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REVIEW ARTICLE

PERFORMANCE OF DYE-SENSITIZED SOLAR CELL UTILIZING THE EXTRACT OF CASSAVA (*MANIHOT ESCULENTA*) LEAVES, GUAVA (*PSIDIUM GUAJAVA*) LEAVES, AND MANGO (*MANGIFERA INDICA*) LEAVES

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ABSTRACT

Dye- sensitized solar cell (DSSC) is a third-generation solar cell that can utilize natural dyes from leaves extract to absorb sunlight and generate electricity. This study aimed to investigate the performance of DSSC utilizing the leaf extracts of cassava, guava, and mango as a natural dye in terms of UV-Vis absorption and energy output. The experimental method was applied wherein the researcher constructed three DSSCs, each treatment applied the same fabrication, and construction. The UV-Vis Spectrum peak value and UV absorption was obtained from UV-Vis Analysis. The multimeter was used to record each voltage to determine the energy output produced by the DSSCs and the commercial solar cell. One-way ANOVA Analysis was used to determine the significant difference in UV absorption of natural dyes. In getting the significant difference between the three treatments and control in pairwise comparison in terms of energy output, One-Way ANOVA Analysis and Post Hoc Tukey were utilized. Based on the data result, there was no significant difference in UV absorption among the three natural dyes. This signified that the same pigment content gave almost the same UV absorbance at common UV Spectrum peak value in wavelength. The DSSC with natural dyes produced a smaller amount of electrical energy compared to commercial solar cells. There was a significant difference in energy output between the three treatments and the control. DSSCs utilizing natural dyes proved to produce electrical energy even in smaller amounts.

KEYWORDS

solar cell, natural dyes, UV absorption, energy output

1. INTRODUCTION

The demand for electricity and carbon emissions concerns due to the growing population and advancement in technologies is dramatically increasing. As per reports from the International Energy Agency (IEA) in 2021, fossil fuel-powered electricity generation was projected to meet 45% of the new demand in 2021 and 40% in 2022. Consequently, carbon emissions from this source have been on the rise each year, which could significantly contribute to the issue of global warming. According to IEA, due to existing policy settings and economic trends, renewable electricity generation (such as hydropower, wind, and solar photovoltaic cells) is expected to increase significantly globally in the next two years, rising by 8% in 2021 and over 6% in 2022. This policy has the potential to tackle rising electricity consumption and concerns about climate change.

Photovoltaic energy is a renewable, inexhaustible, and clean type of energy resource. Dada and Popoola elaborated the significant advances of photovoltaic technology in both materials and systems leading to improvements in efficiency, cost and energy storage capacity (Dada and Popoola, 2023). Further studies have been undertaken in increasing efficiency of solar cells by creating effective materials and procedures that can collect and convert sunlight into electricity. Photovoltaic energy can be modular, which can be installed in house roofs or huge photovoltaic plants. A group researcher explored the suitability of rooftop solar photovoltaic at educational buildings which proved to be effective and can accommodate the institute's energy load demand (Khairi et al., 2022). Utilization of solar cells for storing electricity for future use is feasible. It can be used in remote areas where power lines are not yet available.

In the study, dye-sensitized solar cell (DSSC) has a potential alternative to synthetic-based photovoltaic devices (Sharma, 2018; Venkatesan, et al., 2022). Dye-sensitized solar cells belong to the third generation of photovoltaic technologies which contain more recent, simple, unique and organic chemical compounds (DuBose, et al., 2022). DSSCs using ruthenium dyes reach an efficiency of up to 12% by enhancing material and improved fabrication which is still less efficient than offered by two other synthetic photovoltaic generation solar cells (Sharma et al., 2018). Synthetic dyes, usually ruthenium-based, are more environmentally toxic and costly than natural dyes (Bartolome et al., 2020). Dyes are obtained from the extract of different parts of photosynthetic organisms. The DSSC can be related to how nature performs photosynthesis so while it can help us to gather solar power, it is also safe for our environment (Bagher et al., 2017).

Several researchers conducted various studies about the efficiency of the DSSC which is influenced by light absorption, procedure in fabrication, variation of solvents in the electrolytes, and the types of natural dyes used as photosensitizers. According to the reviews on photovoltaic cell generation, DSSC can produce electricity with a power conversion efficiency of about 11% to 13% (Pastuszaket et al., 2022). Compared to another photovoltaic cells, DSSC has lower power conversion efficiency and that is the challenge to researchers to improve DSSC to its fullest potential because it is feasible, low cost, and practical to use especially to residents without electrical supply.

Renewable sources of energy like dye-sensitized solar cells can help the residents to generate their supply of electricity. Through various studies

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of producing improved and efficient DSSC by utilizing materials found in their areas, people can produce electricity independently (Mazumder et al., 2020). Thus, the researcher was eager to pursue the study about the effectiveness of DSSC utilizing the extract of cassava leaves, guava leaves, and mango leaves as a natural dye which serves as the photosensitizer, substances such as ethanol, betadine, distilled water, and vinegar which are available in the kitchen to be used to develop a low cost, home-made, and a “do-it-yourself” dye-sensitized solar cell. If this DSSC is proven feasible, it could be a great help to residents who have no electricity supply in their place in producing a low-cost and easy-to-prepare electricity-generating device. It is practical to use compared to the commercial solar panel because the residents can make their device to generate electricity instead of purchasing the product online since they don’t have access to electricity, thus, internet too.

There were studies conducted by researchers in different regions and other countries about the characterization of DSSC and its energy efficiency that gave proof that DSSC has the potential to produce electricity even for minimal use. DSSC is a third-class generation solar cell composed of a working electrode and counter electrode, which allows the light energy to absorb and harness to generate electricity (Bartolome, et al., 2020). In recent study, utilized various types of natural dye namely, chlorophyll, beta-carotene, and anthocyanin as a substitute for ruthenium-based which is a rare metal complex in DSSC (Cari, et al., 2018). Chlorophyll type of natural dye comes from the spinach leaves extract and yields a maximum efficiency of 7.2 x 10-2 % compared to other types. Chlorophyll pigment can be found in the leaves of pomegranate, bougainvillea, papaya, spinach, green grass, seaweeds, and algae (Arof et al, 2017). Some researcher used dry turmeric, verdant turmeric, and power turmeric as a photosensitizer in DSSC (Hossain, et al., 2017). A group researcher made DSSC using Damakase (Ocimum lamiifolium) and Dambursa leaves extract, a local plant in Ethiopia as a natural dye (Lejamo, et al., 2017). Some researchers investigated the extract of green grasses as light harvesters in DSSC (Shanmugan, et al., 2015). In other study, authors investigated tropical plants and the performance of leaf extract as a natural dye (Bartolome, et al., 2020).

Cassava, guava, and mango are tropical plants that can grow in any kind of soil. These plants can be found in hillsides, mountains, plains, farms, homes, and even in school gardens. They do not require more attention for watering and putting fertilizer. They are adaptive to the environment. Residents can benefit from the fruits/ root crops from the cassava, guava, and mango trees because they are a source of food. Some people use the leaves of mango and guava as natural tea which contain essential nutrients. Residents usually dispose of mature leaves of cassava, guava, and mango; thus, the researchers will utilize only the green mature leaves for the study.

Instead of disposing, the researcher will collect the leaves from cassava, guava, and mango for this study. Photosensitizers from the extract of cassava leaves, guava leaves, and mango leaves are one of the main components in the production of the DSSC in this study. Substances such as acetone, ethyl alcohol, betadine, distilled water, and vinegar which are available in the kitchen will be utilized as solvents and electrolytes in DSSC production. This study intended to investigate the performance of the DSSC utilizing natural dyes from cassava leaves, guava leaves mango leaves, and low-cost materials in the fabrication and construction of the dye-sensitize solar cell.

2. RESEARCH METHOD

The quantitative research design employed in this study includes hypothesis testing of a variable that can be manipulated by the researcher and variables that can be measured, calculated, and compared (Singh, 2021). The experimental method was applied to test the different treatments in producing and investigating dye-sensitized solar cells’ performance and its difference to the control variable. This study developed three DSSCs utilizing the extracts of cassava, guava, and mango leaves served as natural dye to make statistical comparisons between three treatments and a controlled variable and to demonstrate relationships between the independent variables and the outcome of this study.

DSSC consisted of the following parts shown in Figure 1: (a) a pair of ITO (Indium tin oxide) conductive glass (b) the working electrode, titanium dioxide (TiO2) paste made from the mixture of titanium dioxide powder, distilled water, and acetic acid and 5mL of natural dye from extract of cassava leaves, guava leaves, and mango leaves; (c) the electrolyte, the 10% povidone-iodine drop throughout the cell, and (d) the counter electrode, graphite from pencil applied on the conductive side of ITO glass.

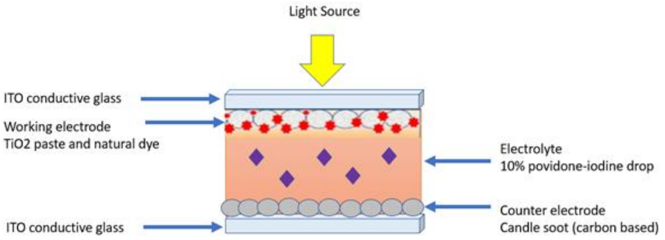

Figure 1: Parts of the dye-sensitized solar cell

The experiment was conducted at Biñan City Senior High School- Sto. Tomas Campus Science Laboratory where materials and facilities were available. The UV-Vis Analysis of the leaf extract of cassava, guava, and mango was analyzed at the DLSU Spectroscopy Laboratory using Shimadzu UV-Visible Spectrophotometer UV-2600 located at DLSU Laguna Campus in Binan, Laguna. The research methodology of the DSSC development which includes collection of materials; product development which includes extracting the leaves, fabrication of DSSC and construction of DSSC; testing the produced DSSCs; gathering the data and data analysis modified from (Bartolome, 2020).

2.1 Collection of Materials

Preparation of materials such as ITO conductive glass (Welljoin, OEM, Philippines), TiO2 powder (Dalkem, CAS No. 1317-70-0, Philippines), extracts from cassava leaves, guava leaves, and mango leaves,95% ethanol (TLS, Laboratory use only) as a solvent in extraction, acetic acid, and distilled water (Wilkins, Philippines), 10% povidone-iodine (betadine), graphite from a pencil, digital multimeter, hot plate, binder clips, and alligator clips were first prepared for smooth conduct of the experiment.

2.2 Product Development

2.2.1 Extraction of Sample Leaves Extract

The natural dyes were extracted from cassava leaves, guava leaves, and mango leaves. The leaves were rinsed three times with water removed dirt using distilled water and air-dried for 72 hours to remove moisture. The dried leaves were powdered and filtered to attain a small uniform particle size. Maceration extraction is the extraction method used for this experiment (Marsoul et al., 2020). In extracting the leaves, 5g of powder of cassava leaves, guava leaves, and mango leaves were submerged individually in 50 mL ethanol for 48 hours. The extracts were filtered using the qualitative filter paper. The filtrates were contained in 60 mL- amber bottles and placed in a dark place at room temperature to preserve.

2.2.2 Fabrication

Fabrication of the DSSC included testing the ITO glass test to determine the conductive side of the ITO glass and preparing the working electrode, electrolyte, and counter electrode. First, the charged side of the ITO glass was determined. ITO glass has a one-sided coated film with a certain resistance value (> 80% and 18 ohms/ cm2 of sheet resistance). To identify the conductive side of the ITO glass, a conductivity test was performed with a digital multimeter to test the resistance value. The side of the ITO glass that had resistance value was considered the conductive side while the uncoated or the other side that had no value during testing was considered the non-conductive side. Thus, the conductive side of the ITO glass was used as the working electrode and counter electrode of the DSSC. Once the conductive side was identified, edge tape was placed on both sides of the glass.

The working electrode consisted of a combination of TiO2 paste and a natural dye. In the preparation of the TiO2 paste, first, 15 grams of TiO2 powder were initially mixed with a small drop of distilled water in a mortar and pestle for 10 minutes. After another 5 minutes of continuous stirring, one drop of acetic acid or vinegar was slowly added to achieve a slurry. The resulting thick paste was applied to the conductive side of the ITO glass using the doctor’s blade technique, where the paste is evenly coated on the ITO glass by rolling the glass rod. After the TiO2 paste was applied, it was air-dried for 10 minutes. The tape was removed, and the glass was allowed to dry. This was followed by sintering at 450 degrees celsius for 30 minutes on a hot plate. The TiO2 paste sintered electrode was immersed in 5mL of natural dye for 2 hours and then washed with distilled water to remove the excess dye.

The counter electrode was made by covering the conductive side of ITO glass with fine pencil graphite to obtain a uniform carbon film. The 10%

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povidone-iodine served as an electrolyte and was applied as a working electrode and counter electrode sandwiched. The DSSC fabricated in TiO2 coated on ITO glass immersed in an ethanol solution of mango leaf extract and carbon from a pencil as a counter electrode produced a maximum voltage of 350 mV (Uno, et al., 2020).

2.2.3 Constructing a DSSC

After the working electrode and counter electrode had been separately prepared, the conductive sides of the two ITO glasses containing the TiO2 paste and carbon film were joined together and attached by binder clips on both sides. A small drop of 10% povidone-iodine, which serves as an electrolyte was added in between the two conductive ITO glasses and evenly sucked throughout the surface. The cell must be cleaned well before putting alligator clips on both sides and then connecting the multimeter for testing.

2.3 Testing the Produced DSSC in Terms of UV Absorption and Energy Output

After the permit letter for conducting research was approved by the research adviser, the researcher prepared the necessary documents for conducting a UV-Vis Spectrometry test in the laboratory facility at De la Salle University (DLSU) Spectroscopy Laboratory. With the approved agreement of sample analysis, and preparation of extracts, the sample analysis underwent characterization to determine the UV-Vis spectrum peak value and absorption. Putting the working electrode and counter electrode face-to-face and binding it with a paper binder made the DSSC functional. Testing the DSSC by putting alligator clips at both sides of the ITO conductive glass and connecting it to the digital multimeter was conducted to measure the voltage of the DSSC.

2.4 Gathering the Data

The result of UV analysis was retrieved from the De la Salle University (DLSU) Spectroscopy Laboratory. The ten (10) highest UV-Vis Spectrum Peak Values and their respective absorption of natural dyes were recorded, tabulated, and presented as well as the energy output in millivolt.

2.5 Data Analysis

To describe the data, mean and standard deviation were used. There were ten trials for each treatment in the experiment. After obtaining the amount of UV absorption of each sample using the spectrophotometer, the data were used in determining the difference in UV absorption among the ten treatments using the One-Way ANOVA analysis. To determine the difference between the energy output produced by DSSC utilizing natural dyes, the researcher used the One-Way ANOVA Analysis. This statistical treatment aimed to compare the electrical energy output from each treatment of plant extracts. To further determine which treatment comparison had significant differences, a Post Hoc Tukey HSD was conducted.

3. FINDINGS AND DISCUSSION

Three treatments and the control were investigated and analyzed. Each treatment had the same preparation and fabrication, and the same amount of substances but different natural dyes.

3.1 UV-Vis Absorption of Natural Dyes

In this study, UV absorbance was used to determine the performance of the sample leaves extracts in absorbing light for DSSC.

Table 1: UV-Vis Spectrum Peak Value (nm) and absorbance (Abs) of cassava, guava, and mango leaves extract

Pick Peak	Cassava Leaves Extract		Guava Leaves Extract		Mango Leaves Extract	
	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs
1	747.00	0.03469	666.00	2.96278	664.50	2.02920
2	665.50	2.93746	609.00	0.88023	608.00	0.74181
3	609.50	1.00315	538.50	1.16989	537.50	0.90268
4	538.50	1.15209	442.00	4.78553	444.00	4.65672
5	469.00	4.85310	421.00	4.71727	430.50	4.67037
6	459.50	4.87034	390.50	5.60125	387.00	6.13210
7	415.50	5.40488	385.50	5.70726	353.00	7.12783
8	368.00	5.78685	381.50	5.70043	316.00	10.0000
9	341.50	5.68678	363.50	7.15260	311.00	10.0000
10	329.00	5.38672	342.50	5.65211	286.50	6.19726

Source: UV-Vis Analysis using UV-Vis Spectrophotometer (UV-2600 Series)

Table 1 presented the data of UV-Vis spectrum peak value (nm) and absorbance (Abs) of cassava, guava, and mango leaf extract in 10 peak picks. It revealed that the cassava leaf extract exhibited the highest peak absorption spectra at wavelength 747.00 nm with 0.03469 Abs, followed by a wavelength of 665.50 nm with 2.93746 Abs. From the list, the wavelength at 368.00 nm absorbed the highest, 5.78685 Abs. In the findings showed that the coefficient of degradation of the cassava leaf extract was small, which signified quite feasible as a sensitizer in DSSC (Nurlela, et al., 2017). The chlorophyll dye from cassava leaf extract exhibits an optical absorption with an absorbance peak at 400 and 663 nm in the study conducted, about the performance of DSSC utilizing chlorophyll-anthocyanin dyes (Aziza, et al., 2023). These results showed similarity with this recent study.

The guava leaf extract used as a natural dye in DSSC recorded a wavelength at 666.00 nm with 2.96278 Abs on its highest peak followed by a wavelength of 609.00 nm with 0.88023 Abs. The guava leaf extract exhibited 5.70726 absorbance at a wavelength of 385.50 nm. This result is close compared to the investigation conducted by Taya, S et al (2015) on the absorption bands of guava leaves (dried) extract at 400 nm and 667. The mango leaf extract yielded a UV absorbance of 2.02920 at wavelength 664.50 in its highest peak absorption spectra, followed by a wavelength 608.00 with 0.74181 absorbance. The wavelength 316.00 has an absorbance of 10. Based on study on the progress of Mangifera indica as a photosensitizer, the peak absorption of mango leaves extract is at 265 nm with three visible bands at 255 nm, 265 nm and 370 nm which yielded 0.345% energy conversion efficiency (Uno et al., 2015).

Chlorophyll a has maximum absorption at 430 nm and 662 nm, while chlorophyll b maxima fall to 455 nm and 644 nm. The limited absorption in the green region gives plants their characteristic color (Blankenship, 2014). According to a study, the green-colored dye had the highest absorbance followed by yellow-colored dye and purple-colored dye respectively (Chumwangwapee et al., 2023). The green-colored dye contained chlorophyll pigment which is commonly found in plant leaves such as lettuce, and spinach. The data results showed the absorption spectrum at a wavelength between 250 nm to 800 nm of extracted dye from the samples which exhibit little differences. This is because all samples were plant leaves where chlorophyll is a major pigment. This natural dye is absorbed by the DSSC and exploits the light energy to be used to produce electricity. It revealed that the mango leaf extract got the highest mean, which implied that it got the highest UV absorption compared to cassava and guava leaf extract.

3.2 Energy Output

After the fabrication and construction of the DSSC, energy outputs of three DSSCs were measured using the digital multimeter. In this investigation, voltage was used to measure the energy output of the DSSCs. Voltage describes the electric potential difference between charges. The amount of voltage was indicated by volt (V). Since DSSCs produce a small amount of energy, millivolts (mV) were appropriate to describe the energy output of the sample DSSCs. Direct sunlight during bright and hot days from 12 noon to 2:00 in the afternoon was used in the experiment.

Table 2: Energy Output in millivolts (mV) produced by the DSSC utilizing the extract of cassava leaves, guava leaves, and mango leaves every 10 minutes

Trial (every 10 minutes)	Cassava leaves extract	Guava leaves extract	Mango leaves extract	Commercial solar cell(control)
1	223	376	309	1200
2	230	370	308	1190
3	232	387	300	1200
4	224	289	280	1150
5	232	289	200	1142
6	232	215	223	1188
7	235	208	274	1187
8	216	209	278	1173
9	226	209	279	1156
10	206	210	208	1195
Average	**225.6**	**276.2**	**265.9**	**1178.1**

The data presented in Table 2 showed little difference for each trial. Among the three DSSCs utilizing different natural dyes, the DSSC with guava leaf extract got 276.2 mV followed by 265.9 mV from DSSC with mango leaf extract and 225.6 mV from DSSC utilizing cassava leaf extract. The three sample DSSCs demonstrated almost the same yield of energy output. The controlled variable got 1178.1 mV energy output which had a higher difference to the three treatments.

A group researcher experimented with the performance of DSSC utilizing 20 leaf extracts including guava leaves (Taya, et al., 2015). The maximum voltage produced by DSSC utilizing guava leaf extract was 582 mV with an overall 0.498% efficiency higher compared to mint and basil leaves. The investigation revealed that the option of TiO2 binder solution used influences the increase in the efficiency of DSSC. Compared to another sample, although guava leaves contain chlorophyll, it can produce lower efficiency because of weak bonds between the dye molecules and TiO2 films.

Among the three treatments, guava leaves got the highest means which indicates the highest energy output compared to DSSCs with cassava and mango leaf extract. The data revealed that the commercial solar cell remained to have the highest yield of electricity. DSSCs utilizing guava leaf extract had the highest standard deviation which implied spread out of data.

Table 3: One-Way ANOVA Test of Difference on UV Absorption of Natural Dyes from Cassava, Guava, and Mango Leaves Extract

Source		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
UV Absorption	Between Treatments	11.7827	2	5.8913	0.86328	0.433093
	Within Treatments	184.257	27	6.8244		
	Total	196.0404	29			

**Significant at .05 level

In data results shown in Table 3, the F-ratio value of 0.86328 and the p-value of 0.433093 which is larger than the 0.05 level of significance, revealed that the null hypothesis was accepted. Therefore, there was no significant difference in UV absorption of the three treatments. The data signified that the natural dyes from green leaf extracts which contain chlorophyll pigment have almost the same UV absorbance in wavelength range of 350-800 nm.

A group researcher investigated the performance of DSSC in chlorophyll-based photosensitizer extracted from the leaves of pomegranate, bougainvillea, papaya, spinach, and green grasses (Arof et al., 2016). Since all the samples contain chlorophyll which can absorb light in almost the same range of wavelengths, this study focused on the kind of solvent and its soaking time of natural dye in DSSC. It was revealed that the DSSC performance depends on the soaking time and solvent used. There were differences in the absorption peaks in different samples – alugbati, Talisay leaves and spent coffee grounds due to the presence of different pigments (Bartololome et al, 2020)

Table 4: One-Way ANOVA Test of Difference on Energy Output in DSSCs Utilizing Natural Dyes from Cassava, Guava and Mango Leaves Extract and commercial solar cell

Source		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Energy Output	Between Treatments	6392698.1	3	2130899.3667	1051.37	<.00001
	Within Treatments	72971.8	36	2026.9944		
	Total	6465669.9	39			

**Significant at .05 level

Table 4 showed that the p-value was <.00001 which is less than the 0.05 level of significance, concluded to reject the null hypothesis. Therefore, there was a significant difference in energy output in DSSCs utilizing natural dyes from cassava, guava, and mango leaf extracts and in the commercial solar cell. To further analyze, Post Hoc Tukey HSD (honestly significant difference) multiple-comparison analysis was employed to determine which treatment gave a significant difference.

The data revealed that Treatment 1 was significantly different from Treatment 4 (p-value= .00000). There was also a significant difference between Treatment 2 and Treatment 4 (p-value= .00000) and Treatment 3 to Treatment 4 (p-value= .00000). Therefore, the researcher-made DSSCs showed a significant difference to Treatment 4 which is the commercial solar cell served as the control variable for this study. The pairwise comparison among Treatment 1, Treatment 2, and Treatment 3 revealed no significant differences.

Chlorophyll pigment like natural dyes serves as a photosensitizer because of its ability to absorb photons from sunlight and transform it into electrical energy as shown in the data which can be produced around 200 mV to 300 mV. Bartolome et al (2020) revealed that the current outputs of the DSSC utilizing different pigments were significantly different from each sample cell.

Another interesting finding from this study was the chance of the combined DSSCs to light a small LED light. The small LED light was lit with a little spark (not bright) by the combined three DSSCs utilizing natural dyes which produced 767.7mV on average. Evidence was shown in appendices. It means that DSSCs can be used to run a handy device that requires a small amount of electricity.

4. CONCLUSIONS

The data results implied that the natural dyes from cassava, guava and mango leaves extract contain chlorophyll pigment. There was no significant difference in UV Absorption among the three treatments which signified that the same pigment content gave almost the same UV absorbance at common UV Spectrum peak value in wavelength. The performance of sample DSSCs in terms of energy output is quite insufficient but proven to produce electrical energy that can be an alternative renewable energy source. The null hypothesis stating that there was no significant difference in energy output between the three treatments and the control, was rejected.

LIMITATION AND FURTHER RESEARCH

In light with the findings, improved technique, fabrication and materials are needed to gain better results. Further studies on other species of leaves with different pigment content, improved techniques of extraction, fabrication, construction of DSSC, and characterization on other significant parameters such as internal resistance, open circuit voltage, short circuit current, maximum power and fill factor may be investigated to analyze the progress and feasibility of the DSSCs for other purposes. A Proto-type DSSC model to run handy devices like e-fan, battery-powered audio devices or flashlight may be created to give glimpses into innovations that can be used during calamities.

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University Central Instrumentation Facility in Binan, Laguna for conducting the sample UV-Vis Analysis.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

Kathleen E. Espina: Conceptualization, data analysis, data gathering, methodology, writing- review and editing. Dr. Albert D. Yazon: Supervision, data analysis, review. Dr. Karen A. Manaig: Technical editing, supervision. Dr. Sherwin B. Sapin: data analysis, review of statistical treatment. Dr. Lerma P. Buenvinida: Visualization, supervision, review.

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