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Influence of Hydroethanolic Mixtures on Characteristics of *Bougainvillea glabra* Bracts Dyes: Textile Dyeing, Fastness Properties and Application as Indicator in Acid-Base Titration

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ABSTRACT
The study investigated the extraction, characterization and dyeing potential of natural dyes obtained from *Bougainvillea glabra* bracts using different solvent systems. Fresh plant materials were extracted using maceration techniques with three solvent systems: distilled water, 90 % and 10 % ethanol. The resulting extracts were analyzed using UV–Visible and Fourier Transform Infrared (FTIR) spectroscopy to determine their chromophoric and functional group compositions. The UV–Vis spectra showed strong absorption peaks between 200–400 nm, indicating the presence of phenolic and flavonoid compounds, while FTIR results confirmed hydroxyl, alkenyl, alkyl and carbonyl groups responsible for dyeing characteristics. Cotton fabrics dyed with the extracts were evaluated for light, washing, rubbing, ironing and perspiration fastness. The 90 % ethanolic dye extract demonstrated the highest colour intensity and fastness properties, followed by the 10 % ethanol and aqueous dye extracts respectively. The use of the extracts as indicator in acid-base titration produced a change in colour which is an indication that it can be an alternative to common synthetic indicators. The study revealed that solvent polarity significantly affects quality of pigment and dye-fibre affinity. Therefore, *B. glabra* dye extracts presented a viable eco-friendly alternative to synthetic colourants for textile coloration and other industrial applications.

Keywords: Dye, Extraction, Solvent, Mixture, Fastness, Eco-Friendly, Dyeing

INTRODUCTION

Colour significantly impacts nearly all aspects of human life, influencing decisions related to clothing, home decoration, and even food selection (Manikprabhu and Lingappa, 2013). In addition to its visual appeal, colour carries profound cultural, emotional, and symbolic meanings across various societies (Yusuf *et al*., 2017). Natural colours are mostly derived from plants, animals and minerals of which plants comprise the majority (Bhandari *et al*., 2025). Dyes are chromophoric substances with a capacity to interact chemically or physically with substrates, leading to selective absorption of specific wavelengths of light and resulting in display of colour (Alegbe and Uthman, 2024). For centuries, flowers have been essential sources of natural dyes, producing bright and environmentally friendly colours from petals, leaves and other plant components. These floral dyes not only strengthen the connection between humans and nature but also serve as sustainable options in response to growing environmental concerns regarding synthetic colourants. With increasing awareness of sustainability, the study and use of flower-based dyes have gained importance as ecologically sound and culturally meaningful alternatives. Rising consumer preference for natural and eco-safe products has increased industrial development towards green, biodegradable and sustainable extraction processes (Tiwari, 2015). The dyeing of textile substrates depends on dyeing parameters such as fibre structure, time, temperature, pH of the dye bath and dye molecule (Shirsath *et al*., 2024).

The beautiful arrays of flowers in nature can be utilized to extract excellent natural dyes for colouring textile fibres and fabrics (Kalyani and Rafeekher, 2025). Such dyes are biodegradable, non-toxic and economically viable and greatly contributing to environmental preservation. While many brightly coloured flowers can yield pigments, most do not adhere firmly to fabrics and do not retain their vibrancy over time. Mordants are employed to overcome this shortcoming because they function as glue that makes the dyes to bind to the fabrics which prevent fading. Mordanting processes can be pre-mordanting (treating fabrics with mordants before dyeing), meta mordanting (adding the mordants directly to the dye bath) and post mordanting (treating the fabrics with the mordants after dyeing). Globally, the genus *Bougainvillea* is a climbing plant native from South America and widely distributed and renowned for it's ornamental, ecological, and medicinal significance. It belongs to the family *Nyctaginaceae*. Their tolerance for both humid and arid environments, combined with minimal maintenance requirements, has contributed to their global popularity as ornamental plants due to the colour of its bracts commonly known as flower (Sadgir *et al*., 2025). The bract acts as the modified leaves that surround the plants true flower. They have a thin dry papery texture which confers the name "paper flower" on the plant. *Bougainvillea* has large and vibrant coloured bracts which are widely used in landscape gardening (Liu *et al*., 2025). The pigment composition in *Bougainvillea* cultivars primarily includes carotenoid, chlorophyll, flavonoid (Zhang *et al*., 2024) and betalain (Liu *et al*., 2025). The conventional extraction process is a crucial stage in natural dye production because they are simple, cost-effective and require limited equipment, making them widely applicable. However, issues related to solvent toxicity and chemical residues have encouraged the advancement of greener extraction methods and reducing or avoiding the use of harmful organic solvents. Aqueous extraction is one of the most common and environmentally friendly methods used for isolating plant-derived colourants due to its simplicity, safety

and suitability for heat-stable compounds. Despite its efficiency in producing dyes applicable to textiles, aqueous extraction has certain drawbacks, including long processing time, high water consumption, and potential degradation of thermolabile pigments when subjected to elevated temperatures (Mia *et al*., 2021). Therefore, the aim of this research work is to extract and characterize natural dye from the paper flower (*Bougainvillea glabra*) using mixtures of aqueous and non-aqueous (organic) solvents as alternative to pure solvent extraction and evaluate its suitability for ecofriendly dyeing of cotton fabrics as well as other industrial applications.

MATERIALS AND METHODS

Sample Collection and Pretreatment

Fresh *Bougainvillea glabra* bracts (250 g) were harvested from the Sport Pavilion area, Osun State Polytechnic, Iree, Boripe Local Government Area. The leaves were collected early in the morning to retain maximum pigment concentration. They were rinsed thoroughly with distilled water to remove dust and surface impurities. Fresh bracts were used in order to preserve the natural moisture and active chromophoric compounds (Rahman *et al*., 2021: Oyeleke *et al*., 2022).

Figure 1: Freshly Collected *Bougainvillea glabra* Bracts

Dye Extraction

The fresh bracts of *B. glabra* (Figure 1) were chopped to enhance more extraction. 200 g of the paper flower leaves was transferred into a 1000 ml plastic container. 600 ml of the 90 % ethanolic solvent was then added to the container, ensuring the sample was fully immersed. The mixture was tightly covered and left overnight at room temperature to allow complete diffusion of the dye compounds into the solvent phase (Kannan *et al*., 2021; Oyekanmi *et al*., 2023). The mixture was sieved using a clean sieving cloth to separate the filtrate from the plant residue. The residue was rinsed twice with 200 ml of the same solvent to recover any remaining dye extract. The combined filtrates were then poured into a 1 L bottle and labelled appropriately. This procedure was repeated for all the other two solvent systems.

Analysis of the Dye Extracts

Spectroscopic Analyses of the Extract

The UV–Visible absorption spectra of the dye extracts were recorded using a UV–Vis spectrophotometer within the wavelength range of 200 - 800 nm. A small portion of the filtered dye solution was transferred into a quartz cuvette and scanned to determine the maximum absorbance wavelength.

For Fourier transform infrared (FTIR) analysis, the dried sample was mixed with KBr and compressed into pellets, then analyzed in the 4000 - 6500 cm^{-1} range using an FTIR spectrometer.

Preparation of Cotton Fabric for Dyeing

Prior to the dyeing process, the cotton fabric was cut into five equal pieces, each measuring 3 × 3 cm, to ensure uniformity. The samples were scoured by boiling in a mild detergent solution for about 30 minutes, followed by thorough rinsing in distilled water to eliminate residual soap and dirt. The cotton fabrics were then air-dried at room temperature and kept for further analysis.

Mordanting and Dyeing of Cotton Fabric

Simultaneous mordanting and dyeing of cotton fabrics were performed by introducing the mordants directly into the dye bath. Potassium dichromate ($K_2Cr_2O_7$) and copper (II) sulphate ($CuSO_4.\ 5H_2O$) were employed as synthetic mordants, while lime juice was used as a natural mordant. Each prepared 3 × 3 cm scoured cotton fabric piece was immersed in the dye- mordant bath and the process was maintained at 60 ^oC over a water bath for 45 minutes with occasional stirring to ensure uniform dye penetration. After dyeing, the samples were carefully removed, rinsed with distilled water and air-dried in shade. Another set of scoured cotton fabric samples was dyed using the dye extracts without mordants to evaluate the influence of mordanting on colour uptake and fastness properties.

Fastness Properties of Dyed Fabric

The dyed and mordanted cotton fabrics were evaluated for their fastness properties following standard ISO test methods. Washing fastness - ISO 105-C10 (2006), light fastness - ISO 105-B01 (2014), rubbing fastness - ISO 105 –X12 (2013) and perspiration fastness - ISO 105-E04 (2013).

RESULTS AND DISCUSSION

Dye extract using 90 % ethanol gave a reddish-brown (A on Figure 2), this suggests that a mixture leaning toward ethanol enhances extraction of less polar pigment components such as conjugated derivatives as well as phenolic cofactors, flavonoids, and tannins that contribute to deeper tones. High concentration of ethanol in hydroethanolic solvents was reported to outperform pure solvents in yield and color strength by Zakaria *et al*. (2025).

The 10 % ethanol dye extract produced a dark brown colour (B on Figure 2) which reflect that while water is dominant, the small ethanol fraction helps disrupt cell walls and release bound pigments or phenolic matrices more than pure water, but not as effectively as the 90 % ethanol system. This is in line with the submission of Kumar *et al*., (2023).

A B C

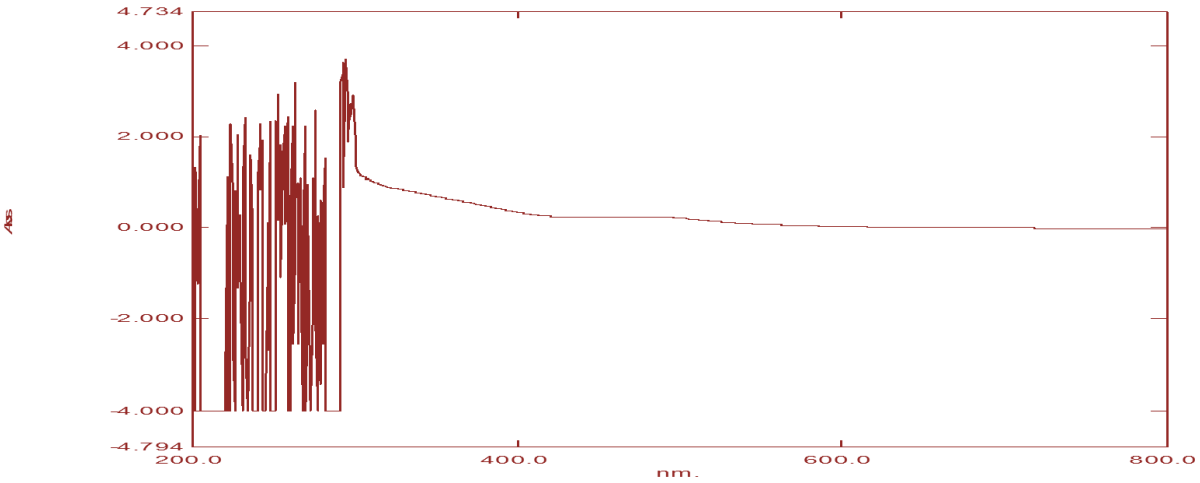
Figure 2: Dye Extracts from *B. glabra* Bracts Using 90 % Ethanol (A), 10 % Ethanol (B) and Aqueous (C)

The colour observed could also be linked to co-extraction of oxidized or degraded phenolics or polymeric products such as tannin oxidation (Ali *et al*., 2023). The orange-pink colour (C on Figure 2) observed with aqueous extract suggests the presence of polar pigment species or precursors in the sample (Pratiwi *et al*., 2025) which can be attributed to the co-extraction of many non-chromophoric polar compounds (sugars, salts, tannins) by the aqueous solvent and this may have diluted the visible colour intensity of the sample which resulted in the colour observed.

The UV - Visible spectrum of the paper flower dye extracts in different solvents are revealed on Figure 3. The 90 % ethanol showed several absorption peaks between 200 and 440 nm. The major absorptions occurred at 202 nm (1.320) and 221 nm (1.119), with additional moderate peaks at 242 nm (0.846) and 317 nm (0.921). These peaks fall within the ultraviolet region, indicating the presence of $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$ electronic transitions typically associated with phenolic compounds, flavonoids, and other conjugated organic molecules. The relatively high absorbance values in the UV region suggest strong UV activity, while the gradual decline in absorbance beyond 350 nm reflects the absence of visible-range chromophores, confirming that the extract is largely colourless to pale. The UV–Vis analysis of the *B. glabra* bract in 90 % ethanolic dye extract revealed strong absorption in the UV region around 202–242 nm.

UV–Visible spectrum of dye extracted with 10 % ethanol revealed several absorption bands between 200 and 401 nm, with notable peaks recorded at 224 nm (2.806), 232 nm (2.458), 247 nm (3.883), and 344 nm (3.706). The strongest absorption occurred at 247 nm, representing the maximum wavelength (λmax) of the mixture. These absorption peaks fall within the ultraviolet region, typical of $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$ electronic transitions associated with C–O and C–H bonds in ethanol (Kumar *et al*., 2023). The high absorbance in the UV region and the rapid decline toward the visible range indicate that the solution is colourless but UV-active.

The UV–Visible spectrum of the aqueous extract showed distinct absorption peaks between 221 and 297 nm, indicating strong UV activity. Major absorption maxima were recorded at 227 nm (2.984), 242.5 nm (2.423), 265 nm (3.162) and 297.5 nm (3.187). These prominent peaks within the ultraviolet region correspond to $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$ electronic transitions typically associated with aromatic rings, carbonyl groups and conjugated double bonds. Such transitions are characteristic of flavonoids, phenolic acids and other polyphenolic compounds known for their strong antioxidant and therapeutic potentials. The high absorbance around 265–297 nm suggests the presence of highly conjugated chromophores, while the decline in absorbance beyond 300 nm indicates minimal absorption in the visible region.



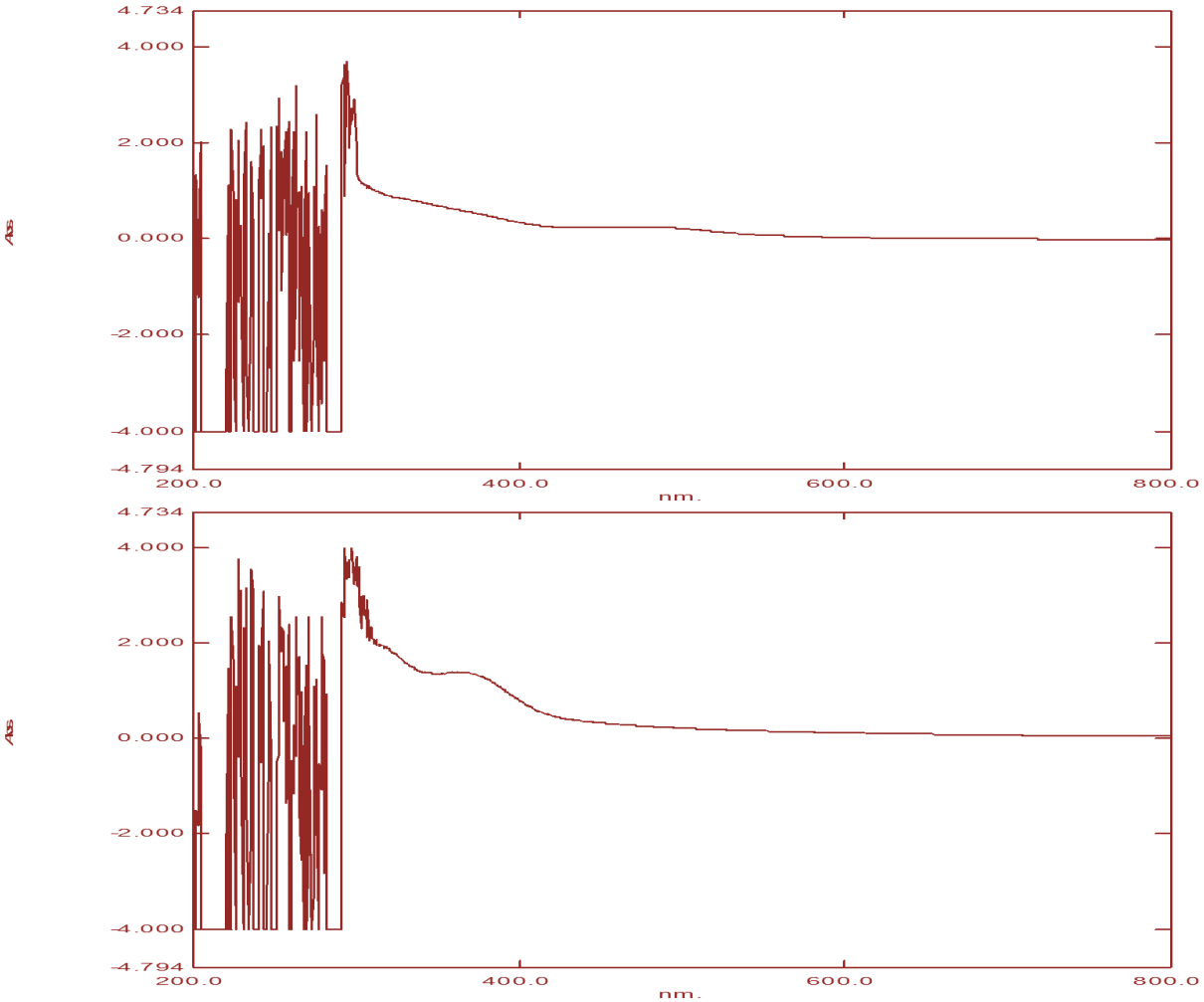


Figure 3: UV Analysis of 90 % ET (Upper). 10 % ET (Middle) and Aqueous (Lower) Dye Extract. (ET – Ethanolic Extract)

The FTIR spectrum of 90 % ethanol dye extract (Figure 4 and Table 1) revealed a broad absorption band at 3304.3 cm^{-1}, corresponding to O–H stretching vibrations within the range of 3200–3400 cm^{-1}. This suggests the presence of hydroxyl groups, likely associated with polymeric compounds such as alcohols or phenols. The presence of hydroxyl groups in the extract contributes to increased polarity and chemical interactions which can further enhance adhesion in various applications (Babawale *et al.,* 2026). A moderate band at 1636.3 cm^{-1} falls within the range of 1620-1680 cm^{-1}, which is attributed to C=C stretching, indicative of alkenyl compounds (unsaturated hydrocarbons). The band observed at 1045.5 cm^{-1} corresponds to the =CH– stretching vibration, confirming the presence of alkyl compounds. Finally, the absorption at 659.7 cm^{-1} represents C–H bending vibrations in the 610–680 cm^{-1} range, which is characteristic of alkyne compounds. The FTIR spectrum revealed characteristic absorption bands associated with –OH stretching (around 3400 cm^{-1}), C=O stretching of quinones (around 1650 cm^{-1}), and C–O–C or C–H bending vibrations (around 1100–1400 cm^{-1}). These functional groups confirm the presence of phenolic, hydroxyl and carbonyl compounds that have been reported as contributor to light absorption and colour development through their conjugated electronic structures (Sisa *et al.,* 2010: Brudzynska *et al*., 2021).

The FTIR spectrum of 10 % ethanol dye extract (Figure 4 and Table 2) displayed a strong peak at 3387.8 cm^{-1}, corresponding to N–H stretching vibrations within the range of 3380–3415 cm^{-1}, indicative of hydroxyl or polymeric compounds. Absorptions at 2974.4 cm^{-1} and 2885.0 cm^{-1} are associated with C–H asymmetric and =CH– stretching vibrations respectively, signifying the presence of alkenyl and alkyl groups. A distinct band at 2927.8 cm^{-1} represents C–H bending characteristic of alkyne compounds. Other bands at 1449.9 cm^{-1} and 1381.0 cm^{-1} correspond to carbonate ion and organic sulphate groups, respectively, suggesting the presence of inorganic ions and hetero-oxy compounds. The dual peaks observed at 1086.5 cm^{-1} and 1045.5 cm^{-1} are assigned to C–N stretching vibrations, typical of primary amines. The band at 879.7 cm^{-1} corresponds to C–O–O– stretching, confirming the presence of peroxide compounds. These observations indicate that 10 % ethanolic dye extract contain a complex matrix of amines, hydroxyl, alkenyl, alkyl, carbonate, sulphate and peroxide groups, suggesting the coexistence of both organic and inorganic constituents.

The FTIR spectrum of aqueous dye extract (Figure 4 and Table 3) exhibited a broad peak at 3304.3 cm^{-1}, this is consistent with O–H stretching vibrations (3200–3570 cm^{-1}) and revealed the presence of hydroxyl groups.

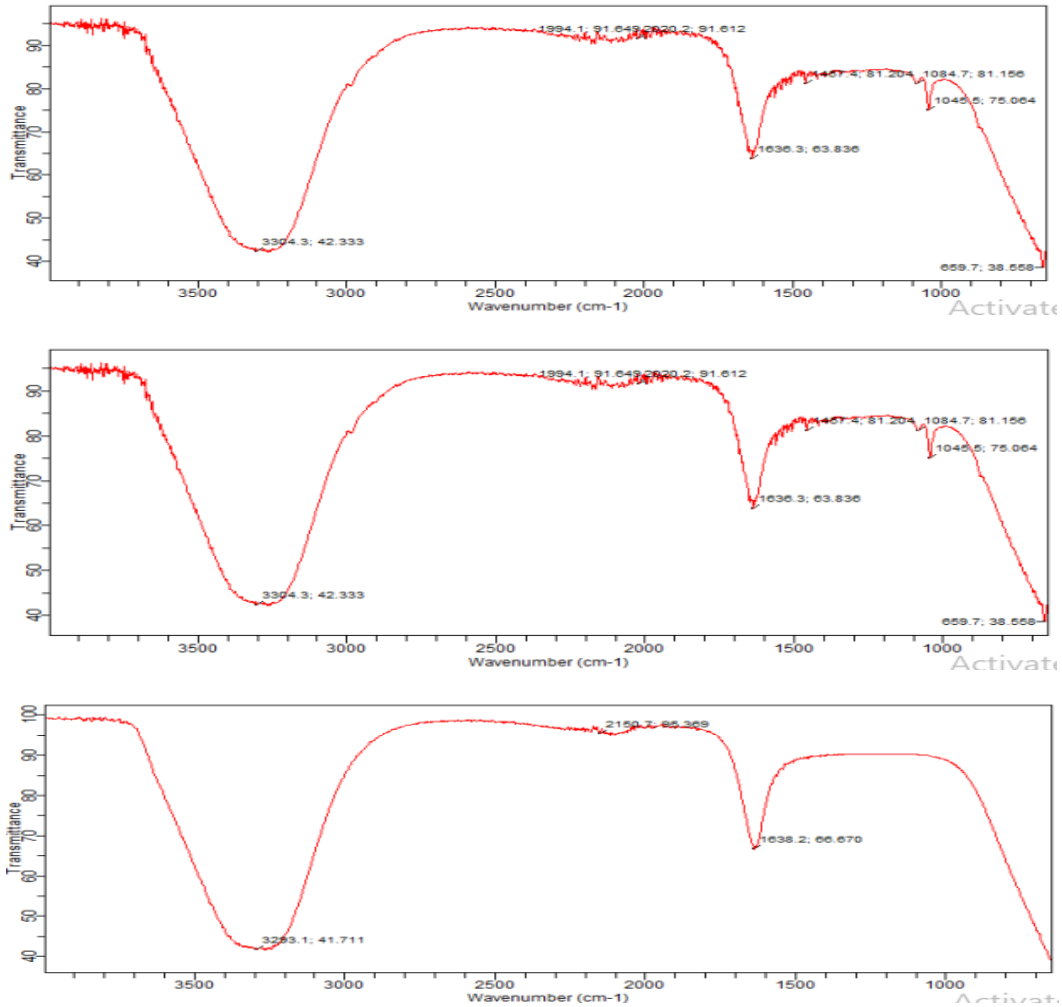


Figure 4: FTIR Results of 90 % ET, (Upper), 10 % (Middle) ET and Aqueous (Lower) Dye Extracts *(Note: ET- Ethanolic extract)*

Table 1: FTIR Spectral Interpretation of Bioactive Constituents of 90 % Ethanolic Dye Extract

Frequency cm^{-1} Test Sample	**Frequency Range cm^{-1} (Reference Article)**	**Functional Group Assignment**	**Phyto-Compounds Identified**
3304.3	3200 -3400	O-H stretching	Hydroxyl group
1636.3	1620 – 1680	-C=C Stretching	Alkenyl Compound
1045.5	1000 – 1055	=CH-	Alkyl Compound
659.7	610–680	C-H Bending	Alkyne Compound

Table 2: FTIR Spectral Interpretation of Bioactive Constituents of 10 % Ethanol Dye Extract

Frequency cm^{-1} Test Sample	**Frequency Range cm^{-1} (Reference Article)**	**Functional Group Assignment**	**Phyto-Compounds Identified**
3387.8	3380 – 3415	N-H stretching	Hydroxyl Group
2974.4	2950 – 2975	C-H Asym. stretching	Alkenyl Compound
2885.0	2880 – 2860	=CH-	Alkyl Compound
2927.8	2915 – 2935	C-H bending	Alkyne Compound
1449.9	1410 – 1490	carbonate ion	Inorganic Ion
1381.0	1370 – 1420	organic Sulphate	Hetero-Oxy
1086.5	1020 – 1090	C-N stretching	Primary Amine
1045.5	1020 – 1090	C-N stretching	Primary Amine
879.7	870 – 890	C-O-O- stretching	Peroxide Compound

Table 3: FTIR Spectral Interpretation of Bioactive Constituents of Aqueous Extract

Frequency cm^{-1} Test Sample	**Frequency Range cm^{-1} (Reference Article)**	**Functional Group Assignment**	**Phyto-Compounds Identified**
3304.3	73200 -3570	O-H stretching	Hydroxyl group
1636.3	2000 – 2260	-C=C Stretching	Acetylenic Compound
1638.2	1620 - 1680	-C= H- Stretching	Alkenyl Compound

A sharp absorption at 1636.3 cm^{-1} corresponds to C≡C stretching (2000–2260 cm^{-1}), suggesting the existence of acetylenic compounds. Another band at 1638.2 cm^{-1} represents C=C stretching, typical of alkenyl compounds. These results confirm that aqueous dye extract is composed mainly of hydroxyl, alkenyl and acetylenic functional groups that reflect a blend of unsaturated and polar organic compounds.

Table 4: Titration Results of the Dye Extracts and Synthetic Indicator

Indicator	Titrant	Titrant HCl (M)	Titre value (cm^3) NaOH (M)	Average	End point colour (cm^3)
Methyl Red	0.1	0.1	28.50 28.50 28.50	28.50	Pink
90 % Ethanol Dye Extract	0.1	0.1	24.80 25.10 25.10	25.00	Pink
10 % Ethanol Dye	0.1	0.1	32.50 32.52 32.48	32.50	Light Pink Extract
Aqueous Extract	0.1	0.1	46.00 46.02 45.98	46.00	Colourless

The titration results (Table 4) provided valuable insights into the potential acid-base indicator characteristics of the extracted dyes from *B. glabra* using different solvent systems. All the dye extracts can be used as indicator for acid-base titration. 90 % ethanolic dye extract produced a titre value that is close to that of the synthetic indicator (28.50 cm^3). These variations in titration readings and colour changes demonstrate that the solvent system significantly influences the concentration of active chromophoric and acidic functional groups within the extracted dye. The 90 % ethanol dye extract with the attendant lower titre value (25.00 cm^3) indicates a greater concentration of proton-donating functional groups such as hydroxyl, phenolic and carboxylic components which align with the observations from FTIR analysis.

In contrast, the 10 % ethanol dye extract exhibited a higher titre value (32.50 cm^3) suggesting lower acidity and weaker buffering potential. The predominance of water in this mixture likely resulted in the extraction of more polar but less acidic compounds, such as sugars, tannins and salts, which dilute the concentration of the active chromophores. The very high titre value observed in the aqueous extract (46.00 cm^3) further indicate minimal presence of acid-base reactive pigments, confirming that water is less efficient in solubilizing the ionizable constituents responsible for its ability to serve as indicator (Rasool *et al*., 2023).

Overall, the ethanol-rich system yielded clearer and sharper colour transitions, indicating that these extracts can serve as eco-friendly natural indicators in acid-base titrations. This observation highlights the solvents role in extracting dye component that are capable of undergoing reversible protonation and deprotonation (Kumar *et al*., 2023). These findings corroborate earlier research indicating that plant-derived dyes, especially those rich in flavonoids and phenolics are suitable for analytical and educational applications (Yusuf *et al*., 2017 and Zakaria *et al*., 2025). The results obtained underscore the potential of the dye extracts from plant sources as non-toxic alternatives to synthetic acid-base indicators (Rasool *et al*., 2023: Olawale *et al*., 2023).

Dyeing Properties

A comprehensive visual colour checks was carried out on dyed cotton fabrics. The colour produced by the mordanted and unmordanted cotton fabrics were presents on Figure 5..

Colour Characteristics of the Dyed Cotton Fabric

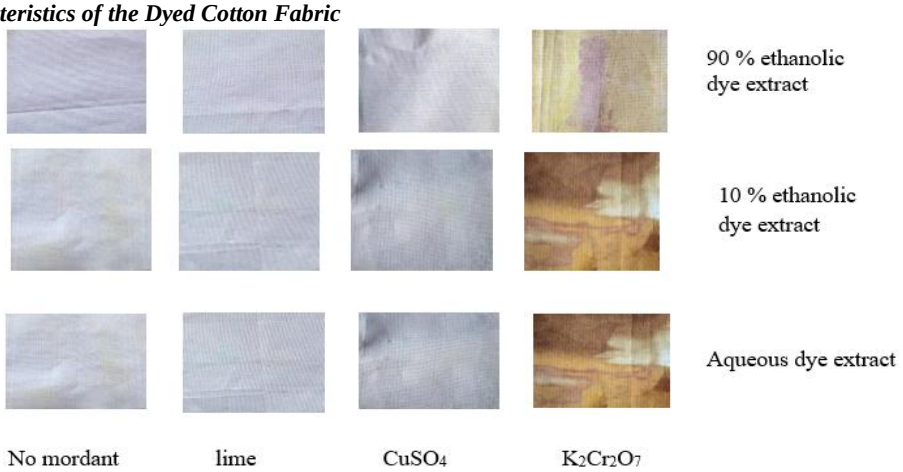


Figure 5: Different Colours Produced by the Mordanted and Unmordanted Cotton Fabrics

Different colours (Figure 5) were observed on cotton fabrics with the use of mordants. Mordants interact with both the dye molecules and the cotton fibre altering how light is absorbed and reflected. The mordants used (lime juice, $CuSO_4.5H_2O$ and $K_2Cr_2O_7$) influenced the colour producing part of the dye (chromophore) resulting in varieties of colours because cotton is mainly cellulose and has limited natural affinity for natural dyes.

Fastness Properties of the Dyed Fabric

Table 5: Fastness Properties of Cotton Fabric Dyed with 90 % Ethanol Dye Extract

Treatments	Wash	Light		Rubbing		Ironing		Perspiration	
		Sun	Arc	Wet	Dry	Wet	Dry	Acid	Alkali
No Mordants	2/3	2	2/3	2/3	2/3	2	2	2	2
$CuSO_4$	3/4	4/5	4	¾	3	3	2/3	3	3
Lime	3	4	¾	4	3	3	¾	3	3
$K_2Cr_2O_7$	3	4	¾	¾	3	3	3	3	3

Table 6: Fastness Properties of Cotton Fabric Dyed with 10 % Ethanol Dye Extract

Treatments	Wash	Light		Rubbing		Ironing		Perspiration	
		Sun	Arc	Wet	Dry	Wet	Dry	Acid	Alkali
No Mordants	2	2	2	2	2	2	3	2	2
$CuSO_4$	¾	4	¾	3	3	2	2	3	3
Lime	3	4	4	¾	3	2	3	3	3
$K_2Cr_2O_7$	3	4	4	3	3	2/3	3	3	3

Table 7: Fastness Properties of Cotton Fabric Dyed with Aqueous Dye Extract

Treatments	Wash	Light		Rubbing		Ironing		Perspiration	
		Sun	Arc	Wet	Dry	Wet	Dry	Acid	Alkali
No Mordants	2	2	2	2	2	2	2/3	2	1
$CuSO_4$	2	4	¾	3	2/3	3	3	2	2
Lime	2	4	4	3	3	3	¾	2/3	3
$K_2Cr_2O_7$	3	¾	4	3	3	3	3	3	2

Grading for washing, rubbing, ironing and perspiration fastness = 1 - Poor, 2 – fair, 3 - moderate, 4 - good, 5 – excellent
Grading for light fastness =1 – Very poor, 2 – poor, 3 – fair, 4 – moderate, 5 – good, 6 – very good, 7 – excellent, 8 - outstanding

The results presented in Tables 5-7 show the fastness properties of cotton fabrics dyed using the different extractants, with and without mordants. The mordants used include copper (II) sulphate ($CuSO_4.5H_2O$), potassium dichromate ($K_2Cr_2O_7$). The fastness properties evaluated include wash, light, rubbing, ironing and perspiration.

Effect of Different Mordants on Fastness Properties

The results clearly indicate that mordanting significantly improves the fastness properties of dyed cotton fabrics compared to unmordanted samples. Fabrics dyed without mordants consistently exhibited poor fastness ratings, generally around grade 2 (fair), indicating weak dye-fibre interaction. This suggests that in the absence of mordants, the dye molecules are only loosely held on the fiber surface, making them susceptible to removal during washing, rubbing, perspiration and exposure to light. In contrast, mordanted fabrics showed marked improvements across all fastness parameters. This enhancement can be attributed to the formation of stable complexes between the dye molecules, mordants, and the cellulose structure of cotton, thereby improving dye fixation and resistance to external conditions.

Copper (II) sulphate ($CuSO_4.5H_2O$) also improved fastness properties significantly, especially in light fastness where values reached as high as grade 4–5 (good/very good) in some cases. However, its performance in alkaline perspiration was slightly lower compared to lime juice and potassium dichromate, indicating a sort of sensitivity to alkaline conditions. Fabrics treated with potassium dichromate ($K_2Cr_2O_7$) exhibited high ratings in light fastness (up to grade 4). This suggests the formation of strong and stable dye–metal complexes, which enhance resistance to photodegradation and mechanical action. Similarly, lime juice showed moderate overall performance in all the fastness properties determined. The effectiveness of lime may be linked to its ability to modify the pH of the dye bath and fiber surface, thereby facilitating a moderate dye uptake and fixation. Unmordanted dyed cotton fabrics consistently showed poor fastness properties, indicating low dye-fiber affinity without mordants.

Influence of Extraction Medium on Fastness Properties

The effect of the extraction medium (ethanol vs aqueous) on fastness properties was also evident. Fabrics dyed with ethanolic dye extracts (Tables 5 and 6) generally exhibited better fastness properties compared to those dyed with aqueous extract (Table 7). Notably from Table 5, the 90 % ethanolic dye extract (highly concentrated organic medium) showed higher ratings in light, rubbing and washing fastness and this can be attributed to the enhanced solubility and extraction of active dye components (semi-polar chromophores and phenolic cofactors). These compounds can engage in hydrogen bonding and form stronger interactions with cotton, improving dye fixation and resistance to fastness conditions. These observations are constitent with the findings of Rasool *et al*., (2023) and Zakaria *et al*., (2025), suggesting that hydroethanolic solvents can yield richer and more stable extracts for textile dyeing when extraction conditions are optimized.

The higher water fraction in 10 % ethanolic dye extract (Table 6) relative to 90 % ethanolic dye extract may likely caused extraction of more hydrophilic and less substantive components, some of which may be loosely bound to fiber and therefore more prone to leaching during wash and perspiration tests.

A high concentration of ethanol content in hydroethanolic solvent has been reported to gives better overall dye fixation than high-water systems (Ali *et al*., 2023). The improvement in fastness properties using the mordants was in line with the findings of Mohammed & Abd-Almoaty, (2024) that both chemical and natural mordants improve the fixation of dye on fabric. Aqueous dye extract (Table 7) showed relatively lower fastness ratings, particularly in alkali perspiration, although mordanting still provided significant improvements.

Summarily, the fastness properties dyed cotton fabrics with of *B. glabra* bract dyes are significantly influenced by both extraction medium in the following order 90 % ethanol > 10 % ethanol > aqueous) and mordants ($CuSO_4.5H_2O$ > $K_2Cr_2O_7$ > lime juice > unmordanted).

CONCLUSION

This research demonstrated that *B. glabra* can serve as an effective source of natural dye for textile applications. Dyes extracted from *B. glabra* bracts exhibited varying fastness properties depending on both the extraction medium and the mordants applied. Mordants play a critical role in forming coordination complexes between the dye molecules and cotton fibers. *B. glabra* bracts extract can be use as alternative to synthetic indicators in laboratory titrimetric analysis.

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