Indian Journal of Fibre & Textile Research
Vol. 50, June 2025, pp. 189-199
DOI: 10.56042/ijftr.v50i2.8125

Ficus religiosa bark as sustainable dye with antibacterial and UV protective functions for protein-based textiles

Neetu Rani[1,a], Lalit Jajpura[2] & B S Butola[3]

[1]Department of Fashion Technology, BPSMV, Khanpur Kalan, Sonipat 131 305, India

[2]Department of Textile Technology, Dr B R Ambedkar National Institute of Technology, Jalandhar 144 011, India

[3]Department of Textile and Fibre Engineering, Indian Institute of Technology Delhi, New Delhi 110 016, India

Received 17 January 2024; revised received and accepted 10 July 2024

The present study explores the sustainable utilisation of *Ficus religiosa* bark extract as a natural dye and functional finishing agent for protein-based textiles—wool, silk, soya, and milk.Extraction variables, i.e. MLR, pH, temperature and time, are optimised to maximise phenolic, flavonoid, tannin and antioxidant contents. The extract is applied using various mordanting techniques with both chemical and natural mordants, and dyeing conditions are optimised through a Box–Behnken response surface design. The dyed fabrics exhibit a rich spectrum of brown hues with good colour fastness. In addition, they demonstrate improved ultraviolet protection and notable antibacterial activity. The dyed fabrics also exhibit improvement in ultraviolet protection. The findings position *F. religiosa* bark extract as a sustainable and potential source of economical and ecological dyeing agent for antioxidant, UV protection and antibacterial finishing properties in textiles.

Keywords: Antimicrobial activity, Antioxidant property, Natural dye, Sustainable textile, UV protection, Wool

1 Introduction

In recent years, growing environmental and health concerns have renewed global interest in natural dyes as eco-friendly alternatives to synthetic counterparts. Natural dyes not only offer varied and rich dye stuff, but also create possibilities of an income through sustainable sale and harvesting of these plants[1,2]. In contrast, synthetic dyes, with an estimated annual consumption of around 10 million tonnes globally, are associated with the release of toxic effluents, contributing to significant ecological imbalance and adverse health effects[3]. Natural colourants are bio-degradable and normally have better congruence with the environment. These are easily available, non-toxic, non-carcinogenic and renewable[4],and few of them have additional functional characteristics like UV protection, anti-oxidant, antimicrobial, mosquito repellent and wound healing properties[5-7]. In combination with biopolymers and natural mordants, natural dyes are increasingly being explored as dual-purpose agents for both dyeing and functional finishing of textiles[8,9].

Among various plants explored for sustainable applications, *Ficus religiosa* L., commonly known as the peepal tree, holds a distinguished position due to its ecological, medicinal, and cultural significance. A fast-growing deciduous tree with a broad canopy and characteristic heart-shaped leaves, *F. religiosa* belongs to the Moraceae family[10]. Traditionally employed in Ayurvedic medicine for treating a wide range of ailments, including asthma, diabetes, and inflammatory disorders[11], the bark of *F. religiosa* is rich in bioactive phytochemicals such as flavonoids, tannins, terpenoids, and cardiac glycosides[11].

Previous studies by Saravanan *et al.* and Habib *et al.* demonstrated the potential of *F. religiosa* bark extract as a natural dye for colouring silk[12,13]. Whereas Akram *et al.*and Saravanan *et al.* explored the dyeing properties of *F. religiosa* bark on cotton fabric with chemical and natural mordants. It was reported that the use of different mordanting methods and mordants affected the depth of shade on the dyed cotton differently[13,14]. However, systematic research investigating the application of *F. religiosa* bark extract on protein-based textile materials, and its use as a multifunctional finishing agent providing antioxidant, antibacterial, and UV protective functionalities, remains limited. Therefore, the present research focuses on colouration and finishing behaviour of protein fabrics dyed with *F. religiosa* bark extract.

[a]Corresponding author.
E-mail: neetu.1987@yahoo.co.in

2 Materials and Methods

2.1 Materials

Four types of protein-based textile materials were used in this study—wool, silk, milk and soya fabric —with areal densities of 180, 56, 58 and 39 g/m^2, respectively. The respective ends/inch and picks/inch for wool, silk, milk and soya fabric were 22×24, 40×41, 39×46 and 42×33, respectively. Wool and silk fabrics were procured from the local market, whereas regenerated milk (casein) and soya fabrics were obtained from Champs Agro Unit, Thane, India. *F. religiosa* bark powder was sourced from Neoteric, Coimbatore, India whereas natural mordants — pomegranate peel, orange peel, harda and amla — were purchased from the local market in Bhiwani, India. These natural mordants were selected due to their higher tannin content and inherent colouration properties[15,16]. All chemicals used for analysis were of analytical or laboratory-grade and purchased from SD Fine Chem Ltd. Additional reagents used for estimation of phenolic, tannic and flavonoid contents as well as antioxidant behaviour of the *F. religiosa* bark extractwere procured from SRL Pvt. Ltd.

2.2 Methods

2.2.1 Extraction of F. religiosa Bark Powder, Dyeing and Mordanting of Textiles

A Soxhlet apparatus was used for the aqueous extraction of *F. religiosa* bark powder in deionized water. The extraction process was optimised by varying one parameter at a time while keeping others constant. The variables studied included pH (1, 3, 5, 7 and 9), temperature (40°C, 60°C, 80°C and 100°C), time (30, 60, 90 and 120 min) and material-to-liquor ratio (MLR) (1:10, 1:20, 1:30 and 1:40). Phenolic content and absorbance of coloured liquor were assessed at maximum wavelength of 750 and 572, respectively as the optimising criteria of extraction. Fabric swatches (20×20 cm) were dyed in 250 mL borosilicate conical flasks. In all the experiments, 10 % owing weight of the fabric (owf) natural dye extract and 10 % owf mordant were used in dyeing and mordanting experiments, respectively. Pre-, meta- and post-mordanting techniques were performed at 1:30 MLR for 30 min at a boil. The dyeing was conducted atconstant shaking speed in a water shaker bath (Globe Tex Industries). To avoid interaction with metallic surfaces, all dyeing processes were carried out in borosilicate glassware.

Three factorial Box and Behnken experimental design were applied for the optimisation of dyeing parameters. Temperature (50°C, 70°C and 90°C), time (30, 60 and 90 min), and pH (3, 5, and 7) were taken as three variables at 1:30 MLR. The K/S value of the dyed sample was taken as a response factor. Acetic acid and sodium carbonate were used to adjust the pH.

2.2.2 Absorbance Value of Extract

The absorbance of dye extracts was measured using a UV spectrophotometer (Systronics).

2.2.3 Estimation of Flavonoid, Tannin and Phenolic Contents

Total flavonoid content was determined using the standard quercetin sample against the extract solution's absorbance. A 25 mg aliquot of extract was dissolvedin 25 mL of methanol up to a 0.300 mg/mL dilution. Further, 2 mL of the aforesaid solution was mixed with 0.1 mL sodium acetate, 0.1 mL $AlCl_3$ and 2.8 mL distilled water. Absorbance was recorded at 750 nm. The flavonoid content was calculated using Eq. 1[17].

$$\text{Total flavonoid content} = \frac{\text{V.DF.x}}{1000\text{w}} \qquad ...(1)$$

where V is the volume of extract solution (mL); x, extract concentration (mg/mL); w, weight of extract (g); and DF, dilution factor of sample solution.

Tannin content was determined by assessing decolourisation of 0.5 % extract solution with reagents i.e., gelatin, copper sulfate ($CuSO_4$), aqueous ferric chloride lead and acetate solution[18].

Total phenolic content (TPC) was assessed using the Folin-Ciocalteu method[19]A 0.1 mL aliquot of 200 µg/mL extract was mixed with 0.1 mL Folin-Ciocalteu reagent (50 %) by vortexing for one minute followed by the addition of 2 mL of 2 % Na_2CO_3. The mixture was incubated for 30 min, and absorbance was recorded at 750 nm. TPC was measured using Eq. 2.

$$\text{Total Phenolic content (TPC)} = \frac{\text{V.DF.x}}{1000\text{w}} \qquad ...(2)$$

where V is the volume of extract solution (mL), x, extract concentration (mg/mL); w, sample weight (g); and DF, dilution factor of extract solution.

2.2.4 Antioxidant Property

The radical scavenging activity (RSA) as a measure of anti-oxidant property was assessed using the Diphenyl-2-picryl-hydrazyl (DPPH) method. A 0.20 mL extract sample was mixed with 3.8 mL of 0.1 mM DPPH ethanol solution[20] and kept in the dark at room temperature for 30 min. Further, the

absorbance of the aforementioned sample was measured on a spectrophotometer at 517 nm. RSA was assessed using Eq. 3 and taking ascorbic acid as a standard for the equivalent value of the antioxidant property and plotting of the graph[21].

$$\text{Radical Scavenging Activity (RSA), \%} = \frac{(1-\text{Absorbance extract})}{\text{Absorbance control}} \times 100 \quad ...(3)$$

where Absorbance control is the absorbance of the control solution; and Absorbance extract, absorbance of extract sample.

2.2.5 Determination of Colour Strength and Colour Fasting

Dyed fabrics were evaluated for colour strength using a computererised colour matching system (Premier Colour scan SS 5100A) with D65 illuminant/ 10^0 observer conditions.

Wash fastness was determined as per IS: 3361 – 1984 (ISO-2) specifications. Rubbing fastness was measured using a crockmeter (Globe-Tex, India) as per AATCC Test Method 8 – 2007. Light fastness was measured using a digital light fastness tester (Globe-Tex, India) as per AATCC Test Method 16- 2004.

2.2.6 UV-Vis and FTIR Spectroscopy

F. religiosa extract and dyed fabric samples were evaluated using a Shimadzu UV-2450 spectrophotometer over the 200–800 nm range. Functional groups were characterised using FTIR spectroscopy with OPUS software.

2.2.7 UPF (Ultraviolet Protection Factor)

UPF values were determinedusing AS/NZS 4399:2017 standard[22] using a UV-2600 lab sphere in the 280-400 nm range. It was assessed using Eq. 4.

$$\text{UPF}=\frac{\sum_{\lambda=280}^{400} E\lambda.\ S\lambda\ .\Delta\lambda}{\sum_{\lambda=280}^{400} E\lambda.S\lambda\ .T\lambda\ .\Delta\lambda} \quad ...(4)$$

where E_λ is Erythemal spectral effectiveness; T_λ, spectral transmittance (%); λ, wavelength (nm); S_λ, solar spectral irradiance (Wm^{-2} nm^{-1}); and Δλ, bandwidth (5 nm).

Fabrics with UPF ≥ 40 are considered "Excellent" (≥97.5 % of UVR blocked), UPF 25 to 39 as "Very Good" (96-97.4 % of UVR blocked), and UPF 15-24 as "Good" (93.3-95.9 % UVR blocked)[23].

2.2.8 Antimicrobial Activity

Antimicrobial activity was tested against *Escherichia coli* (Gram-negative) and *Staphylococcus aureus* (Gram-positive) using the AATCC 100 standard[24]. The bacterial reduction percentage was estimated using Eq. 5.

$$\text{Bacterium Reduction (\%)} = \frac{(A-B)}{A} \times 100 \quad ...(5)$$

where A and B represent bacterial colonies on the control and finished fabric samples after 24 h, respectively.

3 Results and Discussion

3.1 Optimisation of *F. religiosa* Bark Extraction

The present research analyses optimised extraction conditions and the application of *F. religiosa* bark extraction on protein-based fabrics. The extracts obtained under varied MLR, pH, temperature and time conditions were assessed, and the study's findings are depicted in Fig. 1.

3.1.1 Effect of Extraction Time

The effect of time on extraction is studied by keeping the other variables constant, i.e., MLR 1:30, temperature 100°C and pH 5. Fig. 1 (a) shows that the extract absorbance increases initially with an increase in extraction time up to 60 min, and thereafter, there is no significant increase in absorbance values. This may be attributed to the gradual saturation of the solvent with extract contents[25]. A similar trend is observed for phenolic contents' absorbance.

3.1.2 Effect of pH

The effect of pH on the absorbance value of *F. religiosa* bark extract and its phenolic content at 100°C, MLR 1:30 and 60 min is shown in Fig. 1 (b). Maximum absorbance is recorded at acidic pH 5, decreasing with an increase in pH. This behaviour may be attributed to the –OH groups in the extract which convert into anionic compounds at higher pH values[26]. Besides, phenolic compounds are reported to become unstable at alkaline pH[27] explaining the slight decrease in phenolic content with increasing pH.

3.1.3 Effect of Temperature

Dry bark powder of *F. religiosa* was extracted in deionised water by varying the extraction temperature while keeping pH 5, MLR 1:30 and time 60 min constant. Figure 1(c) shows that as the extraction temperature increases, the absorbance values also increase. This can be attributed to the swelling and rupturing of cell walls of *F. religiosa* bark powder, with more intensity. It increases the leaching of colour components from bark to extract[28,29]. However, the increase in absorbance is not significant beyond 80°C. Nevertheless, extracts obtained at 100 °C give higher K/S results compared to those extracted at 80 °C. It

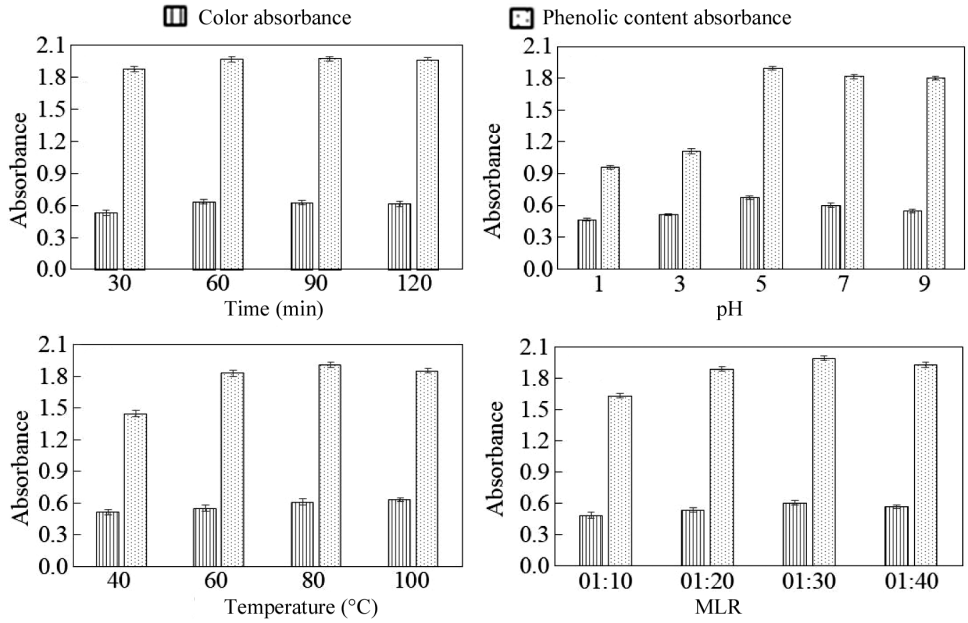

Fig. 1 — Effect of (a) time, (b) pH, (c) temperature and (d) MLR of extraction on *F. religiosa* extract's colour absorbance and phenolic content

may be due to the intense leaching of different chromophore-containing molecules having scattered λmax at 100°C. Thus, 100 °C is selected as the optimum extraction temperature for further experiments. Similarly, phenolic content absorbance increases with an increase in temperature but shows a slight decrease above 80°C due to the instability of phenolic components at higher temperatures[30].

3.1.4 Effect of MLR

Here, the constant variables are time 60 min, pH 5 and temperature 100°C. After extraction, the volume of all extracts is equalised to 1:40 MLR by the addition of deionised water so their comparative colour yield may be analysed. Figure 1(d) shows that extract absorbance increases with an increase in MLR up to 1:30, suggesting more solvent availability enhances the leaching of natural constituents. It seems that the optimum level of collision of extract molecules with each other is achieved at 1:30 MLR, and afterwards, there is no significant increase in absorbance values of extracts[31,32]. A similar trend is observed for phenolic content.

Thus, the optimised extraction conditions for F. religiosa bark are determined aspH 5, time 60 min, temperature 100 °C and MLR 1:30.

3.2 Characterisation of *F. religiosa* Bark Extract

3.2.1 Flavonoid, Tannin and Phenolic Contents

The flavonoid content of *F. religiosa* bark extract is calculated using a standard calibration rutin curve[32] [Fig. 2 (a)]. The observation shows that the *F. religiosa* bark contains 17.37 mg/mL of flavonoid content equivalent to rutin, justifying its potential as an antioxidant finishing agent for textiles.

The tannin content is determined using the standard calibration curve of gallic acid [Fig. 2 (b)]. It is estimated to be 95.36 mg/g dry matter, showing good possibilities of utilisation in textile finishing applications.

Phenolics are known as strong antioxidants that deactivate free radicals, helping to prevent several chronic human infections[32]. The phenolic content of *F. religiosa* bark extract is measured at 61.07 mg Gallic Acid Equivalent [Fig. 2 (d)]. This significant phenolic content reinforces its beneficial applications in textile dyeing and finishing.

3.2.2 Antioxidant Property

As reported by Jiwala *et al*. (2008), *F. religiosa* bark is rich in anti-oxidants[33]. The current study also demonstrates good antioxidant potential for the bark extract against ascorbic acid using the DPPH scavenging assay method[34]. The observed antioxidant assay is 0.519 mg/L equivalent to ascorbic acid [Fig. 2 (c)]. Thus, *F. religiosa* bark extract has good antioxidant properties, encouraging its use in cosmetics like facial wipes and in finishing of textiles.

3.2.3 FTIR Analysis

FTIR analysis identifies functional groups in bark extract based on peak values in IR radiation region

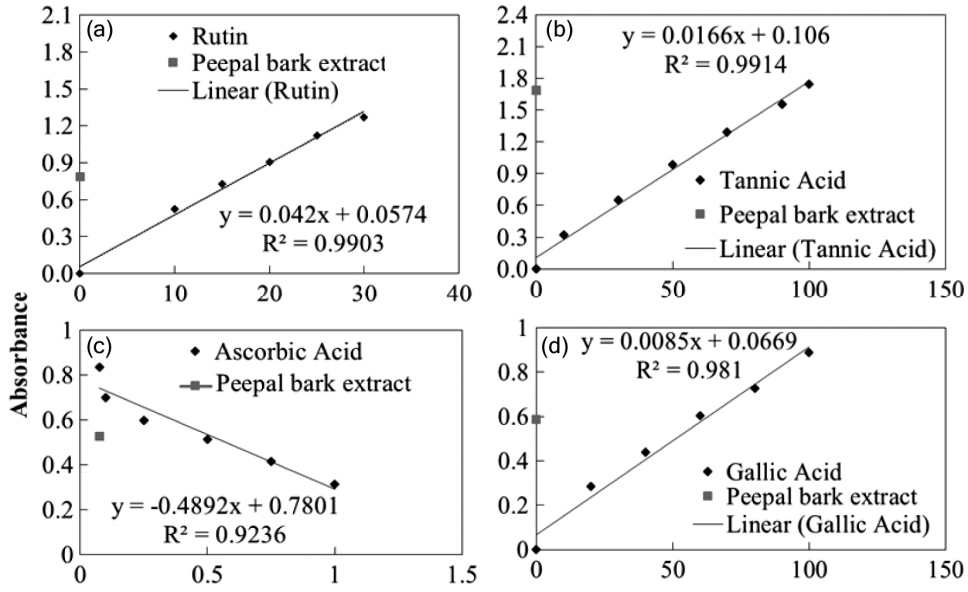

Fig. 2 — Standard absorbance curve of (a) rutin at 750 nm, (b) tannic acid at 750 nm, (c) ascorbic acid at 517 nm and (d) gallic acid at 750 nm

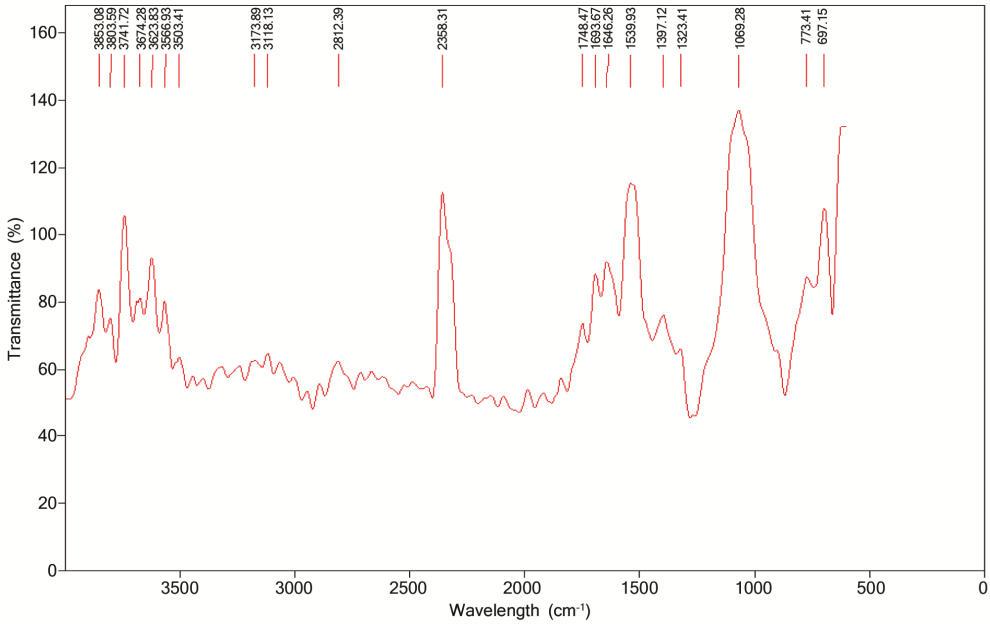

Fig. 3 — FTIR spectra of *F. religiosa* bark water extract

(Fig. 3). Peaks are observed at 697.15 (C=C), 777.41 (C=C), 1069.28 (C-O), 1323.41 (C-N), 1397.12 (O-H), 1373.34 (C-H), 1539.93 (N-O), 1645.26 (C=C), 1693.67 (C=O), 1748.47 (C=O), 2358.31 (N=C=O), 2812.39 (C-H), 3118.13 (O-H), 3173.89 (O-H), 3503.41 (N-H), 3566.93 (–OH), 3623.83 (–OH), 3674.28 (–OH), 3741.72 (–OH), 3803.59 (-OH) and 3853.08 (-OH). The presence of alcohol, amine, phenol, and carboxylic acid functional groups suggests good affinity of the extract for textile material as a colouring agent along with potential inherent medicinal or finishing properties[35,36].

3.3 Dyeing of Proteineous Textile Materials with *F. religiosa* Bark Extract

3.3.1 Optimisation of Dyeing Condition

F. religiosa bark extract was applied on protein-based textile materials (wool, silk, milk, and soya) by exhaust method at MLR 1:30. These dyeing variables are optimised on the basis of maximum colour strength (K/S value). All fabrics exhibit maximum K/S

value when treated with *F. religiosa* bark extract at 90°C for 90 min at pH 3. The optimum pH is lower than the protein fibres' isoelectric points, favouring dye uptake. Consequently, the extract pH is adjusted from 5 to 3 using acetic acidfor further experiments. Strict pH control is necessary as prolonged exposure to pH 3 at 90°C could damage proteinaceous fabrics.

3.3.2 Colour Coordinates and Colour Fastness of Dyed Fabrics

The L*, a*, b* and K/S values of dyed wool, silk, soya and milk fabric with *F. religiosa* bark extract are shown in Tables 1-4. The colour & depth of each fabric sample vary with the type of mordant and mordant technique utilised. Table 1 indicates that in wool dyeing, copper sulphate gives maximum K/S values among chemical mordants, while alum gives

Table 1 — Colour values and fastness properties of dyed wool fabric

Mordant (Mordanting Process)	L*	a*	b*	K/S	Wash fastness			Rubbing fastness		Light fastness	Shade
					Fading	Staining		Dry	Wet		
						Cotton	Wool				
Undyed wool	87.8	-1.2	11.7	0.3							
Dyed wool without mordant	58.1	11.0	19.6	2.5	4	4	3-4	2-3	2	6	
Alum (Pre)	54.6	13.8	22.6	3.6	3-4	3-4	3-4	2	2	6	
Alum (Meta)	62.9	9.4	21.7	2.2	4	4	4	2	2	6	
Alum (Post)	59.8	11.4	20.3	2.4	3-4	3-4	3-4	2-3	2-3	6	
$CuSO_4$ (Pre)	44.7	10.9	17.3	6.0	4	4	4	2	2	6	
$CuSO_4$ (Meta)	47.2	6.2	18.4	5.7	3-4	3-4	3-4	2	2	6	
$CuSO_4$ (Post)	45.6	8.4	18.2	6.2	3-4	3-4	3-4	2	2	6	
$FeSO_4$ (Pre)	44.3	6.1	10.6	4.6	3-4	3-4	3-4	2	2	6	
$FeSO_4$ (Meta)	42.8	1.3	7.0	4.4	4	4	4	2	2	6	
$FeSO_4$ (Post)	44.0	3.1	9.5	4.5	3-4	3-4	3-4	2-3	2-3	6	
Harda (Pre)	52.3	9.9	25.0	6.2	4	4	3-4	2-3	2-3	Darker	
Harda (Meta)	54.6	8.7	26.0	5.8	3-4	3-4	3-4	2	2	Darker	
Harda (Post)	57.1	9.0	29.5	5.8	4	4-5	4	2-3	2	Darker	
Pom. peel (Pre)	50.3	10.0	23.0	6.0	3-4	4	3-4	2	2	Darker	
Pom. peel (Meta)	51.3	7.1	23.2	6.4	4	4-5	4	2	2	Darker	
Pom. peel (Post)	54.9	9.8	27.5	6.0	4	4-5	4	2	2	Darker	
Orange peel (Pre)	51.1	11.1	20.3	4.2	4	4-5	4	2-3	2-3	7	
Orange peel (Meta)	53.7	9.2	20.8	4.0	3-4	4	3-4	2	2	7	
Orange peel (Post)	55.7	9.8	22.0	3.7	3-4	4	3-4	2	2	7	
Amla (Pre)	52.8	13.2	19.6	3.5	4	4-5	4	2	2	7	
Amla (Meta)	53.9	9.7	18.3	3.3	3-4	4	3-4	2	2	7	
Amla (Post)	57.5	10.6	18.8	2.6	4	4-5	4	2-3	2-3	7	

Table 2 — Colour values and fastness properties of dyed silk fabric

Mordant (Mordanting Process)	L*	a*	b*	k/s	Wash Fastness			Rubbing Fastness		Light fastness	Shade
					Fading	Staining		Dry	Wet		
						Cotton	Silk				
Undyed silk	83.9	0.1	13.7	0.3							
Dyed silk without mordant	66.7	7.1	14.8	1.2	4	4-5	4-5	4-5	4	Darker	
Alum (Pre)	57.4	15.7	23.7	2.9	4	4-5	4-5	4-5	4	No change	
Alum (Meta)	64.4	10.3	21.9	1.8	4	4-5	4-5	4-5	4	Darker	
Alum (Post)	62.8	12.6	21.2	1.8	4	4-5	4-5	4-5	4	Darker	
$CuSO_4$ (Pre)	49.7	12.0	15.7	3.6	4	4-5	4-5	4-5	3-4	No change	
$CuSO_4$ (Meta)	56.1	8.1	18.1	2.9	3-4	4-5	4	3-4	3	No change	
$CuSO_4$ (Post)	54.6	8.3	16.1	2.9	4	4-5	4	3	2-3	No change	
$FeSO_4$ (Pre)	45.1	7.9	12.4	4.4	3-4	4-5	4-5	4-5	4	Darker	
$FeSO_4$ (Meta)	48.6	2.7	11.5	3.8	3-4	4	4	2-3	2	Darker	
$FeSO_4$ (Post)	51.5	5.0	13.6	3.2	3-4	4	3-4	2-3	2	Shade change	
Harda (Pre)	57.4	10.8	23.5	3.0	4	4-5	4-5	4-5	3	Darker	
Harda (Meta)	58.4	8.6	25.4	4.1	4-5	4-5	4-5	4-5	3-4	Darker	
Harda (Post)	58.7	9.0	22.4	3.2	4-5	4-5	4-5	4-5	4	Darker	
Pom. peel (Pre)	57.1	10.6	22.7	3.1	3-4	4-5	4-5	3	2-3	Darker	
Pom. peel (Meta)	59.8	9.1	24.3	3.2	3-4	4-5	3-4	4-5	3-4	Darker	
Pom. peel (Post)	58.8	8.8	22.1	3.1	4	4-5	4	4	3-4	Darker	
Orange peel (Pre)	56.8	14.4	20.1	2.4	4	4-5	4-5	4	3-4	No change	
Orange peel (Meta)	61.3	11.3	18.3	1.8	4	4-5	4-5	4	3-4	Darker	
Orange peel (Post)	60.8	10.3	14.2	1.6	3-4	4-5	4-5	4-5	4	Darker	
Amla (Pre)	55.8	11.6	20.8	2.8	4	4-5	4	4-5	4	No change	
Amla (Meta)	59.3	9.4	14.4	1.9	4	4-5	4-5	4-5	3-4	No change	
Amla (Post)	59.5	8.8	17.2	2.0	3-4	4-5	4	4-5	4	Shade change	

Table 3 — Colour values and fastness properties of dyed soya fabric

Mordant (Mordanting process)	L*	a*	b*	k/s	Wash fastness			Rubbing fastness		Light fastness	Shade
					Fading	Staining		Dry	Wet		
						Cotton	Soya				
Undyed Soya	89.1	-0.2	3.7	0.1							
Soya dyed without Mordant	67.1	10.4	14.4	1.0	3-4	3-4	3-4	2-3	2-3	6	
Alum (Pre)	61.3	13.7	17.4	1.6	3	3	3	2	2	6	
Alum (Meta)	67.4	9.6	17.6	1.2	3	3	3	2-3	2	6	
Alum (Post)	72.4	8.4	13.3	0.6	3	3	3	3-4	3	6	
$CuSO_4$ (Pre)	60.5	10.2	12.0	1.4	3-4	3-4	3-4	2	2	6	
$CuSO_4$ (Meta)	63.4	6.8	12.1	1.3	2-3	3-4	3-4	2-3	2-3	6	
$CuSO_4$ (Post)	68.9	6.0	12.6	0.9	3-4	3-4	3-4	3-4	3	6	
$FeSO_4$ (Pre)	55.1	6.1	15.1	2.7	3-4	4	4	2	2	6	
$FeSO_4$ (Meta)	55.4	2.2	8.5	2.0	3-4	4	4	2	2	6	
$FeSO_4$ (Post)	66.3	3.3	16.1	1.6	4	4-5	4	3	2-3	6	
Harda (Pre)	65.5	8.6	16.5	1.3	4	4-5	4	3	2-3	Lighter	
Harda (Meta)	63.0	5.6	17.1	2.	4	4-5	4	3	2-3	Darker	
Harda (Post)	71.1	4.2	19.0	1.4	4	4-5	4	3	2-3	Darker	
Pom. peel (Pre)	61.1	9.5	17.6	2.0	3-4	4	4	2-3	2	7	
Pom. peel (Meta)	63.8	6.6	21.1	2.3	4	4-5	4	3	2	7	
Pom. peel (Post)	68.2	4.3	18.4	1.6	3-4	4	4	3	2	7	
Orange peel (Pre)	61.2	11.4	11.2	1.3	3-4	3-4	4	2-3	2	7	
Orange peel (Meta)	65.4	9.1	11.9	1.1	3	3-4	3-4	3	2	7	
Orange peel (Post)	70.2	7.4	11.4	0.7	4-5	4-5	4	3-4	2-3	7	
Amla (Pre)	62.0	10.7	14.1	1.4	3	3	3	2	2	6	
Amla (Meta)	63.9	6.7	14.2	1.5	3	3	3	2-3	2	6	
Amla (Post)	67.9	5.6	11.2	0.9	3	3	3	3-4	3	6	

the lowest. Among natural mordants, the maximum K/S value is obtained for pomegranate (pom.) peel, followed by harda, orange peel and amla. Wash fastness ranges from fair to very good, light fastness from very good to excellent, and rubbing fastness from poor to fair. Natural mordants perform efficiently, offering a sustainable alternative totoxic heavy metallic salts being used as chemical mordants.

It is observed that in silk dying, ferrous sulphate gives the maximum K/S value, whereas alum gives the lowest K/S value amongst the chemical mordants (Table 2). In the case of natural mordants,

pomegranate peel and harda have higher K/S values, being their own colouring contents than orange peel and amla. The obtained wash fastness varies from fair to very good whereas light fastness varies from very good to excellent. The rubbing fastness ranges from poor to good.

The colour coordinates and fastness properties of soya and milk dyed textiles with *F. religiosa* bark extract are shown in Tables 3 and 4, respectively. All mordants produce a rich gamut of shades such as grey, reddish brown, and brown in soya and milk fabrics, comparable to those observed in wool and silk dyed samples.

Table 4 — Colour values and fastness properties of dyed milk fabric

Mordant (Mordanting Process)	L*	a*	b*	k/s	Wash fastness			Rubbing fastness		Light fastness	Shade
					Fading	Staining		Dry	Wet		
						Cotton	Milk				
Undyed milk	90.8	-0.2	4.1	0.06							
Dyed milk without mordant	66.4	9.4	12.5	0.9	4	4-5	4	3-4	3-4	6	
Alum (Pre)	61.4	10.5	19.4	1.9	3-4	3-4	3-4	3	3	6	
Alum (Meta)	63.3	13.3	17.6	1.4	3-4	3-4	3-4	3	3	6	
Alum (Post)	68.2	5.2	10.3	0.8	3-4	3-4	3-4	3-4	3-4	6	
$CuSO_4$ (Pre)	61.7	7.2	12.8	1.5	3-4	3-4	3-4	3-4	2	6	
$CuSO_4$ (Meta)	61.0	4.9	16.8	2.1	4	4-5	4	3	2-3	6	
$CuSO_4$ (Post)	60.9	4.9	16.8	2.1	4	4-5	4	3-4	3	6	
$FeSO_4$ (Pre)	58.2	10.6	12.9	1.8	4	4-5	4	2-3	2-3	6	
$FeSO_4$ (Meta)	53.5	2.2	8.4	2.2	3-4	4	4	3	3	6	
$FeSO_4$ (Post)	55.8	6.4	13.7	2.3	4	4-5	4	2-3	2-3	6	
Harda (Pre)	64.2	8.6	15.0	1.3	3-4	3-4	3-4	2-3	2-3	6	
Harda (Meta)	63.6	7.3	19.4	2.0	4	4-5	4	3	3	Darker	
Harda (Post)	70.5	5.1	9.7	0.7	3/4	4	4	2-3	2-3	Darker	
Pom. peel (Pre)	63.0	9.6	16.7	1.5	3	3-4	3-4	3	3	7	
Pom. peel (Meta)	67.4	6.5	18.7	1.5	3/4	4	3-4	2-3	2-3	7	
Pom. peel (Post)	69.9	4.5	18.4	1.4	3	3-4	3-4	3	3	6	
Orange peel (Pre)	62.4	10.1	12.3	1.2	3	3-4	3-4	3	3	6	
Orange peel (Meta)	58.0	8.9	10.9	1.7	3-4	4	3-4	3	3	7	
Orange peel (Post)	72.8	7.5	13.2	0.6	3-4	3-4	3-4	3-4	3-4	7	
Amla (Pre)	66.9	9.4	15.3	1.0	3-4	4	3-4	3	3	6	
Amla (Meta)	65.4	6.6	14.4	1.3	3-4	4	3-4	2-3	2-3	6	
Amla (Post)	69.6	4.4	9.9	0.7	3-4	3-4	3-4	3	3	6	

Table 5 — UPF values of all undyed and dyed fabrics

Parameter	Sample							
	Undyed fabric				Dyed fabric			
	Wool	Silk	Soya	Milk	Wool	Silk	Soya	Milk
UPF values	78.90	3.92	2.08	2.13	429.28	8.41	3.83	4.19
UPF rating	50+	<15	<15	<15	50+	<15	<15	<15
UV protection	Excellent	NIL	NIL	NIL	Excellent	NIL	NIL	NIL

Table 6— Bacterial reduction % of *F. religiosa* bark extract and dyed fabric samples

Sample	Bacterial reduction (%)	
	S. aureus	*E. coli*
F. religiosa bark extract	96.16	95.63
Wool	92.79	91.52
Silk	92.21	91.19
Soya	92.25	88.22
Milk	91.09	88.13

The L*, a*, b* values and colour depth (K/S) vary depending on the affinity of the extract with the textile material and the nature of mordant interaction. Across all tested materials, wool exhibits the highest K/S values, which is attributed to its higher thickness and greater grams per square metre (gsm), resulting in enhanced dye uptake. Silk shows a moderate colour depth, while soya and milk fabrics reflect lower K/S values, indicating lighter shades. Overall, dyed textiles with *F. religiosa* bark extract possess fair to very good wash fastness and very good to excellent light fastness. Chemical mordants contribute to improved fastness properties due to their ability to form hydrogen or coordinate bonds with both dye and fabric. In contrast, natural mordants enhance wash fastness due to the tannin content, forming effective complexes with the dye and fabric.

In some cases, rubbing fastness is observed from poor to fair, especially in wet conditions. It may be due to poor migration of dye particles in the interiors of the fabrics, as no wetting agent or surfactant is used during dyeing. Light fastness remains high; however, a darkening or subtle shade change is noted in a few instances, potentially due to mordant oxidation during light exposure.

3.3.3 UV- Protection Properties of Dyed Fabrics

F. religiosa bark extract shows very good absorption capability in the UV region, especially near 200 nm, due tothe presence of specific functional groups such as tannic acid. This UV-absorption capability can be utilised in the improvement of the ultraviolet protection factor (UPF) of dyed textiles. UPF values, calculated according to AS/NZS 4399:1996 standards using total spectral transmittance, are summarised in Table 5. UPF results exhibit that undyed wool has more UPF because of its dense and compact structure, while the other three fabrics exhibit poor UPF values due to fine and thin fabric structures, as mentioned in the material details. UPF values of dyed wool exhibit significant improvement due to the absorption of a significant amount of natural extract. Meanwhile, UPF values of milk, silk, and soya also exhibit improvement with dyeing treatment but in small amounts compared to wool fabrics due to their low GSM, resulting in lower uptake of natural dye extract. These results align with previously reported findings regarding natural dye applications on protein-based textiles[37,38].

3.3.4 Antimicrobial Property of F. religiosa Bark Extract and Dyed Fabrics

The antimicrobial efficacy of *F. religiosa* bark extract and dyed textile samples is accessed via bacterial reduction percentage in liquid media against *S. aureus* and *E. coli* (Table 6). The crude extract demonstrates strong antibacterial properties, achieving bacterial reductions of 96.16 % and 95.63 % against *S. aureus* and *E. coli*, respectively.

Dyed fabrics also display notable antibacterial activity, with bacterial reduction ranging from 91.09 % to 92.79 % against *S. aureus* and 88.13 % to 95.63 % against *E. coli*. Among all tested textiles, dyed wool exhibits the highest antibacterial efficacy, likely due to its coarser and bulkier structure facilitating greater uptake of the extract. Conversely, dyed milk fabric has the lowest bacterial reduction, due to its finer structure and lower dye absorption.

Overall, protein-based fabrics dyed with *F. religiosa* bark extract exhibit a wide potential for use in hygiene, medical, and personal care applications due to their enhanced antibacterial properties.

4 Conclusion

The present study demonstrates that *F. religiosa* bark extracts effectively imparts a diverse range of aesthetically pleasing shades with fair to excellent fastness properties on protein-based textiles such as

wool, silk, soya, and milk fabrics. *F. religiosa* bark extract shows good amounts of flavonoids, tannin and phenolic contents along with antioxidant properties. Among the mordants, both chemical and natural types enhance dye fixation and fastness performance, with natural mordants contributing significantly through tannin-based bonding. Wool exhibits the highest colour strength and UV protection due to its dense structure, while all dyed fabrics show improved UPF values and significant antibacterial activity. Thus, *F. religiosa* bark extract has great potential as a renewable and biodegradable source of dyeing along with UPF, antioxidant and antimicrobial finishing properties to textiles.

References

1 Jothi D, *Autex Res J*, 8 (2008) 49.
2 Purohit A, Mallick S, Nayak A, Das N B, Nanda B & Sahoo S, *Currsci*, 92 (2007) 1681.
3 Goodarzian H & Ekrami E, *World ApplSci J*, 9 (2010) 434.
4 Kulkarni S S, Gokhale A V, Bodake U M & Pathade G R, *Univ J Environ Res Technol*, 1 (2011) 135.
5 Jajpura L, Saini M & Rangi A, *Colourage*, (2016) 44.
6 Rangi A & Jajpura L, *Man-Made Text India*, 48 (9) (2020) 312.
7 Rangi A & Jajpura L, *J Tex Sci Eng*, (2015) 1.
8 Rani N, Jajpura L & Butola B S, *Asian Dye*, (2019) 54.
9 Jajpura L & Rangi A, *J Text Assoc* (2019) 261.
10 Bhalerao S A & Sharma A S, *Int J Curr Microbiol Appl Sci,* 3 (2014) 528.
11 Kumar S, Dimple A, Tomer V, Gat Y & Kumar V, *J Pharmacogn Phytochem*,7 (2018) 32.
12 Habib N, Akram W & Adeel S, *Environ Sci Pollut Res*, 29 (2022) 35048. https://doi.org/10.1007/s11356-022-18507-5)
13 Saravanan P & Chandramohan G, *Univers J Environ Res Technol*, (2011) 268.
14 Akram W, Adeel S, Amin N, Habib N, Inayat A & Mirnezhad S, *J Eng Fibers Fabr*, 17 (2022).
15 Jajpura L, Paul S & Rangi A, *Asian Dye*, 14 (2017) 57.
16 Jajpura L, Paul S & Rangi A, *Man-Made Text India*, (2016) 180.
17 Saravanan P, Chandramohan G, Maria J, Rani J & Sundaram P S, *Int J Recent Trends SciTechnol*, 9 (2013) 72.
18 Hagerman A E, Zhao Y & Johnson S., *Methods for determination of condensed and hydrolyzable tannins*, ACS Symposium Series 662 (1997) 209.
19 Ansari A Q, Ahmed S A, Waheed M A & Juned S, *Euro J Exp Bio*, 3 (2013) 502.
20 Villano D, Fernandez-Pachon M S, Moya M L, Troncoso A M & Parrilla M C G, *Talanta*, (2007) 230.
21 Bayliak M, Burdyliuk N I & Lushchak V I, *Open Life Sci*, (2016) 298.
22 Yu L, Perret J, Harris M, Wilson J & Haley S, *J Agric Food Chem* (2002) 1619.
23 Hatch K L, *AATCC J Res*, 3(2003) 23.
24 Hustvedt G & Crews P C, *J Cotton Sci*, 9 (2005) 47.
25 Haase H, Jordan L, Keitel L, Keil C & Mahltig B, *Plos One*, 21(2017) 1.
26 Castañda-Ovando A, Pacheco-HernándezM L M, Páez-Hernández M E, Rogríguez J A & GalánVidal C A, *Food Chem*, 113 (2009) 859.
27 Farooq A, Ali S, Abbas N, Zahoor N & Ashraf M A, *Asian J Chem*, 25 (2013) 5955.
28 Rangi A & Jajpura L, *J Agroecol Nat Resour Manag*, (2017) 87.
29 Rani N, Jajpura L & Butola B S, *J Basic Appl Eng Res*, (2017) 44.
30 Ali S, Hussain T & Nawaz R, *J Clean Prod*, 17 (2009) 61.
31 Tiwari H C, Singh P, Mishra P & Srivasatava P, *Indian J Fibre Text Res*, 35 (2010) 272.
32 Kähkönen M P, Hopia A I, Vuorela J H, Rauha J P, Pihlaja K, Kujala T S & Heinonen M, *J Agric Food Chem*, 47 (1999) 3954.
33 Jiwala S A, Bagul M S, Parabia M & Rajani M, *Indian J Pharm Sci*, 70 (2008) 31.
34 Pulipati S, Babu P S, Naveena U, Parveen S K R, Nausheen S K S & Sai M T N, *Int J Pharmacogn Phytochem Res*, 9 (2017) 814.
35 Lee J, Kang M H, Lee K B & Lee Y, *Mat*, 6 (2013) 2007.
36 Dhivya S M & Kalaichelvi K, *Int J Curr Pharm Res*, 9 (2017) 44.
37 Rani N, Jajpura L & Butola B S, *J Nat Fibers*, (2020) 115.
38 Rani N, Jajpura L & Butola B S, *J Inst Eng (India): E*, 101 (2020) 19.