

Optical Absorption of an Ethanolic *Mangifera Indica* Leaf Extract Prepared by Cold Maceration, Preliminary Characterization for Potential Dye-Sensitized Solar Cell Application

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ABSTRACT

Natural leaf pigments are low-cost candidates for dye-sensitized solar cells (DSSCs), and their light absorption is the first property to establish. An ethanolic extract of *Mangifera indica* (mango) leaves was prepared by cold maceration in acidified ethanol, without heating, and its UV–Vis absorption was recorded with a double-beam spectrophotometer at seven wavelengths between 200 and 800 nm. The extract absorbed strongly in the ultraviolet and blue region (absorbance 1.43 at 300 nm and 1.47 at 400 nm), absorbed less at 500 nm (0.56), showed a second absorbing region at 600 nm (0.80), and did not absorb at 700 and 800 nm, so the long-wavelength limit of absorption lies between 600 and 700 nm. The pattern indicates light-harvesting behavior across the UV, blue, and orange-red regions, with a weaker window near 500 nm. Because only seven readings were taken, absorption maxima and an optical band gap could not be determined, and no pigment was identified. The work is a preliminary optical characterization; no solar cell was fabricated or tested.

Keywords: *Mangifera indica*, leaf extract, cold maceration, UV–Vis absorption, natural dye, dye-sensitized solar cell

INTRODUCTION

1.0 Introduction

Photovoltaic technology is dominated by crystalline silicon, whose status and prospects continue to be reviewed [1], while third-generation concepts such as perovskite solar cells have emerged as alternatives [2]. Dye-sensitized solar cells (DSSCs) belong to this third generation. They work by absorbing sunlight with a dye loaded inside a mesoporous semiconductor, which produces electricity. These cells are appealing due to their low cost and ease of fabrication and the use of environmentally friendly materials.

The dye is the component that determines how much light a DSSC can harvest. Ruthenium-based complexes remain the benchmark sensitizers, but their cost and the scarcity of the metal limit large-scale use [3]. Dyes obtained from leaves, flowers, and fruits are therefore attractive because they are inexpensive,

renewable, and simple to extract. Their extraction, characterization, and performance have been reviewed [4], and the development of natural-dye cells over recent years has been summarized [5].

Research on natural photosensitizers is still active. A recent review of natural dyes for DSSCs stresses that the choice of dye source remains under study, and it considers both extraction and software simulation as ways to improve performance [6]. Natural pigments in general have also been surveyed, with emphasis on recent advances and future perspectives [7]. This interest has resulted in a low efficiency in cells based on natural dyes and a narrow range of light absorption and stability issues [8].

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

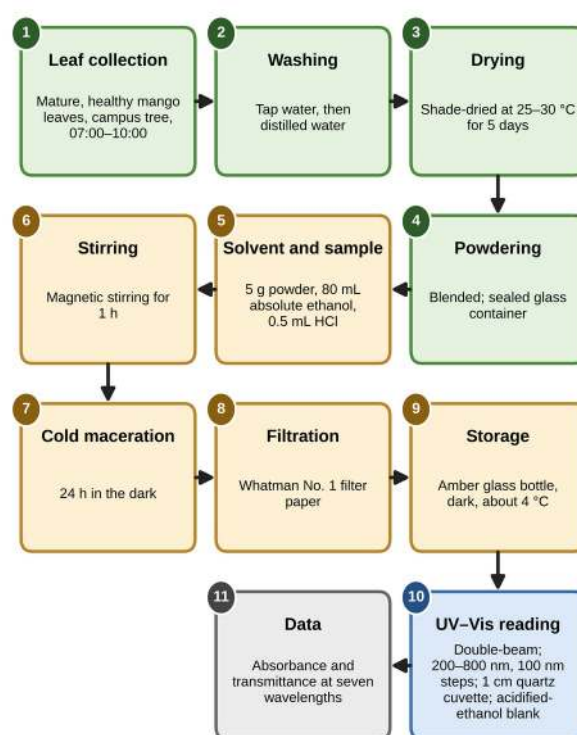


Leaf extracts commonly contain chlorophylls, carotenoids, and flavonoids, which absorb in the ultraviolet, blue, and red regions. *Mango leaves* are widely available in many tropical regions, and cold maceration offers a simple extraction method that needs no heating, which may help to preserve heat-sensitive pigments. Because a sensitizer can only be useful in the part of the solar spectrum that it absorbs, measuring where an extract absorbs is the first step in judging its potential.

The aim of this study was to record the UV-Vis absorption of an ethanolic *mango leaf* extract prepared by cold maceration and to describe, without over-interpretation, where it absorbs. The contribution of this preliminary report is a documented extraction protocol and a transparent record of the first absorption readings, together with a clear statement of what these readings can and cannot show. The study is limited to optical absorption. No device was fabricated, and no photovoltaic performance was measured.

MATERIALS AND METHODS

The procedure, from leaf collection to the absorption measurement, is summarized in Fig. 1. Figure 1 demonstrates the methodology flowchart shows the steps from the collection of mango leaves to the UV-Vis absorption measurement of the extract.



2.1 Plant collection and preparation

The leaves from the mature *mango* trees (*Mangifera indica*) on the university campus were plucked from the *mango* tree in the morning, without any apparent damage, disease, or discoloration in the leaves, to maintain uniformity in the batch. Collection was carried out with prior permission from the University's Agriculture Department, which also confirmed the identity of the plant. No protected or endangered species were involved. The morning collection was chosen to help minimize the loss of pigment as a result of heat, light, and enzyme reaction. The leaves were rinsed with tap water twice to remove dust and coarse particles, then with distilled water to remove soluble contaminants. They were shade-dried at room temperature (25–30°C) for 6 days, ground in a laboratory blender, and stored in a sealed glass container until extraction.

2.2 Dye extraction

The dye was extracted by cold maceration. The solvent was prepared by adding 0.5 mL of HCl to 80 mL of absolute ethanol. 5 g of leaf powder were placed in a 250 mL glass beaker, the acidified ethanol was added, and the mixture was stirred magnetically for 1h at room temperature. It was then kept in the dark for 24 h. After maceration, the mixture was filtered through Whatman No. 1 filter paper, and the filtrate

was transferred to an amber glass bottle and stored in refrigerator about 4°C.

2.3 UV–Vis measurement

Absorption was measured within 24 h of filtration with a double-beam UV–Vis spectrophotometer in multi-wavelength mode, which records discrete readings and not a continuous scan. Readings were taken at seven wavelengths, from 200 to 800 nm at intervals of 100 nm, using a 1 cm quartz cuvette and acidified ethanol as the blank. Absorbance (A) and transmittance (T, %) were recorded, and their consistency was checked with $A = -\log_{10}(T/100)$. The extract was measured as prepared.

2.4 Experimental Data Analysis

The photon energy corresponding to a wavelength λ (nm) was calculated as $E \text{ (eV)} = 1239.84/\lambda$. No smoothing, baseline correction, or curve fitting was applied to the readings, and the values in Table 1 are the instrument values as recorded. No statistical analysis was possible, because each wavelength was measured once.

2.5 Rationale for the Experimental Protocol

Each step of the protocol was chosen to keep the extract as close as possible to the pigments present in the fresh leaf. Mature, undamaged leaves were selected to reduce variation between samples, and morning collection, shade-drying at room temperature, and storage in a sealed container were used to limit heat, light, and moisture exposure. Absolute ethanol was used because it dissolves a wide range of leaf pigments, and a small amount of HCl was added to acidify the solvent. Maceration was carried out in the dark at room temperature to avoid heating and photodegradation, which is the sense in which the method is described as cold. After filtration, the extract was kept in an amber bottle in refrigerator at about 4°C and measured within 24 h so that storage had little time to change the pigments. These choices are stated here as the reasoning behind the method; they were not tested against alternatives in this work.

2.6 Safety and ethical considerations

Absolute ethanol is flammable, and hydrochloric acid is corrosive, so the acidified solvent was handled with suitable laboratory protective equipment, away from ignition sources, and with adequate ventilation. Solvent waste and leaf residue were disposed of according to the laboratory's waste procedure. The leaves were taken from a tree on the university campus, and no protected species or endangered material was involved. No human or animal subjects were used.

3.0 Results and discussion

3.1 Absorption profile

The extract absorbs most strongly between 300 and 400 nm, where the absorbance is 1.43 and 1.47. These two values are nearly equal, so the absorption maximum lies somewhere in this region, but its position cannot be fixed from the present data. The reading at 200 nm is lower (0.85), ethanol itself begins to absorb strongly near this wavelength, so this value is the least reliable of the set. The absorbance falls to 0.56 at 500 nm and rises again to 0.80 at 600 nm. This rise shows a second absorbing region in the orange-red part of the spectrum, separate from the strong UV–blue absorption. Leaf extracts commonly contain chlorophylls, carotenoids, and flavonoids, which absorb in these regions, but the present data cannot identify any pigment, and no phytochemical analysis was carried out. The assignments are therefore left open. In terms of transmittance, only about 3–4 % of the light passes the sample at 300 and 400 nm, compared with about 27 % at 500 nm, 16 % at 600 nm, and almost 100 % at 700 and 800 nm. Absorbance values of about 1.4–1.5 are close to the range where spectrophotometer readings become less reliable, so a diluted sample would provide a more trustworthy measurement. Table 1 represents the absorbance and transmittance of the ethanolic *mango* leaf extract are listed at the seven measured wavelength and Figure 2 illustrates the absorbance of the *mango* leaf extract is plotted at the seven measured wavelengths, with the dotted line serving only as a guide to the eye and not representing a measured spectrum.

Table 1: The Absorbance and Transmittance of the Ethanolic *mango* Leaf Extract Are Listed at the Seven Measured Wavelengths.

Wavelength (nm)	Absorbance (a.u.)	Transmittance (%)
200	0.8451	14.29
300	1.4290	3.72

Wavelength (nm)	Absorbance (a.u.)	Transmittance (%)
400	1.4664	3.42
500	0.5618	27.43
600	0.8017	15.79
700	0.0024	99.46
800	-0.0002	100.05

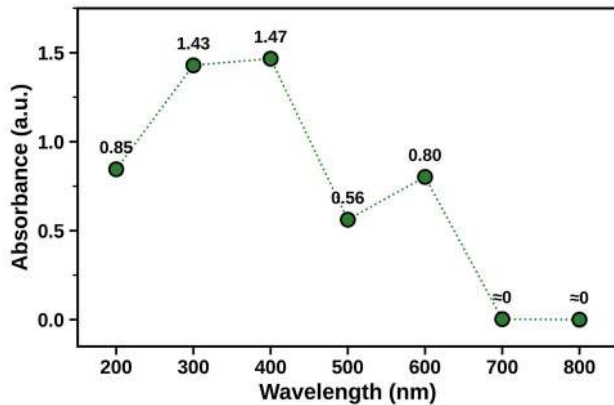


Figure 2: Demonstrates the absorbance of the mango leaf extract is plotted at the seven measured wavelengths, with the dotted line serving only as a guide to the eye and not representing a measured spectrum.

Figure 2 shows a broad region of strong absorption between 300 and 400 nm, a dip at 500 nm, a secondary rise at 600 nm, and a sharp drop to zero by 700 nm. Because the points are 100 nm apart, the exact positions and widths of the bands cannot be read from the figure, and the true spectrum between the points is unknown.

3.2 Absorption limit, band gap, and limitations

The absorbance falls from 0.80 at 600 nm to essentially zero at 700 nm, so the long-wavelength limit of absorption lies between 600 and 700 nm, corresponding to photon energies of about 2.07 to 1.77 eV. This range is set by two readings only. It is not a measured absorption edge, and it is not an optical band gap. A Tauc analysis needs a continuous spectrum with many points across the edge, and seven points spaced 100 nm apart do not provide that, so no band gap is reported. On this evidence alone, the extract can be described only as showing potential light-

harvesting behavior. Whether it could act as a sensitizer depends on properties that were not studied here, such as its binding to a semiconductor surface, its energy levels, its stability, and its performance in a cell. The main limitations are the following:

1. Only seven wavelengths were recorded, so peak positions, widths and shapes are unknown.
2. The extract may have needed dilution, because the highest absorbance values are close to the upper limit of reliable readings.
3. A single extract and a single measurement were used, with no replicates, so the variability is unknown.
4. The pigments were not identified, and no other characterization was performed.

3.2.1 Reliability of the readings

Three features of the measurement affect how far the numbers can be trusted. First, the reading at 200 nm lies at the edge of the useful range for an ethanol solution, because ethanol itself absorbs strongly there, even with an acidified-ethanol blank, the value at 200 nm should be treated as indicative only. Second, the absorbance values of 1.43 and 1.47 at 300 and 400 nm are close to the range where the response of a spectrophotometer ceases to be linear, so the true absorption in this region may be higher or lower than the reported figures relative to the other readings. Third, each value comes from a single reading of a single extract, so the repeatability of the extraction and of the measurement is unknown. These points do not change the qualitative picture of strong UV-blue absorption, a dip near 500 nm, and no absorption at 700 and 800 nm, but they explain why the values are reported as preliminary. Table 2 represents the main observations of the study are summarized together with what they do and do not show.

Table 2: The Main Observations of the Study Are Summarized Together with What They Do and Do Not Show.

Observation	What is shows	What does it not show
Strong absorption at 300–400 nm ($A = 1.43\text{--}1.47$)	The extract absorbs in the UV and blue region	The exact position of the maximum
Lower absorption at 500 nm ($A = 0.56$)	A weaker window in the green region	The width or shape of the window
Second rise at 600 nm ($A = 0.80$)	Absorption in the orange-red region	The position of a red band or the pigment responsible
No absorption at 700 and 800 nm	The absorption limit lies between 600 and 700 nm (about 2.07–1.77 eV)	An optical band gap

3.3 Comparison with related literature

The absorption pattern of the mango extract was compared with recent studies of leaf, flower, and fruit extracts used as natural sensitizers. Absolute absorbance values were not compared because they depend on extract concentration, dilution, and path

length, which differ between studies. The comparison is therefore limited to the positions of absorption bands and to the effect of extraction conditions. Table 4. Illustrates the absorption bands reported in recent studies of natural dye extracts are compared with the readings obtained in the present work.

Table 4: The Absorption Bands Reported in Recent Studies of Natural Dye Extracts Are Compared with the Readings Obtained in the Present Work.

Extract	Reported absorption features	Source
Moringa leaves (chlorophyll dye)	Maximum near 440 nm and peak near 660 nm	[9]
Cassava leaves (chlorophyll dye)	Peaks near 400 and 663 nm	[10]
Mussaenda erythrophylla flowers (ethanol extract)	About 533 nm (anthocyanin) and about 665 nm (chlorophyll a), no such peaks in the water extract	[11]
Hibiscus and pomegranate pigments	About 518 and 510 nm, both near 570 nm on TiO_2	[12]
Mango leaves, acidified ethanol (this work)	Absorbance 1.47 at 400 nm, 0.56 at 500 nm, 0.80 at 600 nm, about 0 at 700 nm	—

Chlorophyll-rich leaf extracts typically show a band in the blue region and a red band near 660–665 nm. The mango extract absorbs strongly at 400 nm, less at 500 nm, and again at 600 nm, with essentially no absorption at 700 nm. The high value at 400 nm and the lower value at 500 nm fit the leaf-chlorophyll pattern, and the rise at 600 nm may be the shoulder of a red band. A chlorophyll red band near 660–665 nm would fall inside the 600–700 nm interval, but the present readings cannot show whether such a band is present. The high value at 300 nm shows that other UV-absorbing compounds also contribute. Anthocyanin-rich extracts behave differently, with bands in the green region near 510–533 nm. No reading was taken between 500 and 600 nm, so the data cannot show whether the mango extract contains pigments of this type. The result for the Mussaenda flower extract is also relevant to the choice of solvent: the ethanol extract showed both pigment types, whereas the water

extract did not show the corresponding peaks, which supports the use of ethanol to recover chlorophyll-type pigments. Extraction conditions affect the pigments that are obtained. The acidity of an anthocyanin extract has been shown to influence DSSC efficiency [13], and the pH of the extract can alter the form of the pigments and therefore their absorption. In the present work the extract was acidified with HCl, but its pH was not recorded, so the effect of acidity cannot be assessed. The method of extraction has also been shown to change pigment attributes in a comparison of extraction methods for anthocyanins from a fruit rind [14], and one study of leaf and other plant extracts compared five solvents, including ethanol, to optimize dye recovery [15]. Chlorophyll-based sensitizers have been examined in DSSCs as well, for example, together with ZnO nanoparticles and a plant-derived nanocellulose electrolyte [16].

Overall, the *mango* extract shows UV-blue absorption and a possible red-region absorption consistent with leaf pigments, in line with the reports above. Its main difference from those studies is not in the chemistry but in the data: they report resolved band positions, whereas the present work reports seven discrete readings. A full scan is therefore needed before the extract can be compared with them peak by peak.

3.4 Future scope and socio-economic impact

The first need is a full scan from 200 to 800 nm at 1 nm steps on diluted samples with replicates. That would locate the absorption maxima and allow a Tauc analysis of the optical band gap. Pigment characterization, such as infrared spectroscopy or phytochemical tests, is needed before any claim about composition. As noted in the introduction, limited light absorption and stability are the main obstacles for natural dyes. Co-sensitization with a second natural dye improved stability under about 450 h of light soaking for a spinach-chlorophyll and *Ixora*-anthocyanin pair [17], so combining the mango extract with a complementary extract is a logical route. Pigment sources beyond higher plants, such as microalgae and cyanobacteria, are also being tested [18]. Device-level work, such as comparing counter-electrode materials [19], would be meaningful only after these steps. Microencapsulation has been reviewed as a way to

handle anthocyanins extracted from fruits [20], and similar protection strategies could be tested for leaf pigments. Energy demand keeps rising in developing regions, as a study of Indonesian provinces linking population density to energy consumption illustrates [21]. About 666 million people still lack electricity, 85% of them in Sub-Saharan Africa, and the global progress report calls for distributed renewable solutions to reach remote, low-income areas [22]. Solar energy has been presented as a promising renewable source for meeting energy demand in agricultural applications in India [23], and a similar argument could apply to rural communities elsewhere. If the efficiency and stability problems are solved, DSSCs made from locally available leaf extracts could support low-cost solar research and teaching in such regions, because the raw material is plentiful and extraction needs only simple equipment. Using leaf biomass for energy materials also fits the circular-bioeconomy idea of valorizing plant biomass, as discussed for *Moringa oleifera* [24], and the search for eco-friendly, cost-effective materials is an active direction in sustainable DSSC research [25]. These benefits are potential only. This only measured light absorption, so it demonstrated none of the potential benefits. Table 3. Describes the measurement plan recommended for a follow-up study is compared with what was done in the present work.

Table 3: The Measurement Plan Recommended for a Follow-Up Study Is Compared with What Was Done in the Present Work.

Aspect	Present work	Recommended follow-up
Wavelength coverage	7 readings, 100 nm apart	Continuous scan, 200–800 nm, 1 nm step
Sample concentration	Measured as prepared	Dilution series, so that the strongest peak stays within the reliable range of the instrument
Replicates	None	At least three independent extractions
Extract pH	Not recorded	Record pH of every extract
Storage and stability	Measured within 24 h of filtration	Repeat scans at fixed intervals during storage
Analysis	Absorbance table and plot	Peak positions and, if justified, a Tauc analysis
Pigment evidence	None	Infrared spectroscopy or phytochemical tests

5.0 Conclusions

An ethanolic mango leaf extract prepared by cold maceration absorbs strongly in the ultraviolet and blue region, shows a second absorbing region near 600 nm, and does not absorb at 700 and 800 nm, so its long-

wavelength absorption limit lies between 600 and 700 nm. These preliminary readings describe where the extract absorbs, but they cannot provide absorption maxima or a band gap, and they do not demonstrate performance in a solar cell. A full-spectrum scan, on

diluted samples with replicates, is the necessary next step.

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Conflicts of Interest

The authors declare no conflict of interest.

Data Availability Statement

“The datasets generated during the current study are available from the corresponding author upon reasonable request.”

CRedit Author Contributions

Ibrahim Abba Ibrahim: Conceptualization, methodology, data collection and Curation, writing the original draft preparation, Submission the Manuscript.

Neha Shrivastava: Characterization, resources, validation.

Hamza Mustapha Umar: Investigation, resources, writing, reviewing and editing.

Dr. Isyaku Bala Zarewa: Data Curation, writing, Software, formal analysis,

Declaration

Ethical Approval

This study did not involve human participants or animals performed by any authors. Not applicable

Plant collection Guidelines

The leaves from the mature *mango* trees (*Mangifera indica*) on the university campus were plucked from the *mango* tree in the morning, without any apparent damage, disease, or discoloration in the leaves, to maintain uniformity in the batch. Collection was carried out with prior permission from the University's Agriculture Department, which also confirmed the identity of the plant. No protected or endangered species were involved.

Consent to Participate

Not applicable

Consent to Publish

Not applicable

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