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Tomato (Solanum lycopersicum) Pigment as Sensitizer in Dye-Sensitized Solar Cell (DSSC)

A Research

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Chapter 1

Problem and Its Background

The demand for electricity and power rises as humanity moves farther into the modern world. Electricity is one of the main necessities of humans. It is utilized everywhere, may it be at home, at school, or at work. People's daily lives become more convenient with the help of electricity for it is one of the most significant inventions of all time. However, according to Energy Secretary Raphael Lotilla, the year 2023 may pose more challenges involving electricity in the Philippines as the economy continues to recover from the pandemic, due to Luzon and Visayas's limited electricity supply having to meet an even higher demand.

Over the past century, the main energy sources used for generating electricity have been fossil fuels, hydroelectricity, and since the 1950s, nuclear energy (*Where Does Our Electricity Come From? - World Nuclear Association*, n.d.). The fossil fuels that people used caused different varieties of damage not only to humans but also to the surroundings. The more electricity generated, the more carbon dioxide is emitted, which lingers in the atmosphere and contributes to global warming. As a consequence, extreme weather is expected. Floods, forest fires, and drought will all occur. In research from Marsh, solar energy is a great alternative to fossil fuels (2018). Solar energy technology is currently the third most used renewable energy source in the world after hydro and wind power (Paiano, 2015). Moreover, solar energy, among other renewable sources of energy, is a promising and freely available energy source for managing long term issues in an energy crisis (Kannan & Vakeesan, 2016).

The DSSCs belong to third-generation solar cells (Ambapuram et al., 2022). According to Lin and Ho, Dye-Sensitized Solar Cells (DSSCs) have received great attention as efficient photovoltaic devices in the last decades (2018). Photovoltaic devices directly convert sunlight into electricity. In DSSC, the dye serves as the light harvester and aids in the production of exciting electrons. All things considered, the DSSCs have low-cost production methods, peculiar optical and mechanical properties with high indoor efficiency, making it a better source of electricity upon further development (Gopal Krishna & Tiwari, 2021).

Furthermore, the variables that will be utilized in this study includes the tomato dye/dye as the sensitizer, indium tin oxide as the conductive glass, graphite as the catalyst in the counter electrode, cuprous oxide as the conductor, and iodine solution as the electrolyte. First, the tomato can produce an eco-friendly dye/dye. It contains anthocyanins that may act to capture photons from sunlight then convert it to usable electricity. It also offers a promising approach in improving the stability of solar cells. Second, the Indium Tin Oxide (ITO) is a well-known n-type degenerated semiconductor and conductive glass that has a wide range of electrical and optoelectronic applications. According to a recent spectroscopic investigation, ITO can both accept and donate electrons upon photoinduced charge transfer. Third, graphite, which is currently utilized in power devices for heat diffusion, possesses an ultra-high thermal conductivity, thin, flexible, resilient structures, and exhibits a potential as a heat dispersion medium for thermal management. Fourth, Cuprous Oxide Nanoparticles (Cu_2O NPs) have the ability to act as a barrier layer in DSSC to obtain high power conversion efficiency. Lastly, visible light can be absorbed by Iodine Solution, resulting in photocurrent loss in the DSSC, which as an outcome, could lead to a more cost-effective DSSC alternative.

Therefore, this study seeks to develop an innovative Dye-Sensitized Solar Cell (DSSC) from Tomato Dye/Pigment, Cuprous Oxide, and Graphite Layer with Iodine Solution in Indium Tin Oxide Conductive Glass, in order to provide a low-cost third generation solar cell which will allow visible light to be converted into electrical energy efficiently and generate power in low-light environments, such as indoor lighting. Further development of this study may lead to a new and cost-effective source of electricity in the Philippines or even around the world.

A. Statement of the Problem

Despite the promising potential of Dye-Sensitized Solar Cells (DSSCs) as a low-cost and efficient alternative to traditional photovoltaic devices, the development of highly efficient and stable dyes remains a significant challenge. As such, there is a need to explore and investigate new sensitizers that are abundant, inexpensive, and environmentally friendly. The following questions below are the information that the researchers wanted to know more about:

1. What is the relationship between the shade of dye/pigment to the amount of electricity to be produced in the DSSC?
2. Will the amount of the tomato pigment impact the efficiency of the power output disc?
3. How much dye in milliliters (mL) is required to produce 1 Volt?
4. How much dye can power up a single pin LED light (LTL-307EE)? How long will it last?

B. Theoretical Framework

This study is supported by the theory of Jasim (2011) "Dye Sensitized Solar Cells - Working Principles, Challenges and Opportunities" at the University of Bahrain. According to this theory, renewable energy sources such as solar energy are a feasible alternative because "more energy from sunlight strikes Earth in one hour than all of the energy consumed by humans in an entire year" (Lewis, 2007). The materials, charge carrier synthesis, and transport inside the cell structure are primarily responsible for the nanocrystalline Dye-Sensitized Solar Cell's (nanocrystalline DSSC) reputation as a low-cost, environmentally friendly, and cell that is capable of being extremely efficient. The nanostructured Dye-Sensitized Solar Cell, also known as the DSSC, is likely to provide an economically credible alternative to the p–n junction photovoltaics that are now in use. In fact, Dye-Sensitized Solar Cells are eco-friendly solar cells that imitate the look of leaves being green. In a Dye-Sensitized Solar Cell, the photoexcitation of dye molecules that have been adsorbed to a nanostructured broad bandage material photoelectrode leads to the transfer of electrons, which in turn results in the generation of energy.

The oxidized dye molecules were able to recreate themselves by stealing electrons from the electrolyte, which were then reduced by the electrons that made it to the cell's counter-electrode. Because the nanostructured Dye-Sensitized Solar Cell DSSC imitates photosynthesis in plants, it offers an interdisciplinary context for students to learn the fundamental principles of biological extraction, chemistry, physics, environmental science, and electron transfer. This has educational implications.

Even before the agricultural and industrial revolutions, the availability of energy had a significant impact on the quality of human life. The rapid and reckless consumption of traditional sources of energy is a major contributor to the impending energy and environmental disasters that are being predicted. The quest for environmentally friendly energy sources or generators is often seen as one of the most pressing issues facing modern society and is high on the to-do lists of many policymakers. Therefore, extensive research activities have resulted in attention being drawn to the many kinds of solar cells that are based on either organic or inorganic materials.

C. Conceptual Paragraph/Framework

The diagram shown below displays the conceptual framework of the study. There are three variables present: the type of dye (tomato dye) as the independent variable, the efficiency of the Dye-Sensitized Solar Cells (DSSCs) as the dependent variable, and the absorption capacity of the tomato dye as the mediator variable.

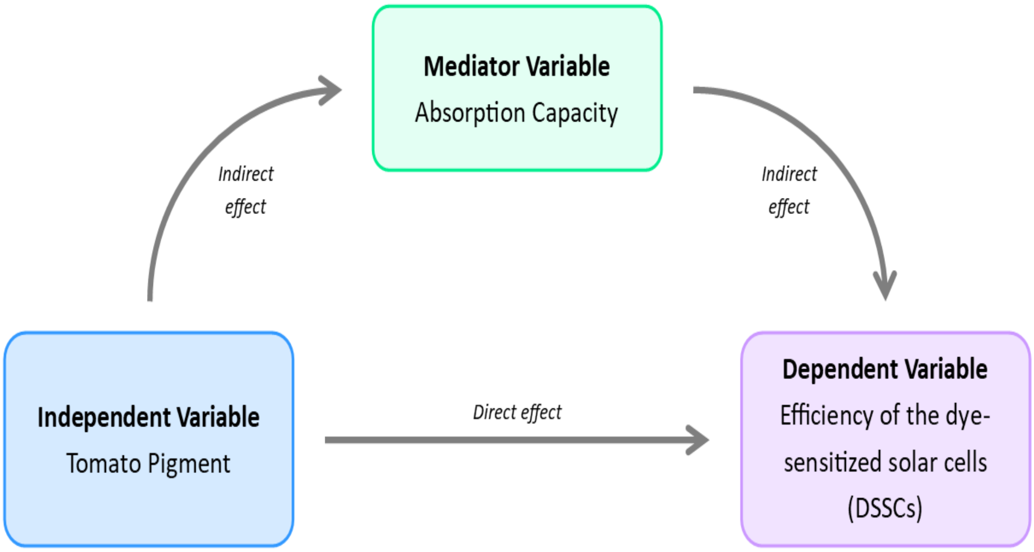


Figure 1: Conceptual Model of the Study

The tomato pigment as an independent variable pertains to the use of a particular dye manipulated by the researchers. Tomato pigment has long been extracted and utilized from different resources as a nature-based dye. Further dyes that have variations in their properties have also been used, such as chlorophyll dyes and anthocyanins extracted from plant dyes. The researchers have control over the type of dye to be used. In this case, the researchers may choose to use tomato dye as a sensitizer.

The efficiency of Dye-Sensitized Solar Cells (DSSCs) refers to the data analysis and interpretation by which the type of dye (tomato dye) will be tested and compared with its efficiency. The efficiency of the DSSC will depend on the type of dye used as a sensitizer, which is the independent variable. Therefore, the efficiency of the DSSC is dependent on the type of dye used in the experiment.

There is also a mediator variable present within the diagram that determines the effects of the type of dye on the efficiency of the Dye-Sensitized Solar Cells (DSSCs). This is none other than the absorption capacity of the tomato dye in the Dye-Sensitized Solar Cells (DSSCs). The absorption capacity of the tomato dye serves as a mechanism through which the type of dye affects the efficiency of the DSSC. The dye's absorption capacity is crucial in DSSC, as it determines how effectively it can capture photons of light and convert them into electrical energy. A high absorption capacity of the tomato dye would capture more photons, resulting in a higher DSSC efficiency. Conversely, a low absorption capacity would lead to lower DSSC efficiency.

D. Statement of the Hypothesis

Hypothesis No.1

Is there a relationship between the shade of dye/pigment to the amount of electricity to be produced?

H_0: There is no relationship between the shade of dye/pigment to the amount of electricity to be produced.

H_1: There is a relationship between the shade of dye/pigment to the amount of electricity to be produced.

Hypothesis No. 2

Will the amount of the tomato impact the efficiency of the power output disc?

H_0: The amount of the tomato has no impact on the efficiency of the power output disc.

H_1: The amount of the tomato has an impact on the efficiency of the power output disc.

Hypothesis No. 3

How much tomato dye/pigment dye is required to produce 1 Volt (V)?

H_0: 0.10 mL tomato dye will not be able to produce 1V

H_1: 0.10 mL of tomato dye will be able to produce 1V

Hypothesis No. 4

Will the concentrated dye solution pigment power up a single pin LED light (LTL-307EE)? How long will it last?

H_0: 0.10 mL tomato dye cannot power up a single pin LED light than 0.05 mL diluted tomato dye. The pin LED light will not last for about an hour.

H_1: 10 mL of concentrated tomato dye can power up a single pin LED light than 5 mL diluted tomato dye. The pin LED light will last for about an hour.

E. Scope and Delimitation

This study will cover the development of a Dye-Sensitized Solar Cell (DSSC) using tomato dye, titanium oxide powder, graphite layer, and iodine solution, and indium tin oxide conductive glass (ITO).

A square conductive glass (ITO) with the measurement of 2x2 cm will be used for each DSSC. Moreover, two factors will be manipulated: First, the pigment or the color intensity of the tomatoes wherein each set of DSSC will use a pigment extracted from the tomato with the shades of orange and red. Second is the amount of the dye/pigment to be utilized. Thus, each sample output will receive 0.05mL (1drop) and 0.10mL (2 drops) of tomato pigment from each shade, together with 25mL of water as the solvent. Therefore, there will be four sets of DSSC sample outputs where: Set A will be 0.05mL of orange tomato pigment; Set B will be 0.05mL of red tomato pigment; Set C is 0.10mL of orange tomato pigment; and lastly, Set D is 0.10mL of red tomato pigment.

The development of the said DSSC outputs will take place in a laboratory, provided with complete materials that will be bought from either the market or the nearest commercial laboratory supply located in Bambang. The preparation and development of the sample outputs will be carried out for three hours. Another two hours will be added to allocate further observations and assessments. The collection of data will take place promptly prior to its development.

Furthermore, the sole instrument needed is the multimeter. This instrument is requisite for the conductivity testing of the ITO glass, as well as in determining the output voltage that would be generated from the sample products in volts (V).

Finally, the expected budget in order to accomplish the development of the sample products will cost from ₱1500 to ₱2000. The exact amount needed for the study may change as the prices of each material varies.

F. Significance of the Study

With the growing demand for electricity, numerous alternative ways of generating power are in line for further investigation. This includes the progression and development of Dye-Sensitized Solar Cells. The findings in this study will contribute to the following sectors:

Future Researchers. This study would be very beneficial for future researchers who will be investigating the same concept in line with the Dye-Sensitized Solar Cell (DSSC). This will help future researchers become more knowledgeable in regards to the processes involved in the development of DSSCs. This study may serve as a future reference for succeeding studies and may help them become better analysts.

The People. The citizens will benefit from dye-sensitized cells. The DSSC is a viable electricity alternative. It may not provide the exact same voltage as electrical energy, but it is very useful to citizens when the power goes out, and it is also useful in terms of lowering the electrical bill. Because the demand for electricity in our time is critical and the methods of using solar panels to reduce electricity bills are costly, not everyone has the opportunity to purchase that equipment. The importance of this study to citizens is that it will assist underprivileged people in lowering their electricity consumption or bill without having to purchase a costly product.

The Government. Dye-Sensitized Solar Cells (DSSC) has a great help also to the government. The use of fossil fuels will decrease, causing us to preserve these non-renewable sources of energy. DSSC can help save energy. Additionally, led by the government, people can be taught alternative ways on how to produce energy like DSSC. Lastly, this research can be innovated to help the government with future energy programs.

G. Definition of Terms

The following terms are defined in the context of this research for a better understanding of the study.

Lycopene. According to Oxford Languages, the definition of lycopene is a red carotenoid pigment present in tomatoes and many berries and fruit

Counter–electrode. The counter or auxiliary electrode allows input potential to be applied to the working electrode. These electrodes serve to complete the circuit and allow charge to flow.

Dye–Sensitized. According to Garter (2022). Use an organic dye to absorb incoming sunlight, resulting in excited electrons and energy that is then transferred to a low-cost material, such as titanium dioxide (TiO2).

Hydroelectricity. Electricity generated by generators powered by turbines that convert the potential energy of falling or fast-flowing water into mechanical energy.

Indium Tin Oxide. It refers to the ternary composition of indium, tin and oxygen in varying proportions.

Nanocrystalline. Have a wide variety of proven and potential applications. They have been used in the manufacture of filters that refine crude oil into diesel fuel (Tech – Target, 2019).

Photoelectrode. Photoelectrons are electrons that are produced when an energetic photon of radiation strikes a molecule, and the photoelectron spectrum is formed by analyzing the spectrum of energies that they possess.

Photosensitive. A condition in which the skin becomes extremely sensitive to sunlight or other types of ultraviolet light and can easily burn (National Cancer Institute, 2019).

Photovoltaic. PV devices generate electricity directly from sunlight using an electronic process that occurs naturally in certain types of materials known as semiconductors.

CHAPTER 2

REVIEW OF RELATED LITERATURE

This chapter covers the ideas, completed thesis, generalization, and conclusion. Those presented in this chapter help readers become acquainted with pertinent and related information to the current study.

FOREIGN

In this modern age where technological breakthroughs are in the palm of our hands, energy certainly has a great impact in affecting our daily lives. An increased rate of energy use would eventually add up to the whole percentage of environmental risks posed by sources of energy that are running out. Consequently, renewable energy such as organic Dye-Sensitized Solar Cell (DSSC) is one of the candidates of viable alternatives. Therefore, having in-depth research investigations about different solar cells, may be the answer to the gradually exhausting sources of energy, specifically, the DSSCs. This section will give a quick overview of earlier and comparable studies that were conducted, with the purpose of discovering more about the topic.

Dye Sensitized Solar Cells - Working Principles, Challenges and Opportunities

Khalil Ebrahim Jasim's (2011) study said that low-cost solar cells have been the subject of a lot of research over the past 30 years. Compared to traditional silicon-based solar cells, DSSCs offer advantages such as ease of production, their performance improves as the temperature rises, they have a bifacial configuration which is good for diffused light, they are transparent for power windows, the color can be changed by choosing the dye, invisible PV-cells based on near-IR sensitizers are possible, and they are more efficient at turning light into electricity when there is a lot of cloud cover or when there is not much light.

Still, based on Khalil Ebrahim Jasim's research, the feasibility of nanocrystalline Dye-Sensitized Solar Cells (DSSCs) as a low-cost, environmentally friendly, and efficient alternative for traditional solar cells was examined. DSSCs imitate photosynthesis in plants by producing energy via electron transfer caused by the photoexcitation of dye molecules. Natural colors derived from Henna, pomegranate, cherries, and raspberries can be utilized to sensitize wide gap semiconductor semiconductors in DSSCs. The efficiency of natural dye extract sensitized nanocrystalline solar cells may be optimized by improving preparation procedures, utilizing different types of electrolytes, reported additives, and sealing. The development of nanocrystalline photovoltaic cells is a possible candidate for large-scale solar energy conversion.

Environment Approachable Dye-Sensitized Solar Cell Using Abundant Natural Pigment-based Dyes with Solid Polymer Electrolyte

The study conducted by Zhang et al. (2018) explores the potential of natural pigments in DSSCs with a solid polymer electrolyte. The study describes the experimental methods used to extract the natural dyes and incorporate it into the DSSCs.

The researchers used red beans (Anthocyanin), barley grass (Chlorophyll) and orange peel (β-carotene) as natural dyes. In the summary of the paper, the researchers mentioned that the absorption of natural dyes sensitizers was determined to be 400 nm to 600 nm using UV–

vis absorption spectroscopy. They found out that the orange peel (β-carotene) has a minimum absorption of 400 nm.

The β-carotene present in orange peels is also present in tomatoes. It is the second main coloured carotenoid present in tomatoes which is responsible for its orangey colors.

The results of the study show that just like orange peels the tomato pigment also exhibited good light harvesting and conversion efficiency in the DSSCs. The authors also found that it showed good stability over time, making it a promising candidate for use as a sensitizer in DSSCs with a solid polymer electrolyte.

LOCAL

Importance of Power Supply/Affordability of DSSC

Even before the usage of power supplies, one of the necessities of humans are fossil fuels. Fossil fuels are one of the main power sources that is required to produce electricity, heat, and energy. Fossil fuels are mainly collected through oil rigs which use underground mining, digging, and collection underneath sea beds and through underground reserves. Fossil fuels are derived from organic matter, which is gradually depleting in our age. According to Setiawan *et al.* (2017) Renewable energy development can be an alternative for fossil fuel which is one of the most adequate alternatives to overcome the environmental and energy crises.

They also stated that, compared to the first two experiments which is the first and second generation, Dye-Sensitized Solar Cell (DSSC) is one of the viable candidates for future solar cells as it doesn't require high purity materials and thus has a low production cost.

In addition to this, Di Wei (2010) stated that the efficiency of Dye-Sensitized Solar Cell (DSSC) is equivalent to the performance of amorphous silicon solar cells—which is in demand now in our time, but with a much lower cost.

REVIEW OF RELATED STUDY

FOREIGN

Fundamentals and Current Status of the DSSC

According to the study in Springer Open (2018), Dye-Sensitized Solar Cells (DSSCs) are a type of thin-film solar cell that has been the subject of extensive research for over two decades due to their low cost, simple preparation methodology, low toxicity, and ease of manufacture. Still, due to their high cost, scarcity, and long-term stability, current DSSC materials have a lot of room for replacement. Existing DSSCs have an efficiency of up to 12% when using Ru (II) dyes and optimizing material and structural properties, which is still less than the efficiency of first- and second-generation solar cells, i.e., other thin-film solar cells and Si-based solar cells, which have an efficiency of less than 30%.

The Dye-Sensitized Solar Cells (DSC) concept offers a technically and economically viable alternative to today's p-n junction photovoltaic devices. Unlike in conventional systems, where the semiconductor performs both light absorption and charge carrier transport, the two functions are separated here. A sensitizer anchored to the surface of a wide-band semiconductor absorbs light. Charge separation occurs at the interface due to photo-induced electron injection from the dye into the solid's conduction band. Carriers are transported to the charge collector via the semiconductor's conduction band. The use of sensitizers with a broad absorption band in conjunction with oxide films with nanocrystalline morphology allows a large fraction of sunlight to be harvested (Sharma, K., et al., 2018).

Improving the Quality and Performance of Dye-Sensitized Solar Cells

Intensive research has been conducted on Dye-Sensitized Solar Cells over the last three decades. Nonetheless, many aspects remain to be investigated in order to improve their performance. dye molecules can be endlessly modified to improve performance. Steric groups, for example, can be introduced to slow down recombination reactions and avoid unfavorable aggregation. More optimal dye packing on the mesoporous TiO2 surface is required to increase light absorption and promote a better blocking effect. Novel redox mediators and HTMs are critical components for achieving higher-performing DSC because they can provide significantly higher output voltage than the traditional triiodide/iodide redox couple (Caramori, S. 2019).

The performance of a Dye-Sensitized Solar cell (DSSC) is theoretically and experimentally examined. The effective electron diffusion coefficient, recombination rate constant, and difference between the conduction band and formal redox potentials are estimated from current-voltage measurements using a macroscopic, first-principles mathematical model of the DSSC (E. Bavarian et al., 2014).

Solvent Characterization of Lycopene Extraction in Tomato Fruits as Sensitizer Candidates in Dye-Sensitized Solar Cell (DSSC)

The use of tomato dye as a sensitizer for Dye-Sensitized Solar Cells (DSSC) has been explored in previous studies. One such study, conducted by Septiani et al. (2022), focused on characterizing the solvent used in the extraction of lycopene from tomato fruits for use as a sensitizer in DSSCs. The study found that using acetone as the solvent for lycopene extraction was more suitable compared to ethyl acetate, based on the results of property analysis of the two solvents used. The researchers also identified the functional groups of the compound formed using an FTIR spectrophotometer and determined the absorbance and maximum wavelength value of the lycopene extract using a UV-Vis spectrophotometer.

The findings of the study support the use of tomato dye as a sensitizer in DSSCs. By characterizing the solvent used in the extraction of lycopene, the researchers provided valuable information that could help improve the performance of DSSCs using tomato dye as a sensitizer. The study also highlighted the importance of selecting the right solvent for dye extraction, as the properties of the solvent can have a significant impact on the resulting extract's properties.

This study provides insights into the characterization of the solvent used in the extraction of lycopene from tomato fruits for use as a sensitizer in DSSCs. Based on the findings, acetone was found to be a more suitable solvent compared to ethyl acetate. These results could help guide future research in the development of DSSCs using tomato dye as a sensitizer, potentially leading to more efficient and sustainable solar energy technologies.

Carotenoid Dye as Sensitizers for Applications of Dye-Sensitized Solar Cell (DSSC)

According to the study conducted by Supriyanto et al. (2018), carotenoid dyes extracted from natural sources such as tomatoes can serve as efficient sensitizers for Dye-Sensitized Solar Cells (DSSC). Because of their ability to bind to the TiO2 interface, which is a critical component of DSSCs, carotenoids are a good candidate for Dye-Sensitized Solar Cells (DSSCs). Carotenoids' carboxyl group allows them to cling to the surface of TiO2, increasing their light-harvesting ability and electron transfer efficiency. Furthermore, carotenoids have a highly conjugated system of single and double bonds, which allows them to absorb light and transfer electrons to TiO2. The researchers characterized the absorbance of the dyes and TiO2 using UV-Vis spectrophotometers and determined the chemical bond between them using FTIR spectrophotometers. They found that the carotenoid dyes had an absorbance peak in the wavelength range of 400 nm–510 nm, which is suitable for use in DSSC.

Based on this study, the highest efficiency of DSSC was obtained using tomato dye at 0.03% concentration due to the interaction between TiO2 and the carboxyl-OH group. This finding supports the potential use of tomato dye as a photosensitizer for DSSC. Furthermore, the use of natural dyes as sensitizers has gained interest due to their low cost, biodegradability, and availability compared to synthetic dyes.

The potential use of tomato dye as a photosensitizer for DSSC could have significant implications for the development of sustainable and renewable energy sources. The study highlights the importance of exploring natural sources of dyes for DSSC applications and their potential to improve the efficiency and cost-effectiveness of solar energy conversion. Further research could focus on optimizing the concentration and stability of tomato dye as a photosensitizer for DSSC and its performance under different conditions.

LOCAL

The use of natural dyes as sensitizers in Dye-Sensitized Solar Cells (DSSCs) has gained significant attention in recent years due to their low cost, environmental friendliness, and good performance. In this review, the researchers will focus on studies that have used dye extracted from Tomato (Solanum lycopersicum) dye as Sensitizer in dye – Sensitized Solar Cell (DSSC) as sensitizers in DSSCs.

Performance of Dye-Sensitized Solar Cells with Natural dye from Local Tropical Plants

According to the study "Performance of Dye-Sensitized Solar Cells with Natural Dye from Local Tropical Plants" in the Mindanao Journal of Science and Technology, solar energy conversion (photovoltaic [PV]) systems are now prevalent in the market and have been identified in many different applications, from the household level to industrial or commercial scales. Where among the several components of a solar PV system, the solar cell is the one that converts the photons from different light sources into usable energy.

Dye-Sensitized Solar Cell (DSSC) is a class of third generation solar cells that are formed by placing a semiconductor between a photosensitized anode and an electrolyte, allowing the light to pass through the cell (Bauer et al., 2002). Clear glass substrates are used as electrode substrates because of their cheapness, availability, and high transparency in the visible spectrum. DSSCs are also credible alternative concepts for inorganic solid-state photovoltaic devices (Ludin et al., 2014).

CHAPTER 3

METHODOLOGY

This chapter reveals the methods of research to be employed by the researcher in conducting the study which includes the research design/purpose of the study, significance of materials, data gathering instruments and procedure, and its development establishing its validity and reliability, and the appropriate statistical treatment of data.

A. Purpose of the Study and Research Design

The goal of this quantitative study is to recognize the efficiency of tomato dye as a sensitizer of Dye-Sensitized Solar Cell, as well as to recognize how much power it can produce. To meet the main objectives, the researchers will be creating a Dye-Sensitized Solar Cell and will be using the dye of a tomato as its sensitizers.

The study will employ quantitative research methods. The researchers will apply a true experimental style of research to evaluate the effectiveness of the Tomato dye (Solanum lycopersicum) as a sensitizer in DSSCs and to determine its potential as a viable alternative to conventional dyes.

A true-experimental design is a study in which the researchers can manipulate the research variables and are not randomized. It aims to recognize causal relationships among variables and relies on statistical analysis. The variables of this study can be manipulated by the researchers. The study can be conducted without having a pre-test and a post-test as it only seeks for the outcome. Thus, making it a true-experiment design.

The study utilizes the use of multimeter and experimental manipulations as research instruments. Whereas in experimental manipulations, the researchers will manipulate the amount of independent variable, tomato dye to measure the dependent variable which is the produced electrical current. A multimeter is an instrument that measures the electrical current flowing through a circuit or conductor. The multimeter will be used to measure the current that will be produced by tomato dye in DSSCs.

B. Methods

3.1 Collection of the Materials

The required materials, including ITO-coated glass, titanium dioxide nanopowder, iodine solution, nitric acid, and isopropanol solution, will be obtained from the commercial laboratory located in Bambang. Additionally, the red and orange tomatoes, as well as the graphite layer from the pencil, will be purchased from a nearby market. The Bunsen burner heating tripods, alcohol lamps, droppers, and beakers will be borrowed from Mr. Reginald Pabico.

3.2. Preparation of the Materials

Initially, eight conductive ITO glasses will be prepared, wherein two glasses will be allocated for each set. After that, 10mL of titanium dioxide nanopowder will be diluted from 5mL of nitric acid to make a paste.

3.3 Pigment Extraction

The tomatoes will undergo a thorough rinsing process in water for three times to eliminate any contaminants. Once cleaned, the tomatoes will be diced into smaller pieces. It will be boiled in 25mL of water for 45 minutes until it exhibits coloration/pigmentation. Subsequently, the boiled tomatoes will be crushed using a blender to further break down the pulp, and the resulting mixture will be strained using a fine strainer for maceration. The obtained dye will be stored in a sanitized container, with the two shades of tomato dye separated, ready for DSSC application.

3.4 Conductivity Testing of Indium Tin Oxide

Each ITO Conductive Glass will be examined to determine the appropriate side for use. A digital multimeter will be configured to measure the resistance in ohms, and it will be connected to the ITO glass. The side that displays zero or near-zero resistance will be identified as the correct side, indicating the presence of the conductive coating.

3. 5 Fabrication of the Dye-Sensitized Solar Cell

The initial four sets of ITO Coated Glass will be bordered using a tape on all four sides, leaving the central portion of the glass. This tape border will create a distinct area for the following steps. The paste derived from the diluted Titanium Dioxide Nanopowder will then be evenly applied to the uncoated middle section of the ITO Glass where the conductive coating is present. After that, the tape bordering the sides of the ITO Glass will be carefully removed. Subsequently, the glass will be positioned on the Bunsen burner tripod. It will be subjected to a 15-minute heating process. This process will be closely monitored to slightly melt the Titanium Dioxide on the anode and strengthen the material.

3.5.1 Dyeing of the Cell

For set A, 0.05mL of the orange tomato dye will be dropped on top of the anode (where the ITO Glass is coated with Titanium Oxide paste). The process for the remaining sets will be the same, but varying in the amount of dye. Set B will be using 0.05 mL of red tomato dye. Set C will have 0.10mL of orange tomato dye and for set D, it will be 0.10mL of red tomato pigment. The pigment will get adsorbed onto the surface of the Titanium Dioxide.

3.6 Preparation of the Counter-Electrode

For each set, an additional piece of ITO Glass will be utilized. The four ITO Glass pieces, measuring 2x2 cm each, will be coated with an adequate quantity of graphite using a pencil. The graphite present in the pencil lead will act as a catalyst, ensuring the continuation of the reaction.

3.7 Assembling of the Cell

The cells will be joined together with binder clips, ensuring that the edges are offset to allow access for the multimeter probes. This will be done to the four sets of DSSC. The Iodine Solution amounting 0.5 mL, which acts as the electrolyte, will be added on top of the offset edges. The binder clips will be squeezed in and out for a few times to let the iodine solution through, until the dye and electrolyte are mixed together. At this stage, the Dye-Sensitized Solar Cell will already be working.

3.8 Assessment of the Dye-Sensitized Solar Cell

The four produced sets of Dye-Sensitized Solar Cells will undergo evaluation to determine their efficiency. The multimeter will be adjusted to measure volts and its alligator clips will be attached to the probes. Subsequently, the clips will be connected to each set of DSSC, allowing the output voltage to be measured and assessed.

3.9 Testing of Dye-Sensitized Solar Cells to pin LED Light

The wires will be attached to the anodes and cathodes by utilizing alligator clips, with the positive clip connected to the cathode and the negative clip connected to the anode. The anode portion of the LED pin will be linked to the working electrode of the DSSC, while the cathode part of the LED will be connected to the counter electrode of the DSSC using the alligator clips.

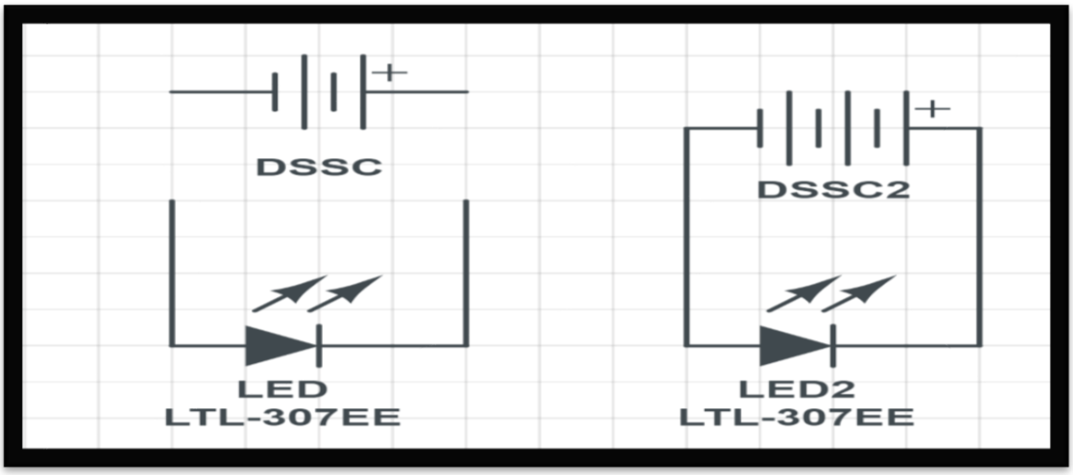


Figure 1: Circuit diagram shows the connection of the DSSC and LED

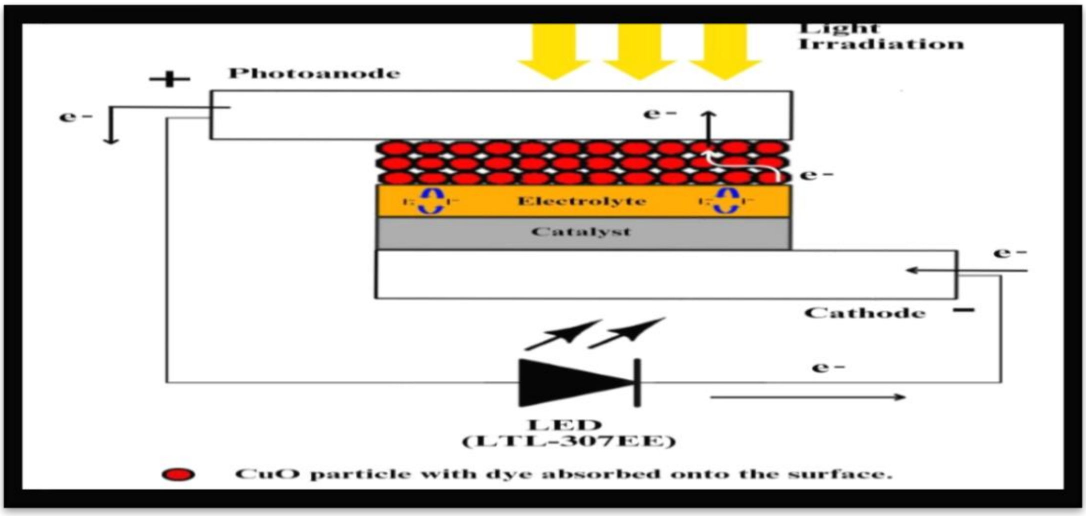


Figure 2: Working mechanism of tomato dye – sensitized solar cells (DSSCs).

C. Data Analysis and Procedure

The One-way Analysis of Variance (ANOVA) will be used by the researchers to compare the performance of the different shades of tomato dye variables coming from red and orange tomatoes as sensitizers in the Dye-Sensitized Solar Cells (DSSC). Through this statistical analysis, the researchers aim to determine the efficiency of the red and orange tomato pigments in accordance with the electricity it will generate to be measured in volts.

Moreover, the researchers will also utilize Multiple Regression Analysis to model the relationship between the tomato pigment and the performance of the DSSCs in terms of time stability. By employing these data analysis techniques, the researchers aim to gain valuable insights into the performance of tomato dye dyes as sensitizers for DSSC.

CHAPTER 4

PRESENTATION, ANALYSIS AND INTERPRETATION OF DATA

This chapter presents a thorough and comprehensive analysis of the research findings regarding the application of tomato pigment as a sensitizer in dye-sensitized solar cells (DSSCs). It offers detailed information on the experimental design, encompassing the methodologies employed, as well as the evaluations of efficiency and stability that form the basis of the experimentation. The outcomes obtained from this study provide valuable insights into the potential of tomato pigment as a sustainable substitute for enhancing DSSC technology. By shedding light on its performance and viability, this research contributes to the broader understanding of utilizing natural pigments in solar cell applications, thus promoting advancements in renewable energy technology.

SOP 1: Dye/Pigment Shade and Electricity Production in DSSCs

SOP 2: Tomato Pigment Quantity and Power Output Efficiency in DSSCs

SOP 3: Dye Quantity in mL for 1 Volt Production in DSSCs

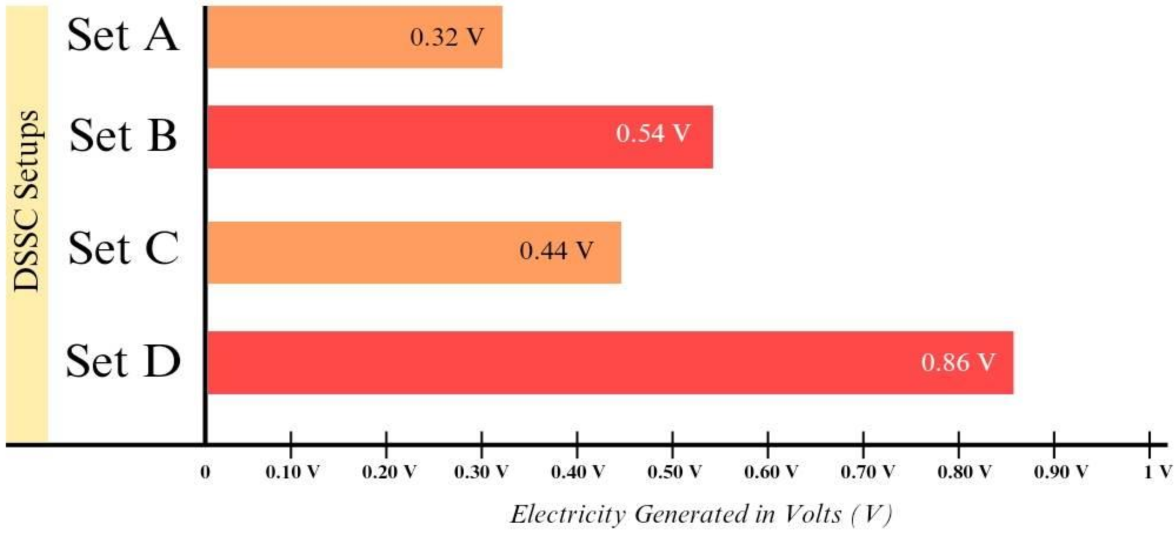
SOP 4: Dye Quantity for Powering an LTE-307EE LED Light and its Duration

Presentation of Data

In this data presentation, the researchers focus on the use of Tomato Pigment in Dye-Sensitized Solar Cells (DSSCs). Natural dyes extracted from orange and red tomatoes were employed to enhance the performance of the solar cells. The main objective of this study is to compare the voltage output between the two shades of tomatoes. The researchers utilized the One-way Analysis of Variance (ANOVA) statistical treatment to analyze the data, and the results will be presented in a table format. This analysis provides valuable insights into the voltage differences between orange and red tomato pigmented DSSCs, contributing to the advancement of solar cell technology.

The Table 1 below is the representation of electricity generated in volts for the four (4) sets of Dye-sensitized Solar Cells. As represented in the graph, set A and set C represent the orange pigment. Set A represents the orange pigment amounting 0.05 mL, while set C represents the orange pigment amounting 0.10 mL. Upon conducting the experiment, set A generated 0.32 V of electricity while set C generated 0.44 V of electricity. For the red pigment, it is represented by set B and set D. Set B represents the red pigment amounting 0.05 mL while set D represents red pigment amounting 0.10 mL. Set B generated 0.54 V of electricity while set D generated 0.86 V of electricity. Therefore, the larger the amount and the darker the pigment, the more electricity it will produce.

Table 1: Electricity Generated in Volts for Four DSSC Setups.



SET A Orange Pigment 0.05 mL	**SET B** Red Pigment 0.05 mL
SET C Orange Pigment 0.10 mL	**SET D** Red Pigment 0.10 mL

Interpretation Table:

Set A ●	——	**0.32 V**
Set B ●	——	**0.54 V**
Set C ●	——	**0.44 V**
Set D ●	——	**0.86 V**

Below is Table 2, which represents the time stability when the four (4) Dye-sensitized Solar Cells produced the said electricity voltage in Table 1. For the orange pigment set A produced 0.32 V of electricity for 7 seconds while set C produced 0.44 V of electricity for 12 seconds. For the red pigment, set B generated 0.54 V of electricity that lasted for 16 seconds while set D generated 0.86 V of electricity that lasted for 23 seconds. Therefore, the greater the amount of dye and the darker the pigment, the more stable the electricity produced is.

Table 2: Time Stability of the Four DSSC Setups.

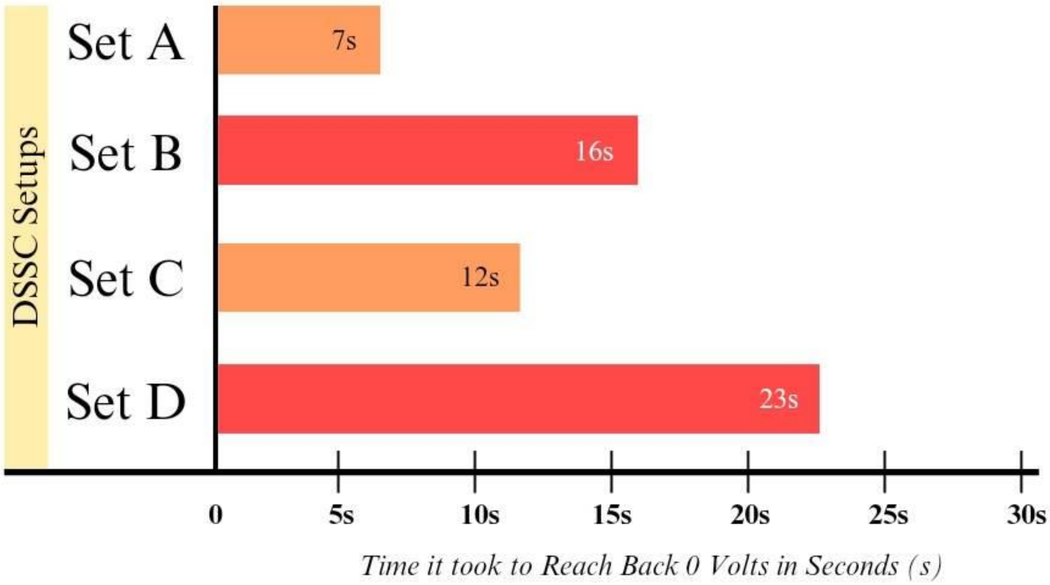
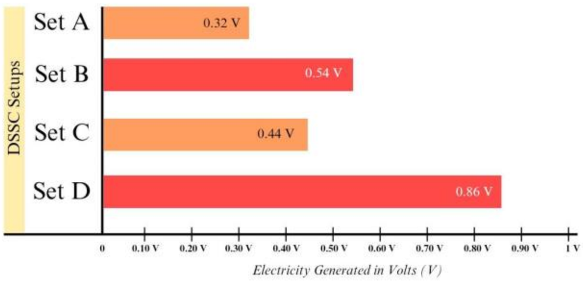


Table 1: Electricity Generated in Volts for Four DSSC Setups.



Interpretation Table:

Set A ●	——	**7s**
Set B ●	——	**16s**
Set C ●	——	**12s**
Set D ●	——	**23s**

Analysis

Based on the results obtained from the one-way ANOVA analysis, the data indicates that Set D, which used 0.10mL of red tomato pigment, demonstrated the highest efficiency power among the tested cells. This particular cell was able to absorb 0.86 volts of solar energy. On the other hand, the sets of orange shade tomatoes only achieved a voltage output of no more than 0.50 volts. The lower voltage output of the other set of red shade tomatoes can be attributed to the lesser amount of pigment used.

The earlier sets of cells were found to be less efficient, primarily due to the shade and the quantity of the pigment used. Notably, orange tomatoes exhibited a weaker capacity of light absorption and conversion, as supported by the readings obtained from the multimeter. To ensure consistency in the pigment, all extracted tomatoes were boiled with the same amount of water, resulting in the optimal desired concentration.

In accordance with the time stability, the recorded time durations for each set are as follows: Set A (orange pigment) lasted for 7 seconds, Set B (red pigment) lasted for 16 seconds, Set C (orange pigment) lasted for 12 seconds, and Set D (red pigment) lasted for 23 seconds.

The Multiple Regression Analysis conducted on the data suggests that Set D, utilizing red shade tomatoes, exhibited the highest level of time stability compared to the other sets. This means that the DSSC in Set D was able to maintain its performance and functionality for a longer duration before experiencing a decline.

All the setups were tested using a multimeter set to 20 volts (V), indicating that the voltage measurement was consistent across all the sets during the time stability assessment.

These findings highlight the potential advantage of using red shade tomatoes in DSSCs when it comes to maintaining stability over an extended period. Further investigation and experimentation could provide insights into the underlying factors contributing to the observed time stability differences among the various DSSC sets.

Interpretation

The analysis indicates a clear relationship between the intensity of tomato shade and the electricity generated. Tomatoes with darker and more intense shade, specifically the red tomatoes, consistently produced higher amounts of electricity compared to lighter-shaded tomatoes, which is the orange tomatoes. This finding suggests that the absorption of solar energy by tomato pigments increases with the intensity of shade, leading to enhanced electricity generation.

Furthermore, the data reveals that an increased quantity of tomato pigment positively correlates with the amount of electricity produced. Tomatoes with higher pigment amount/concentrations consistently exhibited higher electricity generation compared to those with lower pigment concentrations. This indicates that the quantity of pigment directly influences the efficiency of energy conversion in the tomatoes.

Moreover, this study also highlights that the tomatoes with darker/more intense shade are more stable than those light-shaded tomato pigments. Tomatoes with darker pigments present a more consistent electricity generation over extended time, suggesting that a higher quantity of pigment contributes to improved operational stability.

Lastly, a greater amount/concentration of pigment leads to improved stability performance. Tomatoes containing higher levels of pigment demonstrate more reliable electricity generation over longer durations, suggesting that an increased amount of pigment contributes to enhanced time stability performance.

CHAPTER 5

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

Summary of Findings

In this study, an investigation into the potential use of tomato dye as a sensitizer for solar cells yielded promising results. The researchers explored the concept of converting sunlight into electricity through the mechanism of volts, building upon the established knowledge that natural dyes possess pigments that are capable of absorbing visible light. To test the hypothesis, the researchers constructed four distinct sets of solar cells using two conductive glass materials and devised a cell-like structure capable of effectively capturing visible light. Remarkably, the researchers successfully generated electricity in these cells with regard to stability. Measuring the output voltage of each set with a multimeter set to 20 volts. The recorded results were as follows:

Set A: 0.32v

Set B: 0.54v

Set C: 0.44v

Set D: 0.86v

The time consumed is also crucial to the stabilization of the cell here are the time it took to do each set:

Set A: 7 seconds

Set B: 16 seconds

Set C: 12 seconds

Set D: 23 seconds

The findings provided meaning to the factors that contribute to the voltage production of these cells. The researchers observed that the structure of the cell played a crucial role in determining the voltage output, with the highest voltage being generated by set D. This particular set had a distinct structure that allowed for enhanced light trapping. Experiments revealed that the concentration and darkness of the pigment directly influenced the amount of light captured, thus leading to higher power and voltage generation. The importance of considering the heating time of the glass during cell assembly was also crucial. The data found stated that using a larger conductive glass for the cell proved to be more effective, as it allowed for a greater amount of light to be trapped. Perhaps the most significant finding of this study is the potential for natural and environmentally friendly alternatives in the future. The researchers' findings suggest that exploring such alternatives could contribute to sustainable energy solutions and positively impact the solar technology and industry.

Conclusion

In conclusion, the study demonstrated that using red shade tomato pigment (Set D) in dye-sensitized solar cells (DSSCs) resulted in higher efficiency and stability compared to orange shade tomato pigment (Set A, Set C). The DSSC utilizing red shade tomatoes achieved the highest voltage output and exhibited the longest time stability, specifically Set D resulting in a higher voltage output of 0.86 volts. The darker and more intense shade of red tomatoes allowed for better absorption of solar energy, leading to increased electricity generation. Additionally, a higher quantity of tomato pigment positively influenced the efficiency and stability of the DSSCs. These findings highlight the potential of red tomato pigment as a suitable sensitizer for DSSCs, offering promising possibilities for sustainable and environmentally friendly solar energy conversion.

Recommendations

In this section, the researchers aim to offer a set of recommendations to guide future studies and benefit the readers in the field. These recommendations propose meaningful changes that can contribute to the advancements in the performance of Dye Sensitized Solar Cells (DSSCs).

The following suggestions are put forward for further research in this area:

First, the experimental setup should involve the use of ITO-coated glass substrates with larger dimensions than the standard sizes commonly used in DSSC fabrication. Increasing the surface area of the ITO-coated glass allows the utilization of more pigment, for a larger active area for dye absorption and electron transport, thereby potentially improving the overall efficiency of the DSSC.

Second, the researchers recommend the consideration of tomato varieties and ripeness. To expand the understanding of tomato-based DSSCs, future research should investigate the influence of different tomato varieties and their ripeness stages on the efficiency and stability of the cells. Different tomato cultivars may contain varying concentrations of pigments, leading to different light-harvesting properties. Exploring this variation can provide insights into selecting optimal tomato sources for dye extraction.

Third, the researchers recommend the exploration of other natural dye/pigment sources. While this research focuses on tomato-based dyes, the potential of other natural dye sources should not be overlooked. Further investigations into other plant-based pigments, such as those found in fruits, flowers, and vegetables, can provide a broader range of options for sensitizing

DSSCs. Exploring alternative natural dye sources may uncover dyes with superior properties and performance compared to tomato-based dyes.

Lastly, the researchers also recommend the selection of darkly pigmented fruits. Future researchers should focus on selecting fruits with naturally darker pigmentation, as this paper revealed that the color intensity of the pigment has a substantial impact on the electricity to be generated. By utilizing fruits with darker colors, a greater amount of incident light can be absorbed, leading to increased energy conversion efficiency in the DSSC.

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