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Research Paper

Performance of Dye-Sensitized Solar Cell Utilizing the Extract of Cassava (Manihot Esculenta) Leaves, Guava (Psidium Guajava) Leaves, and Mango (Mangifera Indica) Leaves

Kathleen E. Espina[1*], Alberto D. Yazon[1], Karen D. Manaig[1]
Sherwin B. Sapin[1], Lerma P. Buenvinida[1]

[1]Laguna State Polytechnic University, Philippines

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Abstract

Dye- sensitized solar cell (DSSC) is a third-generation solar cells that utilize natural dyes from leaves extract to absorb sunlight and generate electricity. This study aimed to investigate the performance of DSSCs using the leaf extracts of cassava, guava, and mango as natural dyes in terms of UV-Vis absorption and energy output. The experimental method was applied in which the researcher constructed three DSSCs, with each treatment involving the same fabrication and construction. The UV-Vis Spectrum peak value and UV absorption was obtained from UV-Vis Analysis. A multimeter was used to record each voltage to determine the energy output produced by the DSSCs and the commercial solar cell. One-way ANOVA was used to determine the significant difference in the UV absorption of the natural dyes. To determine 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 used. The results showed no significant difference in UV absorption among the three natural dyes. This result signified that the same pigment content gave almost the same UV absorbance at a common UV spectrum peak wavelength. DSSCs with natural dyes produce less electrical energy than commercial solar cells. There was a significant difference in the energy output between the three treatments and the control. DSSCs utilizing natural dyes produced electrical energy in smaller amounts.

Keywords: *dye-sensitized solar cell, UV absorption, energy output*

INTRODUCTION

The demand for electricity and carbon emission due to the growing population and advances in technologies are dramatically increasing. According to the International Energy Agency (IEA) (2021), 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 can tackle rising electricity consumption and climate change concerns.

Several researchers have conducted various studies on the efficiency of DSSCs, which are influenced by light absorption, the fabrication procedure, variations in solvents in the electrolytes, and the types of natural dyes used as photosensitizers. According to the reviews on photovoltaic cell generation by Pastuszak and Węgierek (2022), DSSCs are third-generation solar cells that can produce electricity with a power conversion efficiency of about 11% to 13%. Compared to other photovoltaic cells, DSSCs have lower power conversion efficiency, and that is the challenge to researchers to improve DSSCs to their fullest potential because they are feasible, low cost, and practical to use, especially for residents without an electrical supply.

Corresponding author's email: kathleen.espina@deped.gov.ph

Cassava, guava, and mango are tropical plants that can grow in any soil. These plants can be found on hillsides, mountains, plains, and even in school gardens. They do not require more attention for watering and fertilization. They adapt to the environment. Residents can benefit from the fruits and root crops from the cassava, guava, and mango trees, which are a source of food. Residents usually dispose of mature leaves of cassava, guava, and mango; thus, the researchers only utilized green mature leaves for the study. Thus, the researcher was eager to pursue the study of the effectiveness of DSSCs utilizing the extracts of cassava, guava, and mango leaves as photosensitizers. Substances such as ethanol, betadine, distilled water, and vinegar, which are available in the kitchen, were 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.

LITERATURE REVIEW

Photovoltaic energy is a renewable, inexhaustible, and clean energy source. Dada and Popoola (2023) elaborated on the significant advances in photovoltaic technology in both materials and systems, leading to improvements in efficiency, cost, and energy storage capacity. Photovoltaic energy can be modular and can be installed on house roofs or in huge photovoltaic plants. Khairi et al. (2022) explored the suitability of rooftop solar PV systems at educational buildings, which proved to be effective and can accommodate the institute's energy load demand.

In the study of Sharma et al. (2018), dye-sensitized solar cell (DSSC) has a potential alternative to synthetic-based photovoltaic devices. Dye-sensitized solar cells belong to the third generation of photovoltaic technologies and contain more recent, simple, unique, and organic chemical compounds. Dyes are obtained from the extracts of different parts of photosynthetic organisms. The DSSC can be related to how nature performs photosynthesis; while it can help us to gather solar power, it is also safe for our environment (Bagher, 2017).

Cari et al. (2018) used 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. The chlorophyll type of natural dye comes from spinach leaf extract and yields a maximum efficiency of 7.2 x 10-2 % compared to other types. Chlorophyll pigments can be found in the leaves of pomegranate, bougainvillea, papaya, spinach, green grass, seaweeds, and algae (Arof & Ping, 2017). Hossain et al. (2017) used dry turmeric, verdant turmeric, and power turmeric as photosensitizers in DSSC. Lejamo et al. (2017) made DSSC using Damakase (Ocimum lamiifolium) and Dambursa leaf extract, a local plant in Ethiopia, as a natural dye. Shanmugam et al. (2015) investigated the green grass extract as a light harvester in DSSCs. Bartolome et al. (2020) investigated tropical plants and the performance of leaf extract as a natural dye.

Several researchers have utilized different extraction processes to obtain good sample extracts. Authoria et al. (2023) and Galang et al. (2024) performed leaf extraction using 70% ethanol using a maceration process, which produced a good yield of extract. Owie et al. (2024) revealed that the fruit-pup extract is relatively safe at lower concentrations, which means that the amount of extract matters for specific experiments. Cari et al. (2018) used a Lambda 25 UV-Vis spectrophotometer to characterize the light absorption of natural dyes in DSSCs. The DSSC performance was tested using an IV meter with a Keithley 2620 A 1000 W fluorescent lamp light source. Bartolome et al. (2020) used a digital multimeter to describe the performance of DSSCs in terms of the open-circuit voltage, voltage drop, and current output under closed-circuit conditions. The solar radiation intensity was measured and recorded every 10 minutes using a digital lux meter. Sullano and Sia (2018) characterized the absorption spectra of plant extracts in the visible light spectrum (400-700 nm) using a DR 5000 HACH UV-Vis spectrophotometer. Paper chromatography was then used for the identification of plant pigments using an ether-acetone solvent mixture. Gu et al. (2017) measured the DSSC performance under simulated sunlight (AM 1.5, 100 MW/cm2) in a solar cell tester (XJCM-8) in terms of the open circuit voltage, short circuit current density, fill factor, and power conversion efficiency.

RESEARCH METHOD

The quantitative research design employed in this study used the experimental method to test the different treatments in terms of producing and investigating the performance of dye-sensitized solar cells and their differences from the control variable.

The DSSC consisted of the following parts, as shown in Figure 1: (a) a pair of ITO (Indium tin oxide) conductive glass (b) the working electrode, titanium dioxide (TiO_2) paste; (c) the electrolyte, a 10% povidone-iodine drop, and (d) the counter electrode, graphite from pencil.

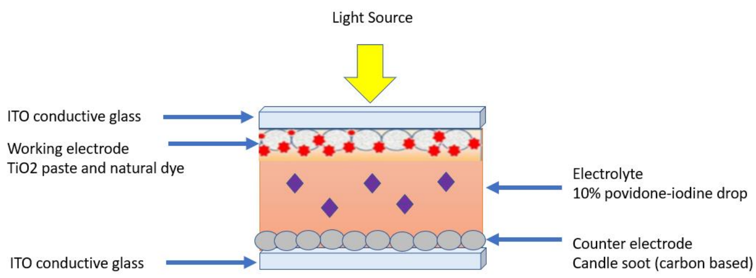

Figure 1. Parts of the dye-sensitized solar cell

The experiment was conducted at Biñan City Senior High School, Sto. Tomas Campus Science Room. The UV-Vis Analysis of the leaf extracts of cassava, guava, and mango was analyzed at the DLSU Spectroscopy Laboratory using a Shimadzu UV-Visible Spectrophotometer UV-2600 located at DLSU Laguna Campus in Binan, Laguna.

Collection of materials

Preparation of materials such as ITO conductive glass (Welljoin, OEM, Philippines), TiO_2 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.

Product Development

Extraction of sample leaf extract

The natural dyes were extracted from cassava, guava, and mango leaves. The leaves were rinsed three times with water to remove dirt using distilled water and air-dried for 72 h to remove moisture. The dried leaves were powdered and filtered to a small uniform particle size. Maceration extraction was used as the extraction method. To extract the leaves, 5g of powder of cassava, guava, and mango leaves were submerged individually in 50 mL of ethanol for 48 h. The extracts were filtered using laboratory filter paper. The filtrates were contained in 60 mL- amber bottles and placed in a dark place at room temperature.

Fabrication

The fabrication of the DSSC included testing the ITO glass to determine its conductive side 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). The uncoated side or the other side with no value during testing was considered the nonconductive side. Thus, the conductive side of the ITO glass was used as the working electrode of the DSSC.

The working electrode consisted of a combination of TiO2 paste and a natural dye. To prepare the TiO2 paste, first, 15 g of TiO2 powder were mixed with a small drop of distilled water in a mortar and pestle for 10 min. After another 5 min of continuous stirring, one drop of vinegar was slowly added to obtain a slurry. The resulting thick paste was applied to the conductive side of the ITO glass using the doctor blade technique. After the TiO2 paste was applied, it was air-dried for 10 min. This was followed by sintering at 450°C for 30 min on a hot plate. The sintered TiO2 electrode was immersed in 5 mL of natural dye for 2 h and washed with distilled water to remove excess dye.

The counter electrode was made by covering the conductive side of the ITO glass with fine pencil graphite to obtain a uniform carbon film. The 10% povidone-iodine served as an electrolyte and was applied as a working electrode and counter electrode sandwiched. The cell must be thoroughly cleaned before placing alligator clips on both sides and connecting the multimeter for testing.

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., 2015).

Testing the UV absorption and energy output of the produced DSSC

With the approved agreement to conduct a UV-Vis Spectrometry test in the laboratory facility at De la Salle University (DLSU) Spectroscopy Laboratory, the sample analysis underwent characterization to determine the UV-Vis spectrum peak value and absorption. The DSSC was tested by placing alligator clips at both sides of the ITO conductive glass and connecting it to a digital multimeter, which was used to measure the voltage of the DSSC.

Data analysis

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 millivolts.

The mean and standard deviation were used to describe the data. After determining the UV absorption of each sample using the spectrophotometer, the data were used to determine the difference in UV absorption among the 10 treatments using one-way ANOVA. To determine the difference between the energy outputs produced by DSSCs using natural dyes, the researcher used one-way ANOVA and post-hoc Tukey HSD.

FINDINGS AND DISCUSSION

UV-Vis Absorption of Natural Dye

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

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

Pick Peak	Cassava Leaf Extract		Guava Leaf Extract		Mango Leave 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 values (nm) and absorbance (Abs) of cassava, guava, and mango leaf extract in 10 peak picks. The cassava leaf extract exhibited the highest peak absorption spectra at 747.00 nm with 0.03469 From the list, the wavelength at 368.00 nm was the highest (5.78685 Abs).

The findings of Wibowo and Gunlazuardi (2017) showed that the coefficient of degradation of cassava leaf extract was small, indicating its feasibility as a sensitizer in DSSCs. The chlorophyll dye from cassava leaf extract exhibits optical absorption with an absorbance peak at 400 and 663 nm in a study conducted by Aziza et al. (2023) about the performance of DSSC utilizing chlorophyll-anthocyanin dyes. These results are similar to those of this recent study.

The guava leaf extract recorded a wavelength of 666.00 nm, with 2.96278 Abs on its highest peak. The guava leaf extract exhibited 5.70726 absorbance at a wavelength of 385.50 nm. This result is closely compared to the investigation conducted by Taya 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 a wavelength of 664.50 in its highest peak absorption spectra. The wavelength of 316.00 is 10. Based on Uno et al. (2015) study on the progress of Mangifera indica as a photosensitizer, the peak absorption of mango leaf extract was at 265 nm with three visible bands at 255, 265 and 370 nm, which yielded 0.345% energy conversion efficiency.

Chlorophyll a shows maximum absorption at 430 and 662 nm, while chlorophyll b maxima fall to 455 and 644 nm. Limited absorption in the green region gives plants their characteristic color. The green dye had the highest absorbance, followed by the yellow and purple dyes. The green dye contained chlorophyll pigment, which is commonly found in plant leaves, such as lettuce and spinach. The results show the absorption spectrum at a wavelength between 250 nm and 800 nm of the extracted dye from the samples, which exhibits little difference. This is because all samples were plant leaves, in which chlorophyll is a major pigment. This natural dye is absorbed by the DSSC and exploits the light energy to produce electricity. The results revealed that mango leaf extract had the highest mean UV absorption, which implied that it had the highest UV absorption compared to cassava and guava leaf extract.

Energy Output

After the fabrication and construction of the DSSC, the energy outputs of the three DSSCs were measured using a digital multimeter. In this investigation, the voltage was used to measure the energy output of the DSSCs. Because DSSCs produce small amounts of energy, millivolts (mV) were appropriate to describe the energy output of the DSSC samples. 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 using the extract of cassava, guava, and mango leaves every 10 min

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 do not significantly differ between each trial. Among the three DSSCs that utilized different natural dyes, the DSSC with guava leaf extract was 276.2 mV. The controlled variable achieved 1178.1 mV energy output, which was higher than the three treatments.

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

Among the three treatments, guava leaves had the highest mean energy output. The results revealed that the commercial solar cell exhibited the highest electricity yield. DSSCs using guava leaf extract had the highest standard deviation, implying data spread.

Table 3. One-Way ANOVA for Differences in UV Absorption Among Natural Dyes from Cassava, Guava, and Mango Leave Extracts

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 the 0.05 level*

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

Arof and Ping (2017) investigated the performance of DSSC in chlorophyll-based photosensitizers extracted from the leaves of pomegranate, bougainvillea, papaya, spinach, and green grasses. Since all the samples contain chlorophyll, which can absorb light in almost the same wavelength range, this study focused on the kind of solvent and its soaking time for natural dyes in DSSCs. DSSC performance depends on the soaking time and solvent used. There were differences in the absorption peaks of augusti, Talisay leaves, and spent coffee grounds due to the presence of different pigments (Bartolome et al., 2020).

Table 4. One-Way ANOVA Test of Difference in Energy Output in DSSCs using Natural Dyes from Cassava, Guava, and Mango Leave Extract and Commercial Solar Cells

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 the 0.05 level*

Table 4 shows that the p-value was <.00001 which is less than the 0.05 level of significance, thereby rejecting the null hypothesis. Therefore, there was a significant difference in the energy output of DSSCs using natural dyes from cassava, guava, and mango leaf extracts and commercial solar cells. To further analyze, Post Hoc Tukey HSD (honestly significant difference) multiple-comparison analysis was performed to determine which treatment gave a significant difference. Pairwise comparisons among Treatments 1, 2, and 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 them into electrical energy, as shown in the data, which can be produced from approximately 200 to 300 mV. Bartolome et al. (2020) reported that the current outputs of DSSCs using different pigments differed significantly from each sample cell.

Another interesting finding of this study was the possibility of the combined DSSCs to produce small LED lights. The small LED light was lit with a small spark (not bright) by the combined three DSSCs, which produced an average of 767.7 mV. Hence, DSSCs are feasible for running a handheld device that requires a small amount of electricity.

CONCLUSION

The results indicate that the natural dyes from cassava, guava, and mango leaf extract contain chlorophyll pigments. 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 a common UV spectrum peak wavelength. The performance of the sample DSSCs in terms of energy output is quite insufficient but has been proven to produce electrical energy, which can be an alternative renewable energy source. The null hypothesis that there was no significant difference in energy output between the three treatments and the control was rejected.

LIMITATION & FURTHER RESEARCH

This study focused on investigating the performance of DSSCs using natural dyes from cassava, guava, and mango leaves in terms of UV absorption using the UV-Vis spectrophotometer and the energy output or electricity produced by a digital multimeter. The solar cells of the three treatments were exposed to sunlight. The performance of the DSSC utilizing leaf extract was compared to the commercial solar cells found in string lights.

Considering these findings, improved techniques, fabrication methods, and materials are needed to achieve better results. Further studies on other species of leaves with different pigment contents, improved techniques for extraction, fabrication, and construction of DSSCs, and characterization of other significant parameters, such as internal resistance, open circuit voltage, maximum power, and fill factor, may be conducted to analyze the progress and feasibility of DSSCs for other purposes. A prototype DSSC model to run handy devices like e-fans, battery-powered audio devices, or flashlights may be created to give insights into innovations that can be used during disasters.

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