

Dyeing of jute with binary mixtures of jackfruit wood and other natural dyes — Study on colour performance and dye compatibility

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Varying proportion of binary mixtures of aqueous extracts of jackfruit wood (JFW) with other natural dyes, like manjistha (MJ), red sandal wood (RSW), mariegold (MG), sappan wood (SW) and babool (BL), have been used to dye bleached jute fabric pre-mordanted with 20% myrobolan followed by 20% aluminium sulphate. Binary combinations of JFW with each of the five natural dye extracts have been evaluated for colour strength (K/S value) and its coefficient of variation, brightness index (BI), changes in hue (ΔH), metamerism index (MI), total colour differences (ΔE) and colour fastness to washing, light and rubbing. Dyed fabric samples have been further treated with the cationic dye fixing agents *n*-cetyl-N-trimethyl ammonium bromide, cetrinide and Sandofix-HCF to improve wash fastness. Treatment with 1% benzotriazole is also given to improve light fastness. The compatibility of these binary pairs has been assessed by the analysis of ΔC vs ΔL and K/S vs ΔL plots for the progressive depth of shade produced by varying time and temperature profile as well as by varying total concentrations of the binary pairs of dyes taken in equal proportion. A simple method of assessing relative compatibility rating of pairs of dyes has been proposed, where a new index called colour difference index [$(\Delta E \times \Delta H) / (\Delta C \times MI)$] has been postulated and the compatibility ratings determined. The results of this proposed system of compatibility rating are found to be in well agreement with the results of conventional methods of plots analysis. The order of relative degree of compatibility of these binary pairs of natural dyes applied on pre-mordanted jute is found to be JFW : RSW \geq JFW : BL \geq JFW : MJ \gg JFW : MG \gg JFW : SW.

Keywords: Babool, Cationic dye, Dye fixing agent, Colour fastness, Jackfruit wood, Jute, Manjistha, Mariegold, Natural dye, Red sandal wood, Sappan wood, UV-absorber

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1 Introduction

Jute is composed of cellulose (54-60%), hemicellulose (20-24%) and lignin (12-14%). In addition to the primary and secondary –OH groups of cellulose present in both cotton and jute, there are some –CHO and –COOH groups in jute, as well as some –C=C– unsaturations and phenolic –OH groups in the lignin component. Thus, the receptivity, affinity and absorption characteristics of any dye including natural dyes will be different for jute and cotton due to their varying chemical composition and chemical functionality pattern. Hence, it is felt essential to study the compatibility of mixture of selective natural dyes and their colour fastness properties for both jute and cotton separately. The present work deals with the study of dyeing of jute with the binary mixture of jackfruit wood and various natural dyes.

With world wide growing consciousness of environmental and chemical hazards of some of the synthetic dyes, the use of ecofriendly natural dyes particularly for natural fibre products like jute and cotton textiles is being preferred. However, all the natural dyes may not be essentially ecofriendly. Dyeing with natural dyes has not achieved wide acceptability in organized sector due to their limited availability, limited shades and lack of standard procedures of dyeing, difficulty in reproducibility and matching as well as lack of scientific knowledge on compatibility and chemistry of such dyes.

There are only a few and discrete studies available in literature describing application of mixture of natural dyes on cotton textiles,^{1,2} reporting the colour interaction, resultant colour strength and metamerism effects. Some studies on compatibility of binary and ternary mixtures of synthetic dyes³⁻⁸ are widely available in literature, whereas such studies with

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mixture of natural dyes on jute or cotton or on any other textiles are scanty^{1,2} and sporadic.

Compatibility of a pair of dyes can be judged by different methods, such as (i) subjective visual assessment of the degree of on-tone build up by a series of dyeing, (ii) theoretical prediction of compatibility⁷ by comparison of rates of dyeing (time of half dyeing) and dyeing kinetics (diffusion coefficients) for each individual dye to derive V numbers or Z values, which are usually specific to the textile substrate and dyeing conditions, (iii) quantitative assessment of change in hue angle (ΔH),⁸ (iv) comparing and plotting ΔC vs ΔL or K/S vs ΔL values for two sets of progressive shades (20-100% with 10-20 point differences) obtained by dyeing with varying dye concentration and also with varying profile of dyeing time and temperature,³ and (v) quantitative compatibility rating for the mixtures of more than two dyes by colorimetric analysis of actual colour strength developed (not on the basis of dye absorbed). The method of plotting ΔC vs ΔL or K/S vs ΔL values has been used in the present study. A newer empirical index called colour difference index has also been proposed for the assessment of relative compatibility rating (RCR) to judge the degree of compatibility of different pairs of natural dyes applied on jute.

Some studies on improving colour fastness behaviour after the application of natural dyes are available in literature.⁹ Most of the natural dyes show inadequate wash or light fastness behaviour.¹⁰ In the present work, three types of cationic fixing agents and a UV absorber have been applied to dyed jute to improve the fastness to washing and light respectively.

2 Materials and Methods

2.1 Materials

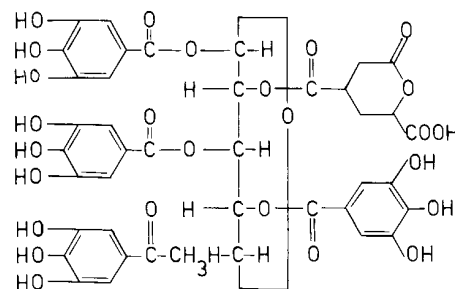
2.1.1 Jute Fabric

Conventional 3% H₂O₂ bleached plain weave (40 inch width) fine hessian jute fabric of decorative variety having 176 tex jute yarns as warp, 164 tex jute yarns as weft, 67 ends/dm, 67 picks/dm, 225 g/m² fabric area density and 0.07mm fabric thickness 0.70, obtained from M/s Champdany Industries, Rishra, Hooghly, was used.

2.1.2 Mordants

Laboratory reagent (LR) grade aluminium sulphate, obtained from M/s E.Merck (India), was used as

chemical mordant. The natural mordant myrobolan (hartaki or harda, *Terminalia chebula*) powder was used. The chemical structure of the chebulinic acid present in the mordant myrobolan is shown in Scheme 1.



Scheme 1 — Chemical structure of chebulinic acid

2.1.3 Natural Dyes

The following selected natural dyes were used for the study:

- Jackfruit wood (JFW) or Kanthal (*Artocarpus heterophyllus* Lam) — The main colour component in the jackfruit wood is morol, a typical flavanol (hydroxy-flavone) being also present in fustic.^{10,11}
- Red sandal wood (RSW) or Raktachandan (*Pterocarpus Santalinus*) — The main colour components in red sandal wood are Santalin A, Santalin B and Deoxysantalin; Santalin A is the main colour component.^{10,12}
- Sappan wood (SW) or Red wood (*Ceasalpinia Sappan* L) — It contains Braziline (C.I Natural Red 24), obtained from Brazilein by oxidation, as the main colour component.¹⁰
- Manjistha (MJ) or Madder (*Rubia cordifolia*) — The major colour components^{13,14} of manjistha are purpurin, manjistin, purpuroxanthin, pseudo-purpurin and nordamncanthal .
- Mariegold (MG) or Genda (*Tagetes patula/ Tagetes erecta*¹⁵) — Petals of mariegold flower contain different flavonoids and carotenoids, namely quectrol and some xanthophylls esters, as main colour components
- Babool (BL) or Babla (*Acacia Arabica*¹⁶) — Several polyphenolic coloured components have been identified in the bark or woody part of babool tree. These are mainly catechin, epicatechin and gallic acid along with minor amount of decatechin, quercetin, and leucocyanidin gallate.

2.1.4 General Chemicals

Commercial grade sodium chloride, acetic acid, sodium carbonate, sodium hydroxide and LR grade 1,2,3 benzotriazole, cetrimide (tetradecyltrimethylammoniumbromide) and CTAB (*n*-cetylN-trimethyl ammonium bromide), obtained from M/s Loba-chem or E-Merck (India), as well as textile auxiliaries grade Sandofix-HCF liquid, obtained from M/s Clariant (India), were used for the study.

2.2 Methods

2.2.1 Extraction and Purification of Colourant from Natural Dyes

Pre-cut and dried chips of selected natural dyes were initially crushed to powder form and then subjected to aqueous extraction under optimized conditions as shown below:

Natural dye	Initial MLR	Temp. during extraction, °C	Time min
Red sandal wood ¹²	1:20	80	90
Jackfruit wood ¹¹	1:10	100	30
Mariegold ¹⁵	1:20	80	45
Manjistha ^{1,2}	1:20	90	45
Babool ¹⁶	1:20	100	120
Sappan wood ¹⁷	1:20	100	120

The aqueous extracts of corresponding natural dyes were filtered and then concentrated by evaporation in water bath to a desired concentration level required for final application.

For chemical characterization and study of dyeing kinetics, the concentrated aqueous extracts of the selected natural dyes were filtered and the filtrates were evaporated to a semisolid mass under water bath. The semisolid mass was then put in a cage of wrapped filter paper and further subjected to extraction in soxhlet apparatus using 1:1 ethyl alcohol/ benzene mixture for 10 cycles at 70°C for 2h. The alcohol- benzene extract of the colour component was finally subjected to evaporation in a water bath at 50°C to get a semi-dry mass of the pure colour component. Finally, this dry mass of the colour component was washed with acetone followed by methyl alcohol and finally dried in air to obtain the dry powder of the pure colour component.

2.2.2 Mordanting

Bleached jute fabrics were pre-mordanted using myrobolan followed by aluminium sulphate in sequence using the procedure given here under.

Myrobolan 'gel' prepared by soaking myrobolan in water overnight (12 h) was diluted to an appropriate concentration (20% w/w) and filtered. Bleached jute fabrics were then first mordanted with 20% myrobolan solution using 1:20 MLR at 80°C for 30 min. After the treatment, the fabric was dried in air without washing to make it ready for second mordanting.

The myrobolan- treated jute fabrics were then treated with 20% aluminium sulphate at 80°C for 30 min using 1:20 MLR. After the second mordanting, the fabric samples were finally dried in air without washing to make them ready for subsequent dyeing.

2.2.3 Dyeing

Pre-mordanted jute fabrics were dyed with aqueous extracts of either single or selected binary pairs of natural dyes in varying proportion (100:0, 75:25, 50:50, 25:75 and 0:100), applying overall 40% (owf) concentration of selected dyes (based on the amounts of source material) at 100°C for 60 min using 1:50 MLR. Ten gram sodium chloride was used as only additive. In each case, the dyed samples were repeatedly washed with hot and cold water and finally dried in air. Finally, the dyed samples were subjected to soaping with 2g/L soap solution at 60 °C for 15 min, followed by repeated water wash and atmospheric drying under sun.

2.2.4 Application of Cationic Dye-fixing Agents and UV-Absorber

Dyed jute fabrics were padded (using two bowl lab padding mangle) with aqueous solutions containing respectively 2 % cetrimide, 2% CTAB, 2% Sandofix-HCF and 1% benzotriazole (pre-dissolved in water at 60°C) in presence of 0.5% NaOH, maintaining 100% wet pick-up in the fabric by 2 dip-2nip process followed by drying cum heat treatment at 100°C for 15 min using laboratory hot air stenter in sequence.

2.2.5 Measurement of Colour Strength and Related Colour Interaction Parameters

The *K/S* values of the dyed jute fabric were determined by measuring their surface reflectance using a computer-aided Macbeth 2020 plus reflectance spectrophotometer followed by calculating the *K/S* values using following Kubelka Munk¹⁸ equation with the help of relevant software:

$$K/S = \frac{(1 - R_{\lambda, \max})^2}{2R_{\lambda, \max}} = \alpha C_d$$

where α is the constant for a particular textile substrate and dye system; K , the coefficient of absorption; S , the coefficient of scattering; C_d , the concentration of dye; and $R_{\lambda_{\max}}$, the surface reflectance value of the sample at a particular wavelength where maximum absorption occurs for a particular colourant.

From the measured K/S values for 100% individual dye applied on a pre-mordanted jute fabric, the calculated K/S values (as K/S values are additive and liner) were obtained for samples dyed with a specific properties of a selected pair of dyes (dye A and dye B) using following equation:

$$\text{Calculated } K/S^a = \left(\frac{m}{100} K/S^b \right) + \left(\frac{n}{100} K/S^c \right)$$

where (^a) is observed for $m:n$ proportion of A & B dyes; (^b) is observed for 100% dye A; and (^c) is observed for 100% dye B.

Also, the coefficient of variation percentage (CV%) of K/S values was determined from the 10 point K/S data taken at 10 different points of the corresponding dyed fabric samples.

The total colour difference (ΔE) values were observed by measuring L^* , a^* , b^* values before and after treatment using a computer-aided Macbeth 2020-plus reflectance spectrophotometer along with associated Colour-Lab plus software using the following CIELab equations¹⁸:

$$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

where

$$\begin{aligned} L^* &= 116 (Y/Y_0)^{1/3} - 16 \\ a^* &= 500 [(X/X_0)^{1/3} - (Y/Y_0)^{1/3}] \\ b^* &= 200 [(Y/Y_0)^{1/3} - (Z/Z_0)^{1/3}] \end{aligned}$$

Chroma (psychometric chroma) values in CIELab colour space were calculated as follows:

$$C_{(ab)}^* = (a^2 + b^2)^{1/2}, \Delta C^* = C_{1(ab)}^* - C_{2(ab)}^*$$

where $C_{1(ab)}^*$ and $C_{2(ab)}^*$ are the chroma values for standard sample and produced sample. CIE 1976 metric Hue-Difference¹⁸ (ΔH) can be given for CIELab system using the following relationship:

$$\Delta H_{ab} = [(\Delta E_{ab}^*)^2 - (\Delta L^*)^2 - (C_{ab}^*)^2]^{1/2}$$

General metamerism index (MI) was calculated employing Nimeroff and Yurow's equation¹⁸ as follows:

$$MI = \frac{\Sigma(\Delta R\bar{x})^2}{X^2} + \frac{\Sigma(\Delta R\bar{y})^2}{Y^2} + \frac{\Sigma(\Delta R\bar{z})^2}{Z^2}$$

where ΔR values refer to the difference in reflectance values between two pieces of the same fabric sample measured at two different wavelengths (under two viewing conditions i.e wavelength conditions of viewing illuminant used in the measurement); and \bar{x} , \bar{y} and \bar{z} are the standard CIE-observer function for three primary colours, while X, Y and Z are the CIE tristimulus values (average) of the respective samples chosen for determining MI values as mentioned above.

Brightness index (BI) was calculated as per ISO-2470-1977 method¹⁹ using the following relationship:

$$\text{Brightness index} = \frac{\text{Reflectance value of substrate at 457 nm}}{\text{Reflectance value of standard diffuser/white tile at 457 nm}} \times 100$$

2.2.6 Compatibility Tests for Selected Binary Pairs of Natural Dyes

2.2.6.1 Conventional Method

Following selected binary pairs (50 : 50) of natural dyes were applied on the pre-mordanted jute fabrics using overall 20 – 100% (owf) of the respective extracts:

- M1 – Jackfruit wood + Manjistha (JFW & MJ)
- M2 – Jackfruit wood + Mariegold (JFW & MG)
- M3 – Jackfruit wood+ Red sandal wood (JFW & RSW)
- M4 – Jackfruit wood + Babool wood (JFW & BL)
- M5 – Jackfruit wood + Sappan wood (JFW & SW)

In compatibility tests of binary pairs, pre-mordanted jute fabric samples were dyed in two different sets (Set I and Set II) of progressive depth of shade for each selected binary pair of dyes taken in equal proportions (50:50).

In Set I, the progressive depth of shade was developed by varying dyeing time and temperature profile during dyeing. For each pair of dyes (M1-M5), five separate small pre-mordanted jute fabric samples were dyed using EEC make laboratory beaker dyeing machine with temperature controller for different dyeing periods (10-60 min). The samples were taken

out from the dyebath at the intervals of 10 min from 60°C onwards, maintaining the heating rate of 1°C/min. The penultimate sample was taken out after 50 min at 100°C and the last one at the end of the dyeing process after 60 min.

In Set II, the progressive depth of shade was developed by varying total concentration of dye mixture from 20% to 100%. For each pair of dyes, five separate small pre-mordanted jute fabric samples were dyed at the increments of 20% points by applying 20 – 100% (owf) each pair of dye (M1-M5) taken in equal proportion (50:50) at 100°C for 60 min.

For both Set I and Set II dyeing, all the dyed fabrics were subjected to normal washing, soaping, and rinsing before final air drying. The differences in the CIELab coordinates, namely ΔL , Δa , Δb and ΔC for all the dyed fabrics using Set I and II methods with respect to the standard undyed fabric sample were obtained from separate measurement of the same using the above-mentioned Macbeth 2020 plus reflectance spectrophotometer and associated software and computer. The compatibility of a selective pair of dyes can be judged^{3-6,17} from the degree of closeness and overlapping of the two curves ΔC vs ΔL or K/S vs ΔL observed using the two sets of dyeing (Set I & Set II).

2.2.6.2 Proposed Method

An alternative method of assessing compatibility of binary pairs of dyes is also proposed. After the application of different proportions of binary pairs of dyes on the same fabric, the magnitudes of the respective ΔE , ΔC , ΔH and MI values, irrespective of their sign and direction, may be utilized to obtain colour difference index (CDI) using the following proposed empirical relationship:

$$CDI = \frac{\Delta E \times \Delta H}{\Delta C \times MI}$$

The closer the CDI values for binary pairs of dyes, the higher is the compatibility rating (between 0 and 5, where rating 5 shows as the maximum or excellent compatibility, rating 1 indicates minimum or worst compatibility and rating 0 is considered as completely non-compatible). Proposed relative compatibility rating (RCR) or compatibility grading system may be represented as follows:

Compatibility grade	RCR	Highest values of differences between maximum CDI values and individual CDI values*
Excellent	5	>0 but ≤ 0.05
Very good	4-5	>0.05 but ≤ 0.10
Good	4	>0.10 but ≤ 0.20
Moderate	3-4	>0.20 but ≤ 0.30
Average	3	>0.30 but ≤ 0.40
Fair	2-3	>0.50 but ≤ 1.00
Poor	2	>1.00 but ≤ 5.00
Very poor	1-2	>5.00 but ≤ 10.0
Worst	1	> 10.0 but ≤ 15.0
Non-compatible	0	>>15.00

*For dyeing using different proportions of mixtures of selective pair of dyes on the same fabric under the comparable dyeing conditions.

2.2.7 Colour Fastness

Colour fastness to washing²⁰ of the dyed samples was determined as per the IS: 764-1984 method following IS-3 (equivalent to ISO-III) wash fastness method using a Sasmira Launder-O-Meter and relevant grey scale.

Colour fastness to rubbing²⁰ (dry and wet) was assessed as per the IS: 766-1984 method using a manual crockmeter and relevant grey scale.

Colour fastness to light²⁰ was determined as per the IS: 2454-1984 method using a Shirley MBTF (Philips-500 Watt Mercury bulb Tungsten Filament Lamp) Microsal Fade-O-meter and eight blue wool standards with known light fastness grade 1-8.

3 Results and Discussion

The study deals with the following three major objectives for the coloration of bleached jute fabrics with selected binary pairs of natural dyes: (i) colour strength and related parameters, (ii) colour fastness of dyed jute fabrics, and (iii) compatibility of selected binary pairs of dyes.

It has been reported¹² earlier that the pre-mordanting using 20% myrobolan followed by 20% aluminium sulphate is the most suitable system for dyeing bleached jute fabric with red sandal wood dye. Hence, the same system of pre-mordanting of jute fabric has been used for this study.

3.1 Colour Strength and Related Parameters

Table 1 shows the observed (O) and calculated (C) surface colour strength (K/S values) for pre-mordanted jute fabrics dyed with binary pairs of dyes. It is found that the differences (D1) in the observed and calculated K/S values are minimum for JFW : BL. The order of increase in the differences (D1) between

Table 1 — Observed and calculated K/S values and related parameters of pre-mordanted jute fabrics dyed with selected binary pairs natural dyes
 $[\lambda_{\max} = \text{JFW-480 nm, MJ-430 nm, MG-430 nm, RSW-420 nm, BL-410 nm, and SW-520 nm}]$

Dye combination	K/S values									
	100:0 ^a		75:25 ^a		50:50 ^a		25:75 ^a		0:100 ^a	
	A	B	A	B	A	B	A	B	A	B
M1 (JFW: MJ)										
O	5.46	4.77	6.65	5.98	6.10	5.51	7.19	6.68	7.75	7.51
C	—	—	6.03	5.44	6.60	6.13	7.17	6.82	—	—
D1	—	—	+0.62	+0.54	-0.50	-0.62	+0.02	-0.14	—	—
D2	+0.69		+0.67		+0.59		+0.51		+0.24	
M2 (JFW: MG)										
O	5.46	4.42	9.24	8.09	10.23	8.25	11.21	10.41	13.36	12.91
C	—	—	7.43	6.53	9.41	8.66	11.38	10.78	—	—
D1	—	—	+1.81	+1.56	+0.82	-0.41	-0.17	-0.37	—	—
D2	+1.04		+1.15		+1.98		+0.8		+0.45	
M3 (JFW: RSW)										
O	5.46	1.68	7.02	3.73	7.59	4.51	7.95	5.41	7.08	7.38
C	—	—	5.86	3.10	6.27	4.53	6.27	5.95	—	—
D1	—	—	+1.16	+0.63	+1.32	-0.02	+1.68	-0.54	—	—
D2	+3.78		+3.29		+3.08		2.54		-0.3	
M4 (JFW: BL)										
O	5.46	5.20	5.71	5.59	6.43	6.25	6.60	5.67	6.73	6.33
C	—	—	5.77	5.48	6.09	5.76	6.40	6.04	—	—
D1	—	—	-0.06	+0.11	+0.34	+0.49	+0.20	-0.28	—	—
D2	+0.26		+0.12		+0.18		+0.93		+0.4	
M5 (JFW: SW)										
O	5.46	1.04	6.30	2.27	7.16	3.06	8.67	3.15	11.27	15.09
C	—	—	6.90	4.55	8.36	8.02	9.81	11.57	—	—
D1	—	—	-0.6	-2.28	-1.2	-4.96	-1.14	-8.42	—	—
D2	+4.42		+4.03		+4.10		+5.52		-3.82	

^aProportion of binary pairs of dyes ($m : n$).

A— K/S at λ_{\max} of dye A; B— K/S at λ_{\max} of dye B; O— Observed K/S value; and C— Calculated K/S value.

D1— Differences between observed and calculated K/S values.

D2—Differences between two sets of observed K/S values at λ_{\max} (A) and at λ_{\max} (B).

the observed and calculated K/S values for the various pairs of dyes applied are:

$$\text{JFW:BL} < \text{JFW:MJ} < \text{JFW:MG} \leq \text{JFW:RSW} < \text{JFW:SW}$$

The metameric effect, considering the differences (D2) in the K/S values measured at λ_{\max} for dye A and λ_{\max} for dye B for each pair of natural dyes is also found to be minimum for the mixture of jackfruit wood and babool (JFW & BL). The order of increasing differences between the two sets of observed K/S values at two different λ_{\max} values for each pair of natural dyes ($D2=O_A-O_B$) is as given below:

$$\text{JFW:BL} \leq \text{JFW:MJ} < \text{JFW:MG} < \text{JFW:RSW} < \text{RSW:SW}$$

Table 2 shows the K/S values at a common wavelength (420 nm) for pre-mordanted jute fabrics dyed with selected binary pairs of dyes in different

proportions (75:25, 50:50 and 25:75). Data are also given for total colour differences (ΔE), changes in hue (ΔH), changes in chroma (ΔC), metamerism index (MI) and brightness index (BI). The data for total colour difference show the minimum ΔE values for the combination M4 (JFW: BL), irrespective of the proportions of the mixture of each selected pair of dyes.

Comparison of the negative values for change in chroma (ΔC) shows that the changes in chroma values for the combination M5 (JFW: SW) are always lower or minimum, while a maximum change in the same is observed for M4 (JFW:BL) for all the dye proportions studied.

The values for change in hue angle (ΔH) are found to be positive for the combinations M1, M3 and M5, but negative for M2 and M4. Irrespective of negative or positive signs, the increasing orders of magnitude for the ΔC and ΔH values for each binary pairs of dyes in equal proportion (50:50) are:

Table 2 — Colour strength, brightness index and related parameters of pre-mordanted jute fabrics dyed with selected binary pairs of natural dyes in different proportions

Dye combination	K/S λ_{\max} 420, nm	ΔE	ΔC	ΔH	MI	BI
For 75:25 Proportion						
M1 (JFW : MJ)	6.65	20.20	-8.21	13.51	7.38	9.51
M2 (JFW : MG)	9.24	22.51	-4.02	-2.92	1.51	13.54
M3 (JFW : RSW)	4.86	14.72	-9.96	10.47	6.36	25.34
M4 (JFW : BL)	5.69	6.42	-12.80	-4.63	1.35	13.56
M5 (JFW : SW)	5.20	19.27	-2.73	4.11	1.67	25.01
For 50:50 Proportion						
M1 (JFW : MJ)	6.90	16.39	-6.90	10.63	5.98	9.26
M2 (JFW : MG)	9.23	21.52	-3.01	-2.11	1.13	7.24
M3 (JFW : RSW)	5.59	11.77	-8.67	7.68	5.01	18.65
M4 (JFW : BL)	6.43	7.11	-11.01	-5.27	2.05	11.43
M5 (JFW : SW)	5.79	15.43	-2.42	2.89	1.57	20.15
For 25:75 Proportion						
M1 (JFW : MJ)	7.19	12.65	-4.02	5.10	3.98	7.60
M2 (JFW : MG)	11.21	20.41	-1.91	-1.68	0.71	5.53
M3 (JFW : RSW)	5.95	8.99	-6.65	5.76	3.81	10.54
M4 (JFW : BL)	7.34	6.98	-8.49	-5.07	2.16	10.26
M5 (JFW : SW)	6.47	12.59	-2.01	1.87	1.27	15.42

ΔC – JFW:SW < JFW:MG < JFW:MJ < JFW:RSW < JFW:BL
 ΔH – JFW:MG < JFW:SW < JFW:BL < JFW:RSW < JFW:MJ

The minimum MI values are observed for the combination M2 (JFW:MG) for all the three proportions of dyes mixture. Irrespective of the proportions of pair of dyes, the order of increasing MI is as follows:

JFW : MG < JFW : SW < JFW : BL < JFW : RSW < JFW : MJ

Brightness index (BI) is another important colour parameter for dyed fabrics, being considerably dependent on surface lustre and specular reflectance. Brightness index values for these binary pairs of dyes (50:50) are found to increase in the following order:

JFW:MG < JFW:MJ < JFW:BL < JFW:RSW < JFW:SW.

The use of other two proportions of selected pair of dyes also show a similar results.

3.2 Colour Fastness

Table 3 shows the colour fastness data for selected binary pairs of dyes applied in different proportions (75:25, 50:50 and 25:75) to pre-mordanted jute fabrics after treated with one of the three cationic fixing agents or a UV absorber.

The binary pair M4 (JFW:BL) shows satisfactory fastness to washing without after treatment and the ratings of LOD 4 and ST 4-5 remain unchanged after treating them with any of the three cationic fixing

agents used. Binary pair M2 (JFW:MG) also gives a similar result, showing satisfactory fastness to washing if proportions of JFW is above 50. For 25:75 JFW:MG, the fastness to washing for both LOD and ST is one unit lower and may be improved to a measurable extent by the use of any one of the cationic fixing agents. Dyeing of the binary pair M1 (JFW:MJ) is, to some extent, unsatisfactory before any after treatment but gives satisfactory wash fastness after the treatment with any one of the cationic fixing agents. With the binary pairs M3 (JFW: RSW) and M5 (JFW:SW), however, the fastness to washing is generally unsatisfactory with or without after treatment, except in the case of M5 (JFW:SW) after treated with sandofix-HCF, irrespective of the proportion of binary pair of dyes.

The data for fastness to light indicate that the after treatment with 1% benztrazole generally increases the fastness rating by one point for all the five binary pairs of dyes, irrespective of their proportion. The presence of UV-absorber in the dyed jute fibre enhances the light fastness by preferred absorption of the UV radiation. This reduces the attack on the natural dyes and the lignin component of the jute fibres that results in more rapid fading and decolouration respectively in the absence of benzotriazole.

In all the cases, the fastness to dry and wet rubbing between 4 and 4-5 need no special treatment for its further improvement. Good rub fastness in all these

Table 3 — Colour fastness data for pre-mordanted jute fabrics dyed with selected binary pairs of natural dyes in different proportions and after treated with one of three cationic fixing agent and a UV absorber

Dye combination	Fastness to											
	Washing								Light		Rubbing (Untreated)	
	Untreated		2% CTAB treated		2% Cetrimide Treated		2% Sandofix-HCF treated		Untreated	1% Ben treated		
	LOD	ST	LOD	ST	LOD	ST	LOD	ST			Dry	Wet
For 75:25 Proportion												
M1 (JFW : MJ)	3	4	4	4-5	4	4-5	4	4-5	3	4-5	5	4-5
M2 (JFW : MG)	4	4-5	4	4-5	4	4-5	4	4-5	3	4	5	4-5
M3 (JFW : RSW)	3	3-4	4	4-5	3-4	4	3-4	4	3	4	4-5	4
M4 (JFW : BL)	4	4-5	4	4-5	4	4-5	4	4-5	3	4	5	4-5
M5 (JFW : SW)	4	4-5	3-4	4-5	3-4	3-4	4	4-5	3	4	5	4-5
For 50:50 Proportion												
M1 (JFW : MJ)	3	3-4	4	4-5	4	4-5	4	4-5	3	4-5	4-5	4
M2 (JFW : MG)	4	4-5	4	4-5	4	4-5	4	4-5	3	4	5	4-5
M3 (JFW : RSW)	3	3-4	3-4	4	3	3-4	3-4	4	2-3	3-4	4-5	4
M4 (JFW : BL)	4	4-5	4	4-5	4	4-5	4	4-5	3	4	5	4-5
M5 (JFW : SW)	3	3-4	3-4	4-5	3-4	3-4	4	4-5	3	4	5	4-5
For 25:75 Proportion												
M1 (JFW : MJ)	3-4	3-4	3-4	4	3-4	4	4	4-5	3	4-5	4-5	4
M2 (JFW : MG)	3	2-3	3-4	4	4	4-5	4-5	5	2-3	3	5	4-5
M3 (JFW : RSW)	2-3	3	3	3-4	3	3-4	3-4	4	2-3	3	4-5	4
M4 (JFW : BL)	4	4-5	4	4-5	4	4-5	4	4-5	3	4	5	4-5
M5 (JFW : SW)	3	3-4	3-4	4	3	3-4	4	4-5	3	3-4	4-5	4

CTAB— *n*-cetyl trimethyl ammonium bromide, Ben—benztrizole, LOD—loss of depth of shade, ST— staining on adjacent bleached jute.

cases indicates that there are no unfixed dyes left on the fibre surface after soaping and washing and that these dyes have penetrated well inside the fibre voids and probably got fixed well by ionic interaction or hydrogen bonding or coordinated complex formation with the mordants or with the functional groups of jute fibre, as the case may be.

3.3 Compatibility Tests

Binary pairs of dyes vary considerably in their response to dyeing processes. A given pair of dyes may exhibit compatibility under one set of dyeing conditions but prove to be incompatible under another set of condition. Regular build-up of the individual dye on a particular fibre dose not always guarantee similar behaviour when applied together. Two methods of test for compatibility of binary pairs of dyes have been used in the present work. In the conventional method, the closeness and degree of overlap have been compared between two sets of curves in the plots ΔC vs ΔL or K/S vs ΔL for two sets of progressive depth of shade^{3-6,17} produced using the Set I and Set II dyeing methods. However, it is felt highly essential to test the compatibility of different pairs of natural dyes by some form of quantitative

term expressed as relative compatibility rating for the various pairs that will help the dyer by providing options for selecting dyes to match a target shade. Therefore, an easy method of determining relative compatibility rating between any pair of natural dyes has been proposed by postulating a new colour difference index as mentioned in section 2.2.6.2.

The closer the CDI values for dyeing with different proportions (75:25, 50:50, 25:75) of the dyes in binary pairs under the same dyeing conditions, the higher is the compatibility rating for that pair of dyes. To test the degree of fitness of this proposed method, the results of the compatibility between the two methods (conventional and proposed) have been compared.

Figure 1 shows the plots of K/S vs ΔL (plots a – e) and ΔC vs ΔL (plots a' – e') for two sets (Set I and Set II) of dyed materials for 5 separate pairs (M1-M5) of natural dyes.

In case of binary pair M1 (JFW: MJ), plots of K/S vs ΔL show that the two curves for Sets I and Set II run similarly with only slight separation, whereas plots ΔC vs ΔL show that the curves for Set I and II are widely spaced and do not approach one another. In the proposed RCR system, the pairs of dyes exhibit

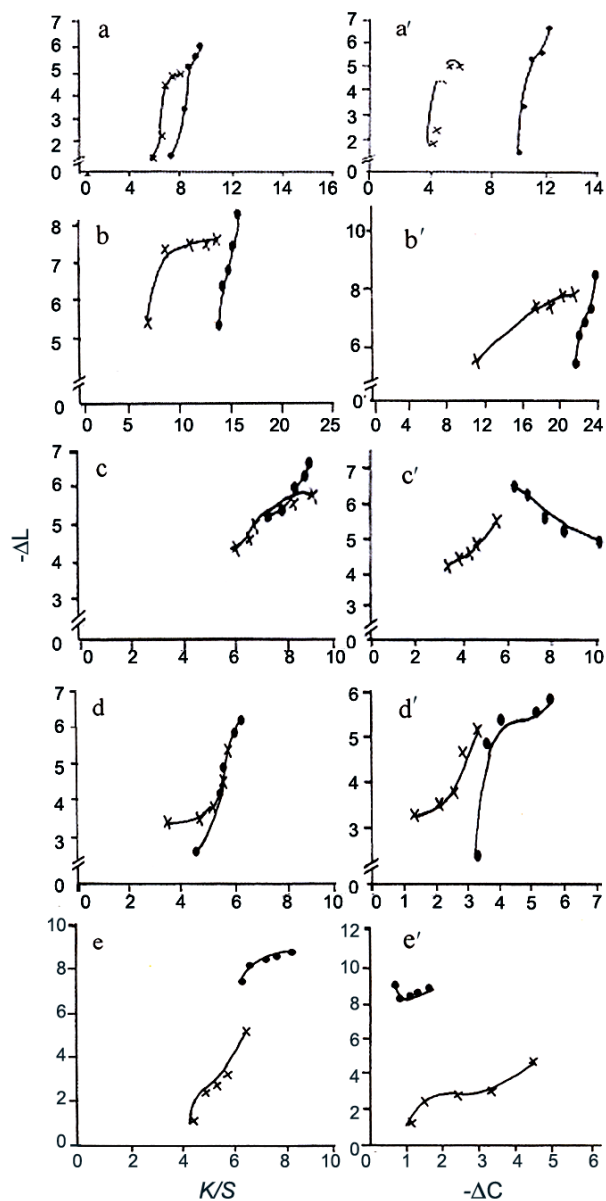


Fig. 1 — Plots of K/S vs ΔL (a-e) and ΔC vs ΔL (a' – e') for dyeing of five binary pairs of natural dyes on pre-mordanted jute fabrics [M1–a and a'; M2–b and b' M3–c and c' ; M4–d and d'; M5–e and e' ; (●) Set I method of dyeing and (x) Set II method of dyeing]

Grade 3 (average) relative compatibility rating (Table 4), showing predominantly closer similarity with the behaviour in the K/S vs ΔL plots.

In case of binary pair M2 (JFW:MG), the two curves for Sets I and II do not show similar build-up behavior in both the plots (b and b'). This is indicative of 'poor' to 'worst' compatibility for this binary pair of dyes. In the RCR system, this binary pair also exhibits Grade 1 (worst) relative compatibility rating (Table 4). Thus, the conventional and the proposed methods show very similar results.

In case of binary pair M3 (JFW:RSW), the plots K/S vs ΔL show that the two curves for Sets I and II partially overlap and only a minor deviation from one another is observed, indicating a moderate degree of compatibility. However, plots ΔC vs ΔL shows that the curves for Sets I and II are widely spaced, indicating a low degree (fair to poor) of compatibility between these dyes. In the proposed RCR system, this binary pair of dyes exhibits Grade 3-4 (moderate) relative compatibility rating (Table 4).

In case of binary pair M4 (JFW : BL), the plots K/S vs ΔL show that the two curves for Sets I and II partially overlap with only slight deviation, indicating a good degree of compatibility. In the corresponding plots ΔC vs ΔL , however, the curves for Set I and II show a significant separation from one another, indicating an average to moderate degree of compatibility. In the proposed RCR method, this pair of dyes exhibits Grade 3-4 (moderate) relative compatibility rating (Table 4).

In case of binary pair M5 (JFW: SW), the two curves for Sets I and II in both the plots show a wide separation without any systematic build-up behaviour with either increasing concentrations (Set II) or increasing dyeing time and temperature (Set I). Thus, these two dyes are totally incompatible with one another when applied as a binary pair by any method. In the proposed RCR system, this pair exhibits the

Table 4 — Colour difference index (CDI) and relative compatibility rating (RCR) for application of selected binary pairs of natural dyes to pre-mordanted jute fabrics

Dye combination	CDI			RCR	Compatibility grade
	75:25 ^a	50:50 ^a	25:75 ^a		
M1 (JFW : MJ)	4.50	4.22	3.71	3	Average
M2 (JFW : MG)	10.82	13.34	25.29	1	Worst
M3 (JFW : RSW)	2.33	2.08	2.04	3-4	Moderate
M4 (JFW : BL)	1.72	1.66	1.93	3-4	Moderate
M5 (JFW : SW)	34.04	11.73	9.22	0	Non-compatible

^aProportion of binary pair of dyes.

Grade 0 (Non-compatible) relative compatibility rating (Table 4).

4 Conclusions

4.1 The order of increase in the differences between the observed and calculated K/S values for the various pairs of dyes is : JFW: BL < JFW: MJ < JFW : MG \leq JFW : RSW < JFW : SW. The order of increasing differences between the two sets of observed K/S values at two different λ_{\max} values for each pair of natural dyes is : JFW : BL \leq JFW : MJ < JFW : MG < JFW : RSW < RSW : SW. The order of increasing metamerism index for the various pairs of the dyes is : JFW & MG < JFW & SW < JFW & BL < JFW & RSW < JFW & MJ.

4.2 The wash fastness data for equal proportion (50:50) of the binary pairs M2 (JFW: MG) and M4 (JFW:BL) are satisfactory even without after treatment. Dyeings of the binary pair M1 (JFW:MJ) are unsatisfactory before any after treatment but give satisfactory fastness after post-treatment with any of the three fixing agents used. With the binary pairs M3 (JFW:RSW) and M5 (JFW:SW) the fastness to washing is generally unsatisfactory with or without after treatment, except in the case of M5 (JFW:SW) after treated with sandofix-HCF.

4.3 Application of 1% benzotriazole as UV-absorber generally increases the fastness rating by one point for all the five (M1 to M5) binary pairs of dyes.

4.4 The results of the proposed system of relative compatibility rating are in good agreement with the results of the conventional compatibility test based on the analysis of K/S vs ΔL and ΔC vs ΔL plots. According to the RCR system, the order of relative degree of compatibility of selected pairs of dyes is :

JFW:RSW \geq JFW:BL \geq JFW:MJ \gg JFW:MG \gg JFW:SW

Thus, this proposed method of the relative compatibility rating system may be useful to identify compatible binary pairs of natural dyes for dyeing jute with binary mixture of natural dyes in various proportions, providing the dyer an option for selecting correct and compatible mixture of natural dyes to match a target compound shade.

Industrial Importance: The present study offers an easy and simple colorimetric method of relative numerical rating of compatibility to identify and select proper compatible natural dyes to get different compound shades with improved wash and light fastness for jute products.

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