Environmental Science and Pollution Research
https://doi.org/10.1007/s11356-022-23417-7

RESEARCH ARTICLE

Environmental friendly silk and cotton dyeing using natural colorant of Bougainvillea *(Bougainvillea glabra)* flowers: the sustainable approach towards textile industry

Warda Rasool[1] · Shahid Adeel[2] · Fatima Batool[3] · Sheikh Asrar Ahmad[1] · Sahar Mumtaz[3] · Muhammad Hussaan[4]

Received: 9 March 2022 / Accepted: 27 September 2022

Abstract
For the current study, Bougainvillea flowers as environment friendly sustainable source of plant-based natural dye have been selected as an alternative to toxic synthetic dyes for dyeing of cotton and silk. Natural colorant from Bougainvillea flowers (*Bougainvillea glabra*) was extracted using aqueous and acidic extraction media. Maximum colorant was extracted in aqueous medium, and further it was used for cotton and silk dyeing. The optimum values of the dyeing parameters including dyeing time, dye to liquor ratio and salt level as exhausting agent were found to be 30 min, 35-mL liquor ratio and 3.0 g for cotton and for silk 45 min dyeing time, 45-mL liquor ratio and 3.0 g exhausting agent in aqueous dye extract. Bio mordanting has been applied to attain a variety of color shades. The utilization of 3% of henna, 4% of turmeric for silk pre-mordanting and for post-mordanting turmeric at 3% and henna at 4% for silk gave a darker shade. For cotton bio mordanting, 2% turmeric rhizome powder, 3% henna leaves powder extract as pre-mordant and 2% turmeric, 3% henna as post-mordant has developed a variety of shade. Overall, it has been found that natural colorant from Bougainvillea flowers is the new dye source for bio-coloration of natural fabrics, and addition of bio mordants has made the process more calming and eco-friendly.

Keywords Anthocyanin · Bio mordanting · Bougainvillea · Color strength · Cotton and silk fabrics · Henna · Turmeric

Introduction

Textile industry utilizes different chemicals including toxic dyes which are non-biodegradable and carcinogenic in nature leading to serious threats to the atmosphere and human health (Garcia et al. 2021; Pishgar et al. 2022). Day by day, continuous rise in environmental pollution and water disposal problems created throughout the world are the result of such toxic effluents of textile (Srinivasan and Sadasivam 2021; Keyhani et al. 2021). However, some disadvantages of synthetic dyes, such as non-biodegradability, non-renewability, mutagenicity and carcinogenicity, have prompted global researchers to investigate alternative of synthetic dyes to reduce environmental pollution and health hazards (Fang et al. 2022).

Revival of natural dyes in fabric dyeing is either an imperative approach to minimize chemical-based ecological contamination or to revive the art of colorant asserts (Yan et al. 2021). Natural dyes are esthetically pleasing and are seen as environment friendly alternatives to dangerous synthetic dyes. It has excellent antibacterial, antioxidant (Sadeghi-Kiakhani et al. 2021), UV protective (Rather et al. 2021b) and antifungal properties (Pal et al. 2021). Bio colorants are gaining widespread attraction in varying fields. Their usage is rising in textile, agriculture, food, cosmetics industry and leather processing (Bujak et al. 2021; Brudzyńska et al. 2021). These colorants have no issue of waste, where even

Responsible Editor: Philippe Garrigues

✉ Fatima Batool
fatima.batool@ue.edu.pk

Shahid Adeel
shahidadeel@gcuf.edu.pk

[1] Department of Chemistry, University of Education Lahore, Vehari Campus, Vehari 61100, Punjab, Pakistan

[2] Department of Chemistry, Government College University Faisalabad, Faisalabad 38000, Pakistan

[3] Department of Botany, Division of Science and Technology, University of Education Lahore, Lahore 54770, Punjab, Pakistan

[4] Department of Botany, Government College University Faisalabad, Faisalabad 38000, Pakistan

Published online: 24 October 2022

their waste can be recycled into useful work. The residue left after isolation can be added in soil to make it fertile (Habib et al. 2022). These dyes can be beneficial for other crops because their sources can be grown with other crops. These natural dye extracts are used in Ayurvedic, Greek and Chinese medication system to cure various diseases. Plant-based colorants give eye-catching shades (Shahidi et al. 2021). Hence, natural dyeing as one of the traditional cultural assets is reviving their place in the world (Mongkholrattanasit et al. 2021).

Bougainvillea (*Bougainvillea glabra*) is an ornamental vine that belongs to the Nyctaginaceae family, and its flower is rich in anthocyanin, betaxanthin, betacyanins, quinines, chlorophylls, carotenoid, flavonoids, alkaloids, proteins, tannins and phenolic compounds (Tegeli et al. 2019; Maran et al. 2015; Shivani et al. 2020; Saleem et al. 2021). Flower extract has excellent anti carcinogenic, anti-inflammatory, anti-microbial and antioxidant properties. Flowers are economically important and are also used as salads and frizzling in Thailand. Flowers vary in colors purple, white, orange and red. Previously, it has been found that natural colorant has been explored from purple and red flowers (Kumar et al. 2017). But, no such extensive studies have been done regarding fabric dyeing. Current studies have been planned to isolate the colorant potential of Bougainvillea (pink) flowers and its applications on silk and cotton fabrics as well as conversion of non-valuable product into value-added product. Cotton is the cheapest and famous textile study which has cellulosic units. Its terminal unit –OH group is used to bind with foreign objects such as –OH of dye and metals ($M+$) (Hosen et al. 2021). Silk is a natural fabric that contains fibroin, which serves as a functional moiety (amide linkage) for colorant bonding (Habib et al. 2022). For improvement in fastness properties, different types of chemical mordant have been applied (Manicketh et al. 2021). Currently, plant-based mordants have also gain popularity due to nontoxic and environment friendly nature (Kandasamy et al. 2021; Zhang et al. 2022; Zhou et al. 2022).

Current research work aimed at the extraction of natural colorants from Bougainvillea flowers using aqueous and acidic mediums and the application of extracted natural colorant on silk and cotton fabric.

Methodology

Sample collection

Bougainvillea (*Bougainvillea glabra*) flowers were collected from Burewala, Pakistan. Plant material was washed, dried and ground into a fine powder. Dye was used for the dyeing of cotton and silk fabrics. Cotton and silk fabric were procured from the local market of Faisalabad, Pakistan. All chemicals used were commercial (Pak made). Sources of biological effective bio mordants such as turmeric rhizomes (*Curcuma longa*) and henna (*Lawsonia inermis*) were obtained from the herbal market of Burewala Pakistan, washed, dried and finely ground.

Extraction of natural colorant

To extract colorant from Bougainvillea flowers, two extraction media, such as aqueous and acidic (vinegar 4 mL/96 mL = v/v), were employed by boiling 4.0 g of dye powder with 100 mL of aqueous and acidic media for 45 min on a hot plate. After boiling, filtrates were employed for silk and cotton dyeing at the Department of Chemistry, University of Education, Vehari Campus, Pakistan. The dyeing of the fabric was carried out at variable selected conditions.

Optimization of dyeing parameters

To evaluate one of the optimum conditions for dyeing, optimization of dyeing conditions has been done.

Dyeing time = 15, 30, 45, 60 and 75 min.

Material to liquid ratio (g:mL) = 1:25, 1:35, 1:45, 1:55 and 1:65.

Material to liquor ratio means for 1 g fabric 25–65 mL of extract

Salt amount = 1 g–5 g/100 mL.

Bio mordanting

For shade development, bio mordants like turmeric (*Curcuma longa*) and henna (*Lawsonia inermis*) in varying concentration (1–5 g in 100 mL of water) were boiled for 30 min. For applying the extracted mordants, the fabrics were boiled in the extracted bio mordant solution before and after dyeing as per procedure described by Habib et al. (2022). After the treatment, the mordanted fabrics were washed in water to remove the loosely fixed mordants (Batool et al. 2022a, b).

Evaluation of color strength and color fastness properties

For evaluation of color strength properties, dyed and mordanted samples have been investigated using Spectra Flash SF 600 at the Department of Chemistry, Government College University Faisalabad using Kubelka–Munk equation $K/S = (1 - R2)/2R$. ISO standard methods for light fastness (ISO 105-B02), for washing fastness (ISO 105-CO6) and for dry rubbing fastness (ISO 105-X12) were employed.

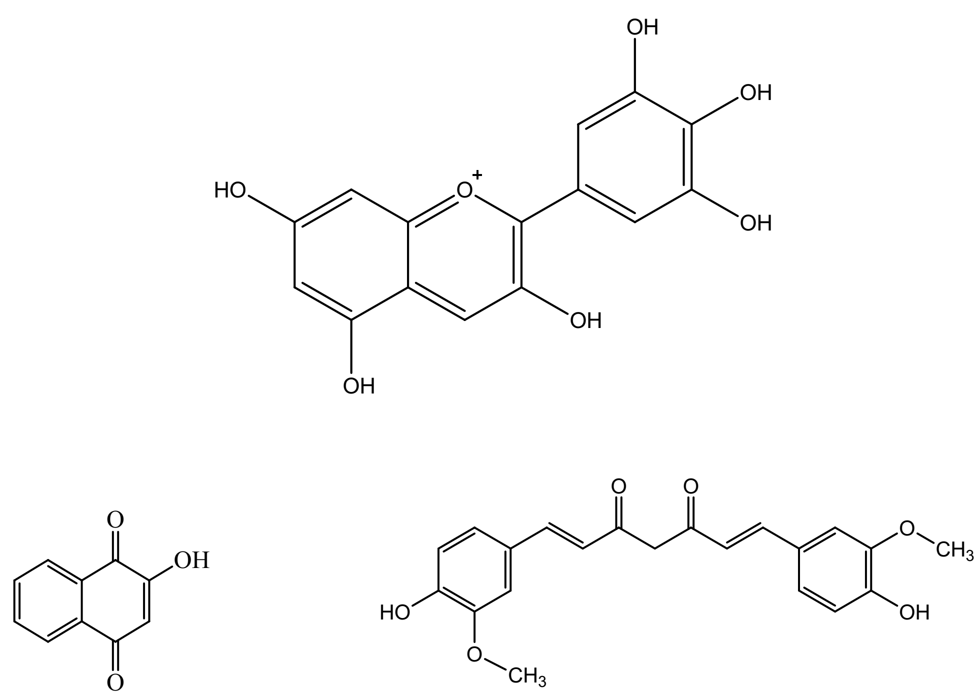
Results and discussion

Extraction of colorant from Bougainvillea was carried out using aqueous and acidic media. It has been observed that maximum colorant was extracted in aqueous medium as compared to acidic medium (Table 1). Optimization results given in Fig. 1a show that utilization of aqueous dye extract for 45 min has given excellent color strength onto silk fabric. In comparison, the dyeing of cotton for 30 min has given better color strength (Fig. 2a), while, silk has shown more affinity towards colorant than cotton fabric. Moreover, above optimal dyeing time caused desorption of colorant molecules and reduces the dye fabric interactions and as a result gave low color strength on dyed sample (Singhee and Samanta 2019). Hence, 45 min., for silk dyeing and 30-min., dyeing time for cotton were found to be optimal dyeing concentration to achieve excellent K/S value. The volume of plant extract also plays an important role in dyeing, because only an optimal volume fills the voids of fabrics (silk/cotton) to give desired results. The data displayed in Figs. 2b and 3b show that for silk 45 mL and for cotton 35 mL of optimal dye extract should be used to get maximum color strength, while using 45 mL of extract for silk and 35 mL of extract for cotton dyeing has shown maximum color strength. Salt is always preferred to be used during dyeing in the textile industry. In natural dyeing, its effect can be seen in various studies (Hussaan et al. 2017). In recent studies, the result (Figs. 2c and 3c) shows that 3 g/100 mL of salt for silk and for cotton has exhausted the dye bath to show maximum color strength. Similarly, using aqueous dye extract having 3 g/100 mL of salt for silk and for cotton has given excellent results. The purpose of salt is to give a suitable atmosphere for the colorant to interact with the fabric through short-range forces via excellent exhaustion (Jabar et al. 2021). Low concentration of salt failed to give maximum colorant, whereas above 3 g/100 mL causes over exhaustion and leads to minimum color strength. In both cases, upon washing, a lot of unfixed colorant are lost and low color strength (K/S) is achieved.

Table 1 Color strength (K/S) value of dyed silk and cotton fabric in natural dye extracted in aqueous and acidic extraction media

Extraction media	Level%	(Silk sample) K/S value	(Cotton sample) K/S value
Aqueous	100	2.3401	1.9781
Acidic (vinegar)	4	0.1032	1.1304

Bio mordanting being an eco-friendly process has gained significant importance in producing a variety



Lawson

Curcumin

Fig. 1 Chemical structure of Anthocyanin of Bougainvillea flower and bio mordants henna (Lawson) and turmeric (Curcumin)

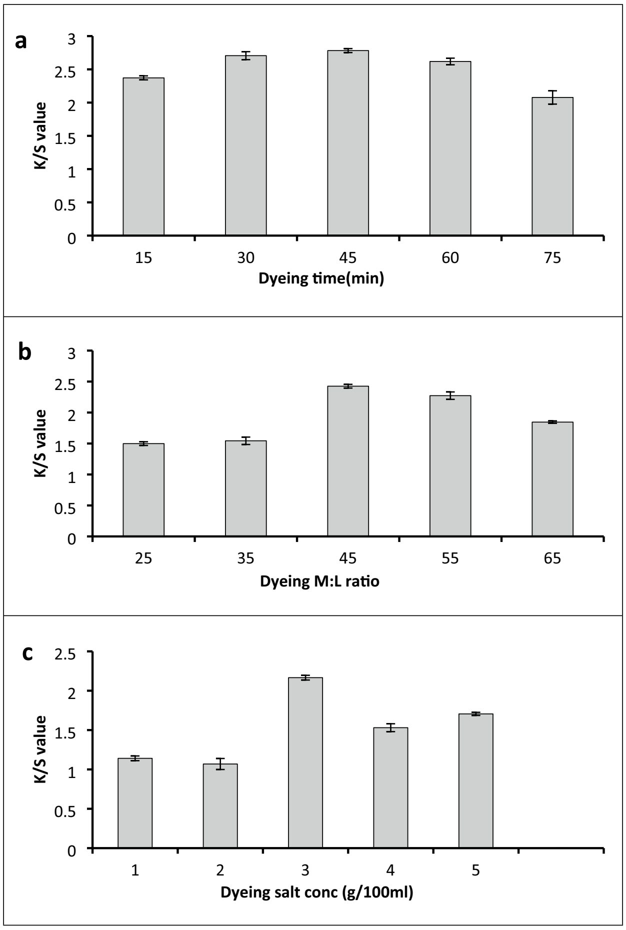


Fig. 2 Effect of (**a**) dyeing time, (**b**) dyeing M:L ratio and (**c**) dyeing salt conc. on the color strength of dyed silk fabrics using aqueous dye extract of Bougainvillea flowers

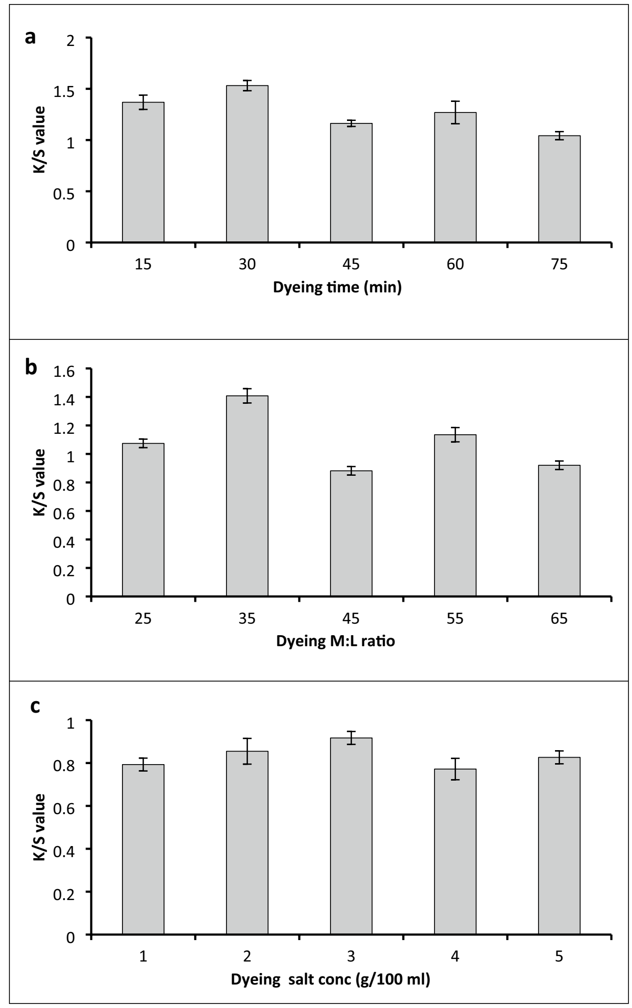


Fig. 3 Effect of (**a**) dyeing time, (**b**) dyeing M:L ratio, (**c**) dyeing salt conc. on the color strength (K/S) of dyed cotton fabrics using aqueous dye extract of Bougainvillea flowers

of shades on naturally dyed fabrics (Zhou et al. 2022). Previous works report that a large number of herbal sources has been used as fixative agents in natural dyeing (Ghaheh et al. 2021; Bhandari et al. 2021; Adeel et al. 2022). In this study, in order to produce a variety of shades with higher fastness rating, turmeric and henna extract have been employed as pre and post bio mordants. Pre-mordanting results show the impact of varying level of bio mordants on the color shade of silk and cotton fabrics dyed using optimized dye extracts of Bougainvillea flowers. Bio pre-mordanting results (Fig. 4a) of silk fabric dyed with optimal extract at given conditions show that 4% turmeric (Curcumin) and 3% henna (Lawson) gave a darker shade with high color strength (K/S), whereas in case of cotton fabric 2% turmeric (Curcumin) and 3% henna (Lawson) as pre bio mordant produced darker shades (Fig. 5a). Functional active molecules of bio mordant interact with –OH of dye molecule and with –OH of cellulosic unit of cotton fabric and amido unit of silk via H intramolecular bonding (Fig. 6a, b) to produce promising shades (Hosseinnezhad et al. 2021; Zhang et al. 2021).

Similarly, the application of turmeric and henna extract after the dyeing of silk and cotton with Bougainvillea dye extract has given the desired results (Figs. 4b and 5b). The graph containing data (Fig. 4b) shows that for silk, 3% turmeric (Curcumin) and 4% henna (Lawson), while 2% turmeric and 3% henna (Lawson) for cotton after dyeing (Fig. 5b) have given a darker shade with good fastness properties. Comparatively, bio post-mordanting has given excellent results by developing darker shades and improving fastness ratings (Table 2) . This is due to the bonding created by the use of plant-based anchors (bio mordants) and the conjugation existing in the functional molecules of bio

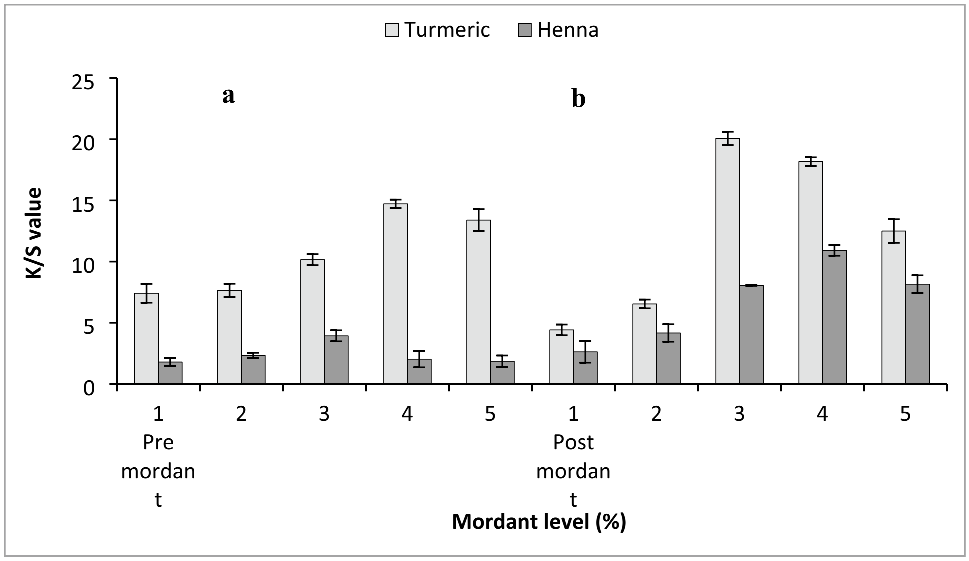


Fig. 4 Impact of bio mordants on the color strength of (**a**) pre-mordanted silk and (**b**) post-mordanted silk fabrics dyed using aqueous extract of Bougainvillea flowers

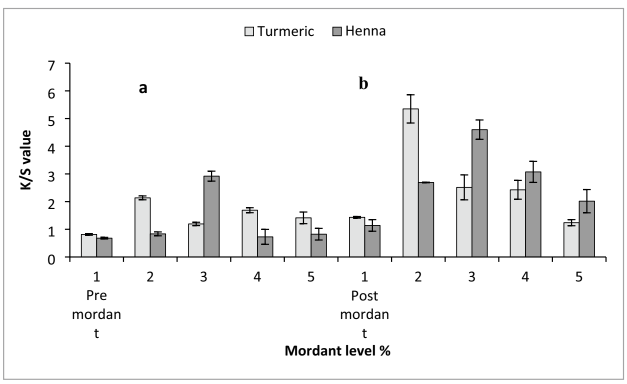


Fig. 5 Impact of bio mordants on the color strength of (**a**) pre-mordanted cotton and (**b**) post-mordanted cotton fabrics dyed using aqueous extract of Bougainvillea flowers

mordants. It has also been observed that both of these bio mordants have contributed to develop new shade that has resisted on detachment from the dyed material (Lykidou et al. 2021).

Colorfastness rating of mordanted silk and cotton fabrics was accessed. The results presented in Table 3 show that bio mordants improved the fastness properties of mordanted fabrics. In case of silk bio mordanting, post-mordanted samples gave higher fastness rating in contrast to silk pre-mordanting. Optimal mordanted samples, 3% turmeric post-mordanted sample and 4% henna post-mordanted sample gave maximum color fastness rating. In case of cotton bio mordanting, post-mordanted cotton gave higher fastness rating in contrast to cotton pre-mordanting. Hence, 2% turmeric post-mordanted cotton and 3% henna post-mordanted sample gave maximum color fastness rating. Bio mordant enhances colorfastness rating more effectively against various agencies light, washing and rubbing fastness. This might be due to occurrence of strong H-bonding with the dye component and with fabrics which in turn resist against light, rubbing and washing (Rather et al. 2021a; Dhanania et al. 2021). Hence, eco-friendly sources of mordants have developed good shades.

Conclusion

Bougainvillea flowers have been proved to be a sustainable natural colorant. Natural colorant has been extracted from Bougainvillea flowers using aqueous and acidic medium, where maximum colorant has been extracted in aqueous medium proved to be excellent and environment friendly medium to give maximum color strength onto the fabric. Optimized dyeing levels for cotton dyeing in aqueous were found to be 30-min dyeing time, 35-mL dye to liquor ratio and 3% salt level as exhausting agent. Similarly, in the case of silk dyeing, 45-min dyeing time, 45-mL volume ratio and 3% salt concentration proved to be optimized dyeing levels. Bio mordanting has been applied to attain a variety of color shades. Bio mordanting of cotton and silk fabrics using bio mordants like henna and turmeric gave a darker shade. Overall, 4% turmeric pre-mordanted silk, 3% henna pre-mordanted silk, 2% turmeric pre-mordanted cotton and 3% henna pre-mordanted cotton fabrics were optimized mordanted samples in terms of producing darker hue with respect to higher color strength (K/S) value, while in case of bio post-mordanting of silk, 3% turmeric and 4% henna and in cotton

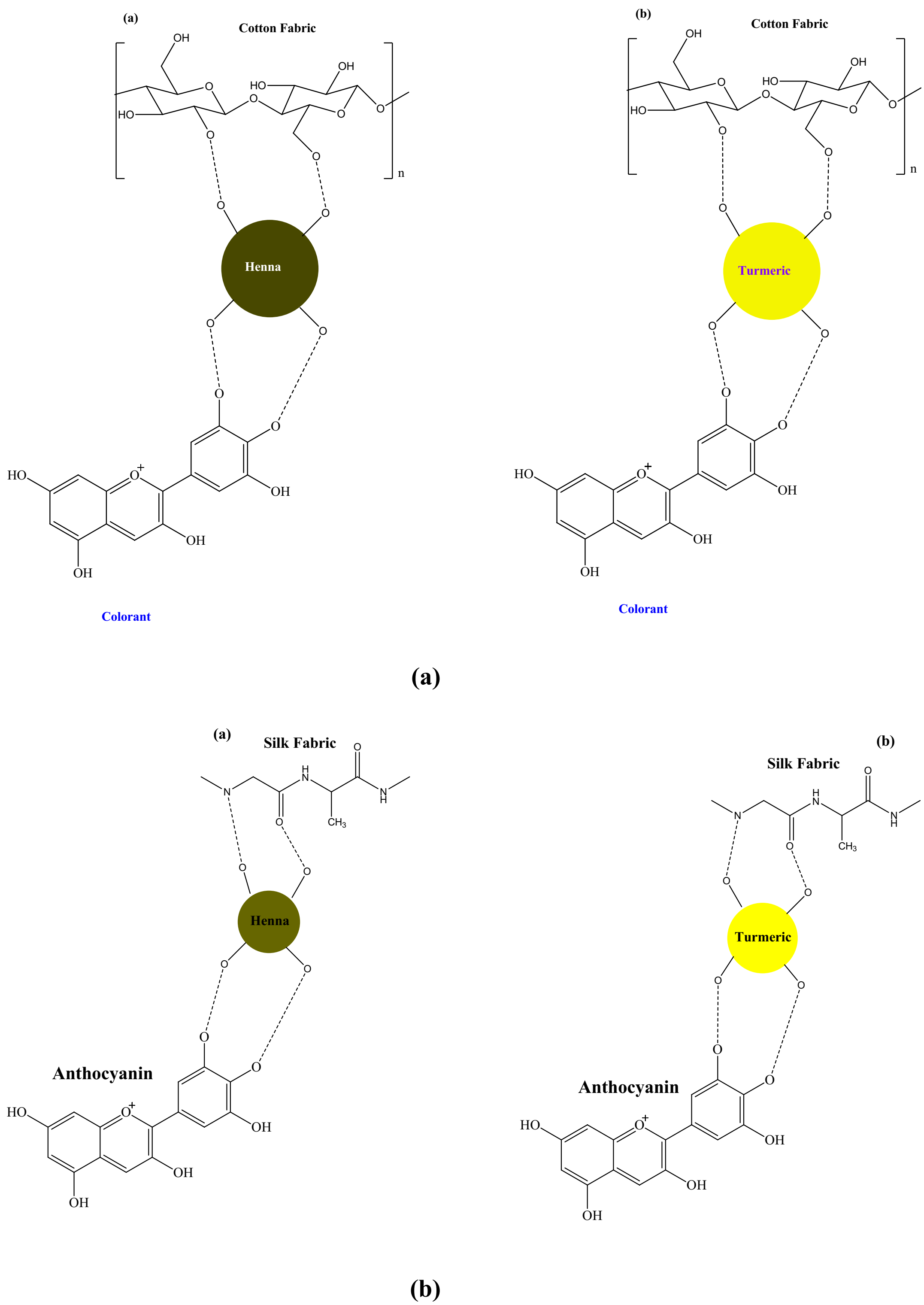


Fig. 6 (**a**) Mechanism of interaction of bio mordants with colorant and with cotton fabric, (**b**) Mechanism of interaction of bio mordants with colorant and with silk fabric

Table 2 Color characteristics and shade of bio mordanted silk and cotton fabrics dyed in Bougainvillea dye extract

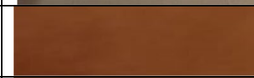
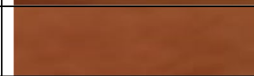
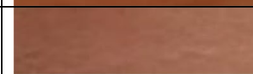
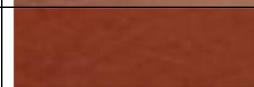
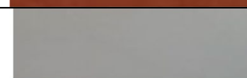
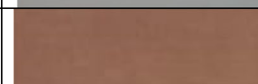
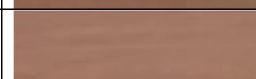
	Mordanted sample	L*	a*	b*	Color shade
Silk	Control	75.45	7.44	22.45	
	Turmeric4% pre mordanted fabric	59.92	5.77	55.88	
	Turmeric 3% post mordanted fabric	57.84	18.39	62.97	
	Henna 3% pre mordanted fabric	67.89	3.35	20.77	
	Henna 4% post mordanted fabric	53.24	15.15	33.51	
Cotton	Control	78.22	3.39	19.79	
	Turmeric 2% pre mordanted fabric	75.22	1.39	41.79	
	Turmeric 2% post mordanted fabric	66.96	9.93	50.15	
	Henna 3% pre mordanted fabric	74.83	2.20	9.36	
	Henna 3% post mordanted fabric	65.44	11.22	28.15	

Table 3 Impact of bio mordants on the color fastness properties of silk and cotton fabric dyed using Bougainvillea flowers dye extract

Mordant type	Mordant conc. %	Turmeric			Henna		
		LF	WF	DRF	LF	WF	DRF
Control		3/4	3	3/4	3	3	3/4
Pre-mordant (Silk)	1	3	3/4	3	3	3	3/4
	2	3/4	3	5	¾	3	4/5
	3	3/4	5	4	4	4	5
	4	5	4	5	5	3/4	4/5
	5	4	3	3/4	3	4/5	5
Post-mordant (Silk)	1	3/4	3	4/5	4/5	3/4	3
	2	4	3/4	3	3	4/5	3/4
	3	4	5	4	4/5	4	3
	4	3	3/4	5	5	4	5
	5	3/4	4	4	4	3	4/5
Control		4	3/4	3	3/4	3/4	3
Pre-mordant (Cotton)	1	3	4/5	3/4	3	4/5	3/4
	2	5	5	4	3/4	3	4/5
	3	3	5	4	4	4	5
	4	3	4/5	3	5	3/4	4/5
	5	3/4	3	4	3	4/5	5
Post-mordant (Cotton)	1	3	3	4	4	3/4	3
	2	5	4	5	3	3	3/4
	3	3/4	4	4/5	4	5	4
	4	3	3/4	5	3	3	5
	5	4	4/5	3	3/4	4	3

LF light fastness, *WF* washing fastness, *RF* rubbing fastness bio post-mordanting, 2% turmeric and 3% henna gave a darker shade in terms of higher color strength (K/S) value. All mordanted fabrics showed excellent fastness ratings in term of light, rubbing and washing fastness. Fastness results showed that optimum mordanted fabrics gave higher fastness properties such as colorfastness to washing, light and dry rubbing. In future, Bougainvillea flowers could be an excellent source of natural colorant and lead to ecofriendly textiles in terms of producing a sustainable environment.

Acknowledgements We are greatly thankful to the Eco friendly Textile Lab at the Department of Chemistry, Government College University Faisalabad, Pakistan for assessment of results of dyed and mordanted samples.

Author contribution This paper is an outcome of BS research work of WR. SAA is supervisor and FB is co-supervisor, guided scientifically for smooth running of the work. SA has helped in assessment of data and experiments. SM and MH have guided to make colorfast shades.

Data availability The work is from BS studies.

Declarations

Ethics approval We approve that this manuscript is part of BS studies.

Consent to participate and consent for publication We give consent to publish our work of BS studies, which is jointly contributed by all authors.

Competing interests The authors declare no competing interests.

References

Adeel S, Kiran S, Shahid M, Habib SR, Habib N, Hussaan M (2022) Ecofriendly application of coconut coir (*Cocos nucifera*) extract for silk dyeing. Environ SciPollut Res 29(1):564–572

Batool F, Adeel S, Azeem M, Iqbal N (2022a) Natural dye color strengthening potential and compounds of selected vegetable residues belonging to Brassicaceae: an approach towards sustainability. Pak J Bot 54(1):329–336

Batool F, Adeel S, Iqbal N, Azeem M, Hussaan M (2022b) Sustainable natural coloring potential of bitter gourd (*Momordica charantia* L.) residues for cotton dyeing: innovative approach towards textile industry. Environ SciPollut Res 29:34974–34983

Bhandari NL, Shrestha S, Bhandari G, Parajuli N, Silwal SB, Adhikari R (2021) Extraction of dye from *Castanopsis indica* for its use in textile dyeing and medicinal purpose with natural mordant. Egypt J Chem 64(11):5–6

Brudzyńska P, Sionkowska A, Grisel M (2021) Plant-derived colorants for food cosmetic and textile industries: a review. Materials 14(13):3484

Bujak T, Zagórska-Dziok M, Ziemlewska A, Nizioł-Łukaszewska Z, Wasilewski T, Hordyjewicz-Baran Z (2021) Antioxidant and cytoprotective properties of plant extract from dry flowers as functional dyes for cosmetic products. Molecules 26(9):2809

Dhanania Y, Singhee D, Samanta AK (2021) Optimization of dyeing process variables for eco-friendly dyeing of cotton fabric with babul bark extract as a natural dye and gallnut extract as a biomordant J Nat Fibers 1–18. https://doi.org/10.1080/15440478.2021.1875955

Fang J, Meng C, Zhang G (2022) Agricultural waste of *Ipomoea batatas* leaves as a source of natural dye for green coloration and biofunctional finishing for textile fabrics. Ind Crops Prod 177:114440

Garcia VSG, de FreitasTallarico L, Rosa JM, Suzuki CF, Roubicek DA, Nakano E, Borrely SI (2021) Multiple adverse effects of textile effluents and reactive Red 239 dye to aquatic organisms. Environ SciPollut Res 28:63202–63214

Ghaheh SF, Moghaddam MK, Tehrani M (2021) Comparison of the effect of metal mordants and bio-mordants on the colorimetric and antibacterial properties of natural dyes on cotton fabric. Color Technol 137(6):689–698

Habib N, Akram W, Adeel S, Amin N, Hosseinnezhad M (2022) Environmental-friendly extraction of Peepal (*Ficusreligiosa*) bark-based reddish brown tannin natural dye for silk coloration. Environ SciPollut Res 29:35048–35060

Hosen MD, Rabbi MF, Raihan MA, Al Mamun MA (2021) Effect of turmeric dye and biomordants on knitted cotton fabric coloration: a promising alternative to metallic mordanting. Clean EngTechnol 3:100124

Hosseinnezhad M, Gharanjig K, Jafari R, Imani H, Razani N (2021) Cleaner colorant extraction and environmentally wool dyeing using oak as eco-friendly mordant. Environ SciPollut Res 28:7249–7260

Hussaan M, Iqbal N, Adeel S, Azeem M, Javed MT, Raza A (2017) Microwave-assisted enhancement of milkweed (*Calotropis procera* L.) leaves as an eco-friendly source of natural colorants for textile. Environ SciPollut Res 24:5089–5094

Jabar JM, Adedayo TE, Odusote YA (2021) Green, eco-friendly and sustainable alternative in dyeing cotton fabric using aqueous extract *Mucuna slonaei* F dye: effects of metal salts premordanting on color strength and fastness properties. Curr Res Green Sustain Chem 4:100151

Kandasamy N, Kaliappan K, Palanisamy T (2021) Upcycling sawdust into colorant: Ecofriendly natural dyeing of fabrics with ultrasound assisted dye extract of *Pterocarpus indicus* Willd. Ind Crops Prod 171:113969

Keyhani A, Nikpassand M, ZareFekri L, Kefayati H (2021) One-pot synthesis of new category of 2-aryl-quinazolinones using OImDSA as an efficient heterocyclic medium. Prog Color Colorants Coat 14(4):233–240

Kumar SNA, Ritesh SK, Sharmila G, Muthukumaran C (2017) Extraction optimization and characterization of water soluble red purple pigment from floral bracts of Bougainvillea glabra. Arab J Chem 10:S2145–S2150

Lykidou S, Pashou M, Vouvoudi E, Nikolaidis N (2021) Study on the dyeing properties of curcumin on natural and synthetic fibers and antioxidant and antibacterial activities. Fibers Polym 15(1):1–7

Manicketh TJ, Francis MS, Joseph G (2021) Extraction of polygenetic natural dyes from *Cordyline fruticose* & *Mussaenda erythrophylla* for textile substrates. Nat Prod Res 1–6.https://www.tandfonline.com/doi/abs/https://doi.org/10.1080/14786419.2021.1903893

Maran JP, Priya B, Nivetha CV (2015) Optimization of ultrasound-assisted extraction of natural pigments from Bougainvillea glabra flowers. Ind Crops Prod 63:182–189

Mongkholrattanasit R, Nakpathom M, Vuthiganond N (2021) Eco-dyeing with biocolorant from spent coffee ground on low molecular weight chitosan crosslinked cotton. Sustain Chem Pharm 20:100389

Pal A, Kumar R, Tripathi YC (2021) Antifungal finishing of fabrics with natural dyes from aerial biomass of Perilla frutescens (L.) Britton. Int J Appl Pharm Sci Res 6(01):8–14

Pishgar M, Gharanjig K, Yazdanshenas ME, Farizadeh K, Rashidi A (2022) Photophysical properties of a novel xanthene dye. Prog Color Colorants Coat 15(2):87–96

Rather LJ, Zhou Q, Ali A, Haque QMR, Li Q (2021a) Valorization of agro-industrial waste from peanuts for sustainable natural dye production: focus on adsorption mechanisms ultraviolet protection and antimicrobial properties of dyed wool fabric. ACS Food SciTechnol 1(3):427–442

Rather LJ, Zhou Q, Li Q (2021b) Re-use of *Cinnamomum camphora* natural dye generated wastewater for sustainable UV protective and antioxidant finishing of wool fabric: Effect of Fe (II) sulfate. Sustain Chem Pharm 21:100422

Sadeghi-Kiakhani M, Tehrani-Bagha AR, Safapour S, Eshaghloo-Galugahi S, Etezad SM (2021) Ultrasound-assisted extraction of natural dyes from Hawthorn fruits for dyeing polyamide fabric and study its fastness antimicrobial and antioxidant properties. Environ Dev Sustain 23(6):9163–9180

Saleem H, Usman A, Mahomoodally MF, Ahemad N (2021) Bougainvillea glabra (choisy): a comprehensive review on botany, traditional uses, phytochemistry, pharmacology and toxicity. J Ethnopharmacol 266:113356

Shahidi S, Khoshechin E, Sharifi DS, Mongkholrattanasit R (2021) Investigation of the effect of various natural dyes on uv protection properties and antibacterial activity of cotton fabrics. J Nat Fibers 1–16. https://www.tandfonline.com/doi/abs/https://doi.org/10.1080/15440478.2021.1944433

Shivani M, Prathibha S, Kavya Sri B, Chintagunta AD, Sampath NS (2020) Extraction of natural dye from and its *Bougainvillea glabra* applications in food industries. Indian J Ecol 47(11):207–211

Singhee D, Samanta P (2019) Studies on dyeing process variables for application of Tesu (*Butea monosperma*) as natural dye on silk fabric. J Nat Fibers 16(8):1098–1112

Srinivasan S, Sadasivam SK (2021) Biodegradation of textile azo dyes by textile effluent non-adapted and adapted *Aeromonas hydrophila*. Environ Res 194:110643

Tegeli VS, Shinde PS, Shiranal PA, Shilwant SV, Surwase PR, Shendage GS, Shirawar MM (2019) A comparative phytochemical analysis of *Bougainvillea glabra* and *Catharanthus roseus*. J PharmacogPhytochem 8(3):2965–2968

Yan X, Hong L, Pei S, Hamilton A, Sun H, Yang R, Yang L (2021) A natural yellow colorant from *Buddleja officinalis* for dyeing hemp fabric. Ind Crops Prod 171:113968

Zhang Y, Zhou Q, Rather LJ, Li Q (2021) Agricultural waste of Eriobotrya japonica L. (Loquat) seeds and flora leaves as source of natural dye and bio-mordant for coloration and bio-functional finishing of wool textile. Ind Crops Prod 169:113633

Zhang W, Wang X, Weng J, Liu X, Qin S, Li X, Gong J (2022) Eco-dyeing and functional finishing of wool fabric based on Portulaca oleracea L. as colorant and Musa basjoo as natural mordant. Arab J Chem 15(2):103624

Zhou Q, Rather LJ, Mir SS, Ali A, Haque QMR, Li Q (2022) Bio colourants from the waste leaves of Ginkgo biloba L. tree: wool dyeing and antimicrobial functionalization against some antibiotic-resistant bacterial strains. Sustain Chem Pharm 25:100585

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.