

Comparative UV–Vis Absorption of Bougainvillea Spectabilis Bract, *Moringa oleifera* Leaf, *Mangifera indica* Leaf and a Combined Moringa–Mango Leaf Extract for Potential Dye-Sensitized Solar Cell Applications

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ABSTRACT

Natural dye extracts from leaves and bracts are being examined as light absorbers for dye-sensitized solar cells (DSSCs), and where an extract absorbs light is the first property to establish. Ethanolic extracts of *Moringa oleifera* leaf, *Mangifera indica* leaf, and *Bougainvillea spectabilis* bracts were prepared by cold maceration in acidified ethanol, a combined moringa–mango (blend) was prepared, and the absorption of each was recorded with a double-beam spectrophotometer between 200 and 800 nm. The extracts are absorbed in clearly different regions. The mango extract absorbed most at 300–400 nm (absorbance 1.43–1.47), the moringa extract most at 600 nm (0.82), and the *Bougainvillea* extract most at 500 nm (0.96) among its valid readings. The leaf extracts did not absorb at 700 and 800 nm, whereas the *Bougainvillea* extract still absorbed there (0.32 and 0.10). The diluted blend absorbed 17–44% more than the expected additive value at 300–500 nm but showed zero absorption at 550 and 600 nm, where both parent extracts do absorb, creating a conflict that cannot be resolved by the current readings. Two *Bougainvillea* readings (200 and 300 nm) were invalid and were excluded. Because the readings are sparse single values, absorption maxima and optical band gaps are not reported, and the comparison is descriptive. The work is a preliminary optical screening; no solar cell was fabricated or tested.

Keywords: natural dye, *Bougainvillea spectabilis*, *Moringa oleifera*, *Mangifera indica*, UV–Vis absorption, dye-sensitized solar cell

INTRODUCTION

1.0 Introduction

1.1 Background

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 use a dye adsorbed on a mesoporous semiconductor to absorb sunlight and generate electricity. The dye is the component that determines how much light a DSSC can harvest, so the choice of dye largely decides what the cell can do.

1.2 Advantages of natural leaf and bract extract dyes

Dyes obtained from leaves, flowers and fruits offer several advantages over synthetic complexes, they are inexpensive, renewable and simple to extract, and their extraction. Mango and moringa leaves are widely available in many tropical regions, and *Bougainvillea* is a common ornamental plant, so the raw materials are plentiful. Cold maceration in ethanol needs no heating and only basic laboratory equipment, and the absence of heating may help to preserve heat-sensitive pigments (this was not tested here). Leaves and bracts are renewable plant material, and the process uses a common solvent and a small

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.

amount of acid. Different plants absorb in different regions, so blends of extracts may offer a way to widen spectral coverage, which this study examines for a mango–moringa blend. The extraction used a blender, a beaker, a magnetic stirrer, filter paper and a spectrophotometer, all common laboratory items.

1.2 Statement of the problem

Synthetic ruthenium dyes are expensive and depend on a scarce metal, which limits their large-scale use. Natural dyes tend to absorb light over a narrower range and with lower efficiency than needed, so the absorption of every candidate extract must be established before it can be judged.

For leaf and bract extracts from locally available plants such as mango, moringa and *Bougainvillea*, a consistent side-by-side comparison of their absorption, and a test of whether a blend of two extracts behaves as the sum of its parents, were needed to decide which extracts deserve further study.

This study therefore asks where each extract absorbs, and whether blending the two leaf extracts changes the absorption in a simple additive way.

1.3 Research gap

The studies deal with single sources or specific pigment pairs. In the studies reviewed here, mango leaf, moringa leaf and *Bougainvillea spectabilis* bract extracts were not compared side by side after the same cold-maceration protocol, and a mango–moringa leaf blend was not reported.

This study addresses these gaps in three ways. It compares three locally available extracts, prepared by one protocol and read on one instrument, over 200–800 nm. It tests a combined moringa–mango (blend) against a simple additive dilution model (Table 3), which can be used as a low-cost screening step before a device is fabricated. It also reports the invalid readings, the baseline problems and the measurement plan needed to resolve them (Tables 5 and 7), so that the readings can be judged and reused.

1.4 Aim of the study

The aim of this study was to compare the UV–Vis absorption of ethanolic extracts of moringa leaf, mango leaf and *Bougainvillea* bracts, and of a combined moringa–mango (blend), and to describe, without over-interpretation, where each absorbs.

1.5 Objectives of the study

The objectives are follow: (i) to record the absorption of each extract between 200 and 800 nm, (ii) to test whether the blend behaves as the sum of its parents at the same dilution, and (iii) to document the data-quality problems and set out a follow-up measurement plan. The study is limited to optical absorption. No device was fabricated, and no photovoltaic performance was measured.

2.0 Literature Review

Recent work on natural-dye DSSCs has moved from single extracts toward mixtures of pigments, and toward a closer look at how pigments interact with each other and with TiO_2 . A 2025 review of underused plant sources for natural pigments lists *Bougainvillea glabra*, whose betalain pigments have been tested as DSSC sensitizers, and notes that crude *Bougainvillea* dyes performed better than purified ones in one study. The same review states that stability, seasonality and extraction efficiency still limit the commercial use of natural dyes [9].

Mixing extracts has been the most common response to the narrow absorption of single dyes. Co-sensitization of natural plant extracts, including pigments from *Bougainvillea*, gave cell performance 12 to 24 times higher than that of any single dye, and the gain was linked to suppressed charge recombination [10]. A time-dependent density functional theory study of chlorophyll b and anthocyanin on TiO_2 clusters found that the acidified anthocyanin–chlorophyll combination had the smallest energy gap of all systems examined (1.85 eV) and complementary absorption, with chlorophyll mainly in the 400–500 nm region and anthocyanin in the 500–600 nm region [11]. In an experimental counterpart, a cocktail of purple sweet potato anthocyanin and papaya leaf chlorophyll reached an efficiency of 0.607 % at the best mixing ratio and immersion time, 133 % above the best single-dye cell, and the mixed extracts kept several absorption peaks between about 370 and 665 nm [12]. The same strategy has been applied to non-plant pigments: co-sensitization of microbial pigments from *Talaromyces atrovirens* GH2 and *Paracoccus bogoriensis* BOG6 gave a best device with a short-circuit current density of 1.59 mA/cm², an open-circuit voltage of 0.35 V, a fill factor of 0.62 and an efficiency of 0.34 % [13].

These studies agree that combining pigments with different absorption windows can improve cell performance. They report mostly device parameters or computed spectra, and in the studies reviewed here the absorption of a mixed extract is not compared with what its parent extracts would give at the same dilution.

3.0 Experimental

The plant materials, the extraction steps, the preparation of the blend and the measurement are illustrated schematically in Figs. 1–3 and described below.

3.1 Plant material and extraction

Mango, moringa leaves and *Bougainvillea spectabilis* bracts were collected in the morning from a cultivated plant on the Mewar University campus, Chittorgarh, Rajasthan, India. The collections were carried out with prior permission from the university's Agriculture Department, which also confirmed the identity of the plants. No protected or endangered species were involved. The leaves and bracts were rinsed with tap water twice and then distilled water, shade-dried at room temperature (25–30 °C) for 5 days and were ground using laboratory blender and stored in a sealed glass container. Figure 1 illustrates schematically as a mango leaf, a moringa leaf and *Bougainvillea* bracts.

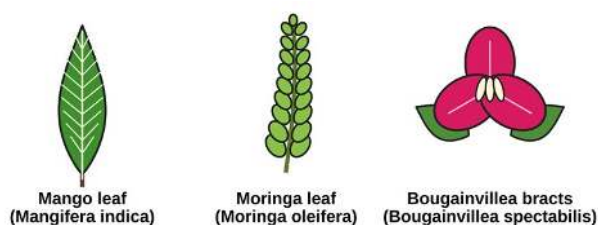


Figure 1 demonstrates as a mango leaf, a moringa leaf and *Bougainvillea* bracts.

The dye of each plant was extracted by cold maceration in acidified absolute ethanol. For each leaf and bracts, 5 g of powder were stirred magnetically for 1 h in a 250 mL beaker with 80 mL of absolute ethanol containing 0.5 mL of HCl, and the mixture was then kept in the dark for 24 h. Each mixture was filtered through Whatman No. 1 filter paper, and the filtrate was stored in an amber glass bottle in the dark at about 4 °C. Figure 2. presents the extraction steps from the washing and shade-drying of the plant material to cold maceration, filtration and storage of the extract.



Figure 2 proves the extraction steps for each leaf and bracts from washing and shade-drying of the plant material to cold maceration, filtration and storage of the extract.

3.2 Preparation of the combined *Moringa*-*Mango* leaf extract (blend)

The blend was prepared by mixing 1 mL of the mango extract, 1 mL of the moringa extract and 1 mL of ethanol (3 mL in total) and homogenizing the mixture before measurement. Each extract was therefore diluted to one third of its original concentration in the blend.

3.3 UV–Vis measurement

Absorption was measured with a double-beam UV–Vis spectrophotometer in multi-wavelength mode, which records discrete readings and not a continuous scan, using a 1 cm quartz cuvette and ethanol as the blank. The *moringa*, *mango* and *Bougainvillea* extracts were each read at seven wavelengths from 200 to 800 nm at 100 nm intervals, and the blend was read at 13 wavelengths from 200 to 800 nm at 50 nm intervals. All readings were taken on the same day. The *Bougainvillea* values were transcribed from a photograph of the instrument display. Absorbance (A) and transmittance (T, %) were recorded, and their consistency was checked with $A = -\log_{10}(T/100)$. Figure 3. Demonstrates the preparation of the blend and the UV–Vis measurement with a quartz cuvette of 1 cm path length and a double-beam spectrophotometer.

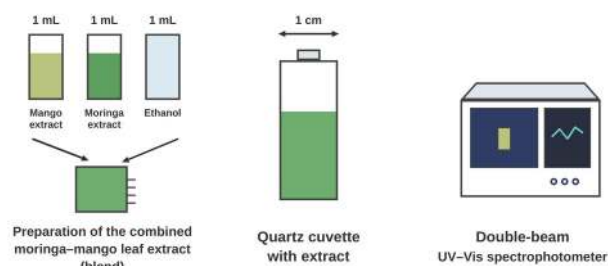


Figure 3 describes the preparation of the blend and the UV-Vis measurement are illustrated schematically, with a quartz cuvette of 1 cm path length and a double-beam spectrophotometer.

3.4 Data handling

The photon energy for a wavelength λ (nm) was calculated as E (eV) = $1239.84/\lambda$. Absorbance readings with a magnitude below 0.01 were treated as zero (≈ 0). Two *Bougainvillea* readings were excluded as invalid: the reading at 200 nm, which sits at the instrument ceiling ($A = 6.0000$, $T = 0.00\%$), and the reading at 300 nm, where the instrument reported a negative absorbance (-1.1637) and a transmittance of 1457.73% , which is physically impossible. No smoothing, baseline correction or curve fitting was applied. Each wavelength was read once, so no statistical analysis was possible.

3.5 Safety and ethical considerations

Absolute ethanol is flammable and hydrochloric acid is corrosive, so the acidified solvent should be handled with protective equipment, away from ignition sources and with adequate ventilation, and waste should be disposed of according to the laboratory procedure. No human or animal subjects were used.

4.0 Result and Discussion

4.1 Absorption of the individual extracts

The *moringa* extract absorbs weakly to moderately in the ultraviolet (0.46 at 200 nm and 0.55 at 300 nm), least at 400 nm (0.23), more at 500 nm (0.64) and most at 600 nm (0.82), and it does not absorb at 700 and 800 nm. Its highest reading is therefore in the orange-red region.

The *mango* extract shows the opposite emphasis. It absorbs most strongly at 300 and 400 nm (1.43 and 1.47), less at 500 nm (0.56) and again at 600 nm (0.80), and it does not absorb at 700 and 800 nm. The values of about 1.4–1.5 are close to the range where spectrophotometer readings become less reliable.

The *Bougainvillea* readings are 0.58 at 400 nm, 0.96 at 500 nm, 0.85 at 600 nm, 0.32 at 700 nm and 0.10 at 800 nm. Its highest reading is at 500 nm, and unlike the leaf extracts, its absorbance does not fall to zero at 700 and 800 nm. This residual absorbance may reflect weak absorption, turbidity of the extract or a baseline offset; it was not investigated, and it should be checked in a repeat scan.

The complementary emphasis of the two leaf extracts, *mango* in the UV-blue and *moringa* in the orange-red, provides a basis for testing their blend. Equal extract concentrations were not verified, so the absorbance values of different extracts cannot be ranked against each other. Table 1 and Figure 4 Presents the absorbance readings of the four extracts are listed at the wavelengths common to all datasets, and the readings marked with an asterisk are invalid and were excluded and the absorbance of the moringa, mango, blend and *Bougainvillea* extracts is plotted against wavelength, with dotted lines serving only as guides to the eye, and the invalid *Bougainvillea* readings at 200 and 300 nm are not plotted.

Table 1: The Absorbance Readings of the Four Extracts Are Listed at the Wavelengths Common to All Datasets, and the Readings Marked with an Asterisk Are Invalid and Were Excluded.

λ (nm)	<i>Moringa leaf</i>	<i>Mango leaf</i>	blend	<i>Bougainvillea bracts</i>
200	0.4644	0.8451	0.1461	6.0000*
300	0.5503	1.4290	0.7731	-1.1637*
400	0.2324	1.4664	0.8068	0.5821
500	0.6394	0.5618	0.5751	0.9614
600	0.8233	0.8017	-0.0015	0.8487
700	-0.0002	0.0024	0.0004	0.3182
800	0.0004	-0.0002	0.0001	0.1016

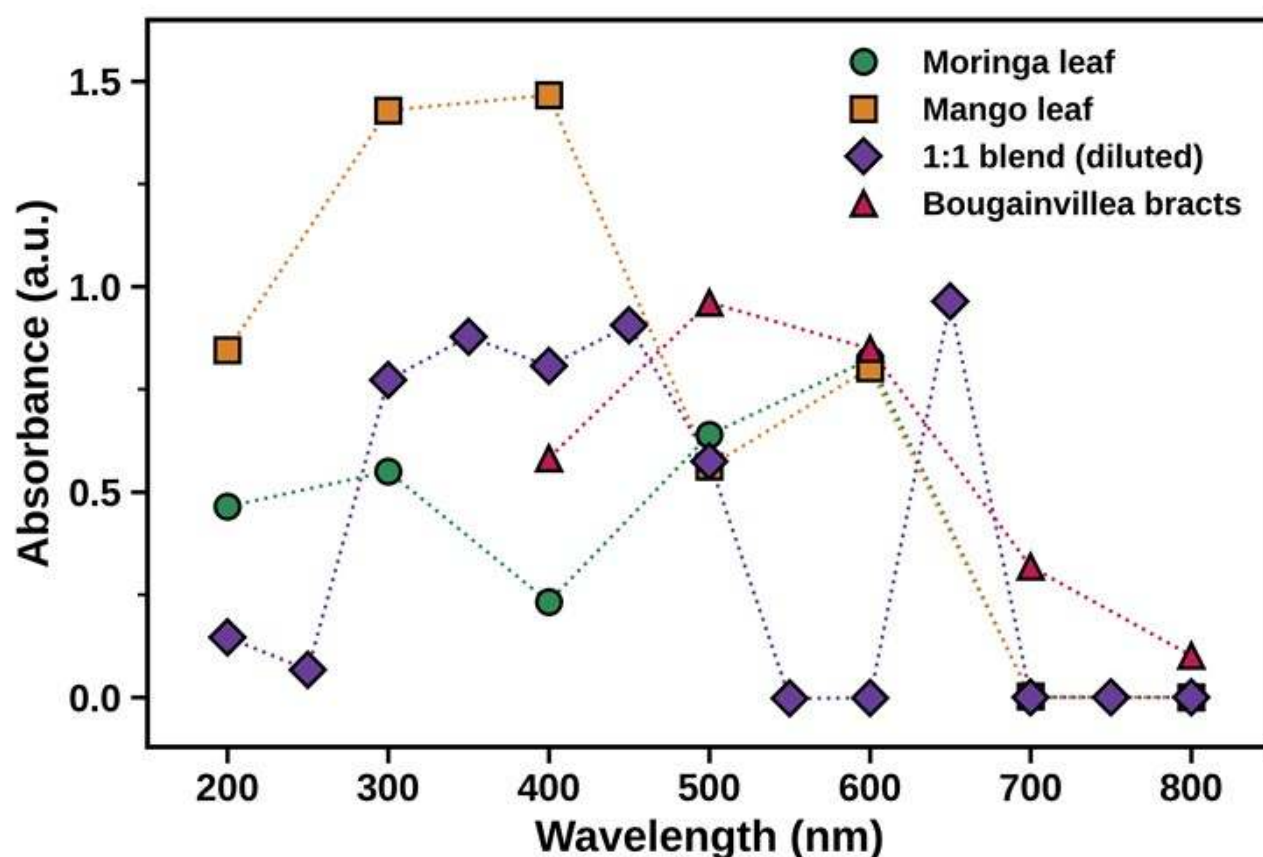


Figure 4 illustrates the absorbance of the moringa, mango, blend and Bougainvillea extracts is plotted against wavelength, with dotted lines serving only as guides to the eye, and the invalid Bougainvillea readings at 200 and 300 nm are not plotted.

The four extracts have different absorption emphases, *mango* in the UV–blue, *moringa* in the orange–red, *Bougainvillea* around 500–600 nm with a tail to 800 nm, and the blend with two groups of high readings near 300–450 nm and at 650 nm. Because the points are 50 or 100 nm apart, the positions and widths of

bands cannot be read from the figure, and the true spectra between the points are unknown.

4.2 The blend, absorption limits and reliability

The blend shows absorbance of 0.77 to 0.91 between 300 and 450 nm (0.77, 0.88, 0.81 and 0.91 at 300, 350, 400 and 450 nm) and 0.58 at 500 nm. It reads zero at 550 and 600 nm, 0.96 at 650 nm, and zero again from 700 to 800 nm. Its absorbance at 200 and 250 nm is low (0.15 and 0.07). The complete set of readings is given in Table 2.

Table 2: The Complete Set of 13 Readings of the Diluted Combined Moringa–Mango (Blend) Is Given at 50 nm Intervals.

Wavelength (nm)	Absorbance (a.u.)	Transmittance (%)
200	0.1461	71.43
250	0.0669	85.71
300	0.7731	16.86
350	0.8780	13.24
400	0.8068	15.60
450	0.9061	12.41
500	0.5751	26.60
550	–0.0022	100.51
600	–0.0015	100.35
650	0.9644	10.85
700	0.0004	99.91
750	–0.0002	100.04

Wavelength (nm)	Absorbance (a.u.)	Transmittance (%)
800	0.0001	99.98

4.2.1 Additive test

If the pigments in the two extracts do not interact, and the individual extracts were measured at the concentrations used in the blend, the absorbance of the blend should equal the sum of the *moringa* and *mango* values divided by three, because each extract was diluted to one third. The observed blend absorbance is above this expectation at 300, 400 and 500 nm, by 17 %, 42 % and 44 %. It is below the expectation at 200 nm, by 67 %, and at 600 nm it is essentially zero where about 0.54 was expected. At 700 and 800 nm the observed and expected values agree, since both are zero.

Three explanations are possible for the excess at 300–500 nm, an interaction between pigments of the two extracts, a difference between the actual concentrations and the assumed dilution, and measurement

error in the multi-wavelength mode. The present single readings cannot separate them and the result at 600 nm is the clearest conflict, because both parent extracts absorb strongly there (0.80 and 0.82), so a zero reading for the blend would need a loss of absorption that a simple mixture does not explain. The blend readings at 550 and 600 nm also exceed 100 % transmittance, which indicates a baseline problem. For this reason, no conclusion about interaction or about the spectral coverage of the blend can be drawn from the present data. Table 3 presents the observed absorbance of the blend is compared with the value expected if the blend were a simple one-third dilution of each parent extract and Figure 5 demonstrates the observed absorbance of the blend is plotted next to the value expected for a simple one-third dilution of each parent extract at the seven common wavelengths.

Table 3: The Observed Absorbance of the Blend Is Compared with the Value Expected If the Blend Were a Simple One-Third Dilution of Each Parent Extract.

λ (nm)	<i>Moringa</i>	<i>Mango</i>	Expected blend	Observed blend	Deviation (%)
200	0.4644	0.8451	0.4365	0.1461	−67
300	0.5503	1.4290	0.6598	0.7731	+17
400	0.2324	1.4664	0.5663	0.8068	+42
500	0.6394	0.5618	0.4004	0.5751	+44
600	0.8233	0.8017	0.5417	−0.0015	−100
700	−0.0002	0.0024	0.0007	0.0004	≈0
800	0.0004	−0.0002	0.0001	0.0001	≈0

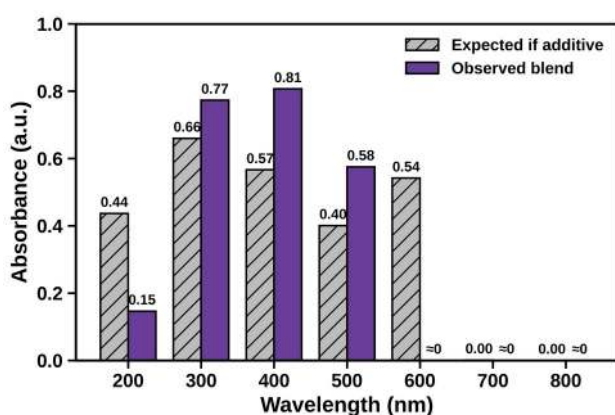


Figure 5 illustrates the observed absorbance of the blend is plotted next to the value expected for a simple one-third dilution of each parent extract at the seven common wavelengths.

The observed bars exceed the expected bars at 300, 400 and 500 nm and fall below them at 200 and 600 nm, and both agree at 700 and 800 nm. The pattern is not uniform, which argues against a single simple

cause such as a wrong dilution factor and points to either wavelength-dependent effects or measurement artefacts. A repeat scan is needed to decide which.

4.2.2 Spectral coverage and absorption limits

Among the measured wavelengths, the regions where each extract reaches an absorbance of at least 0.5 are summarized in Table 4. For the *moringa* and *mango* extracts, absorbance falls from about 0.8 at 600 nm to zero at 700 nm, so the long-wavelength limit of absorption lies between 600 and 700 nm, which corresponds to photon energies of about 2.07 to 1.77 eV. For the blend, the limit lies between 650 and 700 nm (about 1.91 to 1.77 eV). The *Bougainvillea spectabilis bracts* extract still absorbs at 800 nm (about 1.55 eV), so its limit lies beyond the range measured, or its baseline is offset. These ranges are set by only two readings in each case. They are not measured absorption edges, and they are not optical

band gaps. Table 4 proves the measured wavelengths at which each extract reaches an absorbance of at least 0.5 are listed together with its highest valid reading.

Table 4: The Measured Wavelengths at Which Each Extract Reaches an Absorbance of at Least 0.5 Are Listed Together with Its Highest Valid Reading.

Extract	Wavelengths with $A \geq 0.5$ (absorbance)	Highest valid reading
<i>Moringa leaf</i>	300 (0.55), 500 (0.64), 600 (0.82)	600 nm (0.82)
<i>Mango leaf</i>	200 (0.85), 300 (1.43), 400 (1.47), 500 (0.56), 600 (0.80)	400 nm (1.47)
blend (diluted)	300 (0.77), 350 (0.88), 400 (0.81), 450 (0.91), 500 (0.58), 650 (0.96)	650 nm (0.96)
<i>Bougainvillea spectabilis bracts</i>	400 (0.58), 500 (0.96), 600 (0.85)	500 nm (0.96)

The highest reading of each extract is not a measured absorption maximum, because the readings are 50–100 nm apart and the extracts were measured at unequal concentrations.

4.2.3 Reliability of the readings

Several features of the measurement limit how far the numbers can be trusted, and they are listed in Table 5. The main points are the two invalid *Bougainvillea*

readings, the non-zero *Bougainvillea* baseline at 700 and 800 nm, the zero blend readings at 550 and 600 nm, the coarse wavelength spacing, and the absence of replicates. Because of these problems, the report makes no statement about absorption maxima, optical band gaps, pigment identity, or performance in a solar cell. Table 5 proves the data-quality problems found in the readings are listed together with their consequences for the comparison.

Table 5: The Data-Quality Problems Found in the Readings Are Listed Together with Their Consequences for the Comparison.

Issue	Affected data	Consequence
Instrument ceiling ($A = 6.0000$, $T = 0.00\%$) at 200 nm	<i>Bougainvillea</i>	Reading excluded
Negative absorbance with $T = 1457.73\%$ at 300 nm	<i>Bougainvillea</i>	Reading excluded, blank or zero error likely.
Non-zero absorbance at 700 and 800 nm	<i>Bougainvillea</i>	Baseline or turbidity effect not ruled out.
Wavelength step of 50 nm versus 100 nm	Blend versus other extracts	Only the common wavelengths can be compared.
Zero readings with T above 100 % at 550 and 600 nm	Blend	Conflict with parent extracts; reading unreliable.
Blend diluted, other extracts	Blend versus parents	Absorbance values scale differently.
Single reading per wavelength, no replicates	All extracts	Variability unknown.
Ethanol absorbs strongly near 200 nm	All extracts	Reading at 200 nm indicative only.

4.3 Comparison with related literature

The absorption pattern of the extracts 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 6 presents the absorption bands reported in recent studies of natural dye extracts are compared with the readings obtained in the present work.

Table 6: The Absorption Bands Reported in Recent Studies of Natural Dye Extracts Are Compared with the Readings Obtained in the Present Work.

Source	Reported absorption features	Extract
[14]	Maximum near 440 nm and peak near 660 nm	Moringa leaves (chlorophyll dye)
[15]	Peaks near 400 and 663 nm	Cassava leaves (chlorophyll dye)
[16]	About 533 nm (anthocyanin) and about 665 nm (chlorophyll a); no such peaks in the water extract	Mussaenda erythrophylla flowers (ethanol extract)
[17]	About 518 and 510 nm; both near 570 nm on TiO ₂	Hibiscus and pomegranate pigments
Present study	Highest reading 0.82 at 600 nm; 0.23 at 400 nm; about 0 at 700 nm	Moringa leaves, acidified ethanol (this work)
Present study	Highest reading 1.47 at 400 nm; 0.56 at 500 nm; 0.80 at 600 nm; about 0 at 700 nm	Mango leaves, acidified ethanol (this work)
Present study	0.77–0.91 at 300–450 nm; 0.58 at 500 nm; about 0 at 550 and 600 nm; 0.96 at 650 nm; about 0 at 700 nm	moringa–mango (blend), diluted (this work)
Present study	Highest valid reading 0.96 at 500 nm; 0.32 at 700 nm	Bougainvillea bracts (this work)

Chlorophyll-rich leaf extracts typically show a band in the blue region and a red band near 660–665 nm. The moringa extract absorbs most at 600 nm and not at 700 nm, which is consistent with a red-region band between 600 and 700 nm. Its low reading at 400 nm does not show a strong blue band at that wavelength, but the blue band maximum near 440 nm reported for moringa chlorophyll was not measured. The mango extract shows strong UV-blue absorption and a smaller rise at 600 nm that may be the shoulder of a red band. A chlorophyll red band near 660–665 nm would fall inside the 600–700 nm interval for both leaf extracts, but the present readings cannot show whether such a band is present. The blend shows high absorbance near 450 nm and at 650 nm with zero readings between them, which resembles the two-band pattern of leaf-chlorophyll extracts, but its zero readings at 550 and 600 nm conflict with its parent extracts, so this resemblance is not confirmed. In a recent anthocyanin–chlorophyll cocktail study, the mixed extracts kept several absorption peaks between about 370 and 665 nm [12], and a computational study predicts complementary absorption windows for the two pigment classes [11]. The zero readings of the present blend at 550 and 600 nm are therefore more consistent with a baseline problem than with a real property, although only a repeat scan can settle this. The Bougainvillea extract absorbs most at 500 nm, in the green region where anthocyanin-type pigments are reported to absorb. Its pigments were not identified, so this is a comparison of band position only and not an identification. 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, which is consistent with the choice of ethanol, although ethanol was not compared with water in the present work. Extraction conditions affect the pigments that are obtained. The acidity of an anthocyanin extract has been shown to influence DSSC efficiency [18], and the pH of the extract can alter the form of the pigments and therefore their absorption. In the present work the extracts were acidified with HCl, but their 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 [19], and one study of leaf and other plant extracts compared five solvents, including ethanol, to optimize dye recovery [20]. Chlorophyll-based sensitizers have been examined in DSSCs as well, for example, together with ZnO nanoparticles and a plant-derived nanocellulose electrolyte [21].

Overall, the extracts show the kinds of absorption expected of leaf and bract pigments, in line with the reports above. The main difference from those studies is not in the chemistry but in the data: they report resolved band positions from continuous spectra, whereas the present work reports discrete readings. A full scan is therefore needed before the extracts can be compared with them peak by peak.

4.4 Future scope and socio-economic impact

The first need is a repeat measurement of all four extracts and the blend under identical conditions, with a continuous scan, replicates, and a dilution series, as set out in Table 7. That would locate the absorption maxima, remove most of the problems listed in Table 5, and allow the question of pigment interaction in the blend to be answered, together with a Tauc analysis of the optical energy gap where the data allow it. 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 [22], which is another reason to examine blends carefully. Pigment sources beyond higher plants, such as microalgae and cyanobacteria, are also being tested [23]. Device-level work, such as comparing counter-electrode materials [24], would be meaningful only after these steps. Microencapsulation has been reviewed as a way to handle anthocyanins extracted from fruits [25], and similar protection strategies could be tested for leaf and bract pigments. Energy demand keeps rising in developing regions, as

a study of Indonesian provinces linking population density to energy consumption illustrates [26]. 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 [27]. Solar energy has been presented as a promising renewable source for meeting energy demand in agricultural applications in India [28], and a similar argument could apply to rural communities elsewhere. If the efficiency and stability problems are solved, DSSCs made from locally available leaf and bract extracts could support low-cost solar research and teaching in such regions, because the raw materials are 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* [29], one of the plants studied here, and the search for eco-friendly, cost-effective materials is an active direction in sustainable DSSC research [30]. These benefits are potential only. This study measured only light absorption, so none of them is demonstrated. Table 7 demonstrates the measurement plan recommended for a follow-up study is compared with what was done in the present work.

Table 7: Presents 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 or 13 readings at 100 or 50 nm	Continuous scan, 250–800 nm, 1 nm step, spectrum scan mode
Zeroing	Invalid readings for Bougainvillea	Re-zero with the blank before each sample
Concentration	Mixed, partly diluted	Same mass per volume for every extract, dilution series, strongest peak below about 1.0
Blend test	One blend, single readings	Blend spectrum compared with the scaled sum of the two parent spectra
Replicates	None	At least three independent extractions per extract
Extract pH	Not recorded	Record the pH of every extract
Pigment evidence	None	Infrared spectroscopy or phytochemical tests

5.0 Conclusion

The moringa leaf, mango leaf, and Bougainvillea bract extracts differ in where they absorb: mango mainly in the UV-blue, moringa mainly in the orange-red, and Bougainvillea around 500–600 nm with residual absorption up to 800 nm. The blend absorbs above the additive expectation at 300–500 nm but

reads zero at 550 and 600 nm, which conflicts with its parent extracts and cannot be explained by the present data. Two Bougainvillea readings were invalid and were excluded. These preliminary readings give a descriptive screening only. They fail to provide absorption maxima or band gaps, demonstrate any benefit of blending, or show performance in a solar cell.

A repeat scan under identical conditions, with replicates, is the necessary next step.

Funding

This research received no external funding.

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.

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

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

Mubarak Umar: Validation and Visualization

Declaration

Ethical Approval

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

Plant collection Guidelines

Mango, moringa leaves and *Bougainvillea spectabilis* bracts were collected in the morning from a cultivated plant on the Mewar University campus, Chittorgarh, Rajasthan, India. The collections were carried out with prior permission from the university's Agriculture Department, which also confirmed the identity of the plants. No protected or endangered species were involved.

Consent to Participate

Not applicable

Consent to Publish

Not applicable

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HOW TO CITE: Ibrahim Abba Ibrahim, Hamza Mustapha Umar, Isyaku Bala Zarewa, Mubarak Umar, Comparative UV–Vis Absorption of Bougainvillea Spectabilis Bract, *Moringa Oleifera* Leaf, *Mangifera Indica* Leaf and a Combined Moringa–Mango Leaf Extract for Potential Dye-Sensitized Solar Cell Applications, Int. J. Sci. R. Tech., 2026, 3 (10), 1484-1495. <https://doi.org/10.5281/zenodo.23834896>