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RESEARCH ARTICLE

Environmental-friendly extraction of Peepal (*Ficus Religiosa*) bark-based reddish brown tannin natural dye for silk coloration

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Abstract
The present study aims to extract a natural reddish brown colorant from Peepal (*Ficus religiosa*) for silk dyeing using the microwave radiation process (MW). The colorant was isolated in aqueous and acidic media, and MW treatment for 1, 2, 3, 4, and 5 min has been given to both fabric and extract to observe changes in color intensity. The dye variables have been optimized, and for sustainable shade making process with good fastness, 1.0–5.0 g/100 mL of sustainable chemical and bio-mordants has been employed. It has been found that after microwave treatment for 3 min, under selected conditions, the irradiated aqueous extract has given high color intensity onto silk fabric. The utilization of 3% of Al, 4% of Fe, and 2% of tannic acid (T.A.) as pre chemical mordant whereas 4% of Al, 4% of Fe, and 3% of tannic acid as post chemical mordant have given good color characteristics. In comparison, 4% of acacia and 3% of turmeric and pomegranate while 3% of acacia and turmeric and 4% of pomegranate extracts as post-bio-mordant have given excellent color characteristics. It is concluded that MW treatment has an excellent sustainable efficacy to isolate colorant from Peepal bark for silk dyeing, whereas the inclusion of bio-mordants has not only made the process more sustainable and environmental friendly but also best K/S, and $L^*a^*b^*$ values have been acquired.

Keywords Bio-mordants · Eco-friendly extraction · Microwave Radiation · Peepal · Silk

Introduction

One of the major causes of global pollution is the widespread utilization of synthetic dyes (Fadil et al. 2021). About 8000 metric tons of dye-stuff per annum is released worldwide, where approximately, in every processing, 10–50% of their effluent is released into water bodies without purification. This concentration of dye-stuff causes hindrance in the way of light penetrating deep in water bodies and disturbing the water ecosystem (Yılmaz and Bahtiyari 2020). Ultimately their presence lowers the aquatic photosynthetic process and destroys water quality parameters which in turn become harmful for agri-land and aquatic life (dos Santos Silva et al. 2020a). These wastes have carcinogens that are non-biodegradable and take a lot of time, money, and labor for their treatment (Haji and Vadood 2021). Many world-renowned associations such as ETAD (Ecological and Toxicological Associations of Dyes and Pigments), GOTS (Global Organic Testing Standards), EPA (Environmental Protection Agency), UNESCO (United Nations Educational Scientific and Cultural Organization), FAO (Food and Agriculture Organization), World Health Organization (WHO have seriously taken this matter under observation. These global institutes are forcing all industrialists to replace such stuff with green, sustainable, and eco-friendly products in all fields particularly textiles, cosmetics, food and flavor, and pharmaceutical industries (Hosseinnezhad et al. 2020; Salauddin et al. 2021). Among green products, particularly natural dyes have been now revived as the art of cultural

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heritage in textiles. Natural dyes are the dyes obtained from natural sources such as plants, animals, and minerals without any change in their morphology (Chen et al. 2020; Sk et al. 2021). In the current times, with the gradual increase in awareness among people related to eco-friendly and less polluted products, researchers are shifting towards natural dye as the possible substitute for synthetic dyes, and the researches on their possible isolation, standardization, and application in all fields are growing on (Viera et al. 2019; Zheng et al. 2021).

Natural dyes are facing two major problems, i.e., low extraction yield and poor color fastness ratings. A group of researchers is working to overcome these issues for decades. In the natural dyeing process, extraction of colorant is the basic step (Borrás-Enríquez et al. 2021). It is the process in which the cell wall is ruptured and the colorant is extracted out from the plant into solvent media at employed condition. Soaking, stirring, heating, and reflux are some of the important conventional methods, which are used for the extraction of the bio-potent molecule (Hasan et al. 2021; Kovačević et al. 2021). Due to low cost and simplicity, the solvent extraction method is considered as one of the good choices for the extraction of the colorant, but their conventional methods are not energy, time, and labor effective (Handayani et al. 2019). For better extraction, such methods are needed to be replaced with modern methods, which are sustainable, eco-friendly, cheap, energy-efficient, rapid, and effective in color yield of colorant (Chai et al. 2021; Naebe et al. 2021; Kumar et al. 2020). Various radiation techniques such as ultraviolet radiations, gamma radiations, ultrasonic radiations, microwave radiations, and plasma radiations have been widely used for extraction purposes (Haji and Naebe 2020; Mia et al. 2021; del Pilar Sánchez-Camargo et al. 2021).

One of these modern methods is the microwave-assisted extraction (MAE) technique which yields better quality extracts in higher amounts with less consumption of time, energy, and solvent (Xu et al. 2021; Jafari et al. 2019). These rays are volumetrically selective, permit the system to be heated rapidly, and modify the process for better action (Abdelileh et al. 2021; Yeong et al. 2021). The abridged size of equipment and waste, the controlled healing process, and no direct interaction between the source and materials occurred are another gains of this tool (Li et al. 2017). Microwave extraction depends upon the nature of the solvent, volume, extraction temperature, time, microwave power, and properties of the product. Hence, these rays are an environment-friendly source of radiation which can enhance the dye uptake ability of fabrics also by tunning the surface of fabric fibers (Arain et al. 2021).

For improving color quality parameters (fastness and lab), salts of metals called mordants are used. Mordants are the essential component needed for the dyeing of the fabric for achieving the broad spectrum of different shades on natural and synthetic textile materials (Hosseinnezhad et al. 2021a; Hosen et al. 2021). The type and nature of the mordant greatly affect the nature of color and shades of the dyes' textile materials (Yaqub et al. 2020). Most commonly used chemical mordants include salts of aluminum $(Al)^{3+}$, Cr^{3+} (chromium), Cu^{2+} (copper sulfate), Fe^{2+} (ferrous sulfate), Sn^{2+} (stannous chloride) (Hosseinnezhad et al. 2018; İşmal and Yıldırım 2019), but some mordants (salt of Cu, Cr, Co, W) are carcinogenic and make dye effluent much more toxic (Yusuf et al. 2017). Keeping in view the unfriendly nature of the chemical mordants, researchers are now moving towards the biological mordants because bio-mordants are biodegradable and ecosystem friendly and can give new shades with improved color characteristics (Islam et al. 2019; Rather et al. 2019).

Peepal (*Ficus religiosa*) is an evergreen herbal plant that belongs to the Moraceae family (Priya and Singh 2017). Its bark contains several components such as flavonoids, tannins, steroids, and saponins (Sharma et al. 2016; Singh and Jaiswal 2014). This plant extract also shows antiprotozoal, antibacterial, antiviral, and analgesic anti-diabetic characteristics. Its extract is also used to cure wounds, fertilization, diarrhea, asthma, anti-amnesic, antiulcer, anthelmintic, jaundice, etc. (Kumar et al. 2018; Sharma et al. 2019; Tiwari et al. 2019). Its bark contains which when after extraction is used for coloration of fabrics (Sharma et al. 2016; Singh and Jaiswal 2014). Silk is the natural fabric that has fibroin which plays the role of functional moiety (amide linkage) for bonding with colorant. Keeping in the view of the advantages of MW rays for high colorant yield and bio-molecules for getting fast shade, the purpose of current study is to

a) Extract the colorant in a suitable medium using the selected MW ray level
b) Study physiochemical nature of fabrics before and after dyeing
c) Select the dyeing variable for mordanting
d) Select mordanting level (%) for colorfast shade with better fastness ratings

Material and method

The crude powder of periderm (bark) of Peepal (*Ficus religiosa*) has been collected and sieved (20 meshes). Plant powders acting as the source of biological mordants have been ground, sieved, and stored. Silk fabric (20 = GSM) after pretreatment with neutral soap has also been stored for the coloration process. The rest of the chemicals used for isolation, dyeing, mordanting, and fastness procured was commercial (Pakistan-made).

Dye extraction and irradiation process

Aqueous (water solubilized) and acidic (acid solubilized = 1% HCl v/v) extracts have been prepared by taking 4 g of powder with 100 mL of media at boiling. Extract and soaped silk fabrics were given MW ray treatment up to 5.0 min, with the interval of 1 min. After the irradiation process, the dyeing process has been adopted as discussed in Table 1. After dyeing, the data were analyzed statistically using a two-way ANOVA design.

Mordanting treatment

Using optimum irradiation and extraction conditions, the set of experiments was designed to optimized extract pH (2.0–7.0), salt amount for exhaustion (1.0–6.0 g/100 mL), dyeing temperature (35–95 °C), and dyeing time (25–75 min.). For shade production, 1.0–5.0 g of three bio-mordants and 1.0–5.0 g of three sustainable chemical mordants were used. For the application of these mordants, the solutions were boiled in water using given amount and employed before and after dyeing by following already given method of Habib et al. (2021).

Fabric assessment

The undyed silk fabric before and after microwave treatment for 3 min have been subjected for physicochemical analysis (SEM & FTIR) (Adeel et al. 2021a). For analysis of dyed fabrics, data color, SF 600 equipped with the light source (D 6510° observer), was used to get color characteristics. For observing shade fastness, ISO standards for light washing and rubbing were used, and the results were compared at grey scale (Habib et al. 2021).

Table 1 Isolation and dyeing scheme of colorant from Peepal bark powder before and after microwave radiation for silk dyeing

Experimental variables	Microwave irradiation time	Dyeing conditions
NRE-NRS	1–5 min	Extraction in aqueous, acidic Powder to solvent ratio = 1:25 *Extract* pH = 4.0 Contact levels = 55 min at 55 °C, Leveling agent (table salt) = 3.0 g
RE-NRS	1–5 min	
RE-RS	1–5 min	
NRE-RS	1–5 min	
MAD	1–5 min	

Results and discussion

The uniform and leveled action of microwave rays by consuming less time, energy, and solvent are the unique properties that have attracted the attention of people working in the field of natural products (Suktham et al. 2021; Buyukakinci et al. 2021). In this study, its role has been studied for the isolation of the natural brown colorant (tannin) from Peepal bark in aqueous and acidic media for silk dyeing. The results given in Fig. 1 show that irradiation of aqueous extract (RE) and fabric (RS) for 3 min has given better color depth (K/S up to 12.173). On changing medium, the results displayed in Fig. 2 show that irradiation of extract (RE) and fabric (RS) for 4 min has given excellent results (K/S up to 10.412). In comparison, the un-irradiated aqueous extract (NRE) has given low color depth (K/S up to 3.8561), and un-irradiated acidic extract (NRE) also has given good color depth (K/S up to 3.626) onto un-irradiated fabric (NRS). The color coordinates given in Table 2 show that most dyed fabrics are darker in shade and reddish yellow in hue but irradiated aqueous extract (R.E. = 3 min), when employed onto irradiated silk (RS = 3 min), has given darker shades ($L^* = 43.71$) with more reddish yellow hue ($a^* = 29.14$; $b^* = 33.65$). Similarly, on using acidic extract (R.E. = 4 min) for dyeing of irradiated silk (R.S. = 4 min), the shade obtained is less darker ($L^* = 47.19$) in shade and less reddish but yellower in hue ($a^* = 27.15$; $b^* = 36.24$).

This excellent yield is due to the effect of MW rays at the molecular level, where the rays penetrate the matrix, rupture its cell walls, and make the solid–liquid (colorant-solvent) interaction through mass transfer kinetics (Pal and Jadeja 2020; Zghaibi et al. 2019; Wang et al. 2021). The other factor running side by side is the irradiation of the fabric. It has been observed that MW ray treatment didn't alter the functional nature of silk which has been verified by FTIR spectra. The stretching peaks of -NH_2 (3100–3200 cm^{-1}), -C = O (1717 cm^{-1}), and CH_3 (3190 cm^{-1}) have not altered their positions after exposure to MW rays up to 3 min (Figs. 3 and 4). However, the SEM analysis (Figs. 5 and 6) shows that these rays have produced scaling on the surface of the fabrics. The scratching produced after MW rays has modified the coloring behavior of silk which has been observed through the rise of color strength (K/S = 12.173) in an aqueous medium. Hence, it is recommended that both extract and fabrics should be MW irradiated for 3 min. to get excellent yield. The statistical analysis given in Table 3 reveals that selection of treatment ether onto fabric or extract is significant (0.000). The role of dyeing variable, i.e., application of extract at given dyeing conditions, is also significant ($P = 0.001$).

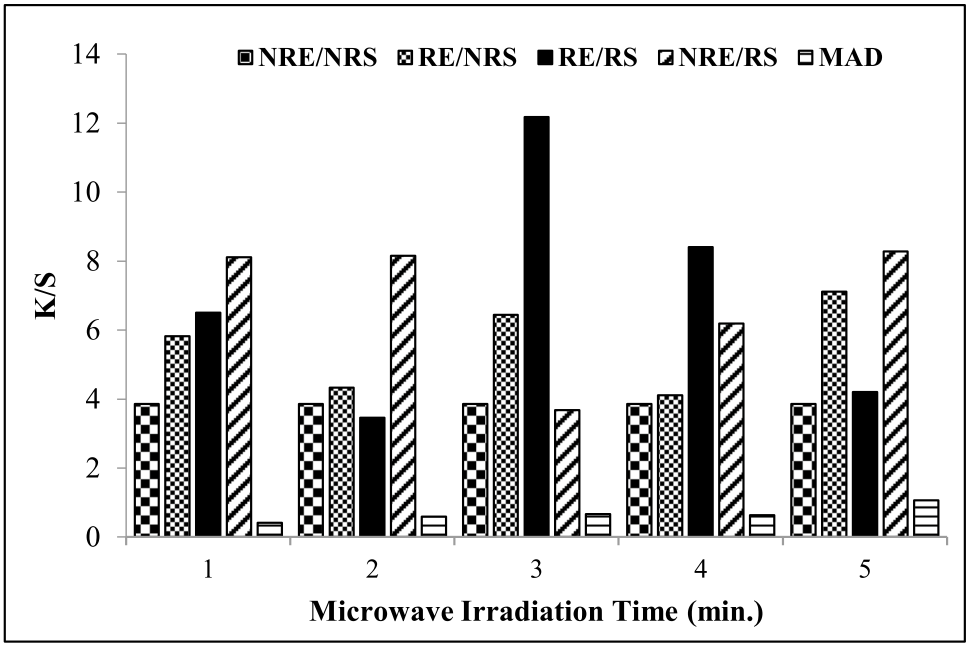

Fig. 1 Application of microwave irradiated and un-irradiated heat solubilized extract (aqueous) of Peepal bark for dyeing of irradiated and un-irradiated silk fabrics

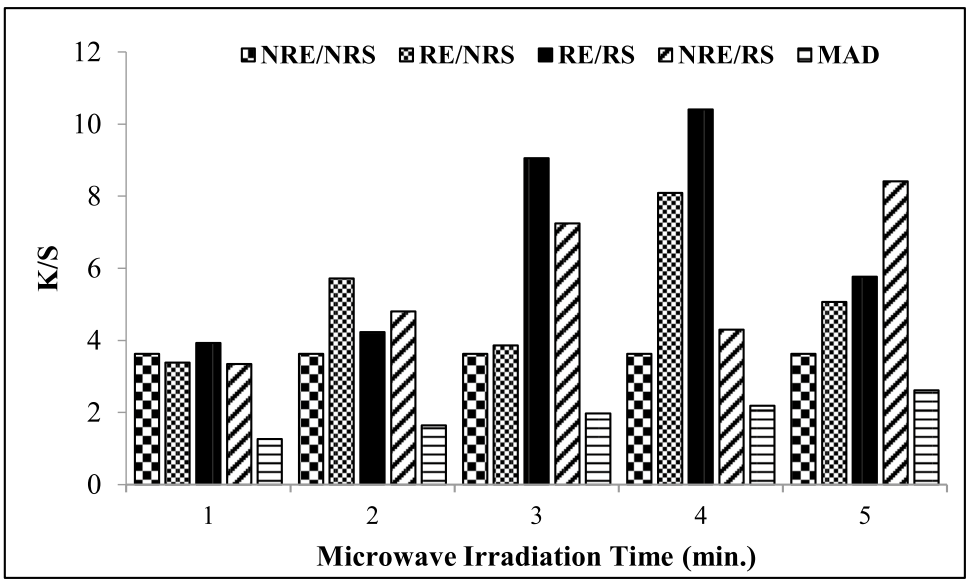

Fig. 2 Application of microwave irradiated and un-irradiated acid solubilized extract (acidic) of Peepal bark for dyeing of irradiated and un-irradiated silk fabrics

In the bio-coloration of silk, optimum dyeing levels are necessary to select for getting a high yield of fast shades. The results show in Fig. 6a–d that irradiation of acidic extract (4.0 *p*H) for 3 min containing 3.0 g/100 mL of table salt as an exhausting agent when employed at 55 °C for 55 min has given good results onto irradiated silk fabric. The role of *p*H of the extract is very essential because silk fabric contains both acidic (-COOH) and basic group (-NH_2), which require an acidic medium to sorb colorant promisingly (Adeel et al. 2021b). Due to low pH, dye molecules (tannin) interact with fabric functional site (amide linkage) via H-bonding to give firm shades of high strength (K/S up to 6.7701). Hence acidic extract of pH 4.0 after MW treatment for 3 min should be used to dye the irradiated silk fabric (RS = 4 min). The color coordinates given in Table 4 show that the other factor is the role of electrolyte (table salt) for achieving excellent exhaustion of colorant from medium towards surface-modified silk fabric. The utilization of salt amount (< 3.0 g/100 mL) can't shift the dye from the bath toward the fiber promisingly, whereas the salt amount (> 3.0 g/100 mL) exhausts the molecules significantly, and colorant molecules are sorbed onto fabric in form of aggregates due to over-exhaustion (Adeel et al. 2021c). In both cases, the colorant molecules cannot fill the voids of fibers, and upon washing shades of low color, strength is observed. But the

Table 2 Color coordinates of microwave silk fabrics dyed by using optimally irradiated or non-irradiated extract of Peepal (*Ficus religiosa*) bark

Microwave radiation Time (min.)	Sample code	K/S	*L**	*a**	*b**
Aqueous extract					
Ctrl	NRE/NRS	3.8561	53.42	22.90	23.94
1	NRE/RS	8.1112	51.19	27.65	36.70
2	NRE/RS	8.1581	49.96	28.19	35.23
3	RE/RS	12.173	43.71	29.14	33.65
4	RE/RS	8.4020	51.23	26.60	37.77
5	NRE/RS	8.2793	51.31	26.59	37.92
Acidic extract					
Ctrl	NRE/NRS	3.6260	53.64	16.88	23.34
1	RE/RS	3.9309	53.97	19.77	25.87
2	RE/NRS	5.7216	53.09	25.35	32.67
3	RE/RS	9.0559	49.43	25.25	36.28
4	RE/RS	10.412	47.19	27.15	36.24
5	NRE/RS	8.4127	46.36	30.28	30.42

Ctrl= Without MW− Treatment

utilization of 3.0 g/100 mL of leveling agent in a selected extract of 4.0 *p*H onto surface modified silk has given excellent tint strength (K/S up to 4.7763). The color coordinates given in Table 4 show that using 3.0 g/100 ml of salt, the shade is darker ($L^*=51.11$) and reddish yellow in hue ($a^*=17.50$; $b^*=21.93$). Irradiation for 3 min has imparted good strength with a darker shade ($L^*=48.18$) but reddish yellow hue ($a^*=13.53$) ($b^*=22.29$).

In the bio-dyeing of silk contact of heat for a particular time play a significant contribution in giving high strength (Khan et al. 2021). The results show that dyeing of irradiated silk (RS) for 55 min at 55 °C using irradiated extract of 4.0 *p*H containing 3.0 g/100 mL of electrolyte (T.S.) has given promising results. The bio-coloration of fabric for a low time (55 min) at a low heat level (55 °C) does significantly not accelerate the colorant molecules. Due to this poor effect, the kinetic energy of dye becomes low, and during dyeing, molecules remain unfixed onto the fabric surface. For high contact levels (55 min) at high temperature (> 55 °C), the dyeing rate becomes recessive, and the rate of stripping becomes dominant, and again molecules face desorption problems which give low yield. But dyeing of fabric at 55 °C for 65 min gives leveled shade of high color strength which might be due to equilibrium of dye bath with fabric. The shade parameters (Table 4) reveal that the dyeing of fabric for 65 min has given a darker tone ($L^*=43.54$) with a reddish yellow hue ($a^*=15.59$; $b^*=18.78$). The fabric dyed at 55 °C has given a darker shade ($L^*=51.02$) with a less reddish yellow hue ($a^*=14.80$; $b^*=21.61$). Overall, at selected levels, the shades are darker in appearance having a reddish yellow tone. Hence MW rays have not only reduced salt amount but also save time and energy for dyeing of silk with Peepal bark extract at selected conditions.

In bio-dyeing of fabric, the problem of poor fastness is tried to overcome either by utilization of electrolytes (Al^{3+}, Fe^{2+}, Cu^{2+}, Co^{2+}, Ni^{2+}) or by tannic acid (T.A.) called chemical mordants. But the salts of Cu^{2+}, Ni^{2+}, Cr^{3+}, Co^{2+}, etc. are toxic and need replacement by some sustainable anchors. In this study, 1.0–5.0 g/100 mL of electrolytes of Al^{+3}, Fe^{+2}, and tannic acid (T.A.) before and after dyeing of irradiated silk at 55 °C for 65 min has been utilized. The results show in Fig. 7a–c that 3.0 g/100 mL of salt of Al^{+3} and 4.0 g/100 mL of salt of Fe^{+2} and 2.0 g/100 mL of tannic acid (T.A.) before dyeing (pre-mordanting) has given good results. The application of salt of Al^{+3} (4.0 g/100 mL) and of Fe^{+2} (4.0 g/100 mL) and tannic acid (T.A. = 3.0 g/100 mL) after dyeing (post mordanting) has given good results.

The color coordinates given in Table 5 reveal that utilization of Al^{3+} salt (3%) before dyeing has given darker shade ($L^*=67.94$) with the less red ($a^*=7.60$) but yellow

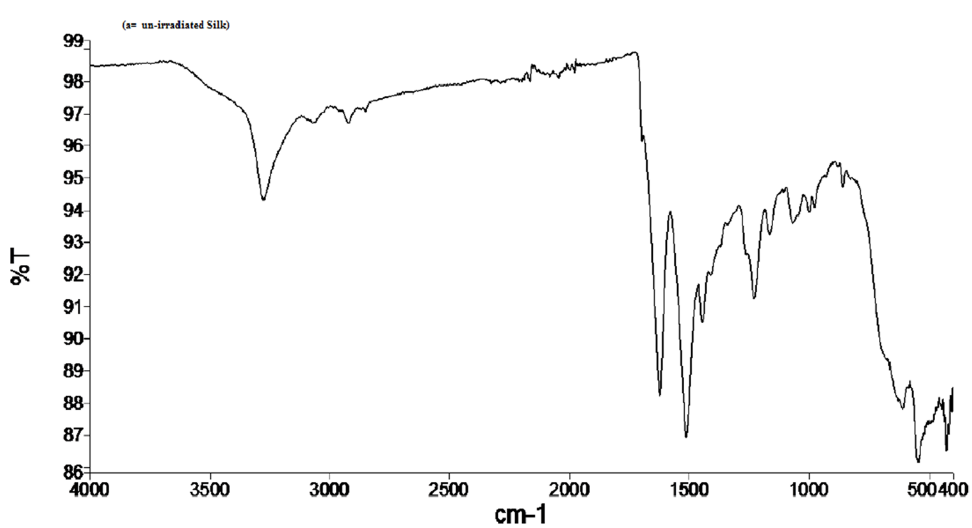

Fig. 3 FTIR Spectra of un-irradiated silk fabric

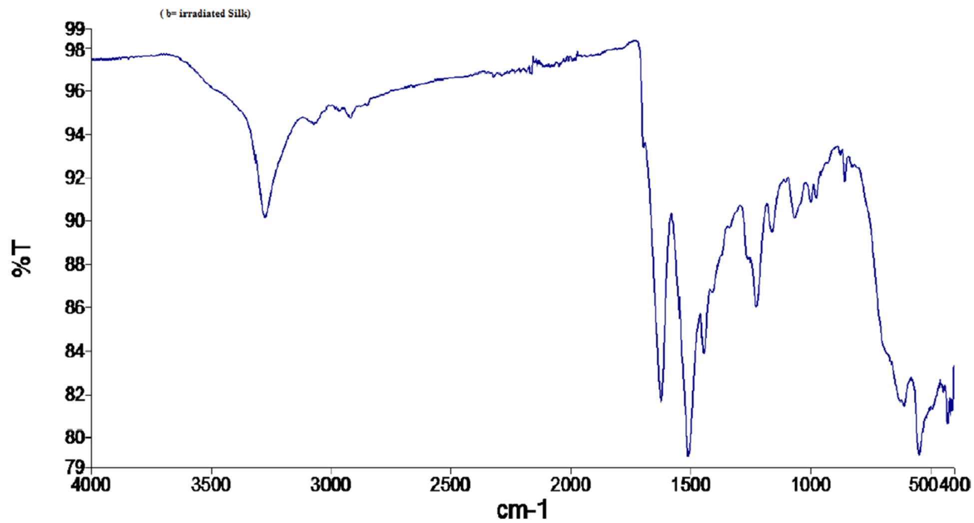

Fig. 4 FTIR Spectra of microwave irradiated silk fabric (RS = 3 min)

hue ($b^*=25.69$) on using the salt of Al^{3+} after dyeing (4% post); the shade becomes brighter ($L^*=73.64$) having less-redder ($a^*=5.71$) but the more yellower tone ($b^*=22.92$). Similarly, utilization (4.0 g/100 mL) of iron salt (Fe^{2+}) before dyeing (pre) has given darker shade with more reddish yellow hue ($L^*=58.69$; $a^*=10.39$; $b^*=25.27$), whereas after dyeing (post) has given brighter shade with more reddish yellow hue ($L^*=65.09$; $a^*=9.45$; $b^*=24.92$). Tannic acid is a good ecofriendly chemical mordant, where its application before dyeing (2% pre) has given a brighter shade ($L^*=58.53$) with a reddish yellow hue ($a^*=10.98$; $b^*=20.03$). However, its application after dyeing (3% post) has given a darker shade ($L^*=53.51$) with a more reddish yellow hue ($a^*=12.30$; $b^*=20.72$). The possible interaction of chemical mordant, by the functional site (-OH of tannin) and amide linkage of silk, has been demonstrated in Fig. 9a.

The role of plant-based biological molecules as bio-mordants has been observed for the last five years (Hosseinnezhad et al. 2021b). These functional biomolecules have gained a special place as an alternative to toxic chemicals as well as for making dyeing processing more eco-friendly and pollution-free (Thakker 2020). In this study, extracts of acacia, turmeric, and pomegranate obtained by employing 1.0–5.0 g with 100 mL water have been utilized before (pre) and after (post) dyeing of silk with Peepal bark extract at selected conditions. It has been found in Fig. 8a–c that 4.0 g/100 mL of acacia extract (K/S = 6.438) and 3.0 g/100 mL of turmeric (K/S = 15.583) and pomegranate extract (K/S = 16.592) before dyeing (pre-mordanting) have given good shades with acceptable fastness ratings, whereas 3 g/100 mL of acacia extract (K/S = 2.2998) and turmeric extract (K/S = 16.985) and 4 g/100 mL of pomegranate extract (K/S = 14.08) after dyeing (post mordanting) have also developed good shades with good to excellent fastness characteristics. The color coordinates and fastness grades are given in Table 5 and show that using the optimal amount of mordants (chemical and bio) has improved these characteristics. The proposed bio-mordant, colorant (tannin), and fabric (amide linkage) interactions have been displayed in Fig. 9b.

On comparison analysis, as pre-chemical mordant, salt of iron (Fe^{2+} = 4.0 g/100 mL) has given fast shade with a reddish yellow hue, and as pre-bio-mordant, the extract of pomegranate (3.0 g/100 mL) has given fast shades with the reddish yellow hue. As post chemical mordant, 3.0 g/100 mL of T.A. (tannic acid) has given good color characteristics, whereas post-bio-mordant, the turmeric extract (3.0 g/100 mL) has given a high yield with a more reddish yellow hue. Bio-mordants have given darker shades with reddish but yellow hue depending upon the nature of plant parts. The results given in Table 5 show that turmeric and pomegranate extract has given darker shades as compared to acacia extract. During pre-mordanting, the utilization of 3% of pomegranate extract has given darker shade ($L^*=41.92$) with reddish yellow hue ($a^*=14.18$) ($b^*=31.76$). But the application of 3% extract of turmeric after dyeing has given a brighter shade ($L^*=54.31$) with a reddish ($a^*=18.34$) yellow hue ($b^*=53.77$).

This excellent color strength with improved fastness grading is due to the formation of a metal dye complex onto the surface tunned silk fabric (dos Santos Silva et al. 2020b; Zhao et al. 2020). A low amount cannot form a stable complex, whereas in the above selected mordant, the over amount may form complex and sorb onto fabrics inform of aggregates. Upon soaping, the overcrowded complex is stripped, and low tint strength with poor fastness rating is observed.. On using bio-mordants, the colorant functional site (-OH) interacts with amide linkage (-NH, COO-) of silk and -OH of bio-mordants through additional H-bonding to form firm shades (Sadeghi-Kiakhani et al. 2020; Habib et al. 2021). Additionally, the

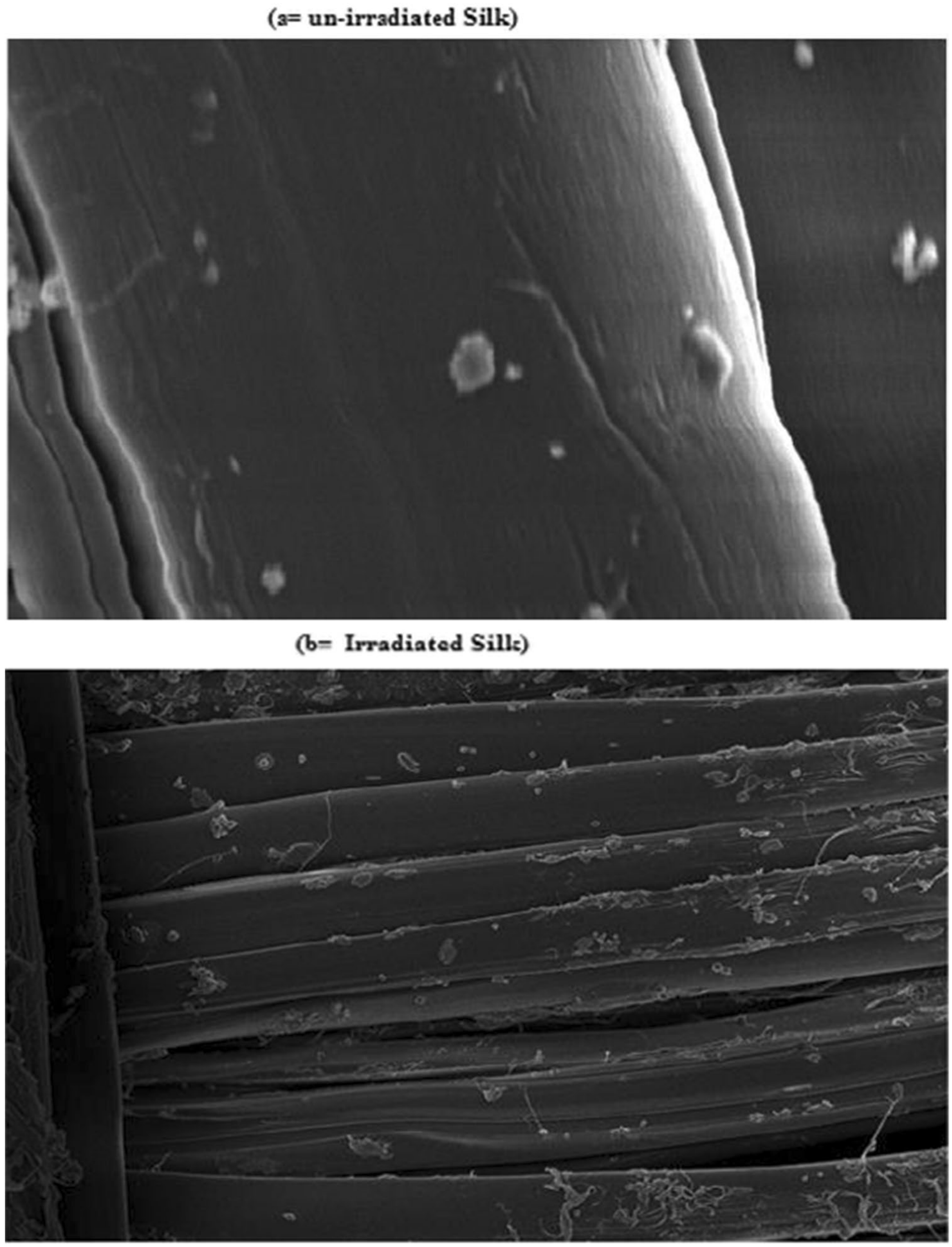

Fig. 5 SEM image of control (**a**) and irradiated silk fabric (**b**)

benzenoid ring present in colorant and bio-mordant also plays their role, where extra conjugation adds value in the bio-coloration of fabrics to develop fast shades (Boruah et al. 2021; Islam et al. 2021). Upon washing, crocking (rubbing) and heat exposure, the bio-mordanted dyed fabrics show maximum resistance to fade Table 6. Hence after assessment of selected chemical and bio-mordanted fabrics, as per ISO standards, the good to excellent fastness at grayscale has been observed by chemical and bio-mordanted dyed fabrics. It is concluded that the made dyeing process of silk is not only more attractive, colorfast, and ecofriendly with Peepal bark-based tannin natural reddish brown dye.

Conclusion

The current era is the age of sustainability wherein the current worsening pandemic scenario that is getting worse is now in need of treatment with nature rather than chemical products. Natural products with exceptional biological

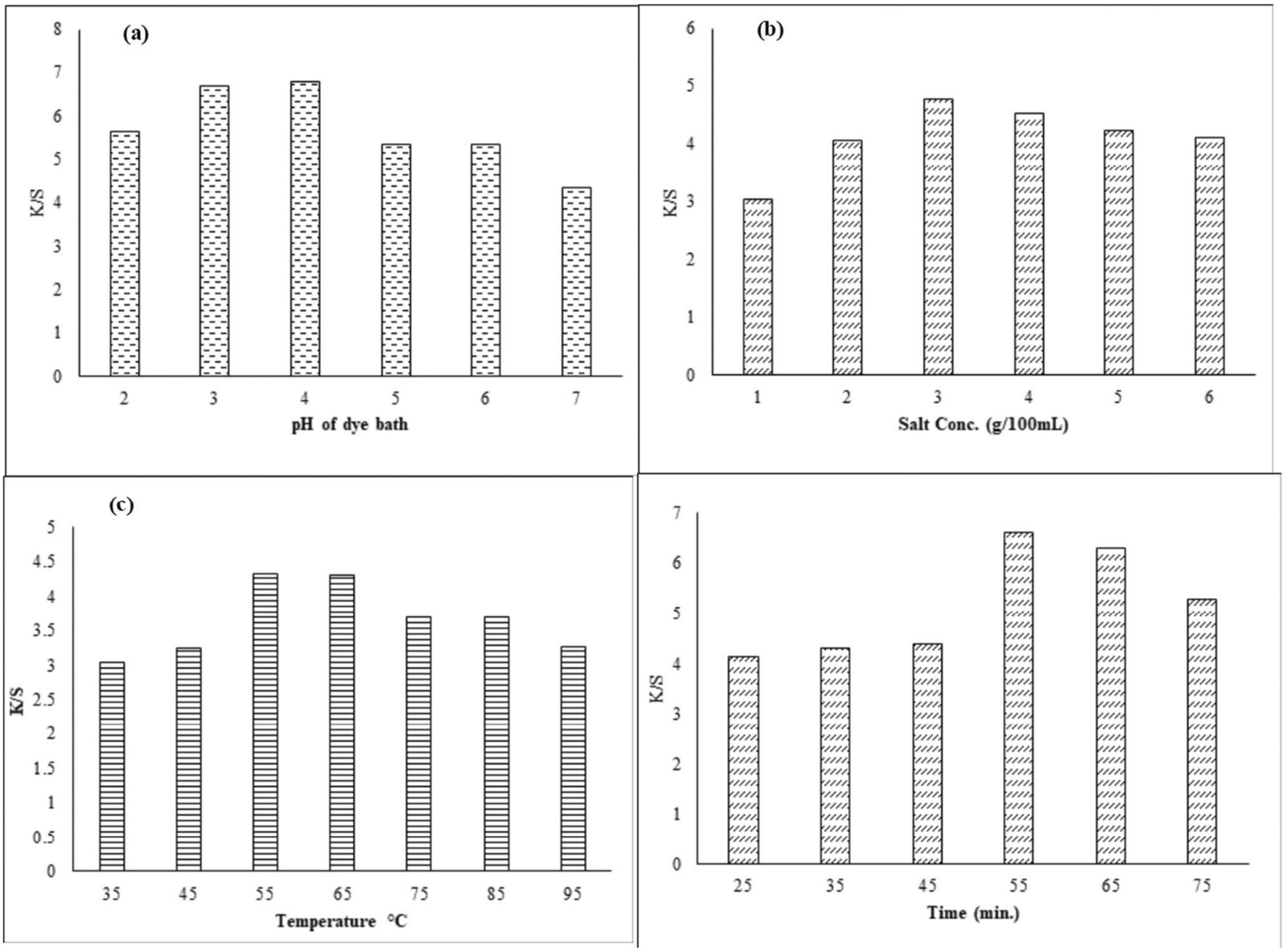

Fig. 6 Effect of irradiated aqueous extract *p*H (**a**) using table salt (**b**) on dyeing of irradiated silk fabric using different temperature (**c**) for different time (**d**)

properties, especially of an antioxidant antibacterial and antiviral in nature, are gaining widespread fame to be utilized in all walks of life. Among these products, Peepal (*Ficus religiosa*) is a great plant with advanced coloring potential for textiles. The addition of MW radiations as an extraction method for natural biological components (tannin) from Peepal for silk coloration and bio-molecules as bio-mordants for getting fast shades has made the method more eco-friendly as well as gorgeous for the global community. The researchers found that Peepal bark extract of 4 pH containing 3 g/100 ml of table salt after MW treatment up to 3 min at 55 °C for 55 min has given excellent shade strength when employed onto MW-treated chemical and bio-mordanted silk before and after dyeing. It is concluded that MW radiation not only has the potential to extract the colorants but also is helpful in exploring new dye yielding plant with high yield of colorants. Also the use of bio-mordants has made the process more sustainable, cleaner, and environmentally friendly.

Author contribution Dr Shahid Adeel is supervisor of the work in whose lab practical work has been done, whereas Mr. Waseem Akram and Ms. Nimra Amin jointly conducted experiments. Dr Noman Habib and Dr Mozhgan have guided the group technically and scientifically, whereas Mr. Ehsan ul Haq has helped in physiochemical analysis of fabrics.

Data availability Not applicable.

Declarations

Ethics approval Not applicable.

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

Competing interests The authors declare no competing interests.

Table 3 Two-way ANOVA analysis for selection of irradiation and isolation conditions for silk bio-coloration in aqueous and acidic medium

Tests of between-subject effects					
Source	Type III sum of squares	df	Mean square	F	Sig
Dependent variable: KS: aqueous extract					
Corrected model	141.731[a]	8	17.716	4.188	0.007
Intercept	572.733	1	572.733	135.373	0.000
MW.rad.time	4.453	4	1.113	0.263	0.897
sample code	137.279	4	34.320	8.112	0.001
Error	67.692	16	4.231	-	-
Total	782.157	25	-	-	-
Corrected total	209.424	24	-	-	-
Dependent variable: KS: acidic extract					
Corrected model	90.925a	8	11.366	4.051	0.008
Intercept	532.954	1	532.954	189.956	0.000
MW.rad.time	21.947	4	5.487	1.956	0.150
Sample code	68.978	4	17.244	6.146	0.003
Error	44.891	16	2.806		
Total	668.769	25			
Corrected total	135.815	24			

Table 4 Color coordinates of microwave silk fabric dyed at optimal condition using irradiated extract

Parameters	Optimum amount	*L* *	*a**	*b**
Extract pH	4.0	48.18	13.53	22.29
Time (min.)	55	43.54	15.59	18.78
Temperature (°C)	55	51.02	14.80	21.61
Leveling agent (T.S. = g/100 mL)	3.0	51.11	17.50	21.93

T.S = sodium chloride

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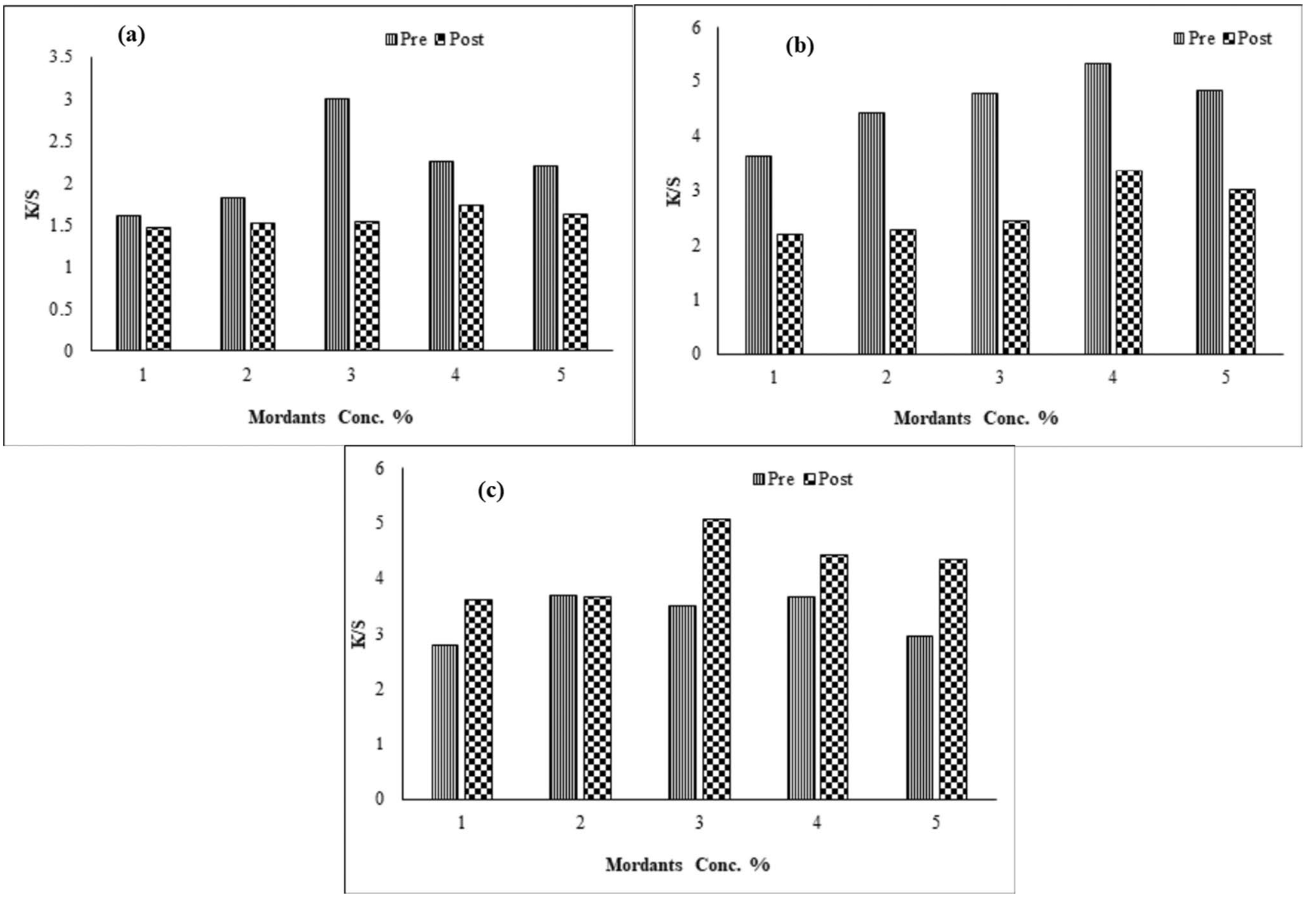

Fig. 7 Effect of pre and post chemical mordant **a** = Al, **b** = Fe, and **c** = T.A. on color strength of irradiated silk fabric (RS) with an irradiated aqueous extract (RE = 3 min)

Table 5 The color coordinates of chemical and bio-mordanting silk fabrics dyed with irradiated extract

Mordant	Mordant conc	*L**	*a**	*b**
Al	3% Pre	67.94	7.60	25.69
	4% Post	73.64	5.71	22.92
Fe	4% Pre	58.69	10.39	25.27
	4% Post	65.09	9.45	24.92
T.A	2% Pre	58.53	10.98	20.03
	3% post	53.51	12.3	20.72
Bio-mordants				
Acacia	4% Pre	48.71	12.65	20.48
	3% Post	64.61	8.12	21.76
Turmeric	3% Pre	42.28	26.93	36.18
	3% Post	54.31	18.34	53.77
Pomegranate	3% Pre	41.92	14.18	31.76
	4% Post	49.18	11.70	32.95

*L** = darker/brighter; *a** = redder; *b** = yellower

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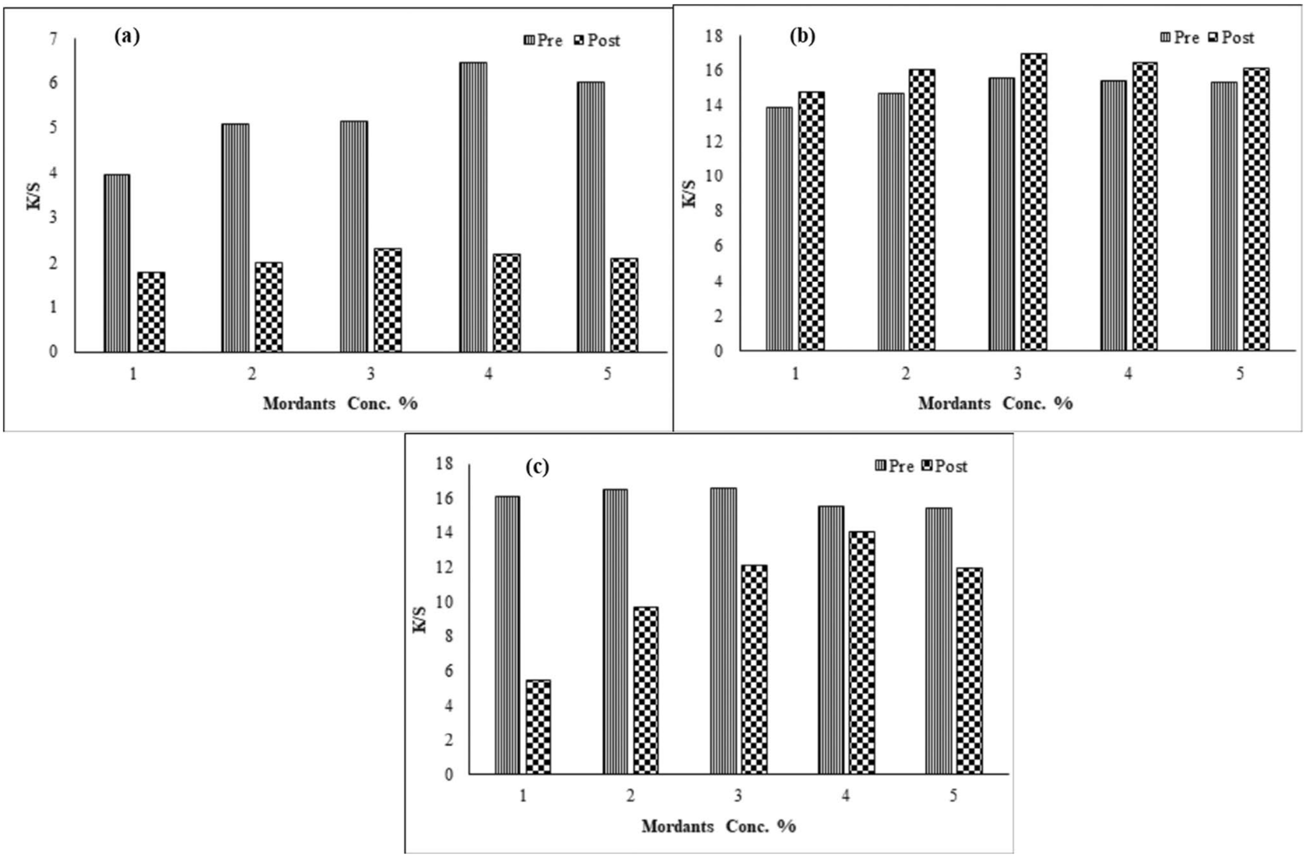


Fig. 8 Effect of pre and post bio-mordant **a** = acacia, **b** = turmeric, and **c** = pomegranate on color strength of irradiated silk fabric (RS) with an irradiated aqueous extract (RE = 3 min)

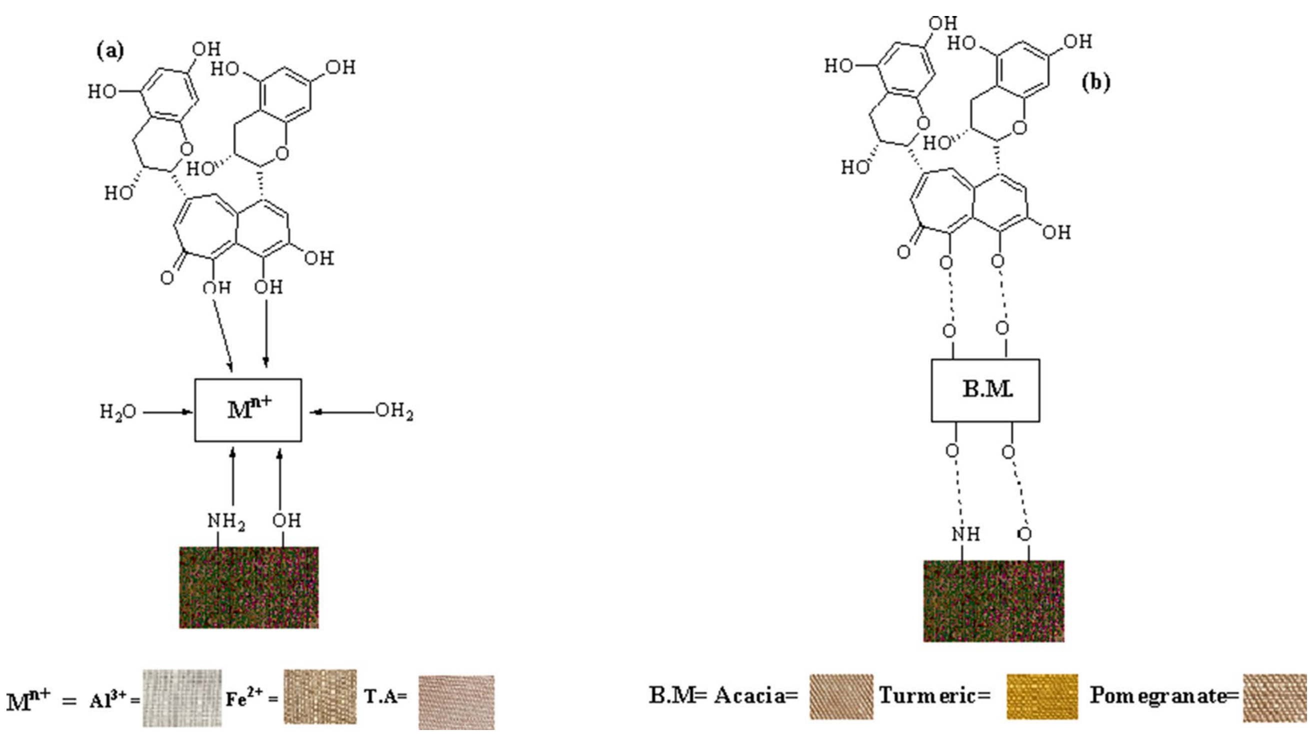


Fig. 9 Proposed mechanism of mordant dye complex with silk fabric

Table 6 The colorfastness ratings of chemical and bio-mordanting silk fabric dyed with irradiated extract

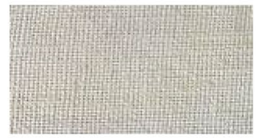
Mordants Used	L.F	W.F.	RF		DCF	PF		Shades
			DRF	WRF		Acidic	Alkaline	
Ctrl	4	3/4	4	3	4	3/4	3/4	
Al 3% Pre	5	5	5	4/5	4/5	4/5	4/5	
Al 4% Post	5	5	5	4/5	4/5	4/5	4/5	
Fe 4% Pre	5	4/5	5	4/5	4/5	4/5	4/5	
Fe 4% Post	5	5	5	4/5	5	4/5	4/5	
T.A. 2% Pre	5	5	5	4/5	5	5	5	
T.A. 3% Post	5	4/5	5	4/5	5	5	5	
Acacia 4% Pre	5	5	5	4/5	5	5	5	
Acacia 3% Post	5	4/5	5	4/5	5	5	5	
Turmeric 3% Pre	5	4/5	5	4/5	5	4/5	4/5	
Turmeric 3% Post	5	4/5	5	4/5	4/5	4/5	4/5	
Pomegranate 3% Pre	5	5	5	4/5	4/5	5	5	
Pomegranate 4% Post	5	5	5	4/5	4/5	5	5	

Table 6 (continued)

LF light fastness; *WF* wash fastness; *c..c* color change; *c.s* color stain; *RF* rub fastness; *DC* dry cleaning; *PF* perspiration fastness

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