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Dyeing of pashmina wool using *Butea monosperma* flower extract

Harshal Patil, Atharva Patil & Ashok Athalye[a]

Department of Fibres and Textile Processing Technology, Institute of Chemical Technology, Mumbai 400 019, India

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Pashmina wool has been dyed with natural dye extracted from flowers of *Butea monosperma* using an aqueous method, and its optimization is done by response surface methodology. The scoured wool is mordanted with tannic acid and dyed with the aqueous extract of natural dye. The dyebath parameters have been optimised by varying concentration, temperature, and time in the range of 10–30%, 50– 90°C, and 40–80 min respectively. Box-Behnken response surface methodology is utilized to standardise the process parameters. The dyed samples are evaluated for colour strength (*K*/*S*), wash fastness, and light fastness. The maximum and minimum *K*/*S*, achieved after dyeing, are 3.41 and 1.31 respectively. The wash fastness performance of the dyed samples shows high colour change, however the staining on adjacent wool and cotton is found minimal. Light fastness rating is found good to moderate and considered to be within the permissible limits. The statistical model suggested by RSM is found significant, with a P value of less than 0.05 and an F value of 39.2, and validated by performing selected experiments of high desirability. The results of the predicted and experimental *K*/*S* are found very close. This study indicates the potential increase in the use of natural dyes in indigenous pashmina wool varieties.

Keywords: *Butea monosperma*, Natural dye, Mordant dyeing, Pashmina wool, Response surface methodology

1 Introduction

Today, the textile industry employs excessive synthetic fibres, dyes, and chemicals to obtain the desired colours standards, physical characteristics, and cost economy compared to natural fibres, dyes, and chemicals[1,2]. However, the production of synthetic materials relies on non-renewable petrochemical sources, some of which contain hazardous and toxic compounds. Such synthetic materials pose significant health risks and adversely affect nature's ecological balance[3,4]. Furthermore, several nations have already implemented rigorous environmental regulations regarding these synthetic materials, prompting end users to concentrate on eco-friendly and sustainable textile products[5,6]. The demand for greener or more natural alternatives is continuously increasing. Therefore, natural fibres and dyes are among the possibilities for creating sustainable, environment-friendly textile goods and processes[7,8]. This interest is reflected in the growth of current research in this field. The main advantage of using a natural resource for textile processing is zero effluent load and safe disposal[9,10].

Pashmina fibre is obtained from the hair of the *Capra hircus*, an Asian domesticated goat mainly in the Kashmir valley of India[11]. Pashmina fibre is a polyamide protein fibre containing 18 amino acids with α-keratin organised in a helical form like wool. Except for cystine, tyrosine (12% greater than in wool), and proline (9% less than in wool), the amino acid composition of pashmina fibre is quite comparable to fine wool[12]. Moreover, it has been found that the cuticle of pashmina fibre is more hydrophilic than that of wool because it contains more polar amino acids, specifically serine, threonine, and tyrosine[13].

The *Butea monosperma*, also known as the flame of the forest, is grown in all regions of India, thriving in the dry season and being a deciduous tree[14]. Each component, from root to its fruit, possesses vital properties such as antioxidant, antifungal, astringent, aphrodisiac, anti-inflammatory, anti-diarrheal, anti-diabetic, anti-stress, laxative and hepatoprotective[15]. The extraction methods, properties and their uses for medicinal, food, and colours are thoroughly investigated and reported by various modern researchers and in ancient Indian literature[15–17]. In India, the colour obtained from the flower of this plant is used as 'Abeer', a colour powder used for the traditional cultural 'holi festival'. The main colouring compounds of the flower are butein, palastrin, isobutrin, butrin, etc., the most abundant of which is the isobutrin[15]. The chemical structure of isobutrin present in *Butea monosperma* flower (Fig. 1).

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[a]Corresponding author.
E-mail: ar.athalye@ictmumbai.edu.in

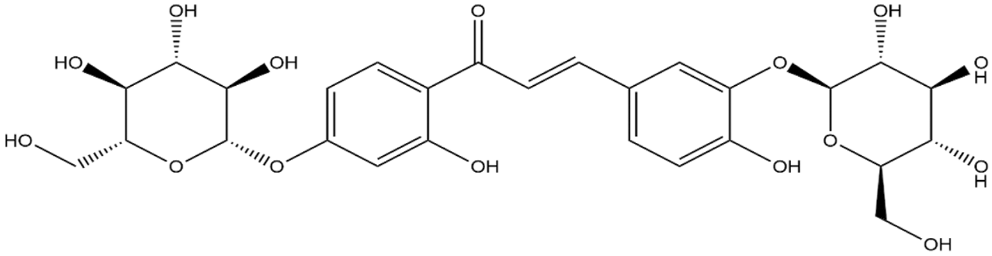

Fig. 1 — Isobutrin chromophore present in *Butea monosperma* flower

The present research was accomplished with the explicit objective of extracting natural dye from the flowers of *Butea monosperma* by aqueous extraction method and its application on pashmina fibre to investigate the combined effect of different parameters, such as dye concentration, temperature and time on the dyeing performance in term of *K/S* using Box Behnken design of response surface methodology (RSM).

2 Materials and Methods

Pashmina wool (cashmere wool) was obtained from Carpet Kart, Bhadohi. *Butea monosperma* flowers were collected from the garden of the Institute of Chemical Technology (ICT), Mumbai. Soda ash (Na_2CO_3), tannic acid and glacial acetic acid were purchased from SD Fine Chemicals, Mumbai; Lissapol D-Paste (anionic detergent) and Greenwash EC Liq (soaping agent) were procured from Croda Chemicals and Rossari Biotech Ltd, Mumbai respectively.

2.1 Scouring

Wool scouring was carried out by the five-bath method in aqueous conditions using anionic detergent and alkali with different concentrations[18]. The recipe for pashmina wool scouring is presented in Table 1. The material-to-liquor ratio was maintained at 1:50. After scouring, the wool was dried and used for mordanting and subsequent dyeing.

2.2 Dye Extraction

Butea monosperma flowers were dried in a hot-air oven at 50°C for 8 h. The dried flowers were ground by a Croma electronic grinder and meshed through a 100-mesh screen to obtain particle sizes of about 150 microns. The powder of *Butea monosperma* flower was extracted with three concentrations of 10, 20, and 30% (w/v). The extraction process was performed for 1 h at 90°C. Then, the extracted dye solution was kept for cooling and further filtered by a vacuum filtration system. The filtrate solution was considered a stock dye solution of concentrations 10, 20, and 30% (w/v) and directly used to dye Pashmina fibres. To determine the yield percentage, the clear brown filtrate was dried to evaporate water. The product yield for brown-coloured dye was around 28%.

Table 1 — Wool fibre scouring

Bath	Recipe and condition
1	Water, temp. 50 °C, time 2 min
2	1 g/L Soda ash, *p*H 9, temp. 55 °C, time 2 min
3	0.5 g/L Soda ash, 2 g/L Lissapol D-paste, *p*H 9, temp. 55 °C, time 2 min
4	0.5 g/L Lissapol D-paste, temp. 50 °C, time 2 min
5	Water, temp. 50 °C, time 2 min

Table 2 — Experimental levels of independent variables for dyeing experiments

Symbol	Parameter	Lower limit	Upper limit
A	Dye concentration, %	10	30
B	Temperature, °C	50	90
C	Time, min	40	80

2.3 Mordanting

Pre-mordanting was carried out by treating scoured pashmina wool with tannic acid (10% of the weight of the material) at 60°C for 60 min. The treated samples were rinsed with water, dried, and used for dyeing.

2.4 Dyeing

The tannic acid mordanted Pashmina wool fibres were dyed in the close bath method (Rota dyer machine) using a dye solution from *Butea monosperma* flower extract for 1 h at 90°C. The *p*H of the dye bath was set at 4.5-5.5 by using 0.5% (w/v) acetic acid. The material-to-liquor ratio was maintained at 1:20 for all dyeing experiments. The dyed wool was washed with a 2 g/L soaping agent at 60°C for 20 min and dried. Three independent dyeing parameters, viz dye concentration (w/w), dyeing temperature (°C), and dyeing time (min), were optimized using the response surface methodology (RSM) and a Box-Behnken design. The levels of independent variables that were selected for the experiment's optimization are listed in Table 2. Five centre points were used in a total of 17 trials.

2.5 Testing and Characterization

The colour strength *K/S* of the *Butea monosperma* dyed pashmina wool was measured using a computer colour matching system based on a spectrophotometer software (Premier Colourscan- SS 5100HW). The measurement of *K*/*S* value was performed under the light source D65 using a 100 standard observer and calculated using the Kubelka–Munk equation19. The fastness characteristics of the dyed wool fibres were evaluated using the established procedures. Launder-O-meter was used to test the dyed samples' wash fastness as per ISO 105 C10. The light fastness was tested as per ISO 105 B02, utilizing a xenon test chamber (Q-LAB) and a xenon-arc lamp as the light source20. The FTIR spectra of the fabric samples were assessed in the range of 4000–500 cm−1 by Shimadzu ATR spectrophotometer. To determine the presence of bioactive ingredients in the aqueous extract, a phytochemical analysis is needed. Saponins, phenolic compounds, tannins, flavonoids, alkaloids, and other bioactive components can be found in naturally occurring species. *Butea monosperma* flower aqueous extract (2mL) was used to evaluate these components. To assess the various bioactive components found in the *Butea monosperma* flower aqueous extract, chloroform, concentrated sulfuric acid, ferric chloride, glacial acetic acid, concentrated hydrochloric acid, and zinc dust were used. The analysis was carried out using the techniques outlined in the literature[21].

3 Results and Discussion

3.1 Phytochemical Analysis

The phytochemical analysis results of the *Butea monosperma* flower aqueous extract shows the presence of flavonoids, glycosides, saponin, phenols, tannins and Terpenoids. The presence of flavonoids is confirmed by adding zinc dust to the extract, followed by a drop-wise addition of strong hydrochloric acid. Usually, this test is referred to as the zinc-hydrochloride reduction test. The appearance of a red tint after a few minutes indicates the existence of flavonoids[22]. The extract is treated with 2 mL of glacial acetic acid containing two drops of 2% iron (III) chloride to confirm the presence of glycosides. After that, the mixture is put into another test tube containing 2 mL of concentrated sulfuric acid. When a brown ring forms during the interphase, glycoside is present[23]. Stable foam production indicates saponin's presence after shaking 2 mL of aqueous extract of *Butea monosperma* flowers[24]. A blue-green or black colour is seen when 2 mL of aqueous extract is combined with 2 mL of 2% iron (III) chloride solution. It suggests that tannin and phenol are present. Terpenoids are detected by adding 2 mL of chloroform to a 2 mL extract, followed by 2 mL of sulfuric acid. When the mixture is gently agitated, a reddish-brown hue in the interphase shows the presence of terpenoids. As a qualitative test, the active components found in the aqueous extract of *Butea monosperma* flowers are subjected to standardised phytochemical screening.

3.2 FTIR Analysis

The FTIR-ATR spectra of the *Butea monosperma* extract dye (Fig. 2) show the vibrational band associated with the -OH stretching (O-H) for polyphenolic extracts. The stretching vibrations of C-H, CH_2, and CH_3 detected at 2920 cm^{-1} are due to the carbohydrates and their derivatives. The band at 1620 cm^{-1} is a conjugation of the C = O vibration of the ketone[17]. The peaks at 1523 cm^{-1} and 1450 cm^{-1} are attributed to aromatic skeletal vibration and CH deformation and are ellagitannin-specific peaks. The peak at 1353 cm^{-1}, ascribed to the symmetric stretching of the ester function's C-O bond, is a distinguishing feature of hydrolysable tannins. Peaks at 1083 cm^{-1}, 872 cm^{-1} and 705 cm^{-1} correspond to gallo-tannins[25].

3.3 Optimization and Validation of the Experiment using RSM

The Box-Behnken design has been used to optimize the *Butea monosperma* dyeing of pashmina wool fibres. The design of experiments (DOE) is conducted according to the BBD matrix, and the results are summarized in Table 3.

Table 4 displays the ANOVA results of the statistical analysis for *K*/*S* of the coloured samples. Regressions with high values of F imply that the null hypothesis is invalid. This indicates that none of the regression coefficients is equal to 0. High values of F

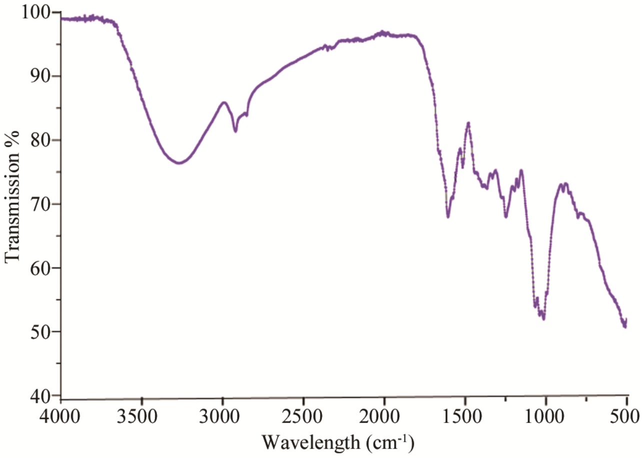

Fig. 2 — FTIR-ATR spectra of the *Butea monosperma* extract dye

Table 3 — Design matrix of *Butea monosperma* dyeing of pashmina wool

Run	Concentration, %	Temperature, ^{0}C	Time, min	*K*/*S*	Wash fastness			Light fastness
					Colour change	Staining on cotton	Staining on wool	
1	30	70	40	2.47	3-4	4-5	4-5	5-6
2	20	50	40	1.31	4	4-5	4-5	4-5
3	30	90	60	3.13	3-4	4-5	4-5	5-6
4	20	70	60	2.72	3-4	4-5	4-5	5-6
5	20	90	80	3.41	3-4	4-5	4-5	5-6
6	30	70	80	2.76	3-4	4-5	4-5	5-6
7	10	90	60	3.05	3	4-5	4-5	5-6
8	10	50	60	1.81	4	4-5	4-5	5
9	20	50	80	1.74	3-4	4-5	4-5	5
10	20	90	40	3.34	4	4-5	4-5	5-6
11	20	70	60	2.4	3	4-5	4-5	5-6
12	10	70	80	3.08	3	4-5	4-5	5-6
13	20	70	60	2.68	3	4-5	4-5	5-6
14	30	50	60	1.619	4	4-5	4-5	5
15	20	70	60	2.83	3	4-5	4-5	5-6
16	10	70	40	2.32	3-4	4-5	4-5	5
17	20	70	60	2.73	3	4-5	4-5	5-6

Table 4 — Analysis of variance (ANOVA) model of *Butea monosperma* dyeing of wool fibre

Source	Sum of squares	df	Mean square	F-value	P-value	
Model	5.51	3	1.84	39.2	< 0.0001	significant
A-Dye concentration	0.0099	1	0.0099	0.2106	0.6539	
B-Temperature	5.2	1	5.2	110.99	< 0.0001	
C-Time	0.3003	1	0.3003	6.41	0.0251	
Residual	0.6093	13	0.0469			
Lack of fit	0.5046	9	0.0561	2.14	0.2408	not significant
Pure error	0.1047	4	0.0262			
Correction total	6.12	16				
R^2	0.9005					
Adjusted R^2	0.8775					
Predicted R^2	0.8193					
Adequacy of precision	19.0472					

also show that the model's fit is improved by including independent variables (*K*/*S*). The P value represents the probability of obtaining the observed findings[26]. The null hypothesis is rejected with the lowest level of significance using the P value. Smaller P values indicate higher probabilities of achieving the observed outcomes. P value of less than 0.05 indicates that the model is significant. Seeing that the F value for *K*/*S* in this study is 39.2 and the P value is < 0.05; the model terms in this study have a considerable impact on the response, and the model is statistically significant[27]. The predicted R^2 and coefficient of determination adjusted R^2 show the excellent precision of the models and are reasonably in agreement. Table 3 shows that the model can more precisely predict the outcomes, as seen by the high R^2 values of 0.90. It is possible to measure the signal-to-noise ratio with sufficient accuracy. It is necessary to have adequate precision that is more than 4. The ratio of 19.04 in this investigation indicates acceptable precision[28]. As a result, applying this model to *Butea monosperma* dyeing parameter optimization could result in an exact and predictable response. Figure 3 displays the variance between the response's actual and expected values as a normal probability plot of residuals. Figure 3 demonstrates that the predicted values obtained from the model and experiments are spread randomly over the plot region and are incredibly close to a straight line. The analytical assumptions, therefore, imply that the selected mode's prediction is accurate, as shown in Table 4 for the R^2 and adjusted R^2.

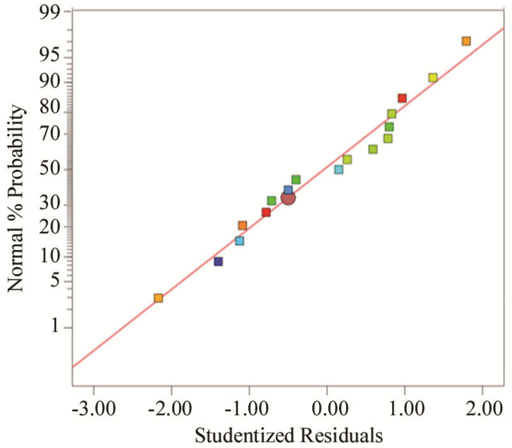

Fig. 3 — Normal probability plot of residuals of response *K*/*S*

3.4 Regression Analysis

Regression equation analysis is employed to forecast the outcomes of individual responses for *Butea monosperma* dyed wool fibre samples. The colour strength (*K*/*S*) of dyed wool fibre is predicted for each process variable, such as concentration of dye, dyeing temperature, and time, utilizing the following equation, which is presented in a coded form:

$$K/S = +2.55-0.0351*A+0.8064*B+0.1938*C \quad \ldots(1)$$

where *A*, *B* and *C* stand for the concentration of dye, dyeing temperature and dyeing time respectively.

3.5 Response Surface Plot

Figure 4 depicts the effect of dye concentration, dyeing temperature, and duration on dyed wool fibres' colour intensity (*K*/*S*). The combined impact of factors on the response (*K*/*S*) of wool samples dyed with *Butea monosperma* is examined using 3D surface graphs, and it is ranged in hue from pale to dark yellow (Fig. 4). Isobutrins found in *Butea monosperma* is responsible for the orange-to-yellow colour of dyed samples. Figures 4(a) and (c) show that the *K*/*S* values of dyed wool fibres rise with a temperature rise when dye concentration and dyeing time are fixed at 20% and 60 min, respectively. At temperatures between 70°C and 90 °C, a deeper *K*/*S* is achieved. It is clear from this that when the dyeing temperature rises, the fibres absorb more dye and exhibit a deeper colour. Also, there is a slight improvement in the *K*/*S* values of the dyed wool when the dyeing duration and dye concentration are increased [Fig. 5(b)]. Figures 5 (a)-(c) demonstrate that the maximum colour strength is obtained when the dye concentration, temperature, and time range between 10% and 15%, 70°C and 90 °C, and 40 min and 50 min respectively.

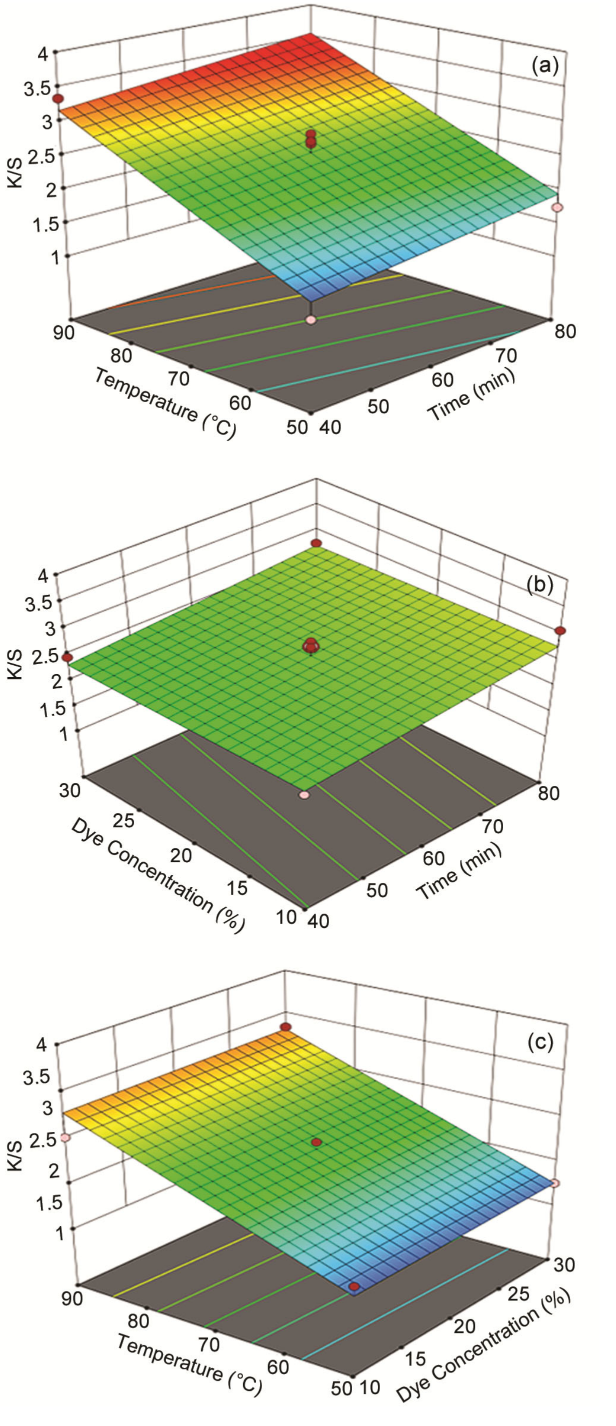

Fig. 4 — Response surface plots (a) temperature and time at a fixed dye concentration of dyeing, (b) dye concentration and time of dye at a fixed temperature of dyeing, and (c) temperature and dye concentration at a fixed dyeing time

3.6 Validation of RSM Model and Verification

The BBD matrix's desirability function optimise the dyeing conditions on wool fibres for optimal colour yield. The range of process conditions and their outputs (*K*/*S*) are shown in Table 5. The desired weightage is

Fig. 5 — Images of raw, scoured, mordanted and *Butea Monosperma* dyed pashmina wool

Table 5 — Ranges of process parameters and their outputs

Parameters	Goal	Lower limit	Upper limit	Lower weight	Upper weight	Importance
A: Dye concentration	Minimize	10	30	1	1	3
B: Temperature	Minimize	50	90	1	1	3
C: Time	Minimize	40	80	1	1	3
K/*S*	Maximize	1.31	3.41	1	1	3

Table 6 — Optimized dyeing process parameters with highest desirability and comparative analysis of experimental and predicted results

Run	Concentration %	Temperature ^{0}C	Time min	*K*/*S*	
				Predicted	Experimental
1	10	67	40	2.256	2.33
2	10	65	40	2.232	2.29
3	10	71	40	2.478	2.38

given to all process conditions and outputs to achieve the goal. The three most desirable suggested dyeing condition combinations are picked for the model's verification. The wool is dyed with *Butea monosperma* using the selected parameters, and the actual results are contrasted with those predicted. The comparison of the experimental and predicted findings is shown in Table 6. It shows that the projected response values for optimum dyeing parameters, derived using the desirability function at the highest desirability, are similar to the experimental results. As a result, the model is accurate, and the pragmatic model equations created using BBD are acceptable for predicting *K*/*S*. Also, there is no discernible difference between the values from the experiment and those predicted by a regression polynomial equation, demonstrating the model's efficacy for optimizing the dyeing parameter to obtain the deepest colour.

3.7 Effect of Mordanting on Natural Dyeing of Pashmina Wool Fibre

The effects of mordanting on the colour strength (*K*/*S*) of dyed wool fibre are displayed in Table 7 and Fig. 5. Wool fibre pre-mordanted with tannic acid shows comparatively darker colour depth and better fastness properties than un-mordanted fibre. The tannic acid pre- mordanting treatment helps in providing a binding site for the dye to adhere to the fibre, thereby enhancing the colour depth and also the fastness. Wool fibres tend to felt/shrink because the scales on the fibre surface diffuse inside each other, causing the length-wise fibre contraction. This tendency increases under high temperatures and prolonged aqueous treatment conditions during high turbulence. The tannic acid pre-mordanting treatment helps to avoid the jamming of surface scales, thereby preventing the undesired felting. Figure 5 illustrates the minimal felting of wool fibres dyed with *Butea monosperma* flower extract under optimal process conditions.

3.8 Colour Fastness Measurements

The outcomes of the tests for light and wash fastness are displayed in Table 7. The wash fastness of samples dyed with *Butea monosperma* is rated as good to excellent owing to the minimal tendency of staining on cotton and wool and moderate colour change. It has been observed that the colour of a dyed fibre changes more in a darker shade than in a lighter one after washing. For the maximum number of samples, the light fastness of dyed wool fibre reveales a nearly identical and equivalent value of 5–6 on a scale of 1–8. Natural dye chromophores have weak light resistance, which is also true of wool coloured with *Butea monosperma*[29].

Table 7 — Effect of mordanting on colour strength (*K*/*S*) of dyed wool fibre
[Conc. 10 %, temp. 65^{0}C and time 40 min]

Run	*K*/*S*	Wash fastness			Light fastness
		Colour change	Staining on cotton	Staining on wool	
Without mordanting	1.81	3-4	4-5	4-5	4-5
With Mordanting	2.29	3-4	4-5	4-5	5-6

4 Conclusion

An aqueous process has been used to extract the natural colour from *Butea monosperma*, which is then successfully applied to scoured pashmina wool fibres. The phytochemical studies display the availability of phenols, tannin, flavonoid, saponin, terpenoids and glycosides in the aqueous extract of the colourant. The FTIR analysis of dye shows the functional groups of all present phytochemicals. The process parameters like dye concentration, temperature, and time are optimized by response surface methodology. The dyed samples are graded based on colour strength (*K*/*S*), washability, and light fastness. The results indicate a bright yellow colour with good intensity, good to moderate washing resistance, and light fastness. Experimental data are used to cross verify and validate the models' predicted recipes. The close similarity between the predicted and the actual findings suggests that the design models significantly predict the process variables that would provide the desired colour intensity (*K*/*S*). The current study contributes to the popularity of fine ancient wool breeds in the competitive world of natural and sustainable textile marketing.

References

1 Patil H & Athalye A, *J Text Assoc*, 83 (2) (2022) 100.
2 Patil H, Athalye A & Adivarekar R V, *Asian Dyer*, 19 (1) (2022) 25.
3 Manickam P & Vijay D, in *Chemical Management in Textile and Fashion,* edited by S S Mutu (Elsevier, UK), 2021, 19.
4 Sandin G & Peters G M, *J Clean Prod*, 184 (2018) 353.
5 Singh A, Kaur A, Patra AK & Mahajan R A, *Biotechnol*, 8(4) (2018) 1.
6 Panda S K B C, Sen K & Mukhopadhyay S, *J Clean Prod*, 329 (2021) 129725.
7 Patil H & Athalye A, *J Nat Fibers*, 20 (1) (2023) 2156017.
8 Patil H, Thamizudheen & Athalye A, *Asian Dyer*, 19 (5) (2022) 23.
9 Perkowski J, Kos L Z & Ledakowicz S, *Ozone Sci Eng*, 18 (1) (1996) 73.
10 Kumawat K L, Patil H & Athalye A, *Indian J Fibre Text Res*, 48 (1) (2023) 80.
11 Yaqoob I, Sofi A H, Wani S A, Sheikh F D & Bumla N A, *Indian J Traditional Know,*11 (2) (2012) 329.
12 Kumar R, Shakyawar D B, Pareek P K, Raja A S M., Prince L L L, Kumar S & Naqvi S M K, *Appl Biochem Biotechnol*, 175 (8) (2015) 3856.
13 Shakyawar D B, Raja A S M, Kumar A, Pareek P K & Wani S A, *Indian J Fibre Text Res*, 38 (2) (2013) 207.
14 Srivastava S, Ray D P & Giri SK, *Environ Biotechnol*, 6(3) (2013) 497.
15 Agarkar S A, Kulkarni R R, Dhas V V, Chinchansure A A, Hazra P, Joshi S P & Ogale S B*, ACS Appl Mater Interfaces*, 3 (7) (2011) 2440.
16 Singhee D & Samanta P, *J Nat Fibers*, 16 (8) (2019) 1453430.
17 Sinha K, Saha P Das & Datta S, *Dyes Pigm*, 94(2) (2012) 212.
18 Kadam V V, Goud V & Shakyawar D B, *Indian J Fibre Text Res*, 38(4) (2013) 410.
19 Patil H I, Kanjilal K, Maiti S & Adivarekar RV, *Asian Dyer*, 17 (1) (2020) 24.
20 Patil H I, Dorugade VA & Shivankar VS, *Int J Text Eng Process*, 2 (4) (2016) 29.
21 Chakraborty L, Pandit P & Roy Maulik S, *J Clean Prod*, 245 (2020) 118921.
22 Jamkhande P G, Patil P H & Tidke P S, *Int J Drug Dev Res*, 5 (3) (2013) 245.
23 Yadava R N & Tiwari L, *J Enzyme Inhib Med Chem*, 22 (4) (2007) 497.
24 Hait M, Behera S K, Chaturwedi A K & Vaishnav M M, *J Pharmacogn Phytochem*, 8 (3) (2019) 2083.
25 Sexena A, Prasad D & Haldhar R, *Int J Electrochem Sci*, 12 (2017) 8793.
26 Palaskar S S, Kale R D & Deshmukh RR, *Color Res Appl*, 46 (6) (2021) 1301.
27 Patil H, Mudaliar S & Athalye A, *Color Technol*, 139 (1) (2023) 97.
28 Patil H, Surve K & Athalye A, *Color Technol*, (2023). doi:10.1111/cote.12684
29 Patil H, Deshmukh I & Athalye A, *J Indian Chem Soc,* 100 (2) (2023) 100925.