baked)	24 hours storage (Baked)	Total difference Chlorophyll (24 hours)	Total different chlorophyll between 8 hours & 24 hours	
							Non Baked	Baked
Chl a mg/L =	49.5076	27.1106	22.397	37.9566	23.9436	14.013	11.551	3.167
Chl b mg/L =	72.5326	34.3465	38.1861	59.7186	30.393	29.3256	12.814	3.9535

From the table 4.11 non baked at 8 hours storage time have a higher chlorophyll content for Chl a & Chl b compared to other sample. Then, for the total different chlorophyll at 8 hours & 24 hours storage shows a significant decrease in chlorophyll between non pre-heated to pre-heated compared to a decrease in chlorophyll during storage time between 8 hours to 24 hours for non pre-heated and pre-heated. It can conclude the chlorophyll content undergoes a significant degradation when performing the heating process compared to the storage time.

4.3 Summary of Completeness of Titanium Oxide on FTO glass

This part is most important element that required the successfully the dye-sensitized solar cell experimental. Therefore, when the TiO_2 on FTO glass is not fully covered, the current voltage measurement value will be affected.

Figure 4. 10: The different completeness TiO_2 between non pre-heated and pre-heated

From the figure 4.10 non pre-heated have a 100% completeness of TiO_2 compare to pre-heated have a 80% completeness of TiO^2. It is because when applied heat pre-treatment which causes TiO_2 on the FTO glass not smooth cover the area that should be covered on the FTO glass.

4.4 Measurement of Open-Circuit Voltage, Voc under direct sunlight

After the dye-sensitive solar cells have been successfully fabricated, the next process will compute with measurement of open circuit voltage, Voc that included the multimeter to measure the output. The measurements made should ensure that the TiO_2 condition is facing under sunlight. In addition, the multimeter probe was placed on +ve carbon and -ve TiO_2 FTO glass. Drop KI on TiO_2 as electrolyte if the value is found to be unstable or the value cannot be read.

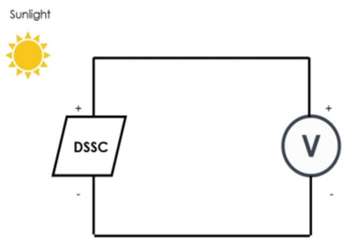


Figure 4. 11: The constructed circuit for measure voltage under sunlight

4.4.1 First Batch on Open Circuit Voltage, Voc

- 8 hours storage time

Open circuit voltage measurement, Voc was measured at the time of measurement from 2.30 pm to 2.45 pm with the sky condition at that time being clear sky. In additional, an expected irradiance is estimate around 450 to 600 w/m².

2nd extraction (non baked)

Voc = 155.4 mV

2nd extraction (baked)

Voc = 94 mV

Figure 4. 12: Open Circuit Voltage for First Batch (8 hours)

Based on Figure 4.12 measurement of open circuit voltage, Voc for the first batch that is the second extraction non pre-heated get the value is 155.4 mV compared to the second extraction pre-heated is 94 mV. This is because when chlorophyll are heated it causes the chlorophyll level to be low and affects the value of open circuit voltage, Voc.

4.4.2 Second Batch on Open Circuit Voltage, Voc

Open circuit voltage measurement, Voc was measured at the time of measurement from 12.00 pm to 1.00pm that sky condition at that time are clear sky. In additional, an expected irradiance is estimate around 525 to 600 w/m².

- 8 hours storage time

1st extraction (non baked)

Voc = 165 mV

3rd extraction (non baked)

Voc = 379 mV

1st extraction (baked)

Voc = 99 mV

3rd extraction (baked)

Voc = 290 mV

Figure 4. 13: Open Circuit Voltage for Second Batch (8 hours)

Based on Figure 4.13 measurement of open circuit voltage, Voc for the second batch at 8 hours storage time the third extraction non pre-heated have a higher open circuit voltage, Voc is 379 mV among the other sample. This is because this sample have a higher chlorophyll concentration level in dye solution.

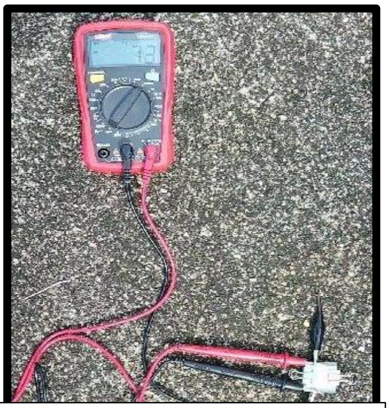
- 24 hours storage time

1st extraction (non baked)

Voc = 99 mV

3rd extraction (non baked)

Voc = 323 mV



1st extraction (baked)

Voc = 73 mV

3rd extraction (baked)

Voc = 225 mV

Figure 4. 14: Open Circuit Voltage for Second Batch (24 hours)

Based on Figure 4.14 measurement of open circuit voltage, Voc for the second batch at 24 hours storage time, the third extraction non pre-heated has a higher second open circuit voltage, Voc where the value is 323mV after the value of Voc at 8 hours storage time the third extraction non pre-heated. This is because when not applied the storage time the open circuit voltage will produce higher value.

Based on the overall result, second batch at 8 hours storage time non pre-heated with third extraction has achieved a higher open circuit voltage among the other sample while second batch at 24 hours pre-heated with first extraction has achieved a lowest open circuit voltage among the other sample. Since, third extraction has a higher concentration in chlorophyll-based compare to the first extraction.

4.4.3 Summary for Measurement Dye-sensitized Solar Cells under direct sunlight

Table 4. 12: The overall of measurement open circuit voltage,Voc

Extraction Time	Storage Time	Pre -Treatment	Voltage Open Circuit (Voc)
1	8	YES	99 mV
2	8	YES	94 mV
3	8	YES	290 mV
1	24	YES	73 mV
3	24	YES	225 mV
1	8	NO	165 mV
2	8	NO	155.4 mV
3	8	NO	379 mV
1	24	NO	120 mV
3	24	NO	323 mV

From Table 4.12 the best sample that is third extraction 8 hours storage time non pre-heated have a higher open circuit voltage, Voc among the other sample. From the overall result shows all Voc values for non pre-heated high versus pre-heated. It can conclude high extraction time and low storage time as well as non heat pre-treatment are high open voltage circuit, Voc contributors.

4.5 Measurement of I-V characteristics DSSCs

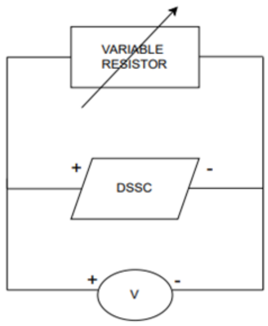


Figure 4. 15: The constructed circuit for measuring I-V characteristics

The measurement of I-V characteristics DSSCs is done using solar simulator. The brand of LED from Greensindoor have specification 100,000k lux and 600 Watt. Besides that, for solar simulator using air mass (AM) 1.0 means in an upright position of 90 degrees. In addition, have specification 181.5k lux and the irradiance 1006.5311 w/m². Lastly, for resistor using variable resistor the value 500k ohm.

In order to measure or plot I-V curve. First of all need to fix the value of resistor. Then, need to varies the value of the resistor from small to largest. Next, after the resistor already fixed, the voltage will be measure on that resistor. Besides that, to get the value of current just used ohm law formula. After that, to get the value of short circuit current density (Jsc), should be divide with active area TiO_2 which mean the area illumination of LED when measure under solar simulator that is (3cm²). The 8 samples have been successfully measured on I-V characteristics. The figure below shows how the measurement of I-V characteristic has been done.

Figure 4. 16: Varies the resistor from small the largest

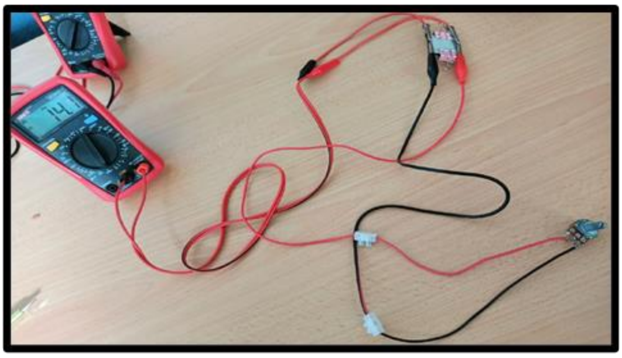


Figure 4. 17: The voltage measured at a fixed resistor

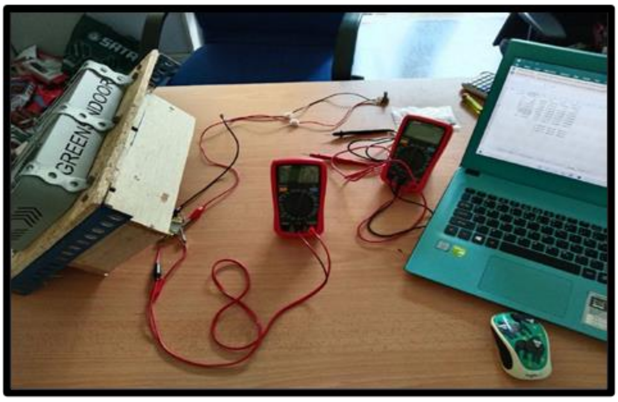


Figure 4. 18: The measurement against DSSC under solar simulator

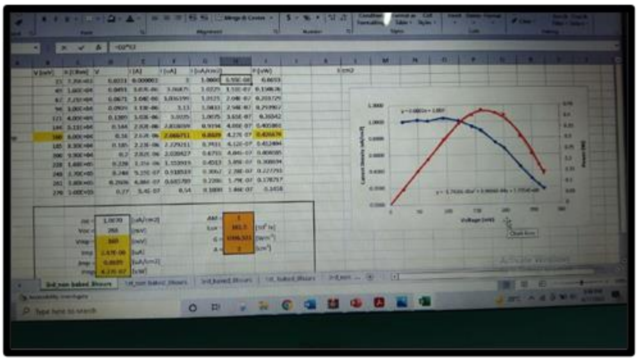


Figure 4. 19: The values that have been recorded in excel

4.5.1 Measurement of I-V characteristics at 8 hours storage time

- Third extraction

Table 4. 13: The data of I-V characteristics & P-V Characteristics for third extraction non pre-heated (8 hours)

R [Ohm]	V [mV]	V	I [A]	I [uA]	I [uA/cm2]	P(W)	P (uW)
7.70E+03	23	0.0231	0.000003	3	1.0000	6.93E-08	0.0693
1.60E+04	49	0.0491	3.07E-06	3.06875	1.0229	1.51E-07	0.150676
2.21E+04	67	0.0671	3.04E-06	3.036199	1.0121	2.04E-07	0.203729
3.00E+04	94	0.0939	3.13E-06	3.13	1.0433	2.94E-07	0.293907
4.00E+04	121	0.1209	3.02E-06	3.0225	1.0075	3.65E-07	0.36542
5.11E+04	144	0.144	2.82E-06	2.818059	0.9394	4.06E-07	0.405801
6.00E+04	160	0.16	2.67E-06	2.666711	0.8889	4.27E-07	0.426674
8.30E+04	185	0.185	2.23E-06	2.229211	0.7431	4.12E-07	0.412404
9.90E+04	200	0.2	2.02E-06	2.020427	0.6735	4.04E-07	0.404085

1.68E+05	228	0.228	1.35E-06	1.353919	0.4513	3.09E-07	0.308694
2.70E+05	248	0.248	9.19E-07	0.918519	0.3062	2.28E-07	0.227793
3.80E+05	261	0.2606	6.86E-07	0.685789	0.2286	1.79E-07	0.178717
5.00E+05	270	0.27	5.4E-07	0.54	0.1800	1.46E-07	0.1458

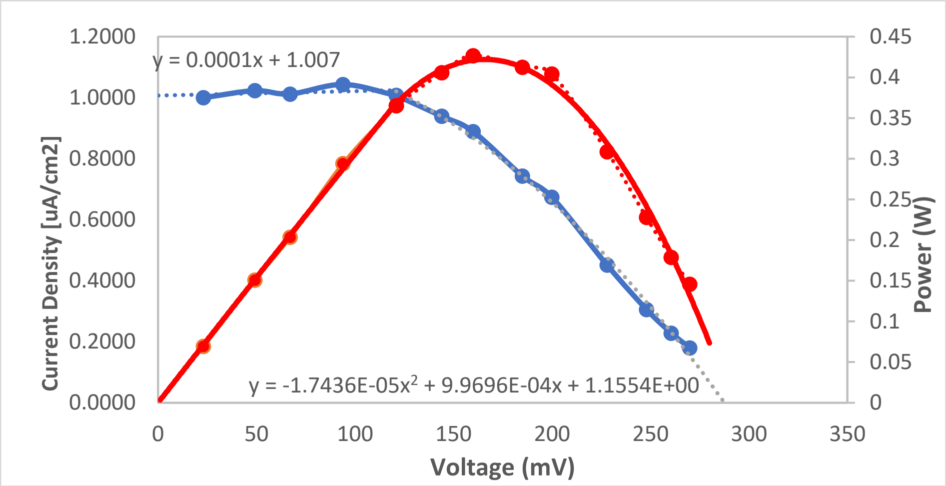


Figure 4. 20: The graph of I-V Characteristics & P-V Characteristics for third extraction non pre-heated (8 hours)

Figure 4.20 shows the I-V and P-V characteristics of the best sample among the other which is third extraction non pre-heated at 8 hours storage. The colour of the blue line indicates the I-V curve, whereas the colour of the red line represents the P-V curve. The trendline, shown by the dashed line, was presented apart from the blue line. Short-circuit current (Jsc) occur at the highest current produced from a solar cell when the open-circuit voltage (Voc) across the device is zero and vice versa. From the graph, short-circuit current (Jsc) and open-circuit voltage (Voc) are located at intercept y and x respectively. The linear regression was included in order to acquire a reasonable approximation of the short-circuit current, while open-circuit voltage (Voc) was approximately calculated using nonlinear regression. Each treandline was from the blue dashed line. In addition to the red line with dots, a trendline representing polynomial regression was added. Thus, it was possible to determine the approximate value of the power maximum point (Pmp).

Table 4. 14: Photovoltaic characteristics of for third extraction non pre-heated (8 hours)

Photovoltaic Characteristics	3rd non baked 8hours
Jsc [uA/cm2]	1.007
Voc [mV]	288
Vmp [mV]	160
Imp [uA]	2.6667E-06
Jmp [uA/cm2]	0.8889
Pmp[uW]	4.26674E-07
FF [%]	49.04005296
Efficiency [%]	0.000141302

Based on Table 4.14 the measurement of I-V characteristics for value of overall electrical performance of DSSC have a higher of value of current density (Jsc) is 1.0070 uA/cm², Voc is 288mV, Fill factor is 49.04% and the efficiency is 0.0001413 %. This is the best chlorophyll concentration level in dye solution.

Table 4. 15: The data of I-V characteristics for third extraction pre-heated (8 hours)

R [Ohm]	V [mV]	V	I [A]	I [uA]	I [uA/cm2]	P(W)	P (uW)
2900	7.09	0.00709	2.44E-06	2.444828	0.611207	1.73E-08	0.017334
5400	13.09	0.01309	2.42E-06	2.424074	0.606019	3.17E-08	0.031731
9990	24.1	0.0241	2.41E-06	2.412412	0.603103	5.81E-08	0.058139
15190	35.3	0.0353	2.32E-06	2.323897	0.580974	8.2E-08	0.082034
2.19E+04	46.7	0.0467	2.13E-06	2.13242	0.533105	9.96E-08	0.099584
2.89E+04	55	0.055	1.9E-06	1.903114	0.475779	1.05E-07	0.104671
4.23E+04	69	0.069	1.63E-06	1.631206	0.407801	1.13E-07	0.112553
6.23E+04	80.9	0.0809	1.3E-06	1.298555	0.324639	1.05E-07	0.105053
8.03E+04	88.9	0.0889	1.11E-06	1.107098	0.276775	9.84E-08	0.098421
2.00E+05	108	0.108	5.4E-07	0.54	0.135	5.83E-08	0.05832

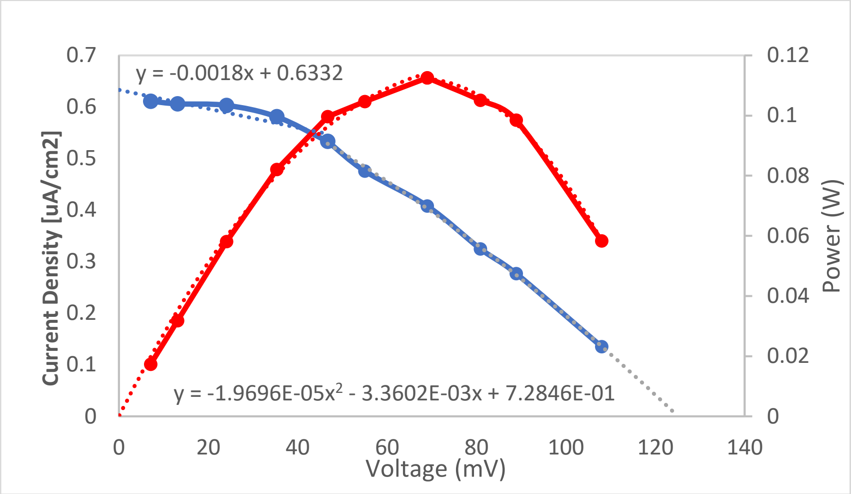


Figure 4. 21: The graph of I-V Characteristics & P-V Characteristics for third extraction pre-heated (8 hours)

Table 4. 16: Photovoltaic characteristics for third extraction pre-heated (8 hours)

Photovoltaic Characteristics	3rd baked 8hours
Jsc [uA/cm2]	0.6332
Voc [mV]	125
Vmp [mV]	69
Imp [uA]	1.6312E-06
Jmp [uA/cm2]	0.4078
Pmp[uW]	1.125E-07
FF [%]	35.55047378
Efficiency [%]	0.0000373

Based on Table 4.16 the measurement of I-V characteristics for the value of overall electrical performance of DSSC have a lowest than non pre-heated, the value of current density (Jsc) is 0.6332 uA/cm², Voc is 125mV, Fill Factor is 35.55% and the efficiency is 0.0000373 %. When applied the heat pre-treatment will effect the value of overall electrical performance of DSSC.

- First extraction

Table 4. 17: The data of I-V characteristics for first extraction non pre-heated (8 hours)

R [Ohm]	V [mV]	V	I [A]	I [uA]	I [uA/cm2]	P(W)	P (uW)
3490	9.5	0.0095	2.72E-06	2.722063	0.680516	2.59E-08	0.02586
5300	14.01	0.01401	2.64E-06	2.643396	0.660849	3.7E-08	0.037034
10390	28.1	0.0281	2.7E-06	2.704524	0.676131	7.6E-08	0.075997
14390	38.3	0.0383	2.66E-06	2.661571	0.665393	1.02E-07	0.101938
1.99E+04	51.1	0.0511	2.57E-06	2.567839	0.64196	1.31E-07	0.131217
2.49E+04	62.1	0.0621	2.49E-06	2.493976	0.623494	1.55E-07	0.154876
3.70E+04	82.6	0.0826	2.23E-06	2.232432	0.558108	1.84E-07	0.184399
4.90E+04	96.1	0.0961	1.96E-06	1.961224	0.490306	1.88E-07	0.188474
6.99E+04	110	0.11	1.57E-06	1.573677	0.393419	1.73E-07	0.173104
5.00E+05	145	0.145	2.9E-07	0.29	0.0725	8.41E-08	0.0841

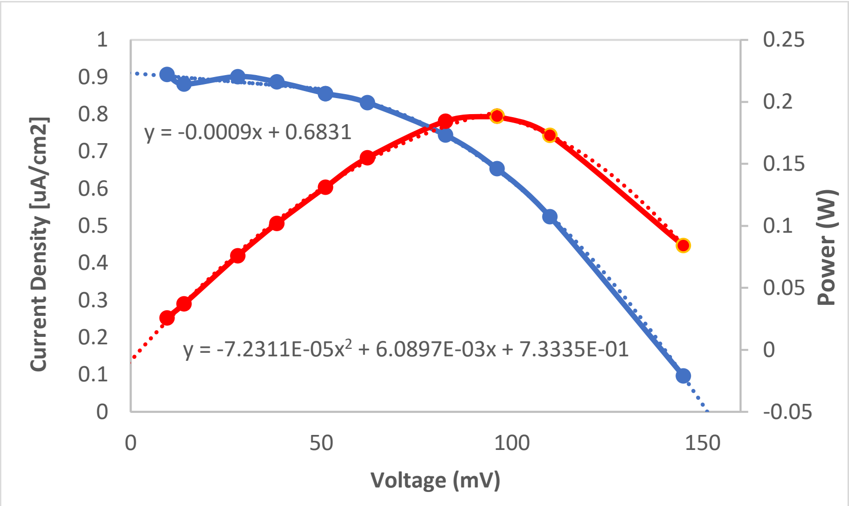


Figure 4. 22: The graph of I-V characteristics & P-V Characteristics for first extraction non pre-heated (8 hours)

Table 4. 18:Photovoltaic characteristics for first extraction non pre-heated (8 hours)

Photovoltaic Characteristics	1st non baked 8hours
Jsc [uA/cm2]	0.6831
Voc [mV]	151
Vmp [mV]	96.1
Imp [uA]	1.9612E-06

Jmp [uA/cm2]	0.4903
Pmp[uW]	1.885E-07
FF [%]	45.6797847
Efficiency [%]	0.0000624

Based on Table 4.18 the measurement of I-V characteristics for the value of overall electrical performance of DSSC is higher than Table 4.16 refer to the third extraction value when using pre-heated, the value of current density (Jsc) is 0.6831 uA/cm², Voc is 151mV, Fill factor is 45.68% and the efficiency is 0.0000624 %. It shows that heat pre-treatment will affect the overall electrical performance of DSSC compared to extraction time.

Table 4. 19:The data of I-V characteristics for first extraction pre-heated (8 hours)

R [Ohm]	V [mV]	V	I [A]	I [uA]	I [uA/cm2]	P(W)	P (uW)
1000	1.9	0.0019	1.9E-06	1.9	0.475	3.61E-09	0.00361
5000	9.2	0.0092	1.84E-06	1.84	0.46	1.69E-08	0.016928
1.00E+04	18.1	0.0181	1.81E-06	1.81	0.4525	3.28E-08	0.032761
1.80E+04	29.9	0.0299	1.66E-06	1.661111	0.415278	4.97E-08	0.049667
2.30E+04	35	0.035	1.52E-06	1.521739	0.380435	5.33E-08	0.053261
3.09E+04	42	0.042	1.36E-06	1.359223	0.339806	5.71E-08	0.057087
4.16E+04	50	0.05	1.2E-06	1.201923	0.300481	6.01E-08	0.060096
7.99E+04	67.8	0.0678	8.49E-07	0.848561	0.21214	5.75E-08	0.057532
9.98E+04	73	0.073	7.31E-07	0.731463	0.182866	5.34E-08	0.053397
3.30E+05	90.1	0.0901	2.73E-07	0.273113	0.068278	2.46E-08	0.024607
5.00E+05	95.1	0.0951	1.9E-07	0.1902	0.04755	1.81E-08	0.018088

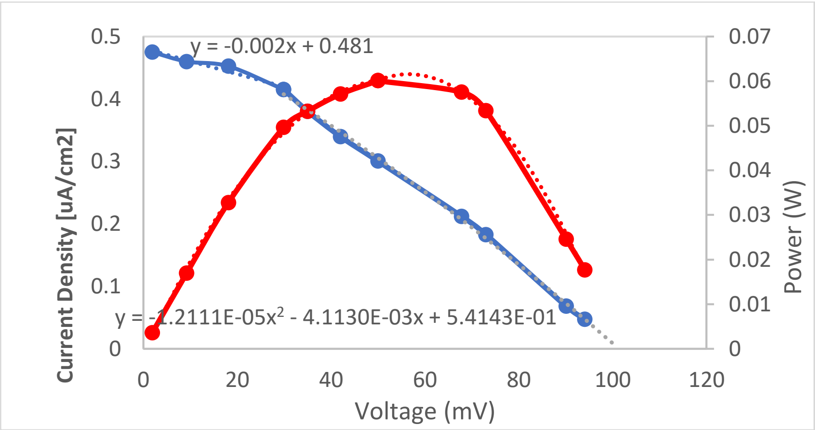


Figure 4. 23: The graph of I-V characteristics & P-V Characteristics for first extraction pre-heated (8 hours)

Table 4. 20:Photovoltaic characteristics for first extraction pre-heated (8 hours)

Photovoltaic Characteristics	1st baked 8hours
Jsc [uA/cm2]	0.481
Voc [mV]	101
Vmp [mV]	50
Imp [uA]	1.2019E-06
Jmp [uA/cm2]	0.3005
Pmp[uW]	6.01E-08
FF [%]	30.92772895
Efficiency [%]	0.0000199

Based on Table 4.20 the measurement of I-V characteristics for the value of overall electrical performance of DSSC is lowest than Table 4.18 refer to the first extraction non pre-heated, the value of current density (Jsc) is 0.4810 uA/cm², Voc is 101mV, Fill factor is 30.93% and the efficiency is 0.0000199 %. Heat pre-treatment plays a large role in the value overall electrical performance.

4.5.2 Measurement of I-V characteristics at 24 hours storage time

- Third extraction

Table 4. 21:The data of I-V characteristics for third extraction non pre-heated (24 hours)

R [Ohm]	V [mV]	V	I [A]	I [uA]	I [uA/cm2]	P(W)	P (uW)
1000	2.8	0.0028	2.8E-06	2.8	0.7	7.84E-09	0.00784
1.31E+04	35.4	0.0354	2.7E-06	2.70229	0.675573	9.57E-08	0.095661
2.37E+04	64.9	0.0649	2.74E-06	2.738397	0.684599	1.78E-07	0.177722
3.07E+04	85.1	0.0851	2.77E-06	2.771987	0.692997	2.36E-07	0.235896
5.90E+04	128	0.128	2.17E-06	2.169492	0.542373	2.78E-07	0.277695
7.40E+04	149.1	0.1491	2.01E-06	2.014865	0.503716	3E-07	0.300416
9.00E+04	159.1	0.1591	1.77E-06	1.767778	0.441944	2.81E-07	0.281253
1.20E+05	172.1	0.1721	1.43E-06	1.434167	0.358542	2.47E-07	0.24682
1.50E+05	180.1	0.1801	1.2E-06	1.200667	0.300167	2.16E-07	0.21624
2.20E+05	192.1	0.1921	8.73E-07	0.873182	0.218295	1.68E-07	0.167738
4.00E+05	205.9	0.2059	5.15E-07	0.51475	0.128688	1.06E-07	0.105987
5.00E+05	215	0.215	4.3E-07	0.43	0.1075	9.25E-08	0.09245

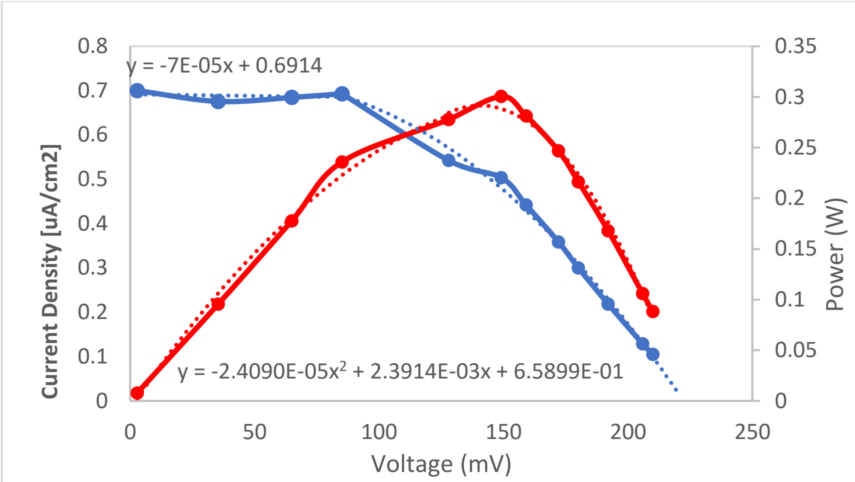


Figure 4. 24: The graph of I-V characteristics for third extraction non pre-heated (24 hours)

Table 4. 22:Photovoltaic characteristics for third extraction non pre-heated (24 hours)

Photovoltaic Characteristics	3rd non baked 24hours
Jsc [uA/cm2]	0.6914
Voc [mV]	222
Vmp [mV]	128
Imp [uA]	2.16949E-06
Jmp [uA/cm2]	0.5424
Pmp[uW]	2.7769E-07
FF [%]	45.23215724
Efficiency [%]	0.0000920

Based on Table 4.22 the measurement of I-V characteristics for the value of overall electrical performance of DSSC have a higher of value of current density (Jsc) is 0.6914 uA/cm², Voc is 222 mV, Fill factor is 45.23% and the efficiency is 0.0000920 % after third extraction at 8 hour storage time non pre-heated (Table 4.14). This is because the storage time does not have a significant impact on value of overall electrical performance.

Table 4. 23:The data of I-V characteristics for third extraction pre-heated (24 hours)

R [Ohm]	V [mV]	V	I [A]	I [uA]	I [uA/cm2]	P(W)	P (uW)
1000	1.39	0.00139	1.39E-06	1.39	0.3475	1.93E-09	0.001932

8.00E+03	10.9	0.0109	1.36E-06	1.3625	0.340625	1.49E-08	0.014851
1.31E+04	16.9	0.0169	1.29E-06	1.290076	0.322519	2.18E-08	0.021802
1.80E+04	22.1	0.0221	1.23E-06	1.227778	0.306944	2.71E-08	0.027134
3.23E+04	30.1	0.0301	9.32E-07	0.931889	0.232972	2.8E-08	0.02805
4.79E+04	37.1	0.0371	7.75E-07	0.77453	0.193633	2.87E-08	0.028735
9.33E+04	49.9	0.0499	5.35E-07	0.534834	0.133708	2.67E-08	0.026688
1.78E+05	59.2	0.0592	3.32E-07	0.331839	0.08296	1.96E-08	0.019645
4.03E+05	65.3	0.0653	1.62E-07	0.162075	0.040519	1.06E-08	0.010583

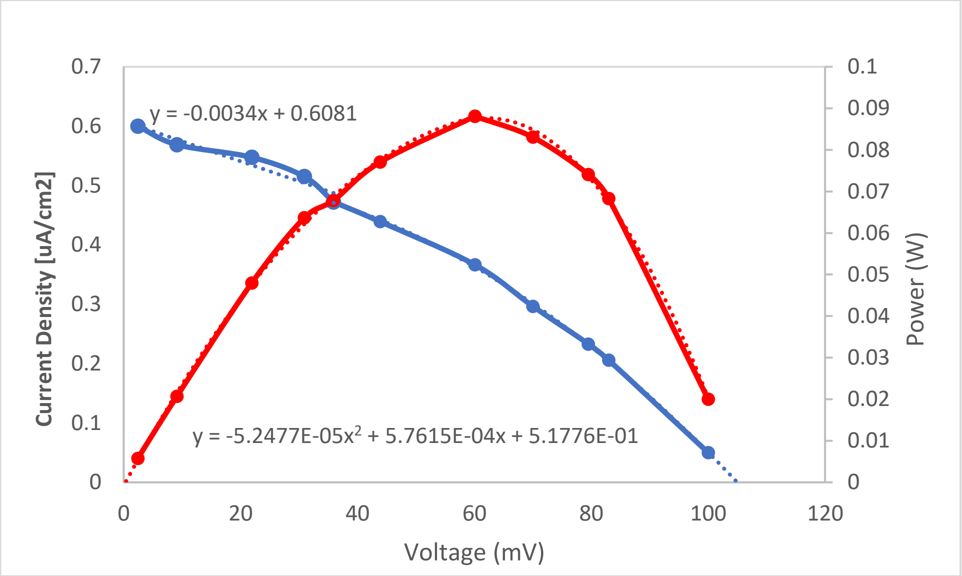


Figure 4. 25: The graph of I-V characteristics for third extraction pre-heated (24 hours)

Table 4. 24: Photovoltaic characteristics for third extraction pre-heated (24 hours)

Photovoltaic Characteristics	3rd baked 24 hours
Jsc [uA/cm2]	0.6081
Voc [mV]	104
Vmp [mV]	60
Imp [uA]	1.4659E-06
Jmp [uA/cm2]	0.3664
Pmp[uW]	8.81E-08
FF [%]	34.76148913
Efficiency [%]	0.0000292

Based on Table 4.24 the measurement of I-V characteristics for the value of overall electrical performance of DSSC have a lowest than Table 4.21 refer to the third extraction non pre-heated, the value of current density (Jsc) is 0.6082 uA/cm², Voc is 104 mV, Fill factor is 34.76% and the efficiency is 0.0000292 % . This is because chlorophyll is heated affects the value of electrical performance of DSSC.

- First extraction

Table 4. 25:The data of I-V characteristics for first extraction non pre-heated (24 hours)

R [Ohm]	V [mV]	V	I [A]	I [uA]	I [uA/cm2]	P(W)	P (uW)
1000	2.49	0.00249	2.49E-06	2.49	0.6225	6.2E-09	0.0062
8000	19.1	0.0191	2.39E-06	2.3875	0.596875	4.56E-08	0.045601
1.40E+04	32.9	0.0329	2.35E-06	2.35	0.5875	7.73E-08	0.077315
2.09E+04	46.9	0.0469	2.25E-06	2.2494	0.56235	1.05E-07	0.105497
2.93E+04	61.1	0.0611	2.09E-06	2.085324	0.521331	1.27E-07	0.127413
3.43E+04	68.1	0.0681	1.99E-06	1.985423	0.496356	1.35E-07	0.135207
4.13E+04	75	0.075	1.82E-06	1.815981	0.453995	1.36E-07	0.136199
5.65E+04	86.3	0.0863	1.53E-06	1.527434	0.381858	1.32E-07	0.131818
1.30E+05	115.3	0.1153	8.87E-07	0.886923	0.221731	1.02E-07	0.102262
2.10E+05	125.3	0.1253	5.97E-07	0.596667	0.149167	7.48E-08	0.074762
4.09E+05	135	0.135	3.3E-07	0.330073	0.082518	4.46E-08	0.04456

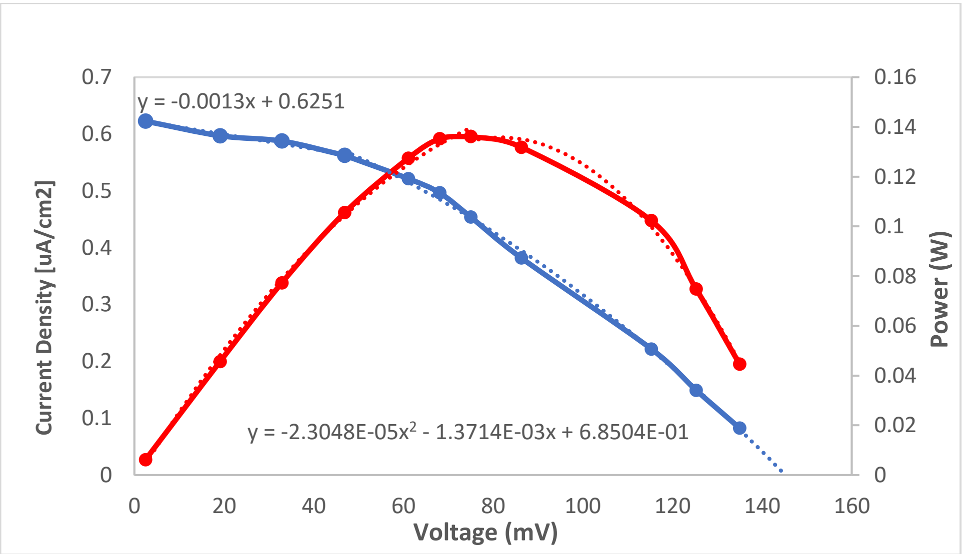


Figure 4. 26: The graph of I-V characteristics for first extraction non pre-heated (24 hours)

Table 4. 26: Photovoltaic characteristics for first extraction non pre-heated (24 hours)

Photovoltaic Characteristics	1^{st} non baked 24hours
Jsc [uA/cm2]	0.6251
Voc [mV]	145
Vmp [mV]	75
Imp [uA]	0.000001816
Jmp [uA/cm2]	0.454
Pmp[uW]	1.362E-07
FF [%]	37.56640317
Efficiency [%]	0.0000451

Based on Table 4.26 the measurement of I-V characteristics for the overall electrical performance value of the first extraction is higher than Table 4.24 refer to the third extraction at 24 hour value when using pre-heated, the value of current density (Jsc) is 0.6251 uA/cm², Voc is 145mV, Fill factor is 37.57 % and the efficiency is 0.0000451 %. It can conclude the extraction time gives a lower impact than pre-heated.

Table 4. 27:The data of I-V characteristics for first extraction pre-heated (24 hours)

R [Ohm]	V [mV]	V	I [A]	I [uA]	I [uA/cm2]	P(W)	P (uW)
1000	1.39	0.00139	1.39E-06	1.39	0.3475	1.93E-09	0.001932
8.00E+03	10.9	0.0109	1.36E-06	1.3625	0.340625	1.49E-08	0.014851
1.31E+04	16.9	0.0169	1.29E-06	1.290076	0.322519	2.18E-08	0.021802
1.80E+04	22.1	0.0221	1.23E-06	1.227778	0.306944	2.71E-08	0.027134
3.23E+04	30.1	0.0301	9.32E-07	0.931889	0.232972	2.8E-08	0.02805
4.79E+04	37.1	0.0371	7.75E-07	0.77453	0.193633	2.87E-08	0.028735
9.33E+04	49.9	0.0499	5.35E-07	0.534834	0.133708	2.67E-08	0.026688
1.78E+05	59.2	0.0592	3.32E-07	0.331839	0.08296	1.96E-08	0.019645
4.03E+05	65.3	0.0653	1.62E-07	0.162075	0.040519	1.06E-08	0.010583

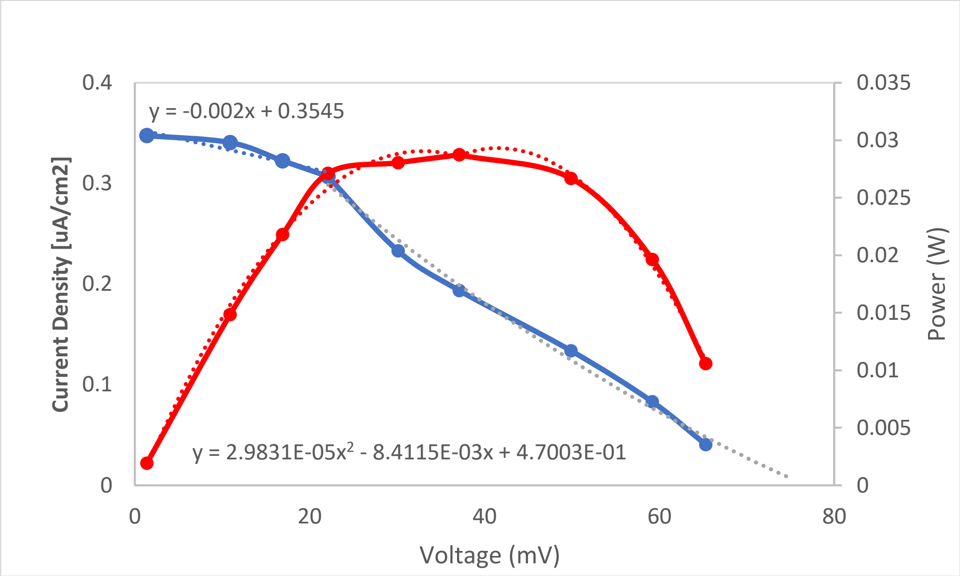


Figure 4. 27: The graph of I-V characteristics for first extraction pre-heated. (24 hours)

Table 4. 28: Photovoltaic characteristics for first extraction pre-heated (24 hours)

Photovoltaic Characteristics	1st baked 24hours
Jsc [uA/cm2]	0.3545
Voc [mV]	77
Vmp [mV]	37
Imp [uA]	7.745E-07
Jmp [uA/cm2]	0.1936
Pmp[uW]	2.87E-08
FF [%]	26.24219222
Efficiency [%]	0.0000095

Based on Table 4.28 the measurement of I-V characteristics first extraction The overall electrical performance value is lowest than Table 4.25 refer to the first extraction non pre-heated, the value of current density (Jsc) is 0.3545 uA/cm², Voc is 77 mV, Fill Factor is 26.24 % and the efficiency is 0.0000095 %. Heat pre-treatment plays a large role in the value overall electrical performance. This is the lowest sample of the overall electrical performance value among the 8 samples.

4.6 Summary measurement of I-V characteristics DSSCs

Table 4. 29: The data of overall electrical performance of DSSC

	3rd (NB) 8h	3rd (NB) 24h	1st (NB) 8h	1st (NB) 24h	3rd (B) 8 h	3rd (B) 24h	1st (B) 8h	1st (B) 24h
Jsc [uA/cm2] =	1.007	0.6914	0.6831	0.6251	0.6332	0.6081	0.481	0.3545
Voc [mV] =	288	222	151	145	125	104	101	77
Vmp[mV] =	160	128	96.1	75	69	60	50	37
Imp [uA] =	2.67E-06	2.17E-06	1.96E-06	1.82E-06	1.63E-06	1.47E-06	1.20E-06	7.75E-07
Jmp [uA/cm2] =	0.8889	0.5424	0.4903	0.454	0.4078	0.3664	0.3005	0.1936
Pmp[uW] =	4.27E-07	2.78E-07	1.89E-07	1.36E-07	1.13E-07	8.81E-08	6.01E-08	2.87E-08
FF [%] =	49.04	45.23	45.68	37.57	35.55	34.76	30.93	26.24
Efficiency [%] =	0.0001413	0.000092	0.0000624	0.0000451	0.0000373	0.0000292	0.0000199	0.0000095

Based on the overall result at Table 4.29, where the third extraction non pre-heated at 8 hours storage have a significance of chlorophyll concentration towards the overall electrical performance of the DSSC. It is because have the best chlorophyll concentration level in dye among the other sample.

4.7 Summary of measurement project

Table 4. 30: The overall of this project

	3rd extraction (non baked) at 8 hours storage	3rd extraction (baked) at 8 hours storage	3rd extraction (non baked) at 24 hours storage	3rd extraction (baked) at 24 hours storage
Total chlorophyll ((mg/L)	122.0401	61.4571	97.6752	54.3366
Current Density [uA/cm2]	0.7552	0.6332	0.6914	0.6081
Open Circuit Voltage ,Voc (mV)	289	125	222	104
Fill Factor (%)	48.88	35.55	45.68	34.76
Efficiency (%)	0.000141	0.000037	0.000092	0.000029

Based on the overall result of this project at Table 4.30, the best sample that is third extraction non pre-heated at 8 hours storage have a higher overall electrical performance of the DSSC among the other sample. It can be conclude external factors significantly affect the chlorophyll concentration on the overall electrical performance of the DSSC.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This study was conducted objectively to investigate the effect of applied external factors to the chlorophyll concentration. External factors are referred to extraction time, storage time and heat pre-treatment. In this project by using external factors, it has a great impact on the reduction of chlorophyll. The chlorophyll content was deeply analyzed based on UV-Vis spectrophotometer's measurement. Besides that, for the extraction time, the third extraction have the higher chlorophyll content compared to the first extraction. It is because the green color of the first extraction is more faded than the more concentrated third extraction. From the analysis that has been made, the chlorophyll content is more easily reduced if heat pre-treatment are applied compared to the storage time. Furthermore, an objective of this project is successfully achieved by analyze the significance of chlorophyll concentration towards the overall electrical performance of the DSSC. The higher chlorophyll concentration level will produce the higher overall performance of the DSSC which includes open circuit voltage (Voc), Current Density (Jsc), Fill Factor (FF) and Efficiency (η). It is recommended to conduct further research on extraction of chlorophyll by using enzymatic extraction. Further research into another factor type may also increase the high yield of chlorophyll concentration.

REFERENCES

Adedokun, O., Adedeji, O. L., Bello, I. T., Awodele, M. K., & Awodugba, A. O. (2021). Fruit peels pigment extracts as a photosensitizer in zno-based dye-sensitized solar cells. *Chemical Physics Impact*, *3*, 100039. https://doi.org/10.1016/j.chphi.2021.100039

Agrawal, A., Siddiqui, S. A., Soni, A., Khandelwal, K., & Sharma, G. D. (2021). Performance analysis of tio2 based dye sensitized solar cell prepared by screen printing and Doctor Blade Deposition Techniques. *Solar Energy*, *226*, 9–19. https://doi.org/10.1016/j.solener.2021.08.001

Ahmed, J. (2020). Green banana processing, products and functional properties. *Handbook of Banana Production, Postharvest Science, Processing Technology, and Nutrition*, 141–168. https://doi.org/10.1002/9781119528265.ch8

Ahmed, U., & Anwar, A. (2022). Application of natural dyes in dye-sensitized solar cells. *Dye-Sensitized Solar Cells*, 45–73. https://doi.org/10.1016/b978-0-12-818206-2.00008-6

Al-Alwani, M. A. M., Ludin, N. A., Mohamad, A. B., Kadhum, A. A., & Mukhlus, A. (2018). Application of dyes extracted from Alternanthera dentata leaves and Musa acuminata bracts as natural sensitizers for dye-sensitized solar cells. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *192*, 487–498. https://doi.org/10.1016/j.saa.2017.11.018

Andualem, A., & Demiss, S. (2018). Review on dye-sensitized solar cells (dsscs). *Journal of Heterocyclics*, 29–34. https://doi.org/10.33805/2639-6734.103

Cahaya, N. Y., Puspitasari, N., & Prajitno, G. (2019). Karakterisasi Dye-sensitized solar cell (DSSC) Menggunakan tio2 Nanopartikel Dan Klorofil Daun alfalfa (Megicago sativa) Sebagai Sensitizer. *Jurnal Sains Dan Seni ITS*, *7*(2). https://doi.org/10.12962/j23373520.v7i2.34596

Chandra, P. (2022). Fabrication techniques and working principle of neoteric dye-sensitized solar cells. *Dye-Sensitized Solar Cells*, 159–179. https://doi.org/10.1016/b978-0-12-818206-2.00003-7

Chemistry International, C. I. (2021). Development of tio2-based dye-sensitized solar cells using natural dyes extracted from some plant-based materials. https://doi.org/10.31219/osf.io/ybxgd

Diantoro, M., Maftuha, D., Suprayogi, T., Reynaldi Iqbal, M., Solehudin, Mufti, N., Taufiq, A., Hidayat, A., Suryana, R., & Hidayat, R. (2019). Performance of pterocarpus indicus willd leaf extract as natural dye tio2-dye/ITO DSSC. *Materials Today: Proceedings*, *17*, 1268–1276. https://doi.org/10.1016/j.matpr.2019.06.015

Ezike, S. C., Hyelnasinyi, C. N., Salawu, M. A., Wansah, J. F., Ossai, A. N., & Agu, N. N. (2021). Synergestic effect of chlorophyll and anthocyanin co-sensitizers in tio2-based dye-sensitized solar cells. *Surfaces and Interfaces*, *22*, 100882. https://doi.org/10.1016/j.surfin.2020.100882

Gong, J., & Krishnan, S. (2019). Mathematical modeling of dye-sensitized solar cells. *Dye-Sensitized Solar Cells*, 51–81. https://doi.org/10.1016/b978-0-12-814541-8.00002-1

Gopal Krishna, B., & Tiwari, S. (2021). Bioinspired solar cells: Contribution of biology to light harvesting systems. *Sustainable Material Solutions for Solar Energy Technologies*, 593–632. https://doi.org/10.1016/b978-0-12-821592-0.00006-6

Govindarasu, R., Subramanian, M. K., Ahamad, T., & Majeed Khan, M. A. (2021). First Principle Investigation of new metal-free organic dye molecular for dsscs: Effects of π-conjugated groups. *Molecular Simulation*, 1–7. https://doi.org/10.1080/08927022.2021.1898607

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

Hiramoto, M. (2020). Proposal for future organic solar cells. *Organic Solar Cells*, 255–267. https://doi.org/10.1007/978-981-15-9113-6_10

IK, U. (2018). Effect of aqueous extract of bitter leaf (Vernonia Amygdalina) against acetaminophen-induced liver damage in rats. *Bioequivalence & Bioavailability International Journal*, *2*(1). https://doi.org/10.23880/beba-16000122

Iqbal, M. Z., Ali, S. R., & Khan, S. (2019). Progress in dye sensitized solar cell by incorporating natural photosensitizers. *Solar Energy*, *181*, 490–509. https://doi.org/10.1016/j.solener.2019.02.023

Jaafar, H., Magesvaran, L., & Ali, A. (2022). Efficient eco-friendly hybrid natural dyes as sensitizer for Dye-sensitized solar cell (DSSC) application. *INTERNATIONAL CONFERENCE ON BIOENGINEERING AND TECHNOLOGY (IConBET2021)*. https://doi.org/10.1063/5.0078631

Jiang, P., Jones, T. W., Duffy, N. W., Anderson, K. F., Bennett, R., Grigore, M., Marvig, P., Xiong, Y., Liu, T., Sheng, Y., Hong, L., Hou, X., Duan, M., Hu, Y., Rong, Y., Wilson, G. J., & Han, H. (2018). Fully printable perovskite solar cells with highly-conductive, low-temperature, perovskite-compatible carbon electrode. *Carbon*, *129*, 830–836. https://doi.org/10.1016/j.carbon.2017.09.008

Kerubo Oyaro, D., Oonge, Z. I., & Odira, P. M. (2020). Anaerobic digestion of banana wastes for biogas production. *Journal of Civil and Environmental Engineering*, *10*(3). https://doi.org/10.37421/jcde.2020.10.347

Korjenic, A., & Raja, K. S. (2019). Stability of fluorine doped tin oxide (FTO) coated substrates under extreme polarization conditions. *ECS Meeting Abstracts*, *MA2019-02*(10), 816–816. https://doi.org/10.1149/ma2019-02/10/816

Kusuma, H. H. (2017). The characteristics of material DSSC (dye-sensitized solar cell) solar cell from extraction of teak leaves. *Journal Of Natural Sciences And Mathematics Research*, *2*(1), 117. https://doi.org/10.21580/jnsmr.2016.1.1.1645

Kutlu, N. (2020). Investigation of electrical values of low-efficiency dye-sensitized solar cells (dsscs). *Energy*, *199*, 117222. https://doi.org/10.1016/j.energy.2020.117222

Li, W., Lv, F., Shu, T., Tan, X., Jiang, L., Xiao, T., & Xiang, P. (2019). Improving the performance of FTO conducting glass by Sio2 and zno anti-reflection films for dye-sensitized solar cells. *Materials Letters*, *243*, 108–111. https://doi.org/10.1016/j.matlet.2019.01.158

López-Covarrubias, J. G., Soto-Muñoz, L., Iglesias, A. L., & Villarreal-Gómez, L. J. (2019). Electrospun nanofibers applied to dye solar sensitive cells: A Review. *Materials*, *12*(19), 3190. https://doi.org/10.3390/ma12193190

Madnasri, S., Hadi, S., Wulandari, R. D., Yulianti, I., Edi, S. S., & Prastiyanto, D. (2019). Performance stability and optical properties of Musa acuminata bracts-based dye-sensitized solar cell. *Materials Today: Proceedings*, *13*, 311–316. https://doi.org/10.1016/j.matpr.2019.03.233

Mehmood, S., Ahmed, U., Kumar, L., Sagadevan, S., Hatamvand, M., Zhan, Y., Rahim, N. A., Ahmed, W., & Shakeel, M. (2022). Semiconducting Metal oxides-based electrodes as the photoanodes of dye-sensitized solar cells (dsscs). *Dye-Sensitized Solar Cells*, 103–136. https://doi.org/10.1016/b978-0-12-818206-2.00004-9

Mengstu, A., Bachheti, A., Abate, L., Bachheti, R. K., & Husen, A. (2021). Health-promoting benefits, value-added products, and other uses of banana. *Non-Timber Forest Products*, 339–364. https://doi.org/10.1007/978-3-030-73077-2_15

Mursal, Malahayati, Azmi, N., & Fatmiyah, S. (2021). Synthesis of tio2-based photoelectrode and natural dye for dye sensitized solar cell (DSSC). *Journal of Physics: Conference Series*, *1882*(1), 012006. https://doi.org/10.1088/1742-6596/1882/1/012006

Ndeze, U. I., Aidan, J., Ezike, S. C., & Wansah, J. F. (2021). Comparative performances of nature-based dyes extracted from Baobab and Shea leaves photo-sensitizers for dye-sensitized solar cells (dsscs). *Current Research in Green and Sustainable Chemistry*, *4*, 100105. https://doi.org/10.1016/j.crgsc.2021.100105

Okoye, I. F., Nwokoye, A. O., & Ahmad, G. (2021). Power voltage characteristics of fabricated DSSC incorporating multiple organic dyes as photosensitizer. *Energy and Power Engineering*, *13*(06), 221–235. https://doi.org/10.4236/epe.2021.136015

Oktariza, L. G., Yuliarto, B., & Suyatman. (2018). Performance of dye sensitized solar cells (DSSC) using syngonium Podophyllum Schott as natural dye and counter electrode. *AIP Conference Proceedings*. https://doi.org/10.1063/1.5034553

Omar, S. R., Karim, S. A., Isa, S. S., & Omar, S. N. (2020). Enlivening the effect of tourists' knowledge and involvement on Malaysian Heritage Food (MHF) towards food tourism image in Malaysia. *Destination Management and Marketing*, 268–290. https://doi.org/10.4018/978-1-7998-2469-5.ch016

Panda, B. B., Mahapatra, P. K., & Ghosh, M. K. (2018). Application of chlorophyll as sensitizer for ZnS photoanode in a dye-sensitized solar cell (DSSC). *Journal of Electronic Materials*, *47*(7), 3657–3665. https://doi.org/10.1007/s11664-018-6215-8

Park, M.-H., Sangwanangkul, P., & Baek, D.-R. (2018). Changes in carotenoid and chlorophyll content of black tomatoes (lycopersicone sculentum L.) during storage at various temperatures. *Saudi Journal of Biological Sciences*, *25*(1), 57–65. https://doi.org/10.1016/j.sjbs.2016.10.002

Pratiwi, D. D., Nurosyid, F., Kusumandari, Supriyanto, A., & Suryana, R. (2017). Performance Improvement of Dye-sensitized solar cells (DSSC) by using dyes mixture from chlorophyll and anthocyanin. *Journal of Physics: Conference Series*, *909*, 012025. https://doi.org/10.1088/1742-6596/909/1/012025

Revathi, S., & Jeyakumari, A. P. (2021). Fabrication of tio2/cds heterostructure photoanodes and optimization of light scattering to improve the photovoltaic performance of dye sensitized solar cells (dsscs). https://doi.org/10.21203/rs.3.rs-187929/v1

Sang-aroon, W., Tontapha, S., & Amornkitbamrung, V. (2019). Photovoltaic performance of natural dyes for dye-sensitized solar cells. *Dye-Sensitized Solar Cells*, 203–229. https://doi.org/10.1016/b978-0-12-814541-8.00006-9

Sathishkumar Chinnasamy, & Sivasubramanian Ramanathan. (2020). Ruthenium(II) dicarboxylated bipyridyl based metal organic polymer as a sensitizer for nanostructured tio2 based dye-sensitized solar cells (DSSC). *Journal of Ceramic Processing Research*, *21*(1), 123–130. https://doi.org/10.36410/jcpr.2020.21.1.123

Siddick, S. Z., Lai, C. W., & Juan, J. C. (2018). An investigation of the dye-sensitized solar cell performance using graphene-titania (TrGO) photoanode with conventional dye and natural green chlorophyll dye. *Materials Science in Semiconductor Processing*, *74*, 267–276. https://doi.org/10.1016/j.mssp.2017.10.046

Sowmya, S., Inbarajan, K., Ruba, N., Prakash, P., & Janarthanan, B. (2021). A novel idea of using dyes extracted from the leaves of prosopis juliflora in dye – sensitized solar cells. *Optical Materials*, *120*, 111429. https://doi.org/10.1016/j.optmat.2021.111429

Vijayan, R., Francis, S., & Mathew, B. (2021). Development of green technology through renewable and Sustainable Materials. *Renewable Materials and Green Technology Products*, 167–182. https://doi.org/10.1201/9781003055471-7

Wang, J., Mao, S., Yuan, Y., Zhang, N., Wu, Q., Liang, M., Wang, S., Huang, K., & Wu, Q. (2021). Effect of storage conditions and cooking methods on chlorophyll, glucosinolate, and sulforaphane content in broccoli florets. *Horticulturae*, *7*(12), 519. https://doi.org/10.3390/horticulturae7120519

Zanjanchi, F., & Beheshtian, J. (2018). Natural pigments in dye-sensitized solar cell (DSSC): A DFT-TDDFT study. *Journal of the Iranian Chemical Society*, *16*(4), 795–805. https://doi.org/10.1007/s13738-018-1561-2

Sagar, N. A., Pareek, S., Sharma, S., Yahia, E. M., & Lobo, M. G. (2018). Fruit and Vegetable Waste: Bioactive Compounds, Their Extraction, and Possible Utilization. *Comprehensive Reviews in Food Science and Food Safety*, *17*(3), 512–531. https://doi.org/10.1111/1541-4337.12330

l-Alwani, M. A. M., Ludin, N. A., Mohamad, A. B., Kadhum, A. A., & Mukhlus, A. (2018). Application of dyes extracted from Alternanthera dentata leaves and Musa acuminata bracts as natural sensitizers for dye-sensitized solar cells. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 192, 487–498. https://doi.org/10.1016/j.saa.2017.11.018

Maharjan, A. (2020). Comparative Study of Characteristics of Dye Sensitized Solar CellsFabricated Using Substrates Coated with Fluorine Doped Tin Oxide and Titanium. *Journal of the Institute of Engineering*, *15*(3), 216–221. https://doi.org/10.3126/jie.v15i3.32184

APPENDIX A
GANTT CHART

Elements	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
Introduction of Project														
Brief explanation														
Plan the dye used														
Decide the technique & wavelength														
Methodology														
Mechanical Extraction														
Storage time of dye & baked or non baked of dye														
Absorbance value by UV-Visible Spectrophotometer														
Fabricate FTO glass the (Dye-sensitized Solar Cell)														
Results														
Cholorophyll Analysis														
Absorption light (Absorbance versus Wavelength)														
Open Circuit Voltage, Voc (Dye-Sensitized Solar Cell)														
I-V characteristics														
Presentation														
Presentation Slide														
Thesis														
Completion of Logbook														

APPENDIX B
FINANCIAL PLANNING

MATERIAL & EQUIPMENTS	QUANTITIES	PRICE (RM)
Fluorine-doped tin oxide conductive glass (FTO)	30 pcs	RM282.00
Ethanol (2.5L)	As much as needed	Available (SV Grant)
Distilled water (2L)	As much as needed	Available (SV Grant)
Spatula	1	Available (SV Grant)
Bunsen burner	1	Available (SV Grant)
Glass beaker	5	Available (SV Grant)
Banana Midrib	4 midrib from banana leaves	Available
TOTAL		**RM282.00**