

Cleaner Production of natural dye from *Arjuna terminalia* for silk and wool dyeing

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Abstract

The effect of microwave (MW) radiations on wool and silk dyeing with extract of Arjun bark (*Terminalia Arjuna*) powder has been investigated. The wool and, silk & dye powder were irradiated to MW treatment for up to 5 minutes. Dyeing was performed using un-irradiated and irradiated wool and silk with irradiated and un-irradiated dye powder extracts. SEM and FTIR analyses were performed to observe morphological and chemical changes in the fabric's surface before and after irradiation. Different dyeing parameters have been optimized using a central composite design through response surface methodology. Pre- and post-mordanting was done using 0.5-2.5g/100mL of sustainable chemicals and mordants. All dyed fabrics were subjected to color analysis using a Spectra Flash spectrophotometer (SF600). ISO standard methods were employed for colorfastness to light, washing, and rubbing. It has been found that 45mL of acidic extract of 3pH when employed at 75°C for 45 min after microwave treatment up to 2 min., the dyed silk fabric has furnished high yield after finishing. For wool, 35mL of methanolic extract of 5pH when employed at 45°C for 55 min after MW treatment up to 1 min. The dyed wool fabric has furnished a high yield after finishing. Before and after the dyeing of silk and wool, the Selected chemical and bio-mordants have developed colorfast shades.

Introduction

Although numerous inexpensive options and synthetic dyes offer good performance (Al-Etaibi et al. 2022; Hosseinneshad et al. 2023a), due to the wide variety of high-fastness properties, tonal variation, and low cost are employed for dyeing textiles. So synthetic dyeing is preferred for dyeing different articles in the modern period of industrialization. But on the other hand, these colorants are dangerous to human health and ecology (El-Asasry et al. 2021). Synthetic colors are harmful, cancerous, and non-biodegradable despite having economic and industrial benefits (Baig et al. 2021). Due to these effects; synthetic dyes have been under consideration globally by environmental organizations. Now these organizations are giving awareness to introduce green products for textiles, particularly natural dyes, for eco-safety around the globe. They also promote using natural colors to protect the environment (Ronyastra et al. 2020). Natural pigments can be found in different microbiological sources such as plants, animals, insects, minerals, and other living things with or without chemical processing. Similarly, these natural dyes can be adequate substitutes for harmful synthetic dyes (Bouatay et al. 2019). Furthermore, these natural dyes are gaining popularity due to their environmental friendliness, low toxicity, and minimal allergic effects (Aggarwal et al. 2021; Kamboj et al. 2021; Haji and Naebe 2020). The environmental friendly nature of effluents and therapeutic properties, such as the anti-oxidant, anti-microbial, antifungal, and anti-viral behavior of natural dyes, further appeal to textile researchers also (Rather et al. 2019).

Extraction procedures should be modified to meet the demand for natural dyes, which are more efficient, compatible, and easy than classical methods (Loum et al. 2021). One of the modern extraction methods is assisted by microwave (MW) heat. The challenges associated with heat transfer and dye fixation caused by traditional methods can be reduced using microwave energy (Gala et al. 2022).

As microwave easily penetrates equally and intensely into textile material and colorant-containing parts of the source, it can heat the particles simultaneously. That's why microwave energy nowadays is widely used in the field of textiles for dyeing (Arain et al. 2021). The poor fastness properties of natural dyeing are overcome by chemical or mordants (dye fixers) because these anchors are used to attach the dye molecules onto the fabric functional sites through a coordinate covalent bond to give a firm shade (Zhang et al. 2021). In this study, *Terminalia arjuna*, a Combretaceae family member, is a safe substitute for harmful synthetic colorants. To obtain a yellowish-brown natural colorant, its economic compatibility with textiles has been assessed (Sinha et al. 2016). Several phytochemicals are present, but the coloring constituents are baicalein and ellagic acid, which are important for imparting shade to material (Adeel et al. 2022a). The plant is also essential from a medicinal point of view as it can also be used for many diseases like heart and respiratory problems (Gupta et al. 2018; Rather et al. 2020).

Silk is a natural protein fiber that consists of two types of proteins fibroin and sericin which are made up of repeating units of amino acids. Having two reactive groups (-OH and -NH₂) silk can be easily dyed with a broad range of dyes through the interaction of these active groups with fabric (Salimpour and Muhammad 2021). Wool is the best-known representative of the large class of animal hairs and is a fibrous protein known as α -keratin fibers. It has a three-dimensional structure and is held together by the hydrophobic effect and electrostatic interactions in wool, amide linkage works to bind the colorant (Ticha et al. 2021). Because of the advantages of plant-based colorants, the current study has been done to evaluate the extraction of dye from irradiated powder. Another aspect to study is the improvement of fastness rating using greener mordants.

Experimental section

1.1. Collection of material

Arjun bark (*Terminalia arjuna*) has been collected from the Botanical Garden in Faisalabad, Pakistan. The bark was dried under shade in open air and ground finely, up to 20 mesh to get powder of homogeneous particle size. Silk and wool fabrics were purchased from the local textile market of Faisalabad, Pakistan. Physio-chemical analysis has been done at PCSIR Lab using The FTIR facility and the Centralized Resource Laboratory University of Peshawar, Peshawar for SEM analysis. FTIR analysis was done at the PCSIR lab. Biological activities of the optimal extract have been done at the Department of Biochemistry, University of Agriculture Faisalabad.

1.2. Dye extraction and irradiation process

The aqueous extract was prepared by dissolving 4g of irradiated Arjun bark powder (RABP) up to 5 min and non-irradiated powder (NABRP/RABP) in 100mL of water heating at boiling temperature, while acid extract by dissolving 0.5mL of conc. HCl per 100mL of water (0.5% HCl V/V). Similarly, the basic extract was prepared by dissolving 0.1g of NaOH in 100mL water (NaOH 0.1%W/V), while methanolic extract was prepared simply by dissolving irradiated powder up to 5 min using Dawlence company domestic MW

oven (1050 W, 2450 MHz) and non-irradiated Arjun bark powder (NRABP/RABP) in 100mL of methanol. The treated powder extracts were used to dye non-irradiated and irradiated silk and wool fabrics for up to 5 min at 60°C for 45 min keeping fabric to extract ratio 1:25.

1.3. Optimization of dyeing conditions

Depending upon extraction media and MW irradiation time a set of 32 experiments was set up on varying the dyeing parameters such as time, temperature, pH, salt conc. and extract volume). Response surface methodology as statistical analysis has been used to observe the significance of results.

1.4. Shade development treatment

Colorfastness and shade development was attained by applying bio and chemical mordants at 65 °C for 55 min. 0.5-2.5g/100mL salt Fe^{3+} , salt of Al^{3+} , and Tannic acid while 0.5-2.5g/100mL extracts of rose, chamomile, and pomegranate powder were used for pre- and post-mordanting of dyed silk and wool fabrics at 65 °C for 55 min (Habib et al. 2022).

1.5. Evaluation of fabrics

Physiochemical analysis of non-irradiated and MW irradiated silk and wool up to 5 min was done subjecting the fabrics to SEM (SEM-model Tescan; 5kV) and FTIR (Perkin Elmer, USA). Data color (SF 600 USA) was used to analyze all the dyed fiber. According to ISO standards for light, washing crock, and dry cleaning, the fabrics that have been mordanted at a particular temperature before and after dyeing were evaluated for fastness ratings.

Results and discussion

Microwaves are electromagnetic rays being used for the isolation of natural dyes gaining fame because these rays act upon the system uniformly (Yameen et al. 2022; Zin et al. 2022). These rays when collide with the system, penetrate deeply and save kinetics in the isolation process these rays when come in contact with plant powder, weaken its cell wall and during boiling make it easy for functional molecules to leach into solvent via solid-liquid interaction by consuming less solvent, time and energy (El Sayed et al. 2023; Mumtaz et al. 2022). Upon utilization for bio-dyeing of silk and wool high color yield in terms of K/S has been observed because the nature of solvent, fabric, and dye molecules work to give desired shade strength. Using an acidic solvent, the isolation of colorant from Arjun powder (ABP) after irradiation for 2 minutes has given a high dye yield. On changing solvent, using the organic medium, radiation of Arjun bark powder (ABP) for up to 4 minutes followed by isolation has parented high color depth (K/S) onto fabric Fig. 1a and b. For wool fabric, un-irradiated powder used for the isolation of colorant in an acidic medium has given a good yield. On using the methanolic medium, irradiation of Arjun bark powder for 2 minutes followed by isolation has imparted excellent color yield Fig. 2a and b. Comparatively using acidic medium irradiation of Arjun bark powder (ABP) and silk fabric for up to 2 minutes has given excellent results upto (7.4327), while using the methanolic medium, irradiation of powder and wool fabric for 2 minutes has shown excellent yield (11.981) Fig. 1a and b.

The other important point to be noted is the irradiation of fabric. Our previous studies show that irradiation of fabric has modified its surface by causing scaling, where the scaled surface when subjected to dyeing sorbed colorant molecules up to a maximum extent. This scaling has been verified by analyzing the fiber surface (wool & silk) through (SEM) spectroscopy as presented in Fig. 3 (a + b) & (c + d). The scanned images before and after radiations have been displayed in Figs. 4a and b. The chemical nature of the fiber (wool & silk) was also observed through spectral interpretation by FTIR. The ATR-FTIR spectra of silk and wool before and after irradiation show that there is no chemical change has occurred because specific functional peaks position of amido groups have not been changed. Hence it can be inferred that MW rays have modified the fiber surface physically without changing its chemistry which is also a positive sign for its use in the natural dyeing process (Barkaat et al. 2023). The color characteristics of dyed fabric in an acidic medium reveal that before irradiation the fabric dyed is brighter, reddish yellow whereas after irradiation, the dyed fabric is darker and more reddish yellow in hue. The methanol-based extract used for dyeing has furnished a brighter but reddish-yellow hue. On using wool fabric, before irradiation acidic extract gives a brighter shade with a reddish yellow tone; whereas after irradiation the shade became darker with more reddish & yellower hue while using methanolic extract before irradiation, the shade of dyed fabric is bright and less reddish & yellower hue, however, after radiation, the shade obtained was darker with more reddish & yellower hue shown in Table 1.

Table 1
selected conditions for dyeing of silk and wool fabric using Arjun bark powder

Silk fabric								
Solvent used	Optimum Radiation time	Sample code used	Color coordinates					
			K/S	<i>L*</i>	<i>a*</i>	<i>b*</i>	<i>c*</i>	<i>h*</i>
Acidic	0min	NRP/NRSF	2.6018	64.31	12.19	23.90	26.82	62.98
Acidic	2min	RP/RSF	7.4327	48.87	14.98	23.39	26.87	57.63
Methanol	0min	NTP/NRSF	0.8632	74.63	6.26	13.69	14.97	65.57
Methanol	4min	RP/RSF	1.8680	64.70	11.66	15.71	19.57	53.42
Wool fabric								
Acidic	0min	NRP/NRWF	6.3217	65.43	13.04	23.37	26.76	60.85
Acidic	1min	NRP/RWF	8.13465	51.07	14.48	22.96	27.34	57.76
Methanol	0min	NTP/NTWF	2.8739	63.76	10.07	14.84	17.39	55.29
Methanol	2min	RP/RWF	11.981	44.37	16.11	19.89	25.60	50.99
NRP = non-radiated powder, NRWF = non-radiated wool fabric, NRSF = non-radiated silk fabric, RP = radiated powder, RSF = radiated silk fabric, RWF = radiated wool fabric								

Statistical analysis shows in Tables 2 and 3 that the dyeing of silk and wool with Arjun bark (ABP) at selected conditions has given significant results. The model used for the analysis of the dyeing pattern to bio-color the wool is fit and linear. The role of pH (0.005), dyeing time (0.083), temperature (0.008), and salt (0.077) is significant. In the two-way interaction role of pH with temperature, (0.000) is highly significant. As well as the role of pH with volume (0.070), volume with temperature (0.008), and salt (0.026) is also significant. During the dyeing process of fiber using natural-based colorants different dyeing parameters (dyeing time, salt concentration, temperature, and pH are very important. Optimal temperature is normally required to high tiny color by enhancing the kinetics of the dye bath. Excellent K/S is achieved by avoiding desorption of dye molecules by reducing fabric dye interaction on optimal dyeing time whereas the use of salt is aimed to obtain good color fastness by developing short-range forces between the fabric and dye at given conditions (Adeel et al. 2022b). An optimum pH is important to develop an H-bonding between dye and fabric which enhances the shade development and fastness properties (Ranjha et al. 2021). The model used for the analysis of the dyeing pattern to bio-color the silk is fit and linear. The role of pH (0.000), temperature (0.012), salt (0.008), pH with pH (0.001), time with time (0.000), and salt with salt (0.000) is significant. In two-way interaction role of pH with salt (0.018) and time (0.041), volume with temperature (0.002), and time with salt (0.003) salt with salt (0.000), is highly significant. As well as the role of pH with pH (0.001), dyeing time with temperature (0.008) and salt (0.026) is also significant. Hence it is revealed that dyeing of silk should be done with 45 mL of extract, 3 pH having 4g/100mL of salt at 55°C for 45 min. similarly, wool dyeing should be done with 35mL of extract, 5 pH having 4g/100mL of salt at 45 °C for 55 min. Tables 2 and 3.

Table 2
Statistical analysis of variance for wool fabric dyed in methanolic medium with
Arjun bark powder extract under microwave effect

Source	DF	Adj SS	Adj MS	F-value	P-value
Model	19	1.12894	0.059418	9.55	0.000
Linear	5	0.20909	0.041818	6.72	0.005
pH	1	0.07754	0.077543	12.46	0.005
Volume	1	0.01616	0.016162	2.60	0.138
Time	1	0.02304	0.023039	3.70	0.083
Temperature	1	0.06810	0.068099	10.94	0.008
Salt	1	0.02424	0.024244	3.90	0.077
Square	5	0.29840	0.059681	9.59	0.001
pH*pH	1	0.07820	0.078203	12.57	0.005
Volume*volume	1	0.08904	0.089041	14.31	0.004
Time*time	1	0.02522	0.025224	4.05	0.072
Temp*temperature	1	0.12504	0.125041	20.09	0.001
Salt*salt	1	0.02216	0.022160	3.56	0.088
2-way interaction	9	0.64426	0.071584	11.50	0.000
pH*volume	1	0.02568	0.025680	4.13	0.070
pH*time	1	0.00173	0.001735	0.28	0.609
pH*temperature	1	0.16622	0.166219	26.71	0.000
pH*salt	1	0.00826	0.008263	1.33	0.276
Volume*temperature	1	0.06914	0.069143	11.11	0.008
Volume*salt	1	0.04225	0.042251	6.79	0.026
Time*temperature	1	0.21599	0.215993	34.71	0.000
Time*salt	1	0.11414	0.114143	18.34	0.002
Temperature*salt	1	0.00083	0.000829	0.13	0.723
Error	10	0.006223	0.006223	-	-
Lock-of-Fit	6	0.01389	0.002315	0.19	0.963
Pure Error	4	0.04834	0.012086	-	-

Source	DF	Adj SS	Adj MS	F-value	P-value
Total	29	1.19117	-	-	-
Model summary	-	-	-	-	-
S	R-sq	R-sq(adj)	R-sq(pred)	-	-
0.0788870	94.78%	84.85%	73.81%	-	-

Table 3
Statistical analysis of variance for silk fabric dyed in acidic medium with Arjun bark powder extract under microwave effect

Source	DF	Adj SS	Adj MS	F-value	P-value
Model	15	3.07403	0.20494	31.70	0.000
Linear	5	0.26289	0.05258	8.13	0.001
<i>pH</i>	1	0.18648	0.18648	28.84	0.000
Volume	1	0.00103	0.00103	0.16	0.696
Time	1	0.03882	0.03882	6.00	0.031
Temperature	1	0.05641	0.05641	8.72	0.012
Salt	1	0.06501	0.006501	10.05	0.008
Square	3	2.26518	0.75506	116.78	0.000
<i>pH</i> * <i>pH</i>	1	0.14109	0.14109	21.82	0.001
Time*time	1	0.16179	0.16179	25.02	0.000
Salt*salt	1	2.25756	2.25756	349.18	0.000
2-way interaction	7	0.31975	0.04568	7.06	0.002
<i>pH</i> *volume	1	0.00013	0.00013	0.02	0.888
<i>pH</i> *time	1	0.03408	0.03408	5.27	0.041
<i>pH</i> *temperature	1	0.00001	0.00001	0.00	0.965
<i>pH</i> *salt	1	0.04857	0.04857	7.51	0.018
Volume*temperature	1	0.10168	0.10168	15.73	0.002
Volume*salt	1	0.00802	0.00802	1.24	0.287
Time*salt	1	0.08832	0.08832	13.66	0.003
Error	12	0.07758	0.00647	-	-
Lock-of-Fit	8	0.06227	0.00778	2.03	0.257
Pure Error	4	0.01532	0.00383	-	-
Total	27	3.15161	-	-	-
Model summary	-	-	-	-	-
S	R-sq	R-sq(adj)	R-sq(pred)	-	-
0.0804078	97.54%	94.46%	76.40%	-	-

Table 4
Influence of chemical mordants on color strength of microwave treated dyed wool and silk fabrics at optimal conditions

Fabric used	Mordanting	K/S	<i>L</i> *	<i>a</i> *	<i>b</i> *	Dyed Fabric
Silk	Fe 1% (Pre)	4.2114	52.03	7.92	14.6	
	Fe 2% (Post)	2.8138	61.64	2.33	15.78	
	Al 0.5% (Pre)	3.8133	62.39	12.19	24.79	
	Al 0.5% (Post)	3.0382	57.81	4.11	19.06	
	Tannic acid 2% (Pre)	3.4826	54.76	14.24	19.43	
	Tannic acid 2% (Post)	3.9	53.05	11.04	16.09	
Wool	Fe 0.5% (Pre)	8.7941	36.32	3.17	10.16	
	Fe 2% (Post)	5.8728	51.62	5.93	21.46	
	Al 1% (Pre)	6.4949	63.69	8.14	23.44	
	Al 2.5% (Post)	2.3331	66.66	7.32	21.35	
	Tannic acid 2.5% (Pre)	4.9098	46.58	9.72	15.1	
	Tannic acid 2% (Post)	5.7996	43.27	12.41	15.98	

Table 5
Influence of Bio- mordanting on color strength of MW treated dyed wool and silk fabrics at optimal conditions.

Fabric used	Mordant	K/S	L*	a*	b*	Dyed Fabric
Silk	Rose 1.5% (Pre)	7.316	47.5	14.59	26.51	
	Rose 2% (Post)	6.7413	50.48	11.33	25.69	
	Chamomile 1% (Pre)	3.8951	57.56	16.87	25.97	
	Chamomile 1.5% (Post)	4.6273	57.07	10.5	23.7	
	Pomegranate 0.5% (Pre)	3.5541	63.52	11.36	25.62	
	Pomegranate 1% (Post)	4.0129	62.44	10.57	26.42	
Wool	Rose 0.5% (Pre)	5.8862	56.63	9.41	25.77	
	Rose 1% (Post)	7.1933	52.39	9.12	25.25	
	Chamomile 1% (Pre)	5.3278	56.42	10.09	24.62	
	Chamomile 1.5% (Post)	5.2922	59.35	6.5	25.1	
	Pomegranate 1% (Pre)	6.688	52.05	10.01	26.22	
	Pomegranate 1.5% (Post)	3.4891	56.63	9.41	25.77	

Mordanting with chemical and bio-moieties for the natural dyeing of silk or wool is necessary to develop permanent shades to fabrics. In this study Fig. 8a silk fabric before bio dyeing, 1% of Fe^{2+} (iron salt), 0.5% of Al^{3+} salt (Pot-Alum), and 2% of Tannic acid (TA) have developed shades of high strength. For wool the

salt of Fe^{2+} ($\text{FeSO}_4 = 0.5\%$), Al^{3+} (Potash alum = 1%), and Tannic acid ($\text{TA} = 2.5\%$) has been employed in wool fabric before dyeing at given conditions Fig. 8b. Similarly, silk fabric after bio-dyeing, 2.5% of Fe^{2+} salt (FeSO_4), 0.5% of Al^{3+} salt (Pot-Alum), and 0.5% of Tannic acid (TA) have developed shades of high strength. For wool fabric after bio-dyeing, salt of Fe^{2+} ($\text{FeSO}_4 = 2\%$), Al^{3+} salt (Pot-Alum = 2.5%), and Tannic acid ($\text{TA} = 2\%$) have been employed at given conditions given in Fig. 9a and b.

This improvement in fastness is attributed to the coordinate bond between central metal ions, colorant, and functional site of fiber i.e silk & wool (Islam et al. 2022; Jabar et al. 2023). The coordinated bonding onto fabric develops a strong, firm, and fast shade that resists changing its appearance. In Al-salt (Al^{3+}) leads to d- orbital due to which shade does not change but becomes brighter that depends upon the nature of the fiber and dye used. In salt of iron, iron metal utilizes its d- orbital where the transfer of electrons may be held to form a coordinate bond with fabric (amido linkage) and dye group ($-\text{OH}$) that can furnish the dark shades (Adeel et al. 2023; Ghaheh et al. 2021). The color coordinates show that most shades are brighter yellow in shade with a reddish tone. For wool, redness was less whereas for silk redness was more but yellowness in the case of silk was more as compared to wool.

In the case of bio-mordanting silk fabric before bio-dyeing, 1.5% of rose extract, 1% of chamomile extract, and 0.5% of pomegranate extract have developed shades of high strength. For wool, 0.5% of rose extract, 1% of chamomile extract, and 1% of pomegranate extract have been employed at given conditions. Similarly, after bio-dyeing, silk fabric after bio-dyeing 2% of rose extract, 1.5% of chamomile extract, and 1% of pomegranate extract developed shades of high strength. For wool fabric after dyeing, 1% of rose extract, 1.5% of chamomile extract, and 1.5% of pomegranate extract have been employed to wool fabric at given conditions. Bio mordanting is the classic state art as a newly developed technique to get high strength new colorfast gamutes. This is because the bio-mordants contain $-\text{OH}$ or $\text{C}=\text{O}$ and $-\text{OH}$ group to bind with $-\text{OH}$ from dye extracts and $-\text{CONH}$ from wool or silk or fabric (Manyim et al. 2023). Here conjugation also plays its role while shifting their characteristic color upon mixing with actual dye color to develop new colorfast shades (Hosseinnezhad et al. 2023b). In this study flavonoid from chamomile, anthocyanins from rose, and tannin from pomegranate interacts with fabric-modified surface and dye (Arjun extract) to develop new tints. In this way not only, the soothing shade was developed but also the process become pollution and effluent free. Hence it has resulted that eco-friendly greener additives should be used.

Conclusion

Green products, such as plant pigments, are gaining global recognition due to their notable Ayurvedic and biological properties. In this study, microwave radiation (MW) was utilized to extract colorants from Arjun bark, and bio-mordants were incorporated to achieve colorfast shades. Sustainable chemical and plant-based extracts were employed as bio-mordants both before and after silk and wool were dyed using natural colorants, with specific conditions to obtain darker shades with various tints. The Colori-spectrophotometer (CS-410) was used to measure changes in color intensity and tonal variation of the

dyed fabrics based on the CIE Lab system. Additionally, ISO standard methods were applied to assess the colorfastness of the fabrics to light, washing, and rubbing using a grey scale. In conclusion, microwave radiation has shown excellent sustainability and effectiveness in extracting colorants from Arjun bark powder for cotton dyeing. Furthermore, the incorporation of bio-mordants has improved the sustainability and eco-friendliness of the process.

Declarations

Conflict of interest:

There is no conflict of interest among authors

Data Availability;

The current work is the part of M.Phil Studies

References

1. Adeel S, Anjum F, Zuber M, Hussaan M, Amin N, Ozomay M (2022a) Sustainable extraction of colourant from harmal seeds (*Peganum harmala*) for dyeing of bio-mordanted wool fabric. *Sustain* 14(19):12226
2. Adeel S, Habib N, Batool F, Rahman A, Ahmad T, Amin N (2022b) Eco-friendly approach towards isolation of colorant from Esfand for bio-mordanted silk dyeing. *Environ Sci Pollut Res* 29(9):13523–13533
3. Aggarwal S (2021) Indian dye yielding plants: Efforts and opportunities. *Nat Res Forum* 45(1):63–86
4. Al-Etaibi AM, El-Asasery MA (2022) Microwave-Assisted synthesis of azo disperse dyes for dyeing polyester fabrics: our contributions over the past decade. *Polym.* 14:1703
5. Arain RA, Ahmad F, Khatri Z, Peerzada MH (2021) Microwave assisted henna organic dyeing of polyester fabric: a green, economical and energy proficient substitute. *Nat Prod Res* 35(2):327–330
6. Baig U, Khatri A, Ali S, Sanbhal N, Ishaque F, Junejo N (2021) Ultrasound-assisted dyeing of cotton fabric with natural dye extracted from marigold flower. *J Text Inst* 112(5):801–808
7. Barkaat S, Mehboob M, Adeel S, Amin N, Habib N, Hosseinneshad M (2023) Sustainable microwave-assisted extraction of santalin from red sandal wood powder (*Pterocarpus santalinus*) for bio-coloration of mordanted silk fabric. *Separ* 10:118
8. Bouatay F, Baaka N, Shahid A, Mhenni MF (2019) A novel natural source *Vicia faba L.* membranes as colourant: development and optimisation of the extraction process using response surface methodology (RSM). *Nat Prod Res* 33(1):59–65
9. El Sayed NA, El-Bendary MA, Ahmed OK (2023) A sustainable approach for linen dyeing and finishing with natural lac dye through chitosan bio-mordanting and microwave heating. *J Eng Fibers Fabric* 18:15589250231155882

10. El-Asasery MA, Hussein AM, El-Din N, Saleh NM, El-Adasy MO, A. B. A (2021) Microwave-assisted dyeing of wool fabrics with natural dyes as eco-friendly dyeing method: part I. Dyeing performance and fastness properties. *Egypt J Chem* 64(7):3751–3759
11. Gala S, Sumarno S, Mahfud M (2022) Optimization of microwave-assisted extraction of natural dyes from jackfruit wood (*Artocarpus heterophyllus Lamk*) by response surface methodology. *Eng Appl Sci Res* 49(1):29–35
12. 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
13. Gupta S, Bishnoi JP, Kumar N, Kumar H, Nidheesh T (2018) *Terminalia arjuna* (Roxb.) Wight & Arn.: Competent source of bioactive components in functional food and drugs. *Pharm Innov J* 7(3):223–231
14. Habib N, Akram W, Adeel S, Amin N, Hosseinneshad M (2022) Environmental-friendly extraction of Peepal (*Ficus Religiosa*) bark-based reddish brown tannin natural dye for silk coloration. *Environ Sci Pollut Res* 29(23):35048–35060
15. Haji A, Naebe M (2020) Cleaner dyeing of textiles using plasma treatment and natural dyes: A review. *J Clean Prod* 265(8):121866
16. Hosseinneshad M, Gharanjig K, Adeel S, Mahmoudi NA (2023a) Clean dyeing of wool yarns using oleaster fruit components as new bio-mordant: a step toward reducing agricultural waste. *Clean Technol Environ Policy*, 1–12
17. Hosseinneshad M, Gharanjig K, Iamin H, Rouhani S, Adeel S (2023b) Environmentally dyeing of wool yarns using of combination of myrobalan and walnut husk as bio-mordants. *Prog Color Color Coat* 16:197–205
18. Islam MR, Khan ANN, Mahmud RU, Haque SMN, Khan MMI (2022) Sustainable dyeing of jute-cotton union fabrics with onion skin (*Allium cepa*) dye using banana peel (*Musa*) and guava leaves (*Psidium guajava*) extract as biomordants. *Pigm. Resin Technol*
19. Jabar JM, Ogunsade AF, Odusote YA, Yilmaz M (2023) Utilization of nigerian mango (*Mangifera indica* L) leaves dye extract for silk fabric coloration: influence of extraction technique, mordant and mordanting type on the fabric color attributes. *Indus Crop Prod* 193:116235
20. Kamboj A, Jose S, Singh A (2021) Antimicrobial activity of natural dyes a comprehensive review. *J Nat Fibers* 4(1):1–15
21. Loum J, Byamukama R, Wanyama PAG (2021) Efficient extraction of natural dyes from selected plant species. *Chem Afr* 4(3):677–689
22. Manyim S, Kiprop AK, Mwasiagi JI, Mecha AC (2023) Cleaner production of bioactive and coloured cotton fabric using euclea divinorum dye extract with bio-mordants. *Tekstilec*, 38–46
23. Mumtaz S, Rana JN, Choi EH, Han I (2022) Microwave radiation and the brain: Mechanisms, current status, and future prospects. *Int J Mol Sci* 23(16):9288

24. Ranjha MMA, Irfan S, Lorenzo JM, Shafique B, Kanwal R, Pateiro M, Arshad RN, Wang L, Nayik GA, Roobab U, Aadil RM (2021) Sonication, a potential technique for extraction of phytoconstituents: a systematic review. *Process* 9(8):1406
25. Rather LJ, Khan MA, Mohammad F (2019) Biomordanting potential of *Acacia nilotica* (Babul) in conjunction with *Kerria lacca* and *Rheum emodi* natural dyes. *J Nat Fiber* 16(2):275–286
26. Rather LJ, Shabbir M, Mohammad F, Li Q (2020) *Terminalia arjuna* dyed woolen yarn-effect of binary and ternary metal salt combinations: A greener route for production of ecofriendly textiles. *J Nat Fibers* 17(12):1693–1705
27. Ronyastra IM, Sutrisna PD, Waluyo PW, Winadi AS, Priyantini HR (2020) Risk modelling in financial feasibility study for caesalpinia sappan natural dyes factory in Surakarta. *Mater Sci Eng* 1003(9):1–6
28. Salimpour AS, Malek MAR (2021) Modification of silk yarn with β -cyclodextrin nanoparticles: preparation, characterization, and natural dyeing properties. *Starch-Stärke* 73(7–8):2000209
29. Sinha K, Aikat K, Das P, Datta S (2016) Dyeing of modified cotton fiber with natural *Terminalia arjuna* dye: optimization of dyeing parameters using response surface methodology. *Environ Prog Sustain Energy* 35(3):719–728
30. Yameen M, Adeel S, Nasreen H, Ghaffar A, Ahmad T, Inayat A (2022) Sustainable eco-friendly extraction of yellow natural dye from haar singhar (*Nyctanthes arbor-tritis*) for bio coloration of cotton fabric. *Environ Sci Pollut Res* 1–14
31. Zin MM, Nagy K, Bánvölgyi S, Abrankó L, Nath A (2022) Effect of microwave pretreatment on the extraction of antioxidant-rich red color betacyanin, phenolic, and flavonoid from the crown of Cylindra-type beetroot (*Beta vulgaris* L.). *J Food Proc Eng*. e14175
32. 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(10):1–12

Figures

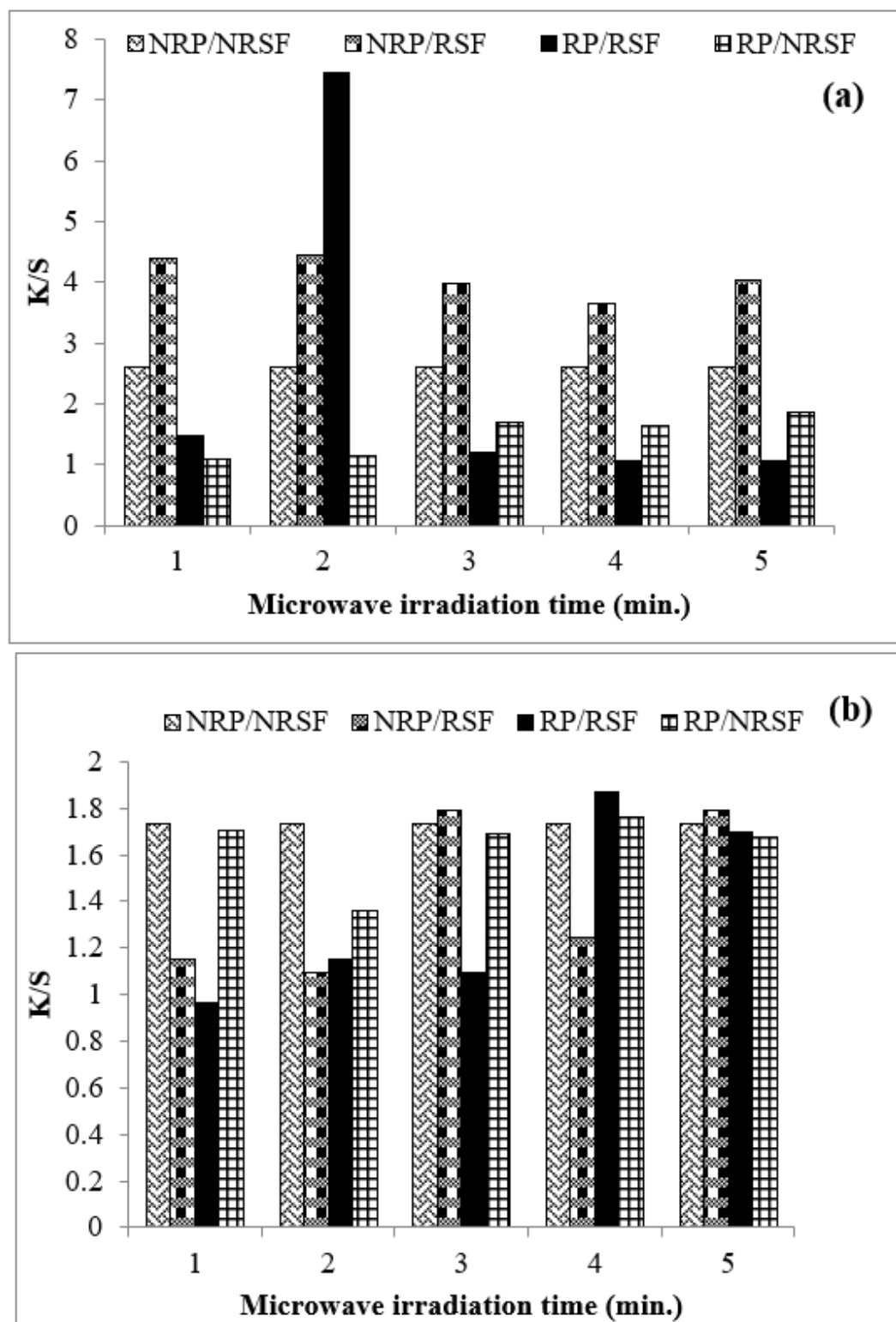


Figure 1

Dyeing of silk using Arjun bark powder extract in an acidic (a) and methanolic media under microwave irradiation

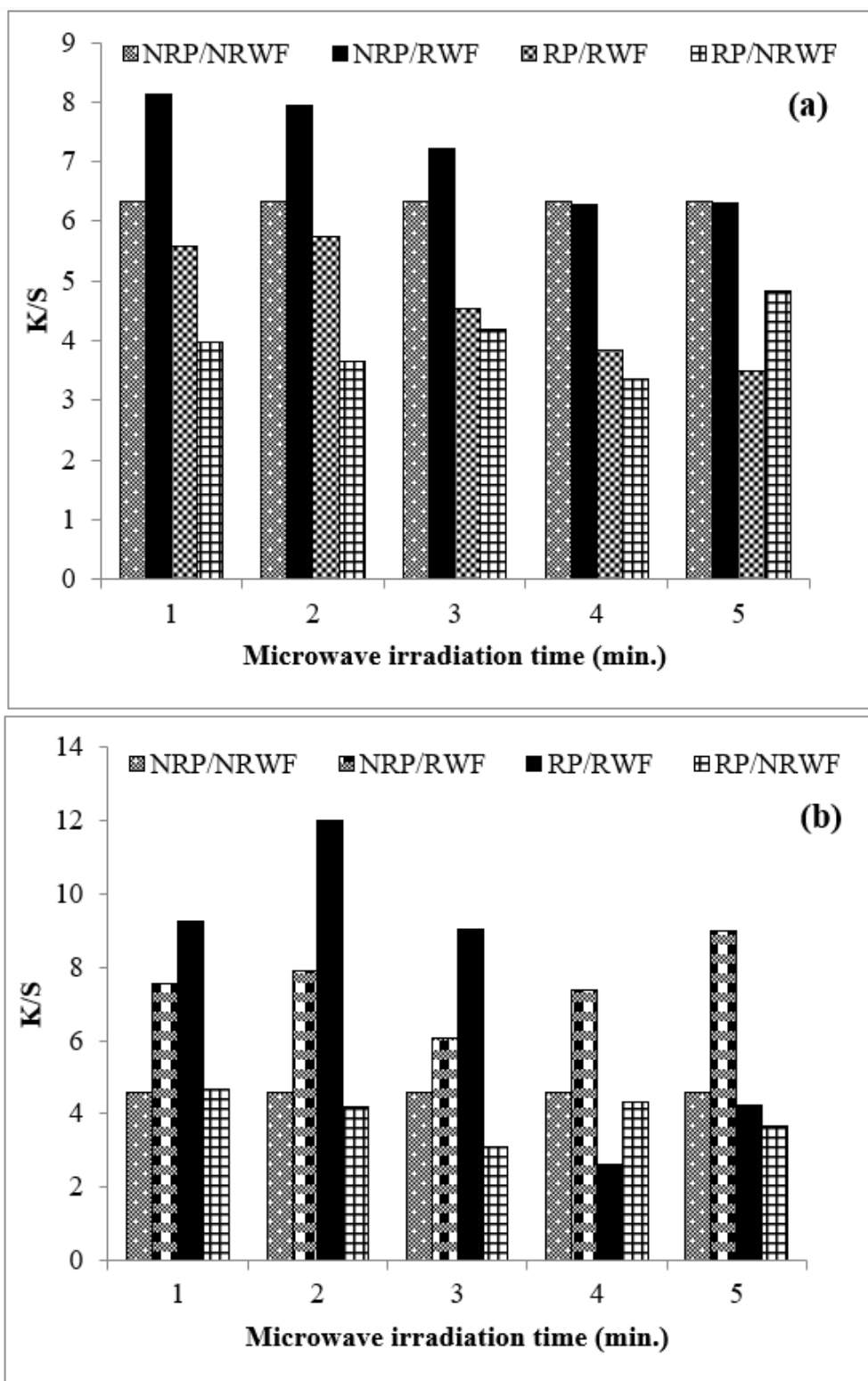


Figure 2

Dyeing of wool using Arjun bark powder extract in an acidic (a) methanolic (b) media under microwave irradiation

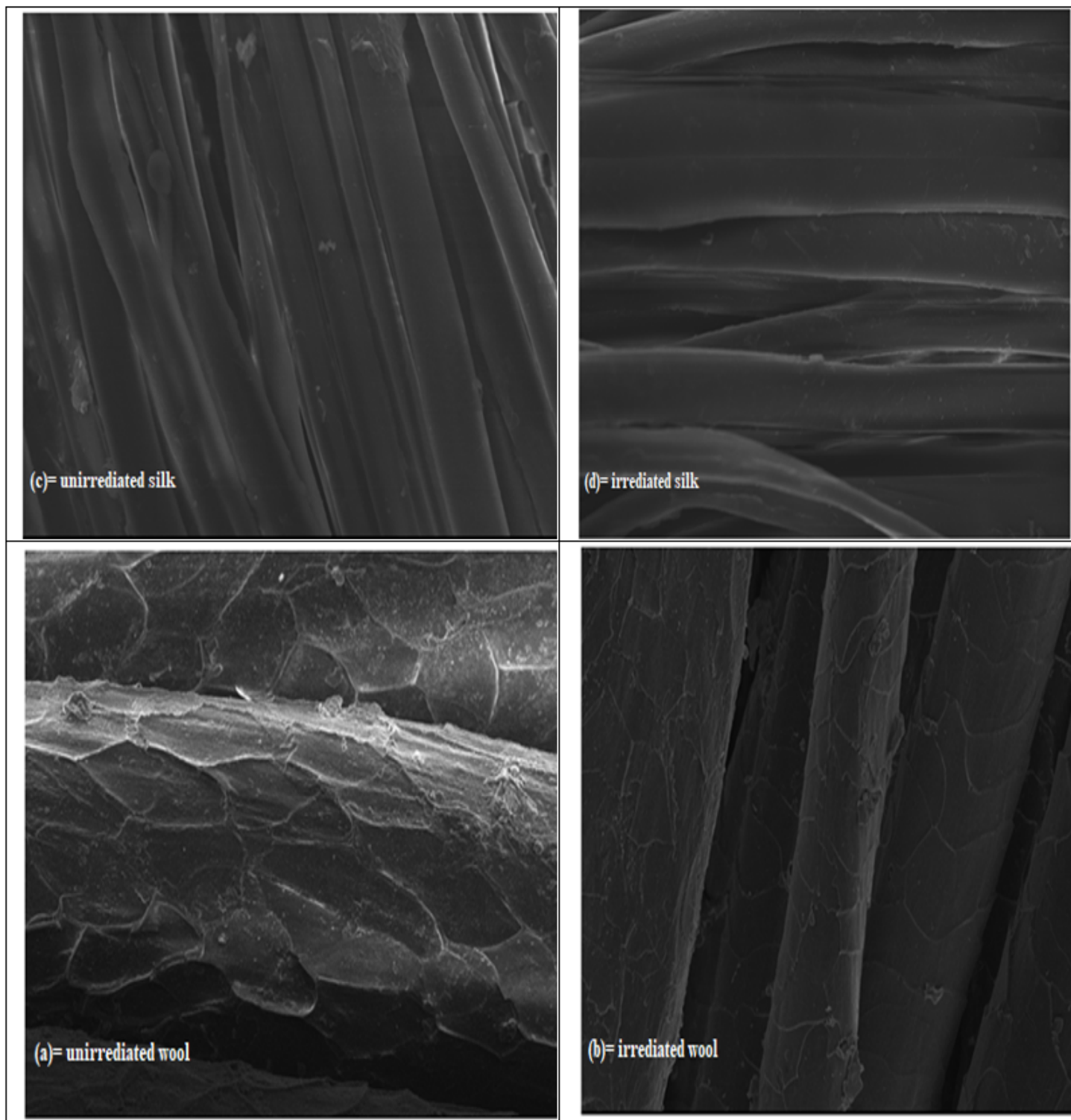


Figure 3

SEM images of unirradiated (a), and irradiated for 2 min (b) wool fabrics

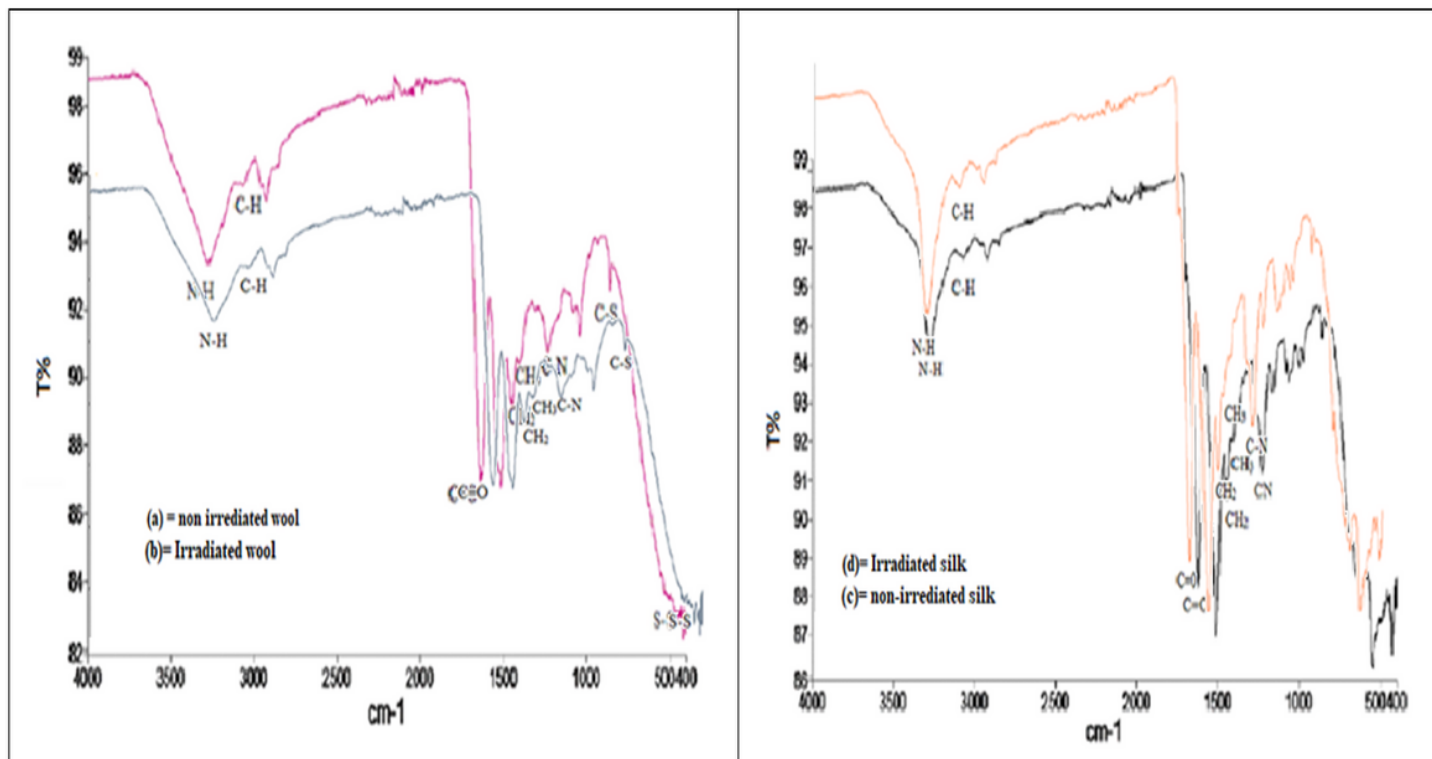


Figure 4

FTIR analysis of microwave non-irradiated irradiated Silk 2 min. (a) & for Wool 1 min. (b)

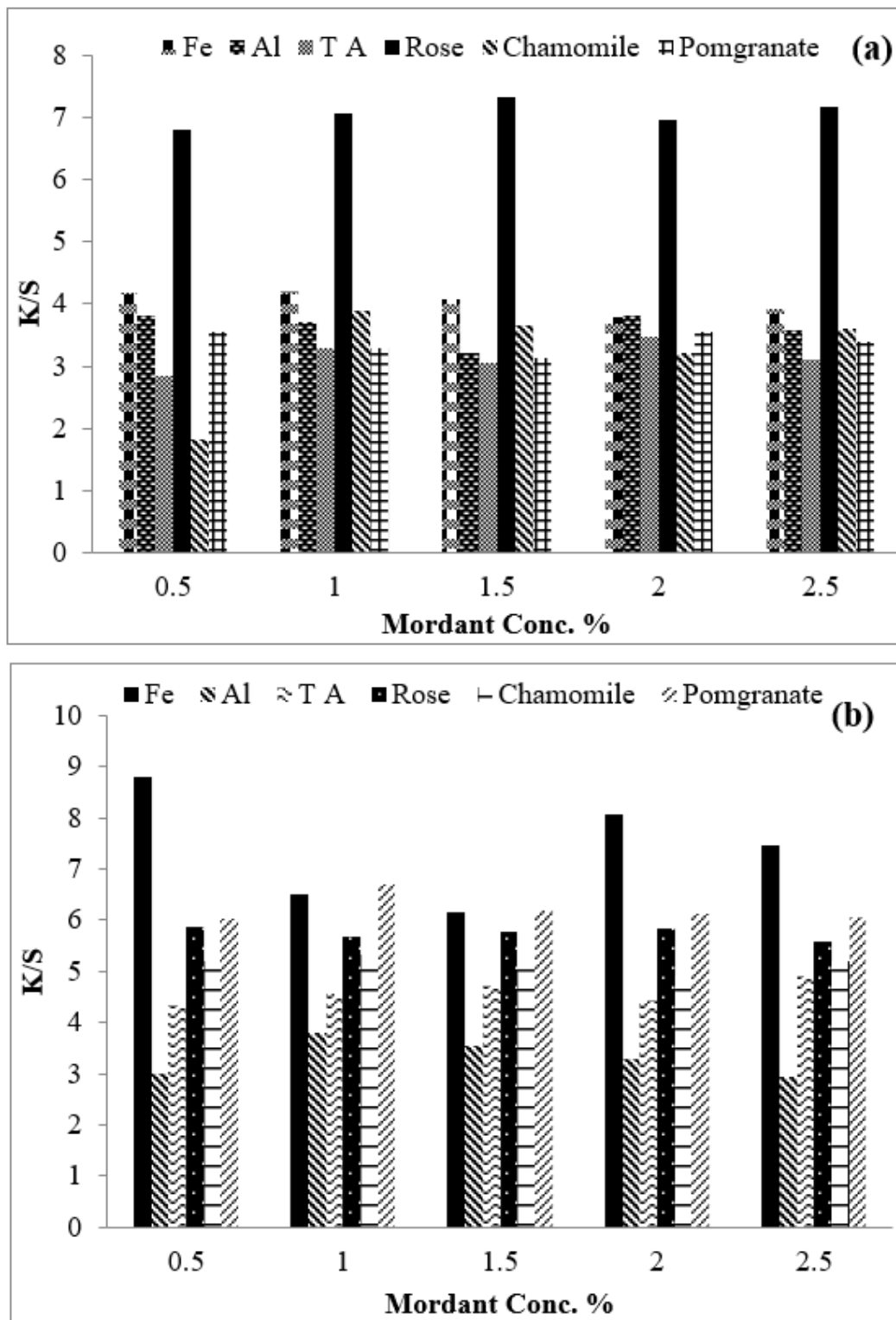


Figure 5

Pre-mordanting using chemical and bio mordants of microwave-treated silk (a) and wool (b) fabrics

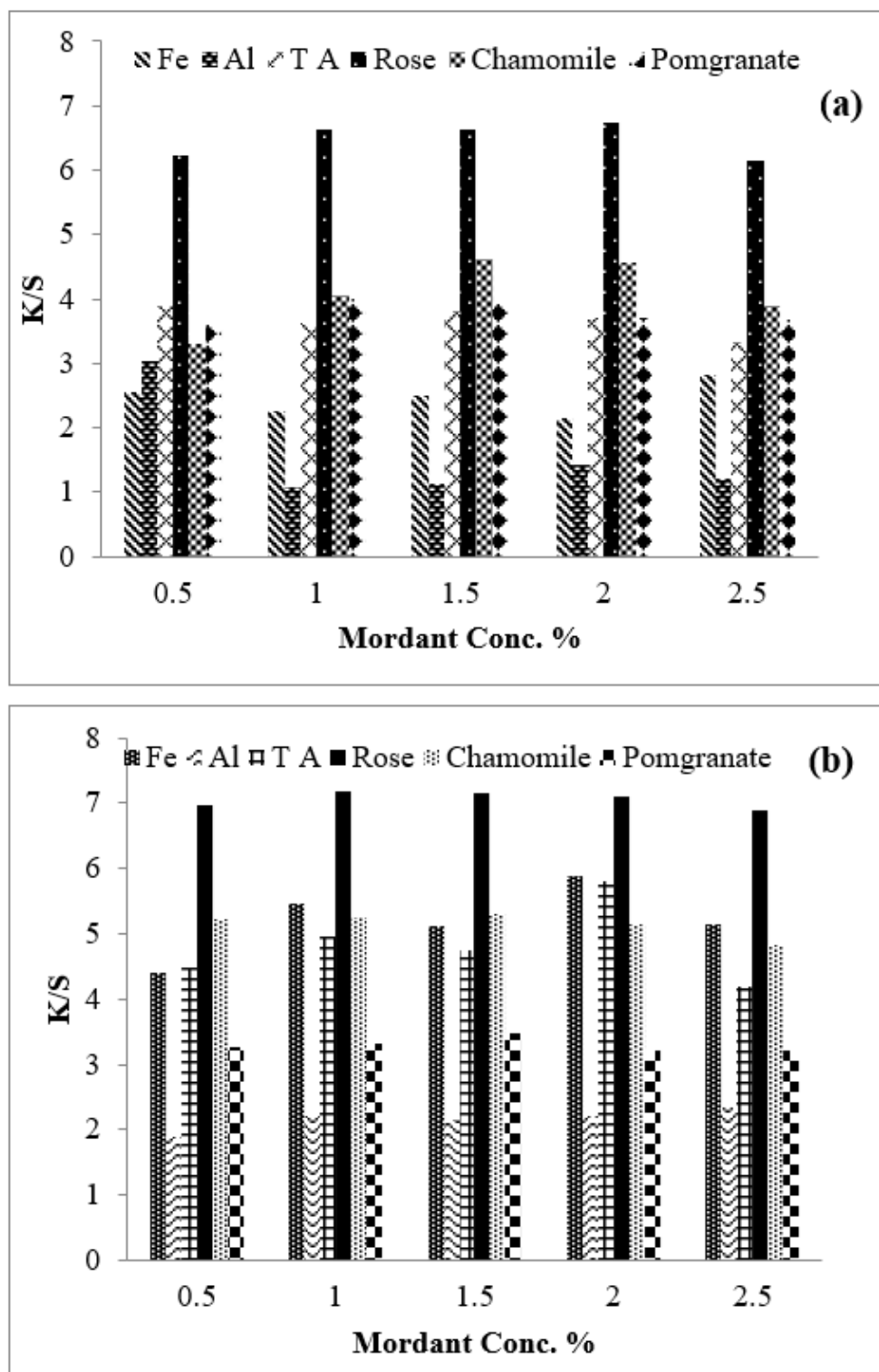


Figure 6

Post-mordanting using chemical and bio mordants of microwave-treated silk (a) and wool (b) fabrics