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RESEARCH ARTICLE

Environmental friendly pollution free bio-dyeing of wool with haar singhar (Coral Jasmine) flower extract

Shahid Adeel[1] · Sehrish Ahmad[1] · Noman Habib[2] · Muhammad Jawwad Saif[3] · Fatima Batool[4] · Muhammad Aftab[5]

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Abstract
The world's move towards revival of eco-labelled products has created a huge urge to explore new means which are healthier for the global community. Among such means, plant-based bio-pigments for coloration of matrix are gaining worldwide fame, particularly in the textile sector. For the purpose of appraising new source of eco-friendly dyes, using microwave irradiation techniques, Coral Jasmine flowers have been explored for the bio-dyeing of wool. The colorant was extracted in acidic medium owing to nature of fabric, and both stuffs have been exposed to microwave treatment up to 5 min. Bio-coloration of MW irradiated and unirradiated wool was done using MW irradiated and unirradiated extract for observing high yield. Central composite design (CCD) as statistical method was utilized to see the significance of dyeing parameters chosen for mordanting to develop colorfast shades. Different concentrations of sustainable chemicals and bio-mordants as per weight of fabric were employed to introduce new shades with improved colorfastness properties. International standard textile methods determining shade permanency (fastness) have been employed onto selected dyed-mordanted fabrics. Good yield of colorant was observed when MW irradiated wool fabric was dyed at 75 °C for 45 min with extract of 7 pH, having 1.5g/100 mL of salt solution; the promising color yield was observed. As per gray scale ratings observed after ISO standard methods, pine nut as bio-mordant and iron salt as chemical mordant have developed colorfast shades. Conclusively, it can be recommended that methods for the isolation of colorants from new dye yielding plants, MW heating method as suitable clean technology and medicinal-based bio-mordants should be employed for getting permanent gamutes.

Keywords *Arbor-tritis* flowers · *C. jasmine* · MW rays. Pine nut hulls · Walnut shells · Wool fabric

Introduction

Environmental impact in all walks of life has forced the producers to introduce greener and sustainable healthier products. The extraction of natural dyes in a sustainable manner necessitates using natural products that account for economic and environmental impact in all walks of life (Elsahida et al. 2019). Among the products, natural colors are renewable, biodegradable, sustainable, and non-toxic that are attracting people around the world (Haji and Naebe 2020; Nathan and Rani 2021). Surprisingly, their effluents can be recycled and waste biomass can be turned into fertilizer. These dyes can produce unique and soothing colors; in some cases, the shades are enhanced with age during use (Haji 2019). The benefits of natural dyes have sparked a worldwide interest in green products. Synthetic dyes have appealing, unusual, and adaptable colors due to which world's contrarily is using them in all fields (Barasa and Olal 2020). Although synthetic dyes have an extensive range of hues and high fastness qualities (Baaka et al. 2019), yet these

Responsible Editor: Philippe Garrigues

✉ Shahid Adeel
shahidadeelchemist@gmail.com

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

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

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

[4] Department of Botany, Division of Science and Technology, University of Education Lahore, Lahore, Pakistan

[5] Department of Statistics, Government College University Faisalabad, Faisalabad 38000, Pakistan

synthetic dyes are under strict observation due to their high toxicity and non-biodegradable hazardous effluent (Alebeid et al. 2020; Gan et al. 2021). The widespread use of synthetic dyes has also raised severe concerns about the toxicity of agricultural land, water bodies, and the global ecosystem (Khattab et al. 2020; Jiang et al. 2019). These colorants are suitable for textiles, but wastewater having carcinogens organic and inorganic non-biodegradable matters are one of big hurdles for global community to live healthier. These effluents of synthetic dyes also raise the harmful levels of chemicals in the environment, such as sulfur, phosphorus, nitrogen, and other heavy metal ions, which encourage destruction of eco-balance (Yusuf 2019).

In comparison, natural dyes are bio-colorants obtained without using chemicals from natural sources, where flora and fauna add value in the niche market of natural dyes (Rani et al. 2020; Rajeswari 2020). As a result of their biological herbal characteristics, now people are compelling to revive the non-toxic art of extraction of bio-colorants and their dyeing of natural fabrics and other fields (Wang et al. 2018; dos Santos Silva et al. 2020; AbdEldaim et al. 2020). Their medicinal mode of action having antiviral, antibacterial, and antifungal properties have also attracted people more towards these colorants in current pandemic situation (Hu et al. 2019; Haji et al. 2020). However, these colorants are facing two major limitations such as low yield and poor shade fastness. The shade strength of natural dye on fabric was boosted by using mordant, as mentioned in the literature (Ryu & Koh 2019; Baig et al. 2021). Researchers are using many techniques to improve colorant yield, but microwave treatment being cheap is available commercial technology. Microwave rays use a solid–liquid transfer technique to maximize biomolecule interaction with the solvent (Chen et al. 2020; Adeel et al. 2022a). Furthermore, microwave rays causes more excellent mass transfer (colorant) into a solvent through a leveled and uniform heating process which results in higher colorant yield (Gong et al. 2020; Wang et al. 2018; Arain et al. 2021; Phan et al. 2020). On the other hand, these rays tune the fabric surface-to improve the sorption behavior and after dyeing (Majumder et al. 2020). Conventionally, the heat is transferred to the material surface via various processes such as conduction and convection, thereby resulting in time and energy-intensive operation. But microwaves are high-speed and uniform which allows the system to save energy, economy, and time. Another benefit is that the size of equipment, solvent value, and effluent are reduced (Buyukakinci et al. 2021; Jafari et al. 2019). In natural dyeing, mordants are used to increase color qualities and fastness. Mordants are essential in biological dyeing processes because they interact with fiber and dye through special bonding (Singh and Sheikh 2020). Chemical and bio-mordants are the two types of mordants used. Bio-mordants produce a wide range of colors, as expected from a mordant, and so have the potential to replace metal salts in wool dyeing for environmentally friendly textile dyeing (Gholampour and Ozbakkaloglu 2020; Mansour et al. 2020; Khan et al. 2021). Chemical mordants utilize the d orbital of metal for making coordinate covalent bond with dye and fabric.

This study has been taken to explore haar singhar (*N. arbor-tristis*)–based yellow natural dye for wool dyeing. After extensive literature survey, it has been found that no such detailed work has been reported to explore the coloring potential of haar singhar flower as yellow natural dye for fabric, however, our research group has also used aqueous extract of haar singhar for wool dyeing using optimal conditions i.e 35 mL of 6 pH having 2 g/100mL of salt at 85 °C for 35 min. The use of microwave radiation (MW) as green heating technology has been included to get high yield of colorant and mild level of dyeing has been selected to obtain good shades. Also, the inclusion of bio-mordants as an alternative to toxic chemical mordants has made process more green and sustainable by giving new colorfast shades. Thus, the current study has been conducted to observe the coloring behavior of haar singhar flowers (*Nyctanthes arbor-tristis*) as a source of yellow colorant for wool dyeing. Haar singhar (*N. arbor-tristis*), commonly called Coral Jasmine (*N. arbor-tristis*), is an essential ayurvedic medicinal herb. Its floral extract contains many biologically active species, but nyctanthin (Fig. 1c) is found as a colorant for fabric dyeing. Its extract (Fig. 1b) has excellent antibacterial, antifungal, immunomodulatory, antipyretic, antioxidant, and hepatoprotective activities (Parekh and Soni 2020). Wool is a famous textile fabric because of its unique qualities, such as smoothness and softness, wrinkle resistance, heat resistance, fire resistance, excellent absorbency, flexibility, and resiliency (Rather et al. 2019). This fiber comprises a single protein called keratin, which contains amide linkage (Fig. 1d) as an interaction site with foreign objects such as dyes (Allafi et al. 2020).

Keeping in view the advantages of microwave rays for colorant extraction and plant phenolics as bio-mordants to develop colorfast shades, the aims of the current study have been:

a) To improve extraction of colorant from *Nyctanthes arbor-tristis* flowers under the influence of microwave radiations
b) To see changes in the nature of fabrics after radiations
c) To check sustainability of data by statistical optimization of dyeing conditions
d) To develop new fast shades under selected conditions of mordanting and dyeing

Materials and methods

Collection of materials

Flowers of haar singhar were purchased, washed with tap water, dried, and ground finely to get fine powder. After sieving, the uniform sieved powder was used for further

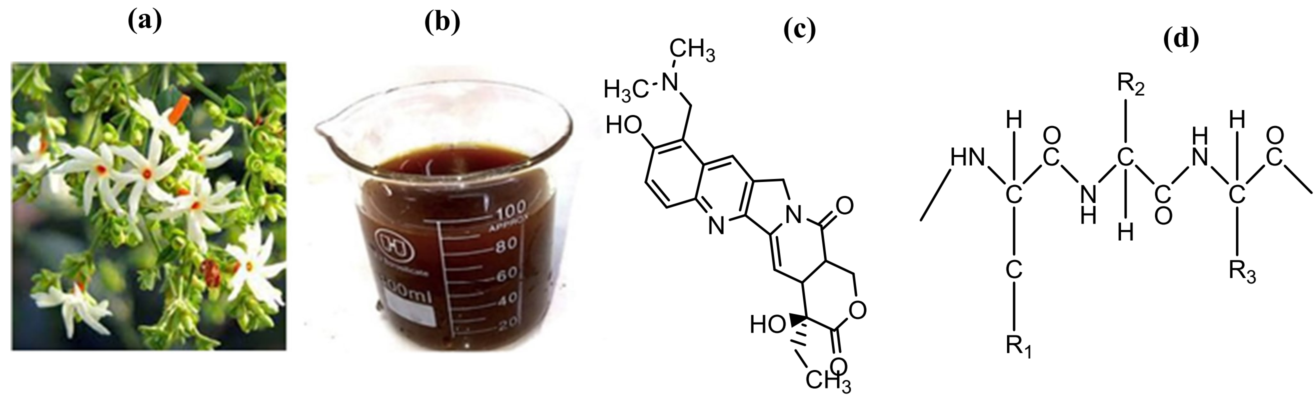


Fig. 1 Haar singhar (**a**), Haar singhar extract (**b**), *Nyctanthes arbor-tristis* (**c**), functional unit of wool (**d**)

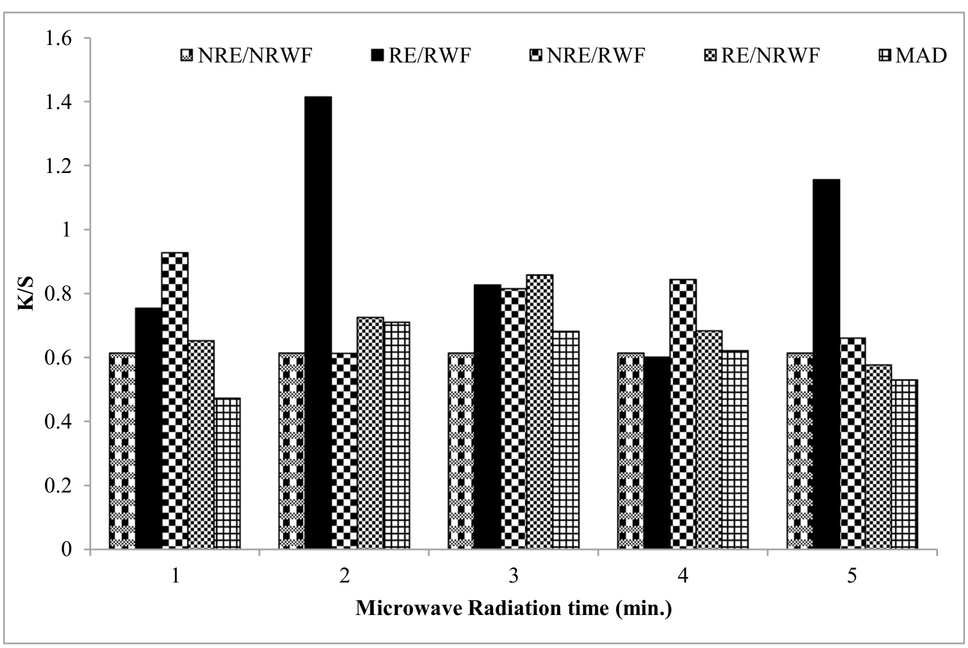
extraction. Wool fabrics were obtained from the textile market. The fabric has been rinsed with lukewarm water containing 1 g/1 L of neutral soap at 45 °C for 30 min, for further dyeing and mordanting process. All the chemicals used in extraction, dyeing, mordanting, and rating of color fastness were of commercial scale.

Table 1 Microwave-assisted extraction and dyeing conditions for the coloration of wool fabric from *C. jasmine* flowers

Medium used	Sample code	Radiation time	Dyeing conditions
Aqueous and Acidic	NRCJE/NRWF	1–5 min	45 mL of extract of pH = 7 using 1.5 g/100 mL of Table salt for 45 min at 75 °C
	RCJE/RWF	1–5 min	
	RCJE/NRWF	1–5 min	
	NRCJE/RWF	1–5 min	
	MAD	1–5 min	

NRE non−irradiated extract, *RE* irradiated extract, *NRWF* non−irradiated wool fabric, *MAD* microwave assisted dyeing

Fig. 2 Dyeing of treated and untreated wool using treated and untreated acid



Radiation and extraction processes

The acidic extracts were prepared by boiling 4 g of Coral Jasmine (*C. jasmine*) powder with 25 mL of acidic medium for 45 min keeping powder to a solvent ratio of 1:30. After boiling, the extract has been filtered and used for dyeing and mordanting. The extract and fabrics have been microwave-irradiated for 1–5 min. After irradiation, treated *C. jasmine* extract (RCJE) and untreated *C. jasmine* extract (NRCJE) were used to dye treated (RWF) and untreated fabric (NRWF) at 80 °C for 45 min, keeping the fabric to extract ratio of 1:30. After dyeing, the dyed fabrics have been washed, dried, and subjected to color analysis. The detailed isolation and dyeing process have been narrated in Table 1.

Optimization of dyeing conditions

For natural polyamide fabrics such as silk and wool, it is necessary to find particular dyeing levels to get color fast shades (Fig. 2). In this study, the central composite design of 32 experiments under the response surface methodology (RSM) as statistical method was employed. To see the effect of temperature, dyeing was carried out at 55, 65, 75, 85, and 95 °C. Similarly, dyeing time has also been optimized by

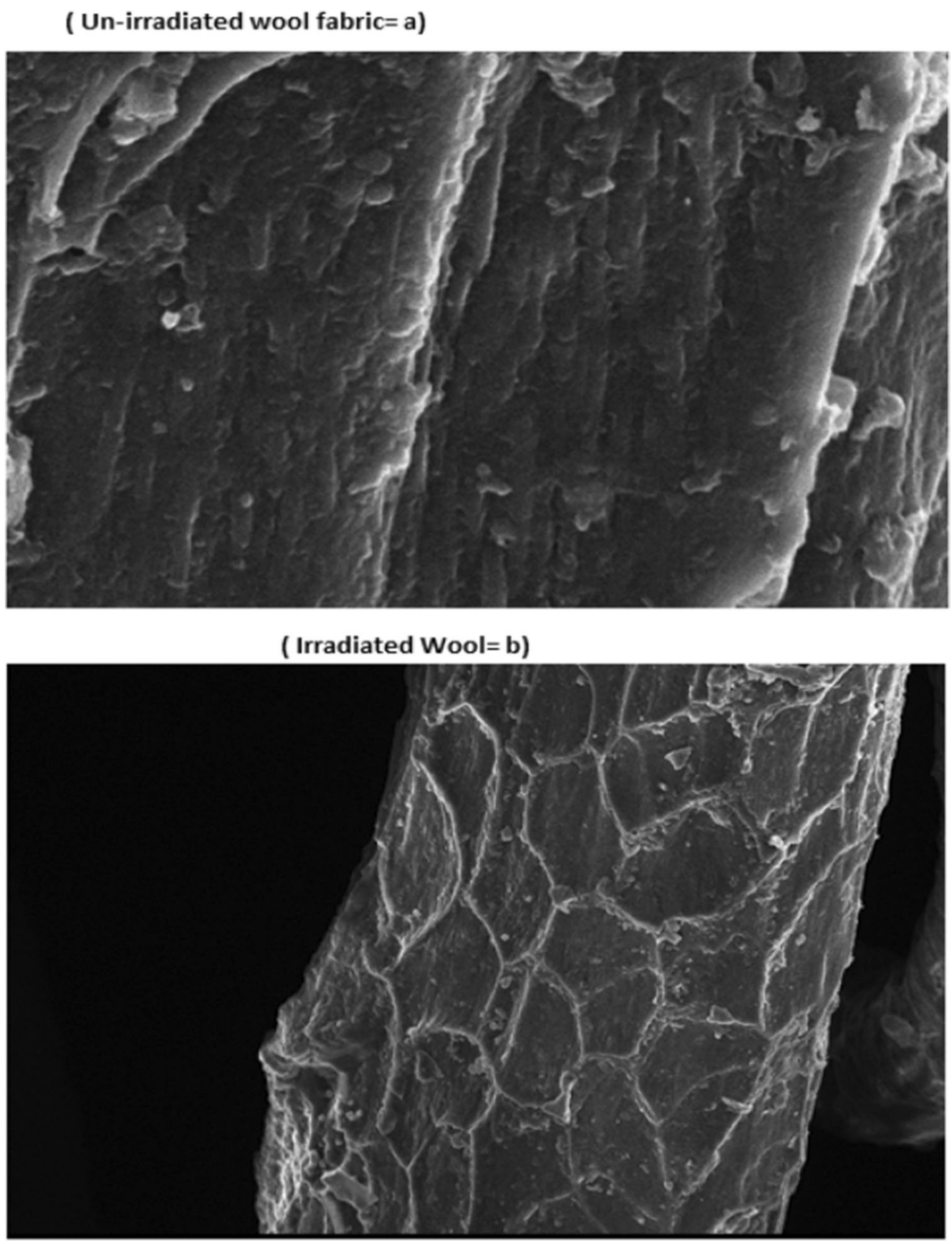


Fig. 3 Scanned images of non-irradiated wool (**a**), irradiated wool (**b**)

dyeing fabrics for 25, 35, 45, 55, and 65 min. In another experimental series, depending on the nature of the fabric, dyeing was performed using haar singhar extracts of different pH values (3, 4, 5, 6, 7) for wool (Fig. 3). In distinction, the dyeing was performed using 0.5–2.5 g/100 mL of table salt as a leveling and exhaustion agent to achieve maximum exhaustion. The detailed sequence and combination of variables have been displayed in Table 2.

Shade development process

To create fast-color new shades at optimal conditions, pre- and post-mordanting use electrolytes of Al^{+3} (aluminum) and Fe^{+2} (iron sulfate) which have been utilized as chemical mordants. For comparative studies, plant phenolics isolated from walnut shells (*Juglans regia*) and pine nut shells (*Pinus gerardiana*) as a source of bio-mordant have been employed. For this purpose, 0.5–2.5 g/100 mL of each mordant has been used at 85 °C for 60 min, keeping mordant to a fabric ratio of 30.1. The rest of the process has been followed by the work of Adeel et al. (2022a, b) (Fig. 4).

Evaluation of fabrics

The surface morphology of irradiated and unirradiated fabrics has been analyzed by scanning electron microscopy (SEM). To find any chemical change in the functional site, spectral images were analyzed using Fourier transform infrared spectroscopy before and after irradiation. Finally,

Table 2 Central composite design with six center runs for optimization of dyeing variables using irradiated acidic extract of *Nyctanthes arbor-tristis*

Experiment no	*A* (pH)	*B* (mL)	*C* (min)	*D* (°C)	*E* (g/L)	Response
1	4	35	35	85	1	*K/S*
2	4	55	35	65	1	*K/S*
3	4	35	35	65	2	*K/S*
4	4	55	35	85	2	*K/S*
5	4	35	55	65	1	*K/S*
6	4	55	55	85	1	*K/S*
7	4	35	55	85	2	*K/S*
8	8	55	55	65	2	*K/S*
9	6	35	35	65	1	*K/S*
10	6	55	35	85	1	*K/S*
11	6	35	35	85	2	*K/S*
12	6	55	35	65	2	*K/S*
13	6	35	55	85	1	*K/S*
14	6	55	55	85	1	*K/S*
15	6	55	55	85	2	*K/S*
16	6	35	55	65	2	*K/S*
17	7	45	45	75	1.5	*K/S*
18	3	45	45	75	1.5	*K/S*
19	5	45	45	75	1.5	*K/S*
20	5	45	45	75	1.5	*K/S*
21	5	45	45	75	0.5	*K/S*
22	5	45	45	75	2.5	*K/S*
23	5	25	45	75	1.5	*K/S*
24	5	65	65	75	1.5	*K/S*
25	5	45	45	55	1.5	*K/S*
26	5	45	45	95	1.5	*K/S*
27	5	45	45	75	1.5	*K/S*
28	5	45	45	75	1.5	*K/S*
29	5	45	45	75	1.5	*K/S*
30	5	45	45	75	1.5	*K/S*
31	5	45	45	75	1.5	*K/S*
32	5	45	45	75	1.5	*K/S*

A extract pH, *B* extract volume, *C* dyeing time, *D* dyeing temperature, *E* salt the color characteristic (*K*/*S* and L^*, a^*, and b^*) values of all dyed fabrics have been investigated through a color spectrophotometer CS-410 (China) at the Department of Chemistry, Government College University, Faisalabad, Pakistan. The rating for colorfastness properties of the selected shades has been evaluated using ISO standard methods of light, rubbing, and washing in the Department of Applied Chemistry.

Results and discussion

Nowadays, microwave radiation has become a sustainable and leveled source of isolation of functional molecules from plants (Hosseinnezhad et al. 2022). These rays uniformly heat the material, transfer the energy to break the core of peanut cell wall, and make the promising interaction of functional potent-isolate (FPI) with solvent (Adeel et al. 2022b). This process is called mass transfer into solvent through less consumption of solvent energy and economy. Thus, this effective solid (plant material) and solvent interaction enhances the yield of a particular moiety (colorant) which is observed onto fabric upon dyeing (Yameen et al. 2022). In this study, the usage of microwaves has been done both for the extraction of color from haar singhar flower (HSF) and for surface modification of fabric to get a good yield (*K*/*S*) (Yameen et al. 2022). The results in Table 2 show that using acidic medium dyeing of wool fabric with HSF extract before radiation has given a better yield ($K/S = 0.6137$). But after 2-min exposure, the dyeing of molecular waves exposed wool (RF) with MW revealed neutral extract (acidic extract) has given an excellent yield ($K/S = 1.4149$). The results show that before radiation the dyeing of fabric with haar singhar flower-based acidic extract (HSF) produced a low yield ($K/S = 0.6137$). But after irradiation for up to 2 min, the wool fabric dyeing using haar singhar flower-based acidic extract (HSF) has given the highest yield ($K/S = 1.4149$). This is because the nature of flower potent isolates, i.e., nyctanthin, the nature of the fabric, and mode of isolation, i.e., MW rays, play their roles in giving better yield. These rays rupture plant cell walls in less time and evolve

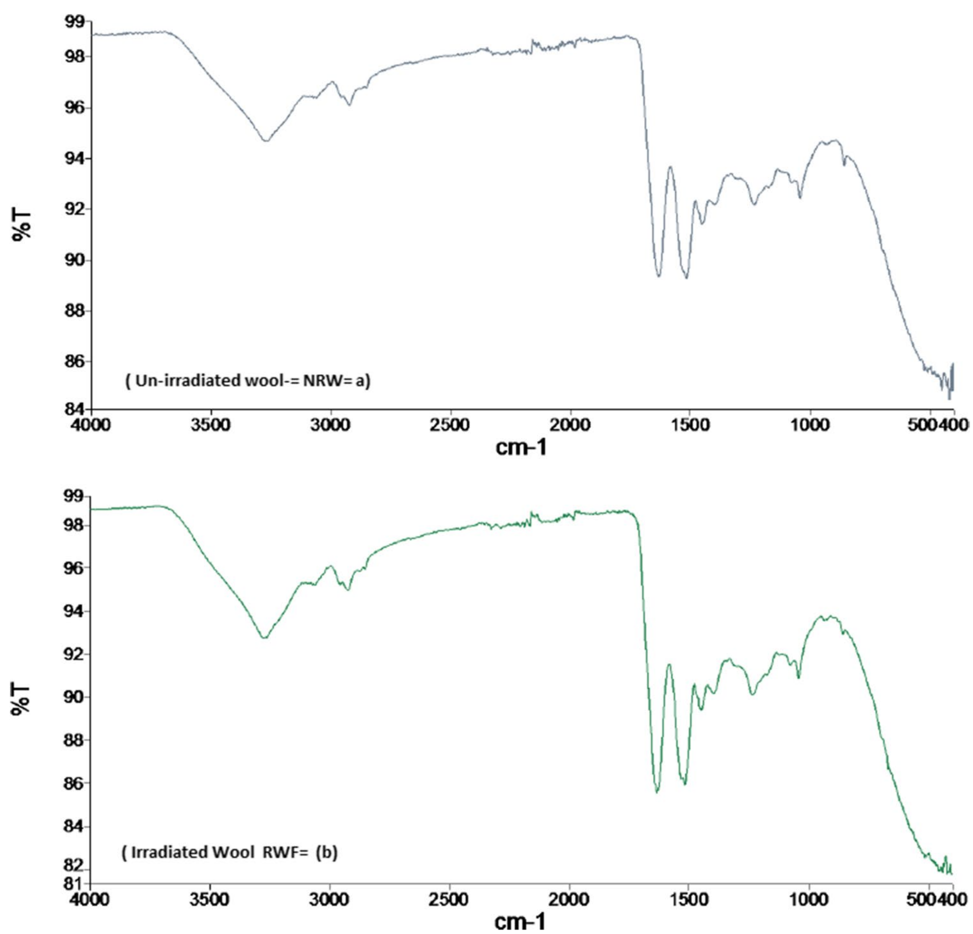


Fig. 4 FTIR images of non-irradiated wool (**a**), irradiated wool (**b**)

Table 3 Optimum results of dyeing of wool fabrics by using haar singhar extract in acidic medium microwave

Radiation time	Conditions	*L**	*a**	*b**	*C**	*h**
CTRL	NRE/NRWF	80.28	−0.29	15.30	15.31	91.07
1 min	NRE/RWF	74.42	0.79	17.09	17.11	87.35
2 min	RE/RWF	75.28	−1.18	27.88	27.90	92.41
3 min	RE/NRWF	76.99	0.05	20.90	20.90	89.85
4 min	NRE/RWF	76.49	0.07	19.69	19.69	89.81
5 min	RE/RWF	74.63	−0.25	24.03	*24.03*	

Control without radiation, *NRE* non−irradiated extract, *NRWF* non−irradiated wool fabric, *RE* irradiated extract, *RWF* irradiated wool fabric

molecules that show effective product upon dyeing (Adeel et al 2022b; Majumder et al. 2020). On the other hand, the rays tune the woolen fibers so that under acidic conditions, the active sites interact with the colorant functional group and sorb dye to their maximum extent. Upon washing, less dye is detached, and a high yield is observed. Hence, isolation should be done in acidic conditions, and the extracting colorant should be applied onto the wool

Table 4 Central composite design with six center runs for optimization of dyeing variables using irradiated acidic extract of *Nyctanthes arbor-tristis*

Experiment no	*A*	*B*	*C*	*D*	*E*	Response
1	4	35	35	85	1	0.5985
2	4	55	35	65	1	0.3575
3	4	35	35	65	2	1.1678
4	4	55	35	85	2	0.6133
5	4	35	55	65	1	0.7056
6	4	55	55	85	1	0.4042
7	4	35	55	85	2	0.9495
8	8	55	55	65	2	0.4320
9	6	35	35	65	1	0.3933
10	6	55	35	85	1	0.4196
11	6	35	35	85	2	0.8920
12	6	55	35	65	2	0.4058
13	6	35	55	85	1	0.7224
14	6	55	55	85	1	1.1540
15	6	55	55	85	2	1.4475
16	6	35	55	65	2	0.4226
17	**7**	**45**	**45**	**75**	**1.5**	**1.5793**
18	3	45	45	75	1.5	0.8642
19	5	45	45	75	1.5	1.4514
20	5	45	45	75	1.5	1.1273
21	5	45	45	75	0.5	0.6654
22	5	45	45	75	2.5	0.5742
23	5	25	45	75	1.5	0.7508
24	5	65	65	75	1.5	0.6175
25	5	45	45	55	1.5	0.6813
26	5	45	45	95	1.5	0.7404
27	5	45	45	75	1.5	0.6125
28	5	45	45	75	1.5	0.4972
29	5	45	45	75	1.5	0.6631
30	5	45	45	75	1.5	0.6729
31	5	45	45	75	1.5	0.6072
32	5	45	45	75	1.5	0.7196

A extract pH, *B* extract volume, *C* dyeing time, *D* dyeing temperature, *E* salt after MW exposure for up to 2 min for acceptable results. The results in Table 3 reveal that using an acidic medium; the shade has become much lighter ($L^* = 80.28$), greener ($a^* = -0.29$), and less yellow in tone ($b^* = 15.30$). But after exposure up to 2 min, the shade has been darker ($L^* = 75.28$), greener ($a^* = -1.18$), and much yellower in hue ($b^* = 27.80$). The color coordinates given in Table 2 show that before irradiation, the shade is brighter ($L^* = 80.28$), greener ($a^* = -0.29$), and yellower with a chromacity of $b^* = 15.30$ and saturation. Using optimum conditions, the fabric dyed with acidic extract was darker ($L^* = 75.28$), had a more greenish-yellow hue, and had the size of chromacity ($c^* = 27.90$), and saturation in color ($h = 92.41$).

A set of thirty two experiments have been performed where the interaction of each factor has been observed during the dyeing of wool with haar singhar flower extract after irradiation. It can be seen that MW rays, when employed for 2 min, to both extract and fabric, not only reduces dyeing time and the salt amount and extract volume, which shows that this treatment is cost and time-effective. The role of pH is found to be highly significant because, moving towards the high pH (8), the active sites are not available, and dye molecules are held weekly, whereas at 7 pH, the colorant functional site is firmly interacted with amide linkage of wool through stable bonding to give high color strength. Dyeing for a low time does not accelerate molecules to rush towards the fabric, whereas too much contact time may disturb the dyeing rate by favoring desorption. After dyeing for 45 min, the molecules are sorbed evenly, and the high yield is observed. The results in Table 4 reveal that dyeing of irradiated wool with irradiated 45 mL of extract of 7 pH containing 1.5 g/100 mL of sodium chloride (Sc = NaCl) when employed at 75 °C for 45 min has given excellent results. The statistical analysis given in Table 5 shows that the model used is fit and linear. Individually, the roles of extract pH ($P = 0.000$), extract volume ($P = 0.014$) and contact of fabric with extract i–e dyeing time ($P = 0.036$) are significant. In two-way interaction, the interaction of salt with extract volume is also significant. Hence, jointly, the parameters contribute well to giving excellent results in one or the other.

Applying metal salts has overcome the limitation of shade permanency of natural dyes. But salts of Ni, Co, Cu, and Cr, etc. have been found carcinogenic and have now been replaced by plant-based molecules. In this study, the electrolytes of iron ($FeSO_4$) and aluminum have been employed to develop colorfast gamuts. The results show that 1 g/100 mL of electrolyte of Al Al^{+3} salt before dyeing of wool with acidic *C. jasmine* extract and 1 g/100 mL of Al^{+3} salt after dyeing has given excellent results (Figs. 5a and 6a). The color coordinates showing shade appearance reveal that before dyeing, the color is brighter ($L^* = 77.04$), reddish yellow ($a^* = 1.51$, $b^* = 25.74$) with good saturation and chromacity. Upon application before dyeing, mordanting with 1% Al salt, the shade becomes little darker ($L^* = 73.69$) and reddish yellow ($a^* = 1.31$, $b^* = 39.37$) in hue with high chromacity and low saturation in color (Table 6). The application of 2.5 g/100 mL of iron salt (Fe^{+2}) before dyeing has given a darker shade ($L^* = 69.86$) with reddish yellow hue ($a^* = 3.16$, $b^* = 31.5$), having low saturation but high chromacity in color Similarly, the utilization of 2.5 g/100 mL of iron (Fe^{+2}) salt after dyeing has developed darker shades ($L^* = 62.61$) with a reddish yellow hue ($a^* = 7.13$; $b^* = 36.89$), showing high chromacity with less saturation. Comparatively using iron electrolytes ($FeSO_4$), the implementation of 2.5 g/100 mL of iron salt before dyeing and 2.5 g/100 mL of Fe^{+2} salt after dyeing of wool with haar singhar extract has given excellent results.

The excellent color strength is due to the interaction of metal electrolytes with colorants and wool amide linkage. Al lacks d orbital, so it cannot change shade but only makes the color bright. But iron utilizes electrons from the d orbital, so the shade becomes darker when interacting with wool's functional sites of colorant and amido linkage of wool. It can be observed that MW treatment to

Table 5 Response surface regression: *K/S* versus pH, volume, time, temperature, and salt using

Source	*DF*	*Adj SS*	*Adj MS*	*F*-value	*P*-value
Model	19	2.66915	0.140482	18.84	0.000
Linear	5	0.92606	0.185212	24.84	0.000
pH	1	0.23222	0.232222	31.15	0.000
Volume	1	0.06931	0.069312	9.30	0.014
Time	1	0.04537	0.045371	6.09	0.036
Temperature	1	0.01461	0.014615	1.96	0.195
Salt	1	0.00550	0.005505	0.74	0.413
Square	4	0.57324	0.143309	19.22	0.000
pH × pH	1	0.50281	0.502814	67.44	0.000
Volume × volume	1	0.02180	0.021804	2.92	0.121
2-Way interaction	10	1.11376	0.111376	14.94	0.000
pH × volume	1	0.02421	0.024206	3.25	0.105
pH × time	1	0.00228	0.002282	0.31	0.594
pH × salt	1	0.00220	0.002204	0.30	0.600
Volume × time	1	0.01163	0.011626	1.56	0.243
Volume × salt	1	0.02692	0.026921	3.61	0.090
Error	9	0.06710	0.007456	—	—
Lack-of-fit	4	0.03769	0.009422	1.60	0.306
Pure error	5	0.02942	0.005883	—	—
Total	28	2.73626	54.7957	—	—

A pH, *B* volume, *C* time, *D* temperature, *E* salt both extract and fabric has allowed taking less mordant to make a firm, level, and uniform metal dye complex onto fabric. Hence, the shade made before and after the application of chemical mordant has provided colorfast gamuts.

Due to the toxicity of some metal salts, the state of the art of shade development has been replaced with antiviral, antioxidant, and antibacterial-based plant functional moieties (Yameen et al. 2022). The results show that extracts from 1.5 g of walnut shell powder before dyeing (pre-bio-mordanting) of wool with *C. jasmine* extract and the extract of 0.5 g of walnut shell powder after dyeing (post-bio-mordanting) has developed colorfast gamuts. Similarly, mordanting with extract from 1.5 g of pine nut shell powder before (pre-bio) and after dyeing (post-bio) has developed excellent shades. Comparatively, pine nut shell containing catechin, a form of tannin after dyeing, has developed a brighter shade ($L^* = 76.94$) with yellowish green hue ($a^* = -0.02$; $b^* = 12.28$) of good chromacity and saturation. Thus bio-mordanting has not only been made more sustainable and ayurvedic but also colorfast with the introduction of new shades. Hence, it is revealed that Al as pre-chemical and Fe as post-chemical are suitable to get new gamuts, whereas walnut as post- and pine nut as pre-mordant are found to be excellent for high-strength tints.

The fastness properties of natural dyes are always dependent upon chemical and bio-mordanting. When these mordants are employed at a particular level before and after dyeing, colorfast shades are produced (Table 7). Using metal salts, the complex formation of fabric creates a strong interaction between the dye and metal. In contrast, plant phenolics utilize the –OH group to make extra H-bonding with fabric and dye to develop colorfast shades.

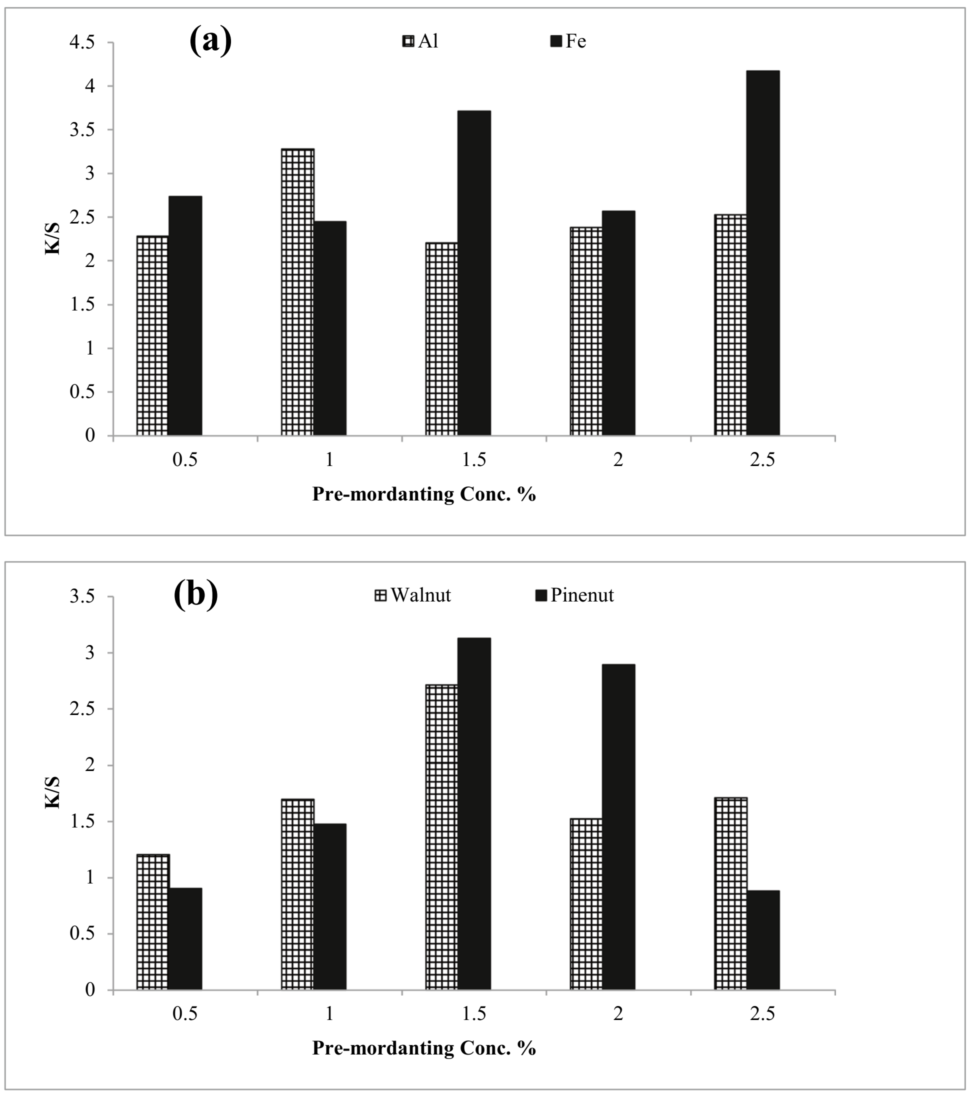


Fig. 5 Pre-chemical mordanting (**a**) and pre-bio-mordanting (**b**)

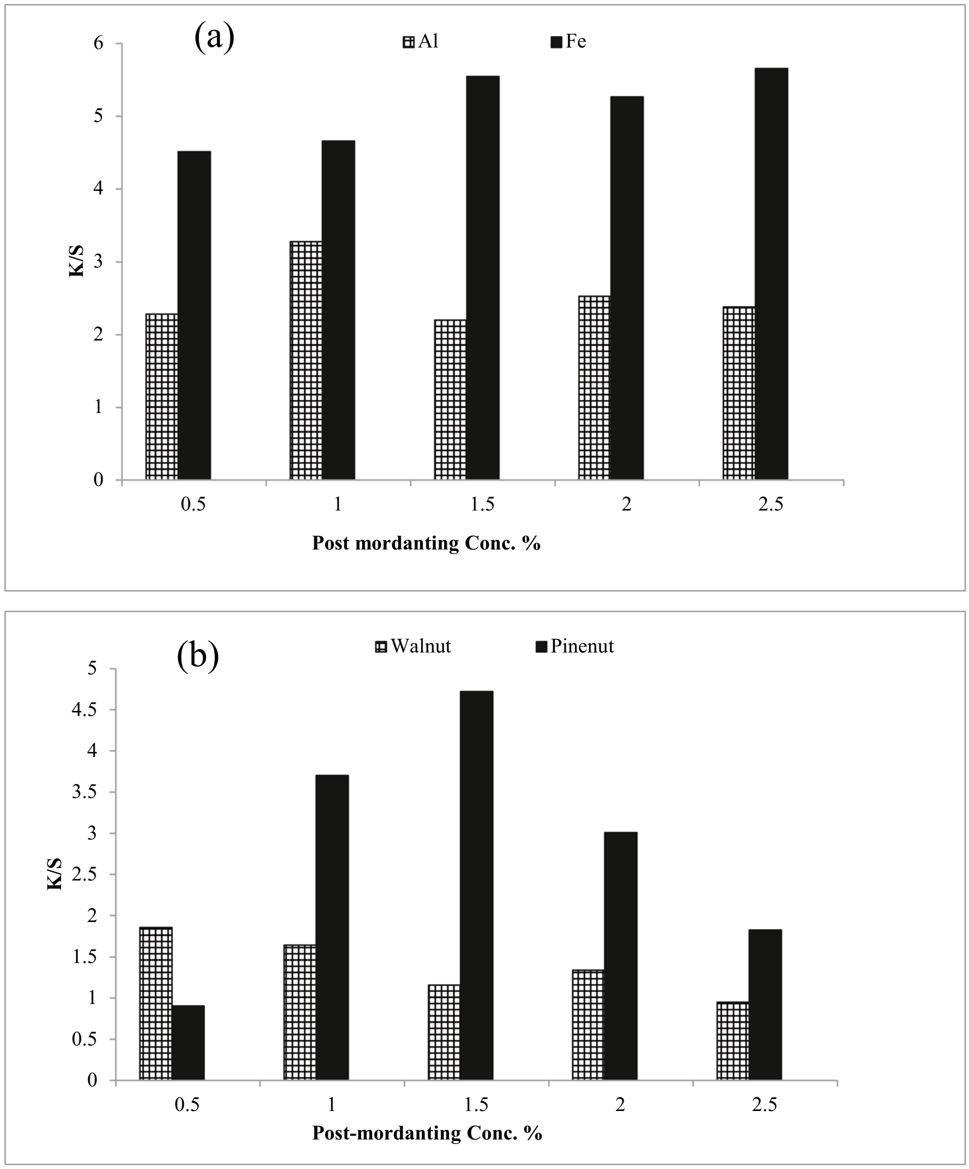


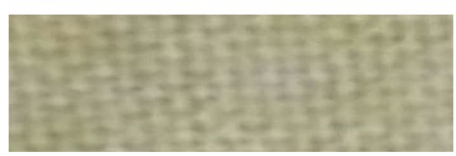
Fig. 6 Post-chemical mordanting (**a**) and post-bio-post-mordanting (**b**)

The addition of the benzenoid ring, mode of interaction, and inclusion of MW rays has played their role in resisting the colorfast shade to fade (Adeel et al. 2021a, b; Yameen et al. 2022). Upon assessment of dyed-mordanted fabrics under ISO standards to light, washing and rubbing, good to excellent ratings have been observed (Table 6). Hence, using the optimal amount of chemical and bio-mordants before and after dyeing has improved the color behavior of *C. jasmine* for wool dyeing. For future studies, it is recommended that such green technologies should be employed to isolated colored pigments from new dye yielding plants for eco-friendly and eco-labelled products.

Conclusion

Plant-based potential molecules such as natural dyes are now gaining importance, wherever the valorization of their valuable waste as pollution-free active ingredients for fabric dyeing has gained worldwide fame. Adding medicinal-based plant phenolics as shade developers and eco-friendly chemical salts to form new shades on wool with flower extract has opened a new dimension. The utilization of eco-friendly tools such as microwave rays for the exploration of nycthanthin from *C. jasmine* flowers as a source of yellow natural dye for wool coloring has been made.

Table 6 Color coordinates and shades of selected mordanted-dyed fabrics

Mordanting conditions	$L*$	$a*$	$b*$	$C*$	$h*$	Shade
Without mordant	80.28	-0.29	15.30	15.31	91.07	
Al (1% Pre)	73.69	1.31	39.37	39.4	88.11	
Fe (2.5% Pre)	69.86	3.16	31.5	31.65	84.27	
Walnut (1.5 % Pre)	75.81	0.15	20.5	20.5	89.59	
Pinenut (1.5 % Pre)	77.01	0.11	12.13	12.13	89.51	
Al (1% Post)	77.04	1.51	25.74	25.74	90	
Fe (2.5% Post)	62.61	7.13	36.89	37.58	79.06	
Walnut (0.5% Post)	77.23	-0.56	16.12	16.13	91.99	
Pinenut (1.5% post)	76.94	-0.02	12.28	12.28	90.11	

This tool has reduced the dyeing levels and the number of mordants to get colorfast shade onto wool fabric. It is suggested that leftover materials' new dye-yielding plants can be introduced as a source of natural dyes for textiles under sustainable tools such as microwaves and ultrasonic waves. Similar for making dye effluent more pollution free, the

Table 7 Color fastness of optimum mordanted-dyed wool fabrics

Mordant concentration	*LF*	*WF*	*DRF*	*WRF*
Without mordant	4	3/4	4	3/4
Al (1% pre)	5	4/5	5	4/5
Fe (2.5% pre)	5	4/5	5	4/5
Walnut (1.5% pre)	5	4	4	4
Pine nut (1.5% pre)	5	4/5	5	4/5
Al (1% post)	5	4	5	4
Fe (2.5% post)	5	4	5	4
Walnut (0.5% post)	5	4	4/5	4
Pine nut (1.5% post)	5	4/5	5	4/5

LF light fastness, *WF* washing fastness, *DRF* dry rubing fastness, *WRF* wet rubbing fastness

inclusion of sustainable metallic salts and plant phenolics can be employed in the dyeing of natural and synthetic fabrics.

Author contribution M.Phil student Miss Sehrish Ahmad conducted the experiments; Dr. Shahid Adeel supervised the whole work; and Dr. Fatima Batool and Dr. Noman Habib Muhammad guided scientifically for the smooth running of the work. Dr. Muhammad Jawwad Saif characterized the fabrics, and Mr. Muhammad Aftab analyzed the whole data statistically to get significant results.

Data availability The work is from M.Phil studies.

Declarations

Ethical approval We approve that this manuscript is part of M.Phil studies.

Consent to participate and publish We consent to publish our work of M.Phil studies, to which all the authors jointly contributed.

Competing interests The authors declare no competing interests.

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