



Extraction of natural colorant from *Bougainvillea Glabra* bracts and its application as coloring agent for natural fibers

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Abstract

This study explores the potential of *Bougainvillea* as a natural colorant for cotton and wool fabrics. The unique aspect of this research lies in the extraction of *Bougainvillea* in three different media: distilled water, 5% acetic acid aqueous, and 50:50 v/v ethanol-water solutions. The extracted solutions and the extracted floral bracts were then characterized by UV-Vis analysis and Fourier transform infrared spectroscopy. The fabrics were treated in these extracted solutions, with the aid of copper sulfate as a mordant agent. The color parameter analysis revealed acceptable color differences for the fabrics after coloring with *Bougainvillea*-extracted solutions. The color difference values are 9.167, 11.512, and 11.792 for the cotton fabrics dyed in acetic acid, ethanol, and water-extracted *Bougainvillea* solutions, respectively. For wool fabrics, the color difference values are in the range of 33.188–42.032. The color difference values increased for cotton and wool fabrics after coloring in *Bougainvillea*-extracted solutions with the addition of mordant. The color fastness against to water, washing, and rubbing were also experimented. The fastness degrees are found to be in the range of 4–4/5 in general. Further, the results were improved by one and/or half degrees with the help of mordant. In conclusion, this study not only demonstrates the potential of *Bougainvillea* as a natural coloring agent for textiles but also provides promising results in terms of eco-friendly and sustainable production.

Keywords *Bougainvillea* · Dye extraction · Bracts · Natural

1 Introduction

Color is critical in determining a consumer's acceptance of a product. Many types of chemicals and dyestuffs are utilized to increase their attractiveness, creating durable and vivid colors on textile materials. The global textile industry heavily relies on synthetic dyes, with approximately 10,000 synthetic dyes available commercially. The annual global consumption of dyes in the textile industry is estimated to be over 1 million tons, with 20–30% of these dyes being lost in wastewater during production. These synthetic dyes often contain toxic and non-biodegradable compounds, contributing to severe environmental and health concerns, including

carcinogenicity and water pollution [1]. Non-biodegradable structures and carcinogens in nature cause serious threats to the ecology, atmosphere, and human health. Due to the toxic effluents of textiles, artificial dyestuffs, and water-consuming processes have become the first responsible for global environmental pollution (Rasool et al., 2022). Considering all the adverse effects of dyestuffs and auxiliary agents, the researchers and producers have explored eco-friendly alternatives to synthetic dyestuffs. Due to the increasing regulatory restrictions on synthetic dyes—such as the European Union's REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) regulations—the textile industry is actively seeking eco-friendly alternatives. As a result, the demand for natural dyes is rising, with the global market for natural colorants expected to reach \$5.5 billion by 2030, growing at a CAGR of 12.4% [2].

Bio colorants are gaining widespread attraction in fields such as textile, agriculture, food, cosmetics, and leather processing as suitable alternatives to synthetic ones. Natural bio colorants present biodegradable, antioxidant, antibacterial, antifungal, non-hazardous, and UV-protective

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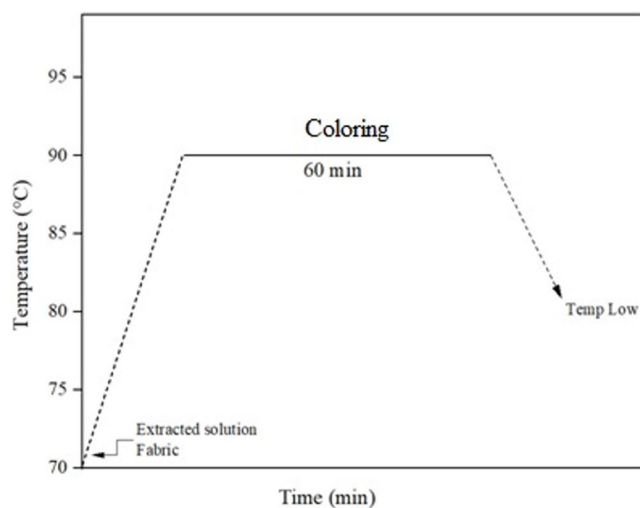
properties according to the origin of the extracted plant [1]. Natural colorants are in demand globally due to the harmful effects of chemical dyeing on human health and the environment [3]. There are many natural resources are used and further explored to produce natural colorants [4–10]. These include agro wastes, food waste, non-valuable plants, and flower plants [11–13]. The natural colorants can be obtained from different parts of the plants, such as leaves, bark, fruits, flowers, and roots [14]. Several methods can extract the colorants from natural resources. The effectiveness of the processes is affected by the extraction process parameters such as process time, temperature, pH level, type of solutions, and material to liquor [15]. Extraction and purification are critical steps in producing natural colors. However, traditional methods often result in low yields, high consumption of solvents, time, labor, and energy, and may even degrade the color molecules. Modern extraction techniques, such as solvent, aqueous, enzymatic, and fermentation methods, and innovations like microwave, ultrasonic, supercritical fluid, and acid/alkaline extractions, are now being utilized to improve dye yield. The development of proper characterization and certification protocols for natural dyes could enhance their availability and quality [16, 17]. The extraction processes of natural colorants do not create any serious ecological problems. This may be due to the extraction processes in which water and lower concentrations of alcohols are utilized mainly [18]. Despite significant progress in overcoming the challenges associated with these colorants, their global industrial use remains limited. Issues such as inadequate knowledge among dyers, the high cost of natural dyes due to raw material scarcity, and the need for suitable extraction and application methods contribute to this slow adoption. The paper highlights the importance of educating society on the benefits of natural-dyed textiles and promoting cultivating colorant-bearing plants to meet industrial demands [19].

Bougainvillea Glabra (Bougainvillea) is an ornamental plant in most areas with a warm climate belonging to the Nyctaginaceae family [20, 21]. Bougainvillea is very popular with its bracts in shiny purple, magenta, pink, and green shiny colors. The natural colorant of Bougainvillea glabra bracts are widely reported to contain betalain-type pigments, predominantly betacyanins, which are responsible for their characteristic red–purple coloration [22]. Bougainvillea is also explored for its usability as a sensitizer for dye-sensitized solar cells [23], indicator materials [24], biopesticides [25]. Bougainvillea is also investigated for its antimicrobial [26], anticancer [27], antioxidant [28], antibacterial [29], antinociceptive and anti-inflammatory activities [30]. Some researches focus on the extraction of dye pigments from Bougainvillea glabra [18, 21, 22, 31–35]. However, there is limited

research on coloring textile fibers with natural colorants from Bougainvillea. Rasool et al. (2023) [36] determined that an aqueous medium is better for extracting colorant from Bougainvillea glabra at presenting maximum color strength for cotton and silk fabrics. Nazir et al. (2024) [37] extracted chromophores from different flowers, including Bougainvillea glabra. Cotton fibers were colored with the extracted chromophores with the help of natural and synthetic mordants. It is revealed that the cotton fabric colored with the chromophores of Bougainvillea glabra exhibited better washing and crocking fastness results. Nguyen et al. (2024) [38] stated that colored cotton fabrics with extracts from Bougainvillea glabra exhibited higher color fastness in the presence of mordants, but profound color change also came into being. Although several studies have investigated the extraction of colorants from Bougainvillea glabra and their application on textile substrates, existing research is primarily focused on aqueous extraction media and cellulose-based fibers such as cotton and silk. In particular, Rasool et al. (2023) demonstrated the feasibility of using aqueous Bougainvillea extracts for cotton and silk dyeing. However, systematic investigations comparing different extraction media (water, acidic, and hydroalcoholic systems) and their effects on both cellulosic and protein-based fibers—especially wool—remain scarce. Moreover, the combined evaluation of extraction efficiency, fiber–dye interactions, colorimetric properties, and fastness performance under identical processing conditions has not yet been comprehensively addressed. Therefore, the present study aims to fill this gap by. This study focused on extracting pigment from Bougainvillea bracts and coloring wool and cotton fabrics in the extracted Bougainvillea solution. This current research aims to extract colorant from bracts of Bougainvillea glabra that is efficient in coloring fibers and leads to significant color differences. Three different mediums, such as distilled water, 5% v/v aqueous acetic acid solution, and 50:50 v/v ethanol-distilled water mixtures, were utilized for this purpose. The efficiency of the extraction was explored by UV-Vis measurement of the extracted solutions and Fourier transform infrared (FTIR) spectroscopic analysis of the extracted Bougainvillea residue. Coloring processes of the fabrics were performed with/without copper sulfate as a mordant in the extracted solutions. The mordant is utilized to study whether it may enhance the color intensity and the fastness of colored fabrics by at least half a degree. Accordingly, CIE-Lab color parameters and fastness to water, washing, and rubbing were measured to evaluate the natural colorant from Bougainvillea.

Table 1 The parameters of the colorant extraction from *Bougainvillea*

Extraction Method	Bracts concentration (%)	Extraction Parameters		
		Time (min)	Temperature (°C)	Concentration
Acetic acid (A)	4	60	80	5%
Ethanol-distilled water (E)	4	240	40	50:50
Distilled Water (W)	4	120	80	100%

**Fig. 1** The graph for colouring procedure

2 Experimental

2.1 Materials

Fresh floral bracts were collected from *Bougainvillea* plant grown in Kaş/Antalya, Turkey in February. Ethanol, acetic acid and also copper sulphate as mordant (M) were purchased from Merck (Germany). 100% cotton fabric (225 g/m²) (Co) and 100% wool fabric (150 g/m²) (Wo) were used for coloring experiments.

2.2 Plant extraction

The collected fresh floral bracts of *Bougainvillea* were air-dried and then ground before extraction. Three different methods were used for the colorant extraction from *Bougainvillea*. Extraction process parameters are given in Table 1. After extraction processes, the residue of the ground bracts was removed by using filter paper.

2.3 Coloring procedure

The coloring processes of cotton and wool fabrics were carried out using the colorant extracted solutions from *Bougainvillea*. The colorant extraction and colouring of the fabrics

were conducted in one single bath consecutively. The process started after adding the fabrics into the extracted solutions at 70 °C, and then the temperature increased to 90 °C and kept stable for 60 min. Then, the temperature decreased, and all the colored samples were rinsed with distilled water, firstly at 40 °C and then at ambient temperature. The fabric samples colored in an aqueous acetic acid medium were neutralized with NaOH treatment. In a novel approach, we examined the effect of mordant by utilizing copper sulfate at 2 w/v % concentration while coloring. Copper sulfate was selected as the mordant in this study due to its ability to enhance color depth, improve dye fixation, and increase fastness properties in natural colorant applications. It facilitates better binding between dye molecules and textile fibers by forming coordination complexes, particularly in protein- and cellulose-based textiles. Both uncolored (R) and colored samples were analyzed for comparison. The coloring procedure was conducted, as illustrated in Fig. 1. The material to liquid ratio is kept as 1:40.

2.4 Fourier transform infrared spectroscopy (FTIR) analysis

FTIR analyses of untreated and *Bougainvillea* extracted residues were performed using the Perkin Elmer Spectrum/BX instrument. The spectra were analyzed in the wave number range of 650–4000 cm⁻¹ with a resolution of 2 cm⁻¹.

2.5 Color analysis

Color strength values of colored cotton and wool fabrics were measured with a Minolta Spectrophotometer CM-3600d. All fabrics were conditioned at 20 °C and 65% relative humidity before analysis. Colour strength values were determined using the Kubelka-Munk formula (Eq. 1). The K/S and ΔE values obtained as a result of the analysis were calculated according to the following calculations.

$$K/S = (1 - R)^2 / 2R \quad (1)$$

Where, K is the scattering coefficient, S is the absorption coefficient and R is the reflectance. Colour coordinates in the CIE-LAB system were used in color evaluations. In the CIE-LAB system, Δa* is the difference between red and green, Δb* is the difference between yellow and blue, and ΔL* is the difference between light and dark. The colour difference is expressed as ΔE* and is calculated as follows: (Eq. 2)

$$\Delta E^* = ((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)^{1/2} \quad (2)$$

2.6 UV-VIS analysis

The prepared solutions were scanned between 300 and 800 nm wavelengths using a Perkin Elmer UV-Vis Spectrophotometer and the characteristic peaks were determined. UV-Vis spectrophotometry is used to measure how dyes absorb light of different wavelengths. Each dye characteristically absorbs certain wavelengths of light. These absorption spectra provide information about the chemical structure and color properties of the dyes. Absorption spectra can be used to determine the concentration and purity of dyes in solution. UV-Vis analysis was used for comparative assessment rather than definitive pigment identification.

2.7 Color fastness tests

Fastness to washing, fastness to water, and fastness to dry and wet rubbing of the colored fabrics were tested according to ISO 105-C06 A1S, ISO 105-E01, and ISO 105-X12, respectively. SDL Atlas Linitest, SDL Atlas M231/PR1 Perspirometer testers, and SDL Atlas rubbing fastness tester were used for fastness to washing, fastness to water, and fastness to rubbing tests, respectively. Fastness tests were carried out using SDC multi-fibre tape fabric. Also, ECE non-phosphate detergent was used in the washing fastness tests.

2.8 Particle size determination

The particle-size measurements of ground *Bougainvillea* bracts before and extraction processes were carried out using an Olympus BX43 optical microscope at 4x magnification.

3 Results and discussion

3.1 FTIR analysis

FTIR analysis identifies functional groups of the untreated *Bougainvillea* bracts and *Bougainvillea* residues after extraction processes in different solutions. FTIR spectra of the *Bougainvillea* show a broad absorption peak at 3299 cm^{-1} , indicating (O-H) bond in stretching vibration mode [32, 39] (Fig. 2). The absorption peaks at 2920 and 2846 cm^{-1} can correspond to related asymmetric and symmetric methyl and methylene stretching groups [40, 41]. The peak at 1733 cm^{-1} shows the presence of a carbonyl group in stretching mode [42]. The peaks at 1517, 1464, 1367, 1318, and 1248 cm^{-1} can be assigned to C = C skeletal vibration of the benzene ring, C-H and C-O-C deformations and stretching vibrations of different groups in carbohydrates [43]. The presence of a C-O bond can be confirmed by the

peaks observable at 1151 and 1101 cm^{-1} absorption bands. The small peak at 719 cm^{-1} can indicate the amine group (N-H), which decreased after all extraction processes like other functional groups. The existence of amine and carbonyl groups can show the betaxanthins group of betalain type pigments, which plays a role in coloring cotton and wool. Betalains which color plants such as *Bougainvillea* bracts are classified into two groups having different conjugation partners, betacyanins and betaxanthins. Amino acids or amines are conjugated to betaxanthins which gives the color changing from red to violet to *Bougainvillea* [44–46].

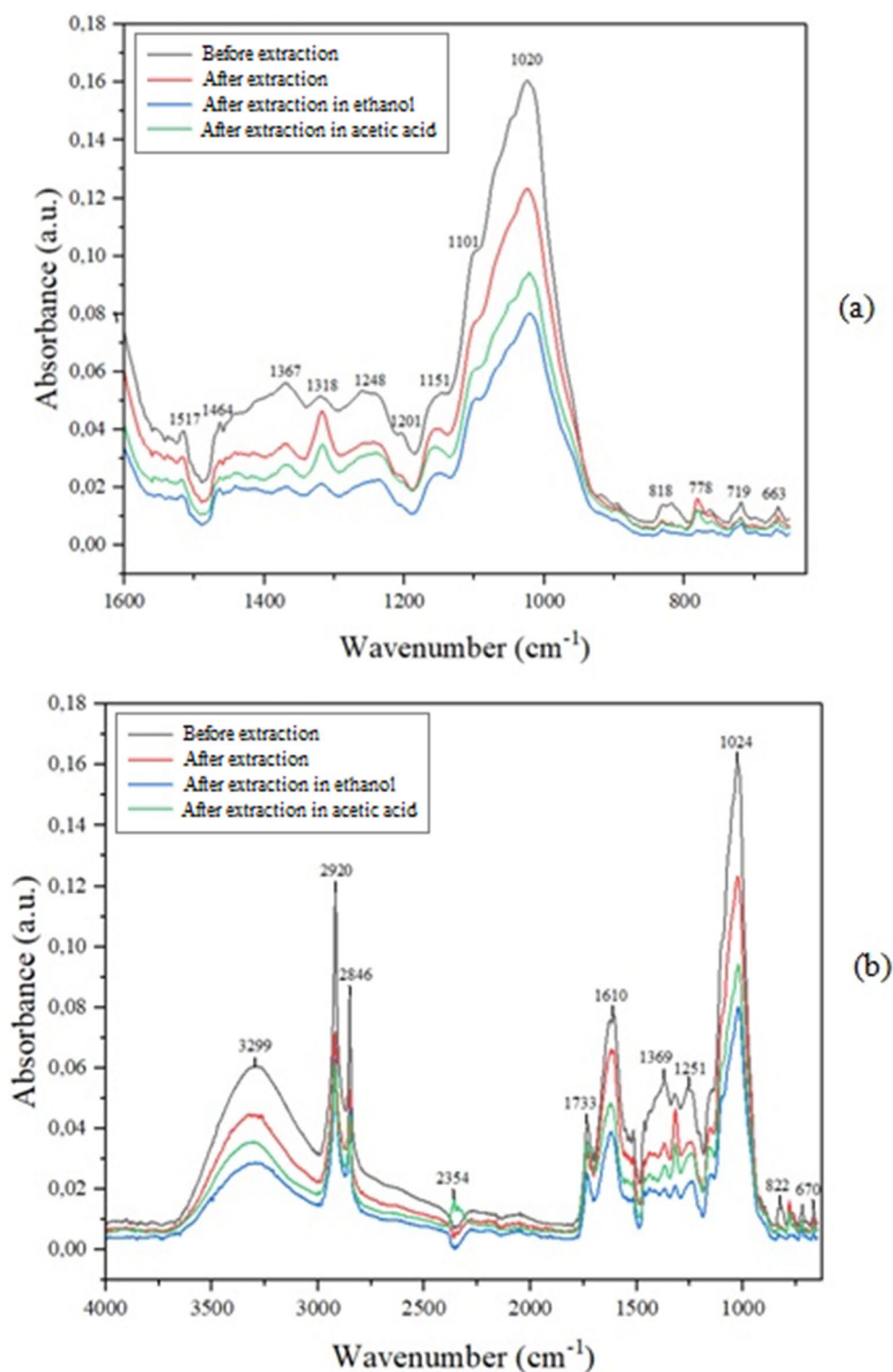
After all extraction processes, the intensities of the absorption peaks of the *Bougainvillea* residues decreased, which may confirm the transfer of the functional groups to the extracted solutions in which the fabrics are colored.

3.2 Color parameters

The color parameters of the cotton and wool fabrics are listed in Tables 2 and 3, respectively. Total color difference (ΔE) values were calculated by comparing with the uncolored fabric. For cotton fabrics, the K/S value was measured as 0.0803, 0.4141, 0.7202, and 1.0563 for CoR, CoA, CoE, and CoW, respectively. These values represent the ability of *Bougainvillea* colorant to penetrate the fabric. Using mordant increased K/S values by 127, 86, and 87% for CoAM, CoEM, and CoWM, respectively. This can indicate that the mordant increases the absorption capacity of the extracted *Bougainvillea* colorant by ensuring better binding to the fibers [47, 48]. Regarding ΔE values, significant color changes were observed in all colored fabrics compared to uncolored cotton fabric. It is possible to state that all of the extracted *Bougainvillea* solutions efficiently colored the cotton fabric. Further, ΔE values visibly increased with the contribution of mordant. This shows that the mordant contributes to obtaining more vibrant and distinct colors by increasing the color stability of the extracted *Bougainvillea* colorant. As a result, the effects of different extraction methods and mordants on the coloring properties of cotton fabrics are determined. The use of mordant increases the absorption ability of the coloring agent, allowing it to penetrate the fabric better and making color changes more noticeable. These data show how process options and mordant can be used strategically in textile dyeing.

Similar to the cotton fabrics, K/S and ΔE data of the uncolored wool fabrics increased with coloring in the extracted *Bougainvillea* mediums (Table 3). Therefore, it is possible to express that *Bougainvillea* is effective in coloring wool fabric. Considering the use of mordant, WoAM (K/S value 22.484, ΔE value 81.391) has the highest absorption capacity and a significant color difference, which can indicate that the mordant increases the binding

Fig. 2 FTIR spectra of the *Bougainvillea* floral bracts residue after extraction processes (a) 4000–650 cm^{-1} (b) 1600–650 cm^{-1}



of the colorant to the fiber and provides an intense color change, respectively [6]. For WoEM (K/S value 7.7144, ΔE value 4.591), the absorption level is lower than the others, but the color difference is relatively small; less color change is observed compared with the initial color. Although the WoEM sample exhibited a moderate

K/S value (7.7144), its corresponding ΔE value (4.591) remained relatively low. This apparent discrepancy can be attributed to limited variations in L^* , a^* , and b^* coordinates relative to the undyed reference fabric. Since ΔE is a cumulative parameter reflecting changes across all three CIE-Lab axes, higher color strength values do not

Table 2 Color parameters of the uncolored and colored cotton fabrics

Fabric Code	R%	K/S	L*	a*	b*	C*	H*	ΔE	Image
CoR	67.153	0.0803	87.972	-0.317	1.333	1.370	13.388	-	
CoA	41.426	0.4141	84.025	1.216	9.464	9.542	82.678	9.167	
CoE	32.053	0.7202	81.157	2.908	10.033	10.446	73.835	11.512	
CoW	25.953	1.0563	81.387	2.834	10.594	10.966	75.023	11.792	
CoAM	27.603	0.9494	76.430	0.241	20.409	20.410	89.324	22.303	
CoEM	22.440	1.3404	72.872	-0.622	22.058	22.067	1.616	25.644	
CoWM	17.323	1.9729	70.805	0.328	27.872	27.874	89.326	31.614	

R%: Reflectance; K/S: Color strength; ΔE : Color difference; L: Lightness; a*: Green to red axis, b*:Blue to yellow, C*:Chroma; H*: Hue angle.

**The uncolored samples were taken as *standart sample* in color analysis.

necessarily translate into proportionally higher perceptible color differences. In this case, the ethanol-based extraction with mordant appears to enhance dye uptake without inducing a pronounced shift in overall color coordinates, resulting in a modest ΔE value. WoWM (K/S value 20.563, ΔE value 87.229) has the highest absorption capacity and color difference. This shows that using mordant in combination with water allows the colorant to bind more strongly to the fabric and produces noticeable color changes. These results reveal the effects of different extraction methods

and the use of mordant on colored wool fabric. Absorption capacity and color change vary significantly depending on extraction methods and the presence of mordant.

The fabrics colored with *Bougainvillea* extracts showed significant color differences compared to uncolored samples. Cotton and wool fabrics displayed different absorption levels, with wool showing higher dye uptake. The use of copper sulfate as a mordant enhanced the depth of color and made the shades more vibrant. The K/S values increased by 127% (acetic acid), 86% (ethanol), and 87% (water) when

Table 3 Color parameters of the uncolored and colored wool fabrics

Fabric Code	R%	K/S	L*	a*	b*	C*	H*	ΔE	Image
WoR	40.373	0.4403	84.089	-1.395	9.042	9.149	8.768	-	
WoA	4.0767	11.285	46.520	4.593	26.914	27.303	80.315	42.032	
WoE	6.5400	6.6780	61.828	9.495	46.639	47.596	78.492	45.030	
WoW	4.8467	9.3406	62.368	8.508	32.098	33.207	75.154	33.188	
WoAM	2.1300	22.484	37.356	4.390	29.000	29.331	81.391	51.145	
WoEM	5.7567	7.7144	54.002	-1.882	23.439	23.514	4.591	33.358	
WoWM	2.3200	20.563	45.723	1.484	30.664	30.700	87.229	44.133	

R%: Reflectance; K/S: Color strength; ΔE: Color difference; L: Lightness; a*: Green to red axis, b*:Blue to yellow, C*:Chroma; H*: Hue angle.

**The uncolored samples were taken as *standart sample* in color analysis.

mordant was applied, confirming better colorant absorption for cotton fabrics. The mordanted samples had a higher color intensity and richer shades, with the best results observed in water-based extractions for wool fabrics. These findings suggest that mordanting significantly improves dye uptake and color retention.

Wool fabrics generally have a high absorption capacity, indicating that the dye penetrates deeply into the fabric

fibers. Regarding color change, both wool and cotton fabrics showed noticeable color changes after treatment. The effect of mordant increased the binding of the colorant to the wool and cotton fabrics. However, while this effect was observed more clearly on the absorption capacity in wool fabrics, it had a more pronounced effect on color change in cotton fabrics. To sum up, wool fabrics stand out in absorption capacity and deeper penetration of the colorant

into the fabric; the effect of the mordant strengthens these properties. Cotton fabrics generally have a lower absorption capacity, and using mordant has a more pronounced effect on color change. Finally, *Bougainvillea glabra* is found to be a potential natural source for coloring commonly utilized natural fibers such as cotton and wool in textile applications.

In order to realize the effect of mordant on the color change of extracted *Bougainvillea*-colored wool and cotton fabrics, ΔE values were calculated using the CIE-Lab system (Table 4). Considering the values, the utilization of mordant in the coloring process leads to significant color change compared to the initial color for both cotton and wool fabrics. Additionally, color difference alters with the extraction methods. To analyze in detail, the effect of mordant on color change differs between wool and cotton fabrics. For instance, ΔE of WoEM (26.999) is higher than that of CoWM (20.415). This can indicate that using mordant for wool fabrics further increases the color change. However, ΔE values of the cotton fabrics (range 13.358–20.415) are lower than those of the wool fabrics (range 9.401–26.999). These results may reveal that fabrics with different fiber types respond differently to the mordant effect, which is an important factor in selecting processes in textile dyeing.

3.3 UV-VIS Analysis

The absorption values of *Bougainvillea* extracted solutions were measured with a UV-Vis spectrophotometer. The data reveals the light absorption capacity of the solutions and, accordingly, their color intensities. Water-acetic acid extracted solution has the highest absorption value at a wavelength of 591.76 nm, indicating that this solution has the most intense color. The UV-Vis absorption spectra of the *Bougainvillea*-extracted solutions were recorded in the wavelength range of 300–800 nm to evaluate their light absorption behavior. The water-acetic acid extract exhibited the highest absorbance

intensity, with a maximum absorbance ($\lambda_{\max}$) observed at approximately 592 nm, indicating a higher concentration of chromophoric compounds in the solution. The ethanol–water extract showed a $\lambda_{\max}$ around 579 nm, while the aqueous extract exhibited a broader and slightly red-shifted absorption maximum at approximately 610 nm.

It should be noted that UV-Vis absorption maxima provide information on the electronic transitions and relative concentration of dye molecules in solution; however, they do not directly determine the perceived color of dyed textiles. The final color appearance of fabrics depends on the overall spectral profile of the dye–fiber system, including absorption bandwidth, scattering effects, and fiber–dye interactions, rather than solely on $\lambda_{\max}$ positions. Therefore, UV-Vis results were used to comparatively assess extraction efficiency rather than to directly assign color tones.

3.4 Textile fastness tests

The fastness to washing, water and rubbing results were compared on a gray scale from 1 to 5 (1 bad, 2 quite good, 3 good, 4 very good, and 5 excellent). The multifiber fabric that is used in fastness tests consists of seven types of fabrics: wool (WO), Polyacrylonitrile (PAN), Polyethylene terephthalate (PET), Polyamide 6.6 (PA 6.6), cotton (CO), and acetate (CA). The fastness data of the colored fabrics are listed in Table 5. It is observable from Table 5 that the fastness results of cotton and wool fabrics are generally between 4/5 and 5. Generally, the fabrics colored in water-extracted *Bougainvillea* solution present the best fastness result. Moreover, incorporating the mordant agent in the coloring step enhanced the fastness data by half or one degree. Thus, adding mordant increased color durability by binding the dye more firmly to the fabric surface [6, 49]. Applying a reproducible coloring method with reliable color fastness for natural colorants/pigments is important for the textile industry and is implemented at an industrial scale [23].

The color fastness properties of *Bougainvillea*-colored fabrics were evaluated according to ISO 105 standards. The results demonstrated good to excellent fastness ratings, with values predominantly ranging from 4/5 to 5. Mordanting significantly enhanced fastness properties, increasing durability against washing, water exposure, and rubbing. The observed values align with industry standards for natural dyes, confirming *Bougainvillea*'s potential as a sustainable textile colorant.

Table 4 ΔE Comparison of fabrics colored with mordant-free and mordant solutions

Fabric Code	ΔE	Fabric Code	ΔE
CoA*	13.358	WoA*	9.401
CoAM		WoAM	
CoE*	15.023	WoE*	26.999
CoEM		WoEM	
CoW*	20.415	WoW*	18.123
CoWM		WoWM	

* The uncolored samples were taken as *standart sample* in color analysis

3.5 Particle size

An illustration of the effect of the extraction methods on the particle size of *Bougainvillea glabra* is shown in Fig. 3. A drastic decrease in dye output is registered for a particle size range of *Bougainvillea* after all extraction processes. The particle size data of the *Bougainvillea* after water and water-ethanol extraction are similar. However, the acetic acid extraction decreased the particle size of *Bougainvillea* from 601.46 μm to 82.29 μm . The smaller the particle size, the more surface contact with the extracting solvent [50]. This can facilitate more colorant extraction, leading to higher absorption value and stronger color. Accordingly, particle size values correlate with UV-Vis absorption and color parameters data (Tables 3 and 4).

4 Conclusion

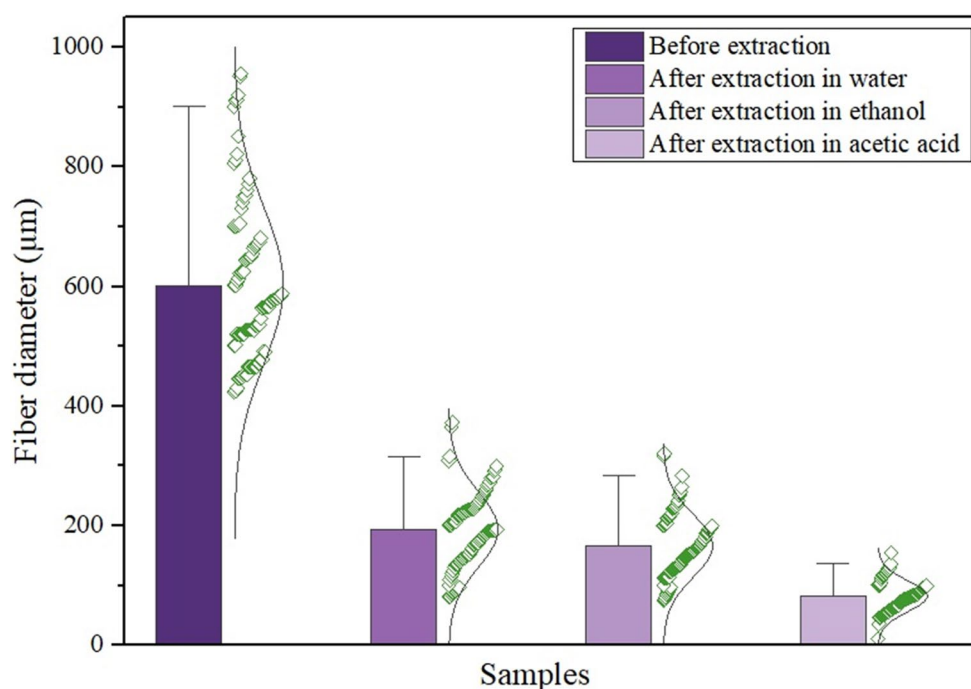
This current research presented the extraction of colorants from *Bougainvillea glabra* in different mediums and the coloring of cotton and wool fabrics with and without the help of a mordant substance. The fabrics colored in water-extracted *Bougainvillea glabra* solution exhibited higher K/S values, whereas the acetic acid-extracted solution created higher color differences than the rest of the fabrics. The extraction medium and characteristics of natural fiber play important roles in determining the color parameters of the colored fabrics. The colored fabrics exhibited good washing fastness but excellent water and rubbing fastness values. FTIR spectra reveal the presence of amine (N-H) and carbonyl groups, indicating the betaxanthins group of betalain type pigments, which is possibly responsible for the coloring of the cotton and wool fabrics—incorporating mordant enhanced color and fastness value, which can be attributed to possibly better binding between the textile and the extracted solution. *Bougainvillea* bracts were found to be a potential coloring agent for textile fibers. It is also concluded that textile materials' extraction and coloring processes can be carried out simultaneously in a sustainable and eco-friendly bath.

The extraction and dyeing process using *Bougainvillea glabra* shows potential for commercial scalability, particularly in sustainable textile applications. While the use of eco-friendly solvents makes the process environmentally favorable, optimization is required to improve extraction efficiency and dye fixation for large-scale production. The reliance on copper sulfate as a mordant, while effective, raises concerns regarding environmental safety, suggesting the need for alternative bio-mordants. Additionally, cost challenges associated with natural dyeing remain, but with increasing consumer demand for sustainable textiles,

Table 5 The fastness results of the colored cotton and wool fabrics

Fabric Code	Fastness to washing					Fastness to water					Fastness to rubbing				
	Staining					Staining					Dry				
	Color change	WO	PAN	PET	PA 6.6	CO	CA	Color change	WO	PAN	PET	PA 6.6	CO	CA	Wet
CoA	4	4/5	5	5	5	5	5	4/5	5	5	5	5	5	5	5
CoE	2/3	4/5	4/5	5	5	5	5	2/3	5	5	5	5	5	5	4/5
CoW	2	4/5	5	5	5	5	5	3/4	5	5	5	5	5	5	5
CoAM	4/5	4/5	5	5	5	5	5	4/5	4/5	5	5	4/5	4	5	5
CoEM	4	4/5	5	5	5	5	5	4/5	4/5	4/5	4/5	4	3/4	4/5	4/5
CoWM	3/4	4/5	5	5	5	5	5	4/5	4/5	4/5	4/5	3/4	3	4/5	4/5
WoA	4/5	4/5	5	5	5	5	5	4/5	5	4/5	4/5	4/5	3	4/5	4/5
WoE	3/4	4/5	5	5	5	5	5	5	5	5	5	5	5	5	5
WoW	2	4/5	5	5	5	5	5	5	5	5	5	4/5	5	5	5
WoAM	4/5	5	5	5	5	5	5	5	4/5	4/5	5	5	4	5	4/5
WoEM	4/5	4/5	5	5	5	5	5	5	4/5	5	5	5	4/5	5	5
WoWM	3	5	5	5	5	5	5	5	4/5	5	5	3	3	4/5	4/5

Fig. 3 Particle size of the ground *Bougainvillea* before and after extraction



commercial feasibility is improving. Future research should focus on optimizing extraction methods and assessing large-scale processing techniques to enhance economic viability.

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Declarations

Ethics approval No results of studies involving humans or animals are reported.

Competing interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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