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RESEARCH ARTICLE

Assessment of wild turmeric–based eco-friendly yellow natural bio-colorant for dyeing of wool fabric

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Abstract

The current study has been designed to observe the coloring efficacy of wild turmeric–based natural yellowish colorant for wool dyeing under microwave (MW) treatments. Extracts and fabrics have been exposed to MW treatment for up to 10 min. Surface morphology and changes in the fabric's chemical nature before and after radiation have been studied through SEM and FTIR, respectively. The results obtained after a series of experiments show that using 45 mL of aqueous extract (pH = 5) in the presence of 1.5g/100mL of table salt as an exhausting agent at 75°C for 45 min has displayed outstanding color depth (K/S) onto microwave-treated wool fabric. On applying biomordants, it has been found that acacia extract (1.5%), pomegranate (2%), and pistachio extracts (1.5%) before dyeing, whereas acacia (1%), pomegranate (1%), and pistachio extracts (2%) after dyeing, have shown colorfast shades of high strength. Comparatively, salts of Al (1.5%) and Fe (1%), and T.A (2%) before dyeing, while salts of Al (1%) and Fe (1.5%) and T.A (1.5%) after dyeing, have given the best results. Generally, it has been originated that salt of Fe (1.5%) as a post-chemical mordant and pomegranate extract (1.5%) as a post-bio-mordant have displayed wonderful color strength. It very well may be inferred that MW treatment, being naturally protected, has just superior the varying strength of colorants on wool fabric. Adding biomordants has transformed the strategy into a more sustainable one.

Keywords Acacia · Bio-anchors · Colorfastness · MW rays · Pistachio hulls · Pomegranate · Sustainability · Wild turmeric

Introduction

Sustainably using natural dyes necessitates using natural products that are both economically and environmentally viable (Baseri 2022; Adeel et al. 2022a). Natural color that is renewable, biodegradable, sustainable, and non-toxic is becoming increasingly popular worldwide (Haji and Naebe 2020; Nathan and Rani 2021; Patel and Kanade 2019). Surprisingly, their feces can be recycled and turned into fertilizer (Rather et al. 2019). The widespread consciousness of zero liberation emissions, global warming, and ecosystem health has sparked a worldwide interest in green products (Mia et al. 2022). Textile dyeing is one of the most ecologically constructive and destructive businesses. In synthetic color dyeing methods, extreme quantities of water and chemicals are used (Khattab et al. 2020; Singh and Sheikh 2021). Because of the numerous negative environmental resurgences of industrial development, such as universal heating and air and water pollution (Haque et al. 2022; Hasan et al. 2022), it is vital to consider the environmental dimension of manufacture and research in every arena (de Marco et al. 2019; Haji et al. 2020). Most synthetic dyes contain toxic and cancer-causing environments, and when released into the environment, they contaminate the environment (Mansour and Ben Ali 2021). These industries shed potentially dangerous chemicals into bodies of water and the environment,

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causing allergic, poisonous, carcinogenic, and severe skin reactions (Alebeid and Pei 2020; Gan et al. 2021). So, after careful observation, international environmental organizations have started to spread awareness about the acute toxic effects of effluent carcinogens and the benefits of green products to shift their focus to natural products. Natural dyes have distinct color chemistry compared to other natural materials (Thakker 2021; Haji 2020; Agrawal and Chopra 2020). Natural dyes have become more appealing because they provide special colors (Hu et al. 2019; Haji and Rahimi 2020). Natural dyes applied to wool-dyed cloth with natural mordants such as pomegranates improve dye uptake and produce the desired color tone (Kiran et al. 2020; Eser and Yavas 2021). Furthermore, these dyes have anti-inflammatory, anti-hemolytic, antipyretic, antifungal, antioxidant, and antibacterial characteristics, making them useful in medicine (Rai et al. 2020; Hosseinnezhad et al. 2021). These dyes are a safe and environmentally friendly way to color textiles and other materials (Rodiah et al. 2022). However, it has been found that these dyes have some issues, such as low production yield and poor fastness rating. Although old methods have been utilized for rapid treatment with efficient results, modern methods have been included in green products.

Microwave radiation is one of the most cutting-edge approaches among modern technologies (Baig et al. 2021). These rays use a solid-liquid transfer technique to maximize biomolecule interaction with the solvent (Chen et al. 2020). Furthermore, this sustainable process of microwave heating has the largest benefit that it yields (Arain et al. 2021; Phan et al. 2020. This procedure fine-tunes the cloth surface, ready to take the dye molecule, resulting in the maximum dyeing rate (Majumder et al. 2020). These rays disintegrate clusters of dye molecules into small units, which sorb into voids of surface-modified fibers promisingly. Hence, MW rays are extremely fast and uniform, resulting in a procedure that saves energy and time. Another benefit is that the size of the equipment, waste, and utilization of solvent materials is reduced (Buyukakinci et al. 2021; Jafari et al. 2019). Mordanting is an old art to improve shade depth, but some toxic salts acting as bridging agents must be replaced with green anchors. These green anchors have mostly planted phenolics that produce new colorfast shades and transfer their good characteristics into fabric upon dyeing. By creating complexes with the natural dyes in the fiber, biomordants are traditionally used in the dyeing process to increase fiber affinity and hence improve the color fastness of dyed textiles.

Wild turmeric (*Curcuma aromatica*) is a fragrant therapeutic plant that belongs to the Zingiberaceae family. It has a wide range of pharmacological properties. It is well known in India for ethnobotanical uses such as stimulant, carminative, snakebite remedy, and beautifying uses (Behura et al. 2021). Its extract has been used to treat gastrointestinal issues, stiff pain, provocative disorders, injuries, skin contaminations, and insect stings, among other things (Umar et al. 2020). The aim of current research is as follows:

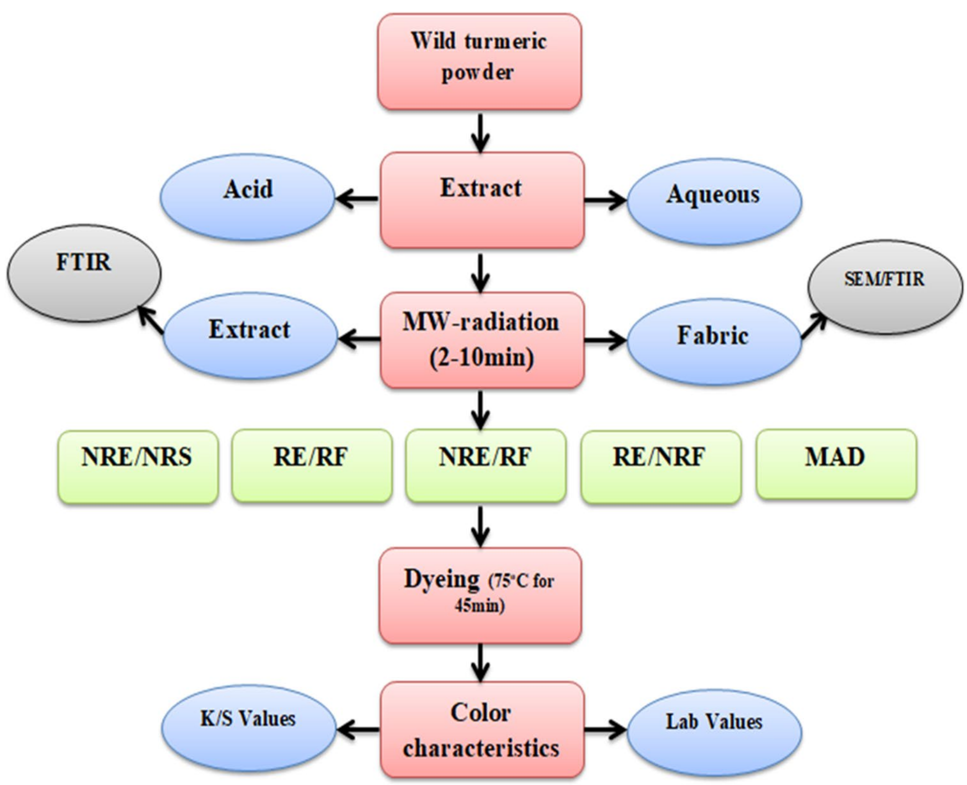

Fig. 1 Schematic view of extraction and application of colorant from wild turmeric for wool

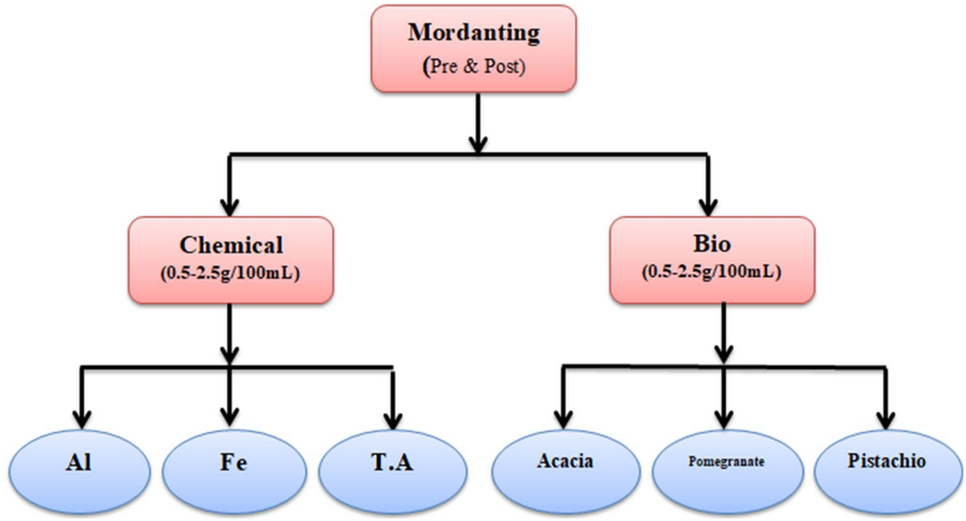

Fig. 2 Schematic view for shade developing process using sustainable chemical and bio-mordants

a) To use MW rays for improving the color yield from wild turmeric.
b) To observe changes at surface of wool and changes in the functional point, i.e., amido linkage of wool through SEM and FTIR.
c) To check the validity of data under central composite design through statistical tool.
d) To get the mordanting level for uniform shades to assent fastness of shades as per standard ISO methods.

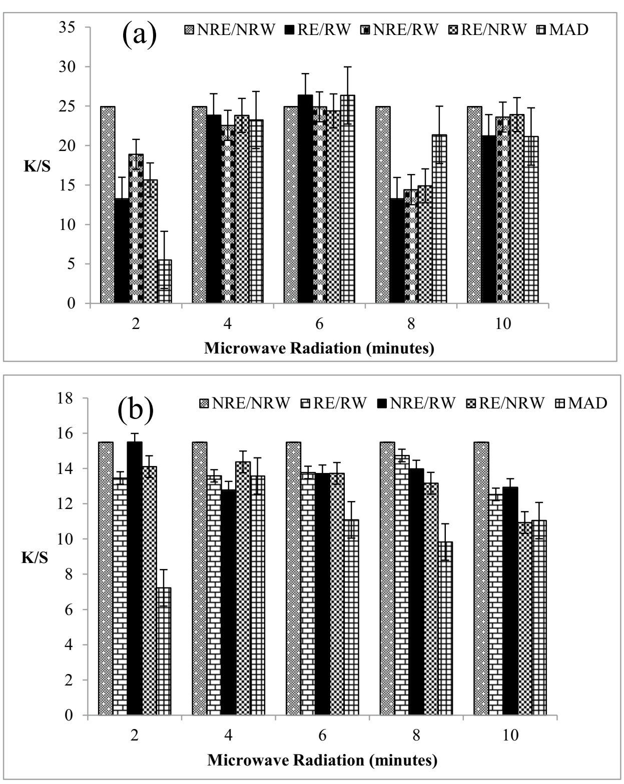

Fig. 3 Application of microwave irradiated and un-irradiated aqueous (**a**) and acidic wild turmeric extract (**b**) for dyeing of irradiated and un-irradiated wool fabrics

Materials and methods

Collection of materials

Wild turmeric (*Curcuma aromatica*) is a source of natural yellow dyes. Interestingly, pomegranate rinds (*Punica granatum*), pistachio (*Pistacia vera*), and acacia bark residue (*Acacia nilotica*) as a wellspring of polyphenolic anchors have been procured from the store, handled, and utilized. Chemical mordants such as Al, Fe, and tannic acid salts have been procured and employed for shade fastness. Wild turmeric rhizomes for the detachment of natural color and biomordants have been grounded finely and through a filter of 20 lattice size to acquire a powder of constant molecule size. Wool fibers have been washed with nonpartisan cleanser at 80°C for 30 min to prepare them for shading.

Irradiation and extract process

Fine plant powder divided (4g) has been boiled with 100mL of aqueous and acidic media for 45 min to isolate colorants, having a media to powder the ratio of 25:1. The extract and fabric have been microwaved for up to 10 min, utilizing a powerful level (NRWF). Treated and untreated extracts (NRE) have been utilized to color-treated (RWF) and untreated fabrics by keeping an extract to fabric proportion of 25:1 at 75°C for 45 min; the complete arrangement of work is given in Fig. 1.

Table 1 Coordinates of selected fabrics dyed before and after radiation in a suitable medium

Medium	Time (minutes)	Sample code	K/S	*L**	*a**	*b**	*c**	*h*
Aqueous	Control	NRE/NRWF	24.941	71.47	8.06	87.54	87.91	84.71
	6 min	RE/RWF	26.393	68.68	8.68	84.68	85.13	84.15
Acid	Control	NRE/NRWF	15.483	68.31	5.40	71.73	71.93	85.70
	2 min	NRE/RWF	15.500	68.20	6.02	68.01	68.28	84.94

*L**= lighter/darker; *a**= redder/greener; *b**= yellower/bluer; *c** = chromaticity; *h*= hue

Optimization of dyeing conditions

Different coloring boundaries like temperature, time of coloring, pH of coloring, and extract capacity improved statistically by utilizing the response surface methodology. To see the impact of temperature, coloring was completed at 65–85°C for 35–65 min, utilizing 35–65mL of concentrates of 3–7 pH, having 1g/100mL of salt as a debilitating agent concluded a sequence of 32 experiments under the statistical model given in Table 3.

Optimization of mordanting conditions

To further develop the color complexity and colorfastness of fabric dyed under ideal circumstances, pre and post-mordanting were completed at 80 °C for 45 min (Habib et al. 2022). For this reason, 0.5, 1, 1.5, 2, and 2.5 g/100 mL of eco-friendly salt of Al (Alum), Fe (iron sulfate), and tannic acid (T.A.) have been used under selected conditions (Fig. 2). In parallel observations, 0.5–2.5 g/100 mL of concentrate of biomordants like pomegranate rinds (*Punica granatum*), pistachio (*Pistacia vera*), and acacia bark powder (*Acacia nilotica*) have been utilized at 80 °C for 45 min, keeping the mordant to fabric proportion of 25:1 before and after dyeing.

Evaluation of fabric and extract

The surface morphology of optimal irradiated and un-irradiated fabrics was investigated using scanning electron microscopy (SEM model Tescan; 5 kV, image size= *x* 1000). The variations in the distinctive peaks of the functional element of wool were observed using FTIR analysis. Finally, all the colored fabrics have been investigated in the Lab and LCh system using data color SF 600 (USA). For fastness rating, ISO standard methods of light (ISO 105-B02), washing (ISO 105-C03), and rubbing (ISO 105-X12) have been used and results have been observed as per the greyscale.

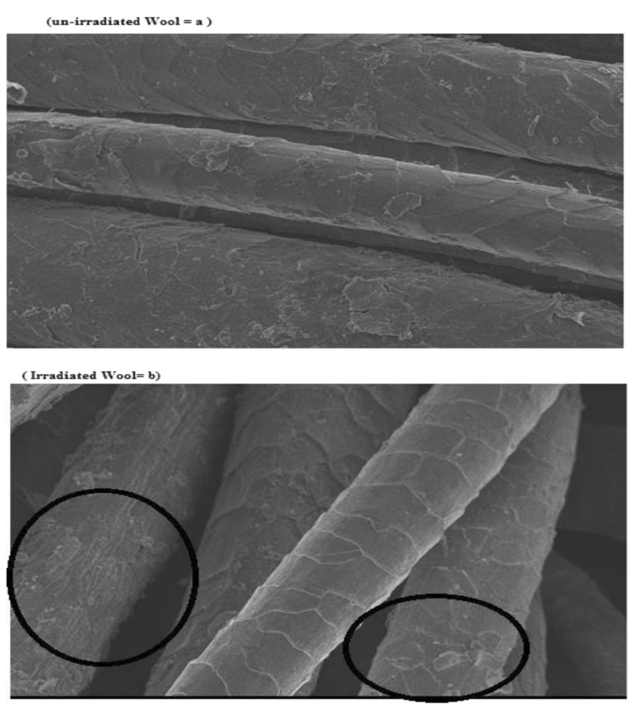

Fig. 4 SEM images of wool fabric before (**a**) and after (**b**) microwave treatment

Results and discussion

Microwaves in natural products are being used based on their fast leveling, uniform, and energy-cost-effective nature (Gala et al. 2022; Wang et al. 2021). These rays evolve the functional molecule at a particular level by rupturing its boundary without altering the chemical nature of a particular bio-potent molecule (Ticha et al. 2021; Hayat et al. 2022). These rays work via the principle of the powder-solvent mechanism, which takes less solvent for the interaction of colorant to enhance mass transfer kinetics and gives a promising yield (Adeel et al. 2021). This good yield cannot be possible to get if a low level (<6 minutes) of rays is given to the isolation system because the rays cannot break the cell wall (Xie et al. 2019). Similarly, over the level (> 6 minutes) of rays also disturbs the actual function of colorant because, along with potentially isolated curcumin, other bio-molecules are also evolved, which during application affects the actual yield (Gong et al. 2022). The same situation has been observed in our studies. The results reveal that before MW rays, the water-born extract (aqueous) has given good color strength (NRE/NRWF=24.941); upon irradiation up to 6 min, the application of treated extract (RE) has given an excellent

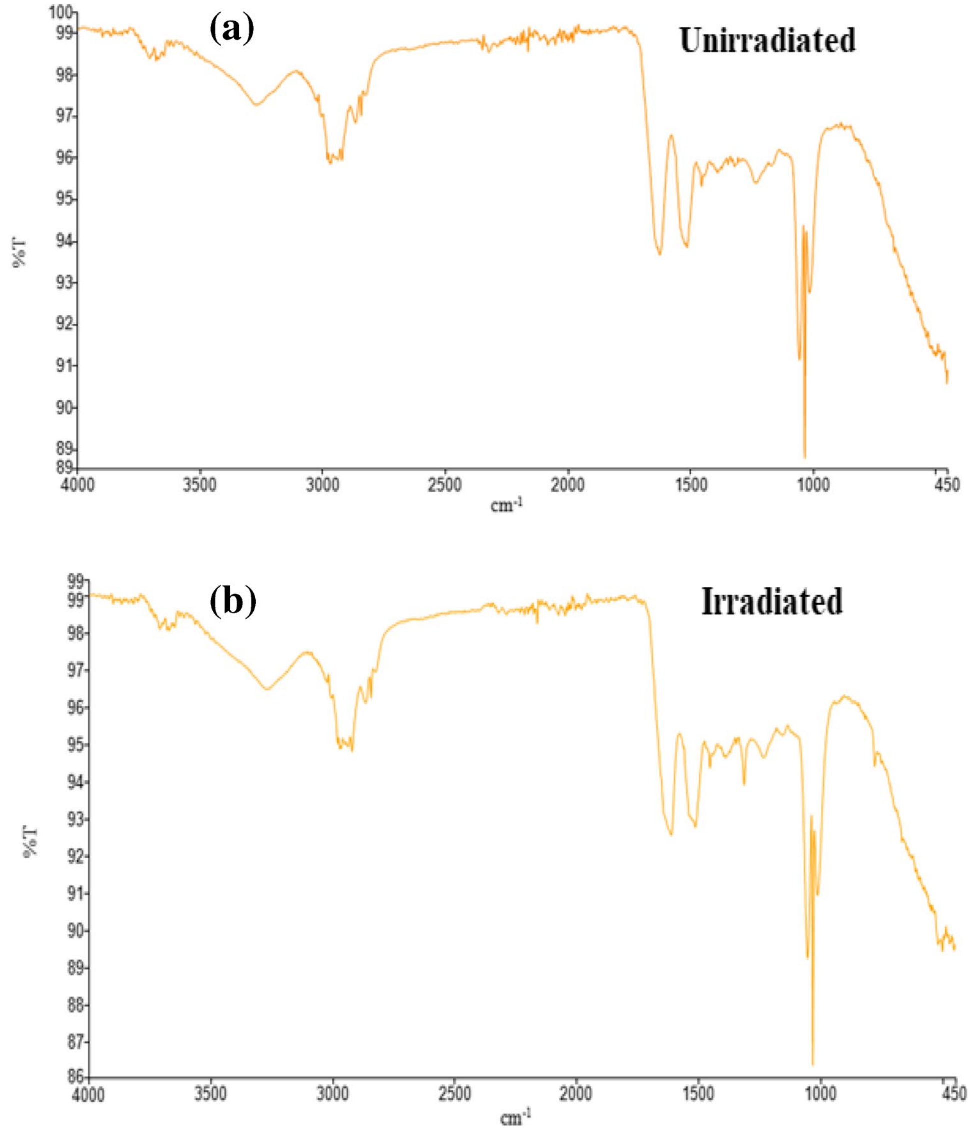

Fig. 5 FTIR spectra of wool fabric before (**a**) and after (**b**) microwave treatment

yield (K/S=26.393) onto the treated wool (Fig. 3a). Similarly, up to 10 min, the treatment of both extract and fabric has given a low yield (K/S=21.209), which might be due to the involvement of other molecules isolated along with curcumin. During dyeing, their appearance has affected shade strength (colorant) strength. The color coordinates given in Table 1 show that before the treatment of extract and fabric (NRE/NRWF), the shade is brighter (L^*=71.47) in appearance and reddish yellowish (a^*=8.06; b^*=87.54). After 6 min of exposure, the shades become darker (L^*=68.68), having a reddish-yellow tone (a^*=8.68; b^*=84.68). Using an acidic medium before treatment of extract and fabric, the shade strength was low (K/S=15.483), having a darker tone (L^*=68.31) but with a less reddish (a^*=5.40) yellow hue (b^*=71.73) given in Table 1 although shade strength was proved to be little (K/S=15.500), having a dark tone (L^*=68.20) with more red but little yellow hue (a^*=6.02; b^*=68.01) shown in (Fig. 3b). Hence, the acidic medium did not support the isolation of curcumin from wild turmeric followed by wool dyeing.

The other aspect is the irradiation of fabric, which imparts its role promisingly to get a high yield after tuning. Work shows that MW rays have scratched the fiber surface, which helps improve its uptake ability. The wool fabric observed under the scanning electron microscope (SEM) shows that in Fig. 4a and b, after irradiation, the wool fabric was peeled, which has given promising results after dyeing. Hence, MW rays have modified the surface physical spectral images before and after irradiation for up to 6 min. The ATR-FTIR spectral images of wool fabric results given in Fig. 5a and b show the stretching peak of –NH (3000–3500 cm^{-1}), the stretching peak C=C (900–1100 cm^{-1}), and the C=O peak (1500–1700 cm^{-1}). After irradiation, their position cannot be altered after microwave treatment for up to 6 min

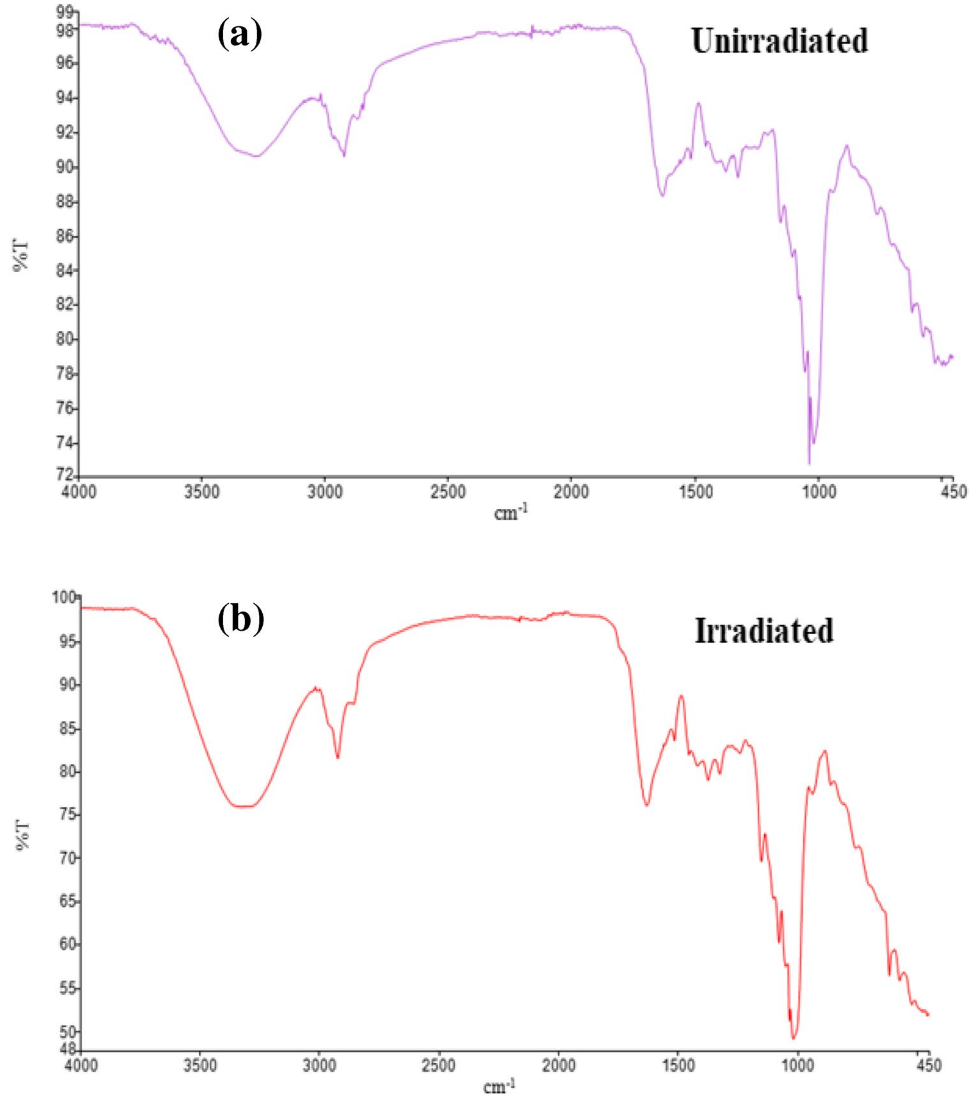

Fig. 6 Spectral view of functional groups present in wild turmeric extract before (**a**) and after (**b**) microwave treatment

(Reference). The ATR-FTIR spectral images of curcumin extract results given in Fig. 6a and b show that before irradiation, the functional spectral peak of –OH was observed near about 3500 cm^{-1} (O–H stretching of the phenol group), C=C was observed at 1599 cm^{-1} (aromatic C=C stretching), and 1501 cm^{-1} (C=O stretching). After irradiation, the spectral peak was not position changed. The functional peaks of –OH, C=C, and C=O were observed simultaneously. The physiochemical analysis shows that MW rays add value to the coloration of wool when dyed with curcumin in the aqueous extract of wild turmeric without altering the chemistry of the fabric. Conclusively, it is recommended that for isolation, aqueous extract, and dyeing, the wool fabric should be MW treated for up to 6 min to get excellent results. Hence, the result in Fig. 3a shows that for excellent color characteristics, isolation should be done in an aqueous medium followed by treatment for up to 6 min for wool dyeing.

Dyeing parameters in wool dyeing always give a promising tint because low or high levels always hinder good results. Dyeing of fabric using a particular volume (45mL) of 5 pH containing 1.5g/100mL of salt has given excellent results when an employee dyed irradiated wool at 75 °C for 45 min after MW treatment for 6 min (Table 2). The low value of extract provides low molecules onto fabric, whereas the high value of extract causes the gathering of aggregates onto fabric. These aggregates do not enter the voids of wool fibers, which mainly remain on the fabric after washing; these unfixed molecules are washed away and give a low tint. Hence, 45mL of aqueous extract should be used after irradiation to get good results. Proteinous fabric dyeing also influences protein extract nature (pH). The highly acidic nature of the extract does not give excellent results. In contrast, moving towards the alkalinity (pH>5), the amido linkage of wool hinders its interaction with the OH of curcumin from wild turmeric.

Table 2 Color strength of fabrics dyed under various conditions employed through versus central composite design

Exp. no.	pH	Volume (ml)	Time (min)	Temperature (°C)	Salt (g/100ml)	F(K/s) color strength
1	4	35	35	85	1	2.4627
2	6	35	35	65	1	3.7640
3	4	55	35	65	1	3.9192
4	6	55	35	85	1	2.1671
5	4	35	35	65	2	4.2763
6	6	35	35	85	2	4.2191
7	4	55	35	85	2	3.6451
8	6	55	35	65	2	2.3453
9	4	35	55	65	1	2.3588
10	6	35	55	85	1	1.6689
11	4	55	55	85	1	1.6132
12	6	55	55	65	1	2.4054
13	4	35	55	85	2	2.1935
14	6	35	55	65	2	2.4531
15	4	55	55	65	2	1.6653
16	6	55	55	85	2	1.7356
17	3	45	45	75	1.5	2.3585
18	7	45	45	75	1.5	5.8977
19	5	25	45	75	1.5	3.7743
20	5	65	45	75	1.5	1.5666
21	5	45	45	75	0.5	2.2314
22	5	45	45	75	2.5	2.3048
23	5	45	25	75	1.5	3.4611
24	5	45	65	75	1.5	3.6442
25	5	45	45	55	1.5	2.4548
26	5	45	45	95	1.5	2.3762
27	5	45	45	75	1.5	3.6076
28	5	45	45	75	1.5	1.5241
29	5	45	45	75	1.5	2.2625
30	5	45	45	75	1.5	6.5322
31	5	45	45	75	1.5	3.7397
32	5	45	54	75	1.5	3.6697

Hence, 45mL of aqueous extract at 5 pH should be used to get excellent results. Salt always acts as a leveling agent, particularly in wool dyeing. The results in Table 2 show that 1.5g/100mL of table salt has exhausted colorant from the extract towards the fabric. This excellent exhaustion has provided an interactive atmosphere between fabric, colorant, and solvent within a short range of attractive forces to give excellent shade strength. A low amount cannot exhaust dye well. In contrast, the utilization of salt above 1.5g /100mL has given over-exhaustion, which has led to the gathering of colorant molecules in the form of aggregates or clusters onto fabric. Poorly fixed colorant molecules are washed away, and a low yield is observed. Hence, it is recommended that 45mL of aqueous extract of 5 pH containing 1.5 g/100mL salt should be used to get effective results. Similarly, dyeing wool with plant pigment also requires particular contact levels. It can be seen that dyeing of irradiated fabric at 75°C for 45 min, using 45mL of aqueous extract of 5 pH containing 1.5g /100mL of salt as an exhaustion agent, has given better results. At low contact levels, the dyeing rate is less, whereas at optimal levels (45 min at 75°C), the equilibrium of the dye bath is disturbed, and low shade strength is found. Statistical analysis given in Table 3 shows that model used for significance of results is fit and linear. For single interaction, the role of extract volume (mL) is pretty significant (P= 0.018), whereas the role of contact of extract with fabric, i.e., dyeing time is also highly significant (P=.002). For two-way interaction (Table 3), heating level in combination with salt amount for exhaustion has been found significant also (P= 0.046) . Overall, MW rays have reduced extract volume, time, and salt amount, which show its effective treatment

Table 3 Statistical analysis for optimization of dyeing variable: individual versus 2-way interaction.

Source	DF	Adj SS	Adj MS	*F*-value	*P*-value
Model	11	14.8176	1.3471	3.21	0.015
Linear	5	9.7876	1.9575	4.67	0.007
pH	1	0.3135	0.3135	0.75	0.399
Volume (mL)	1	2.8812	2.8812	6.87	0.018
Time (minutes)	1	5.9773	5.9773	14.26	0.002
Temperature (°C)	1	0.5519	0.5519	1.32	0.267
Salt (g/100mL)	1	0.2244	0.2244	0.54	0.474
Square	3	4.7314	1.5771	3.76	0.031
pH* pH	1	1.0199	1.0199	2.43	0.137
Time*(minutes) time (minutes)	1	3.4414	3.4414	8.21	0.011
Salt* (g/100mL) salt (g/100mL)	1	0.7367	0.7367	1.76	0.202
2-way interaction	3	3.3264	1.1088	2.65	0.082
pH* volume (mL)	1	0.5637	0.5637	1.35	0.262
Volume*(mL) salt (g/100mL)	1	0.8105	0.8105	1.93	0.182
Temperature*(°C) salt (g/100mL)	1	1.9522	1.9522	4.66	0.046
Error	17	7.1247	0.4191		
Lack-of-fit	14	3.6738	0.2624	0.23	0.977
Pure error	3	3.4510	1.1503		
Total	28	21.9423			

nature. Thus, a high-yielding 45mL extract of 5 pH should be used to dye wool at 75°C for 45 min.

Mordanting in natural dyeing is a key element because this art helps in developing colorfast shades; usually, salts of Al^{+3}, Fe^{+2}, Cr^{+3}, Co^{+2}, Ni^{+2}, etc. are used, but owing to carcinogenic aspects and environmental regulation, only salts of Al and Fe as well as tannic acid and cream of tartar (COT) are preferred (Adeel et al. 2022b). In our studies, the salts

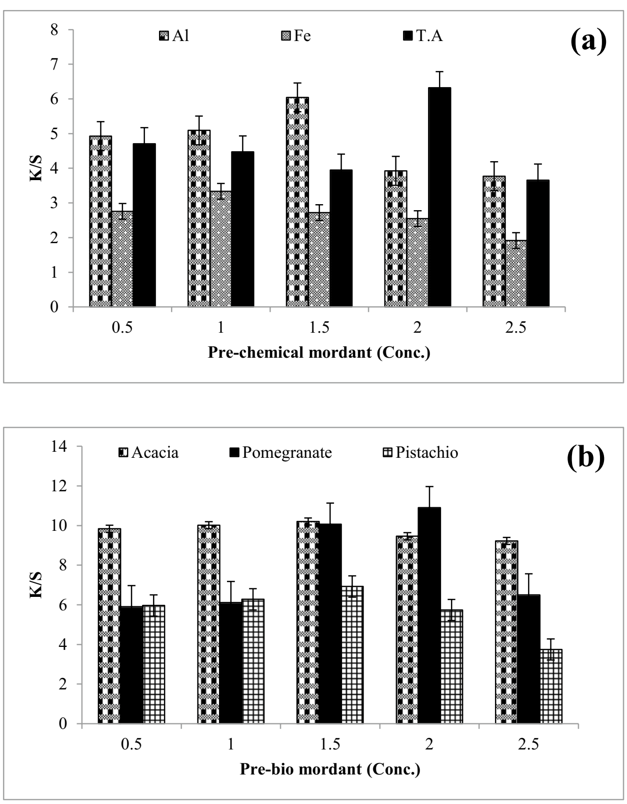

Fig. 7 Chemical mordants (**a**) and bio-mordanting (**b**) before dyeing (pre) of wool with Wild turmeric extracts under selected conditions.

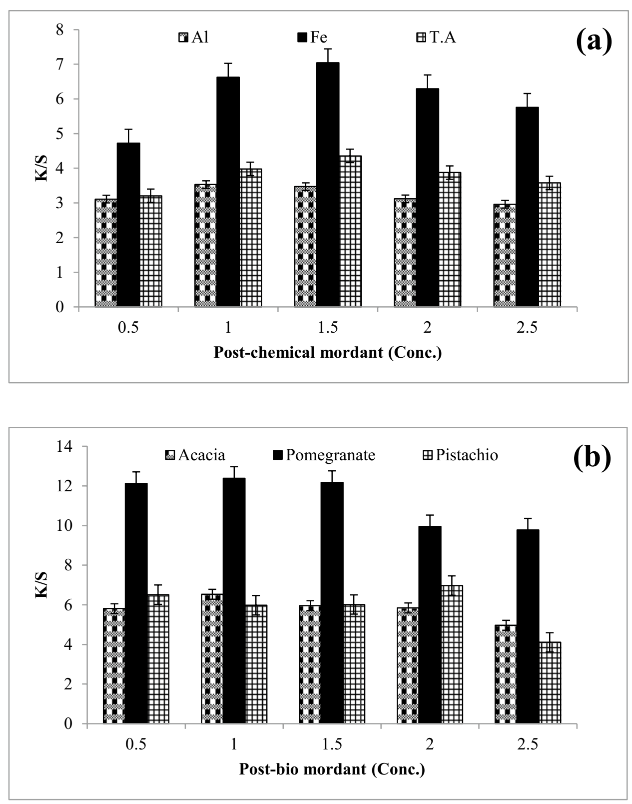

Fig. 8 Chemical mordants (**a**) and bio-mordanting (**b**) after dyeing (post) wool with Wild turmeric extracts under selected conditions

Table 4 Shade variables of optimum dyed and mordanted wool fabrics using wild turmeric extract

Mordant concentration	*L**	*a**	*b**	Shades
Without mordanting (RE/RF)	68.68	8.68	84.68	
Al (1.5% pre)	69.78	4.92	54.03	
Al (1% post)	80.01	-2.82	57.56	
Fe (1% pre)	65.85	2.41	34.10	
Fe (1.5% post)	63.99	6.20	46.60	
T.A (2% pre)	70.50	-0.98	53.11	
T.A (1.5% post)	70.97	-3.49	45.78	
Accacia (1.5% pre)	70.57	-2.97	61.06	
Accacia (1% post)	66.46	0.40	47.74	
Pomegranate (2% pre)	75.54	-4.18	68.91	
Pomegranate (1% post)	72.21	-2.24	67.34	
Pistachio (1.5% pre)	77.12	-3.51	62.75	
Pistachio (2% post)	72.80	-1.97	57.74	

*L**= lighter/darker; *a**= redder/greener; *b**= yellower/bluer

of Al, Fe, and tannic acid (T.A.) have been used. The results given in Fig. 7a show that the application of 1.5g/100mL of Al salt, 1g/100mL of Fe salt, and 2g /100mL of tannic acid before dyeing irradiated wool (RW=6 min) with 45 mL of aqueous extract (5pH) at 75°C for 45 min has given excellent results. Similarly, after dyeing, 1g/100mL of Al salt, 1.5g/100mL of Fe salt, and 1.5g/100mL of tannic acid (T.A.) have developed excellent colorfast shades of promising color depth Fig. 8a. The color coordinates presented in Table 4. show that mostly dyed fabrics are darker in shades and more reddish yellow in hue when obtained upon dyeing after mordanting. The shade after application of 1.5g/100mL of Al salt is darker (L^* = 69.78), reddish (a^* = 4.92), and yellow (b^*= 54.03) in tone. On using 1g/100mL of Fe salt, shades have become darker (L^* = 65.85) and more reddish yellow in tone (a^* = 2.41) and (b^* = 34.10). Similarly, using 2g/100mL of tannic acid, the shade becomes brighter (L^* = 70.50) but greenish-yellow in hue (a^* =−0.98) and (b^*= 53.11). The color coordinates given in Table 4. for post-mordanted dyed fabrics are brighter in the shade and reddish yellow in the hue. The post-mordanted dyed fabric using 1g/100mL of Al salt is much brighter (L^* = 80.01) but less

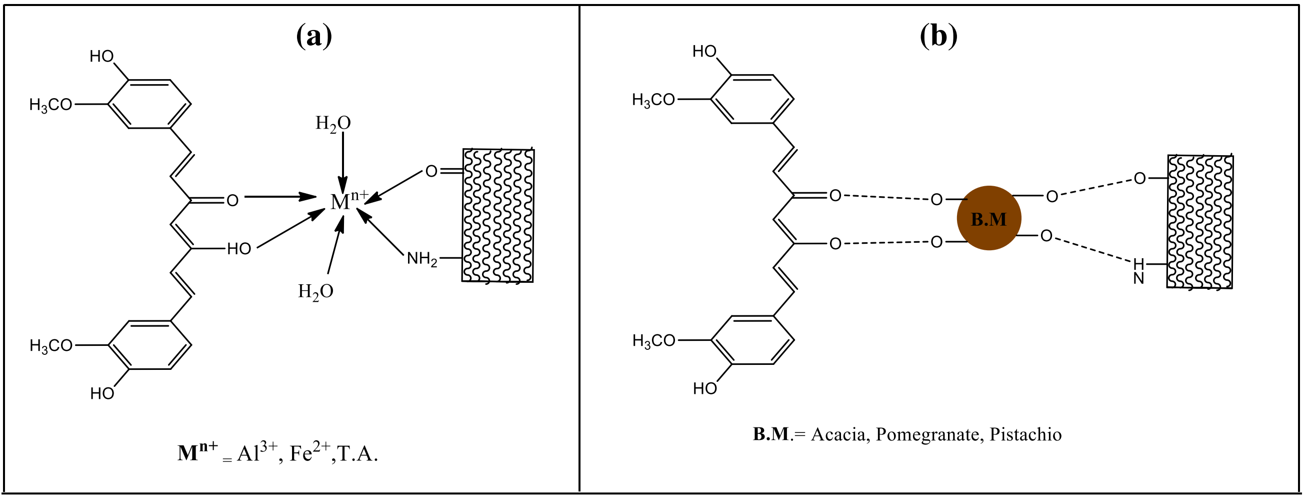

Fig. 9 The proposed interaction of chemical (**a**) and bio-mordanted (**b**) wool fabric with extracted colorant

reddish and yellow in hue (a^* =−2.82; b^* 57.56). Using 1.5/100mL of Fe salt, the dyed fabric is darker (L^*= 63.99) in the shade, having a reddish-yellow hue (a^*=6.20; b^*= 46.60). Similarly, using 1.5g/100mL of tannic acid, the shade is brighter (L^* = 70.97), having less reddish (a^*= −3.49) but more yellow hue (b^* = 45.78). Overall, 2g/100mL of tannic acid as pre-mordant and 1.5g/100mL of Fe salt as post-mordant have given excellent results. In chemical mordants, Al salt only increases the brightness in the shade and causes a reddish-yellow hue to rise. Iron utilizes its d-orbital electron to interact with e of O.H. from curcumin and amido linkage of wool, due to which darker shades are obtained through a coordinate covalent bond. Using tannic acid, there is H bonding among –O.H. of colorant, (–NHCO–) of wool and tannic acid, which results in variable shades. The proposed interaction of mordant with colorant and the wool fabric is given in Table 3. The proposed interaction of the metal dye with fabric has been shown in Fig. 9a.

Table 5 Colorfastness ratings of shades made before and after chemical and biomordanting of wool fabrics at optimum conditions

Mordant concentrations	LF	WF	DRF	WRF
Without mordant	4	¾	4	3/4
Al (1.5% pre)	5	4/5	5	4/5
Al (1% post)	5	4/5	5	4/5
Fe (1% pre)	5	5	5	4/5
Fe (1.5% post)	5	5	5	4/5
T.A (2% pre)	5	4/5	5	4/5
T.A (1.5% post)	5	4/5	5	4/5
Acacia (1.5% pre)	5	5	5	4/5
Acacia (1% post)	5	5	5	4/5
Pomegranate (2% pre)	5	5	5	4/5
Pomegranate (1% post)	5	5	5	4/5
Pistachio (1.5% pre)	5	4/5	5	4/5
Pistachio (2% post)	5	4/5	5	4/5

LF light fastness, *WF* wash fastness, *DRF* dry rubbing fastness, *WRF* wet rubbing fastness

Using plant phenolics, the functional molecules also have anti-viral, antioxidant, and antibacterial characteristics, which can be transferred into fabric upon dyeing. In this study, the extract of acacia, pomegranate, and pistachio hull has been utilized as an alternative to toxic chemical anchors. The results Fig. 7b show that extracts from 1.5g/100mL of acacia, 2g/100mL of pomegranate, and 1.5g/100mL of pistachio hulls before dyeing have given excellent results. Similarly, extract from 1g/100mL of acacia, 1g/100mL of pomegranate, and 2g/100mL of pistachio hulls after dyeing has given excellent color characteristics shown in Fig. 8b. Overall, extract from 2g/100mL of pomegranate as pre and 1g/100mL of pomegranate as post-bio-mordant has developed colorfast shades. The color coordinates given in Table 4. show that using acacia shades is a dark yellow, whereas using pomegranate and pistachio hulls is a bright yellow. Using 1.5g/100mL of acacia extract, the shade is brighter (L^* = 70.57), having less reddish (a^*=−2.97) but a more yellowish hue (b^*= 61.06). Using 2g/100mL of pomegranate extract before dyeing, the shade is much brighter (L^*= 75.54), having a less reddish but more yellow hue (a^*=-4.18; b^*= 68.91). Similarly, at 1.5g/100mL of pistachio hull, the shade is more bright (L^*=77.12), having less reddish (a^*=−3.51) but a yellower hue (b^*=62.75). Similarly, the application after dyeing, 1g/100mL of acacia has developed a darker shade (L^*=66.46) with a reddish-yellow tone (a^*=0.40; b^*=47.74). They use 1g/100mL of pomegranate extract after dyeing has developed a much darker shade (L^*= 72.21) with a less reddish but more yellow hue (a^*=-2.24; b^*= 67.34). On using 2g/100mL of pistachio extract after dyeing, the developed shade is brighter (L^*=72.80), less red

(a^*=−1.97), and yellower in tone (b^*=57.74). The proposed structure of the bio-mordanted fabric and dye extract is shown in Fig. 9b.

The colorfastness of optimally dyed and mordanted wool fabrics was investigated. The ratings of fastness presented in Table 5 show that the shades developed were faster after chemical and biomordanting followed by dyeing at selected conditions. This is because MW radiation increased the dye ability of the colorant and caused it to travel closer to the fabric, apparent by forming a strong link between the fabric and the coloring portion. When rubbing, light, and washing standard methods were used, biomordants have also improved the coloring strength and fastness (Rani et al. 2020). Hence, the color performance of wild turmeric as source of yellow natural dye for wool fabric dyeing was improved by microwave treatment in terms of color rating and fastness. In nut shell, the biomordanting has been identified as a new state-of-the-art technology for shade production and for making fabric dyeing more eco-friendly and sustainable.

Conclusion

Microwave irradiation has a lot of promise for isolating natural colorants under mild conditions and then dyeing wool fabric without affecting the physiological characteristics of the colorant. In this work, MW-assisted wool dyeing with a 3 pH wild turmeric extract made from 4g of wild turmeric powder at 80°C for 45 min resulted in high color strength, indicating that dyeing variables were decreased. The curcumin from wild turmeric was extracted in an aqueous solution and microwaved for 6 min, giving best results than the natural yellow color on irradiated wool fabric, according to the instructions. The use of biomordants in this study is a sustainable approach for plant-based coloring of natural fabrics, which has elevated the value of this cultural art.

Data availability The work is from M.Phil studies.

Author contribution The whole experiments have been conducted by M.Phil student, Aamir Ali. Dr. Noman Habib has supervised the whole work, where Dr. Shahid Adeel and Dr. Fazal-ur-Rehman have guided scientifically for smooth running of the work. Dr. Muhammad Aftab and Ms. Asma Inayat have analyzed the data.

Declarations

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

Consent to participate and publish We give consent to publish our work of M.Phil studies and is jointly contributed by all authors.

Competing interests The authors declare no competing interests.

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