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Studies on compatibility of selective direct dyes for dyeing of jute fabric

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Compatibility of binary mixture of direct dyes has been studied by conventional method as well as a new simplified and easier method for application of direct dyes combination on jute, and the findings of both the methods are compared. In conventional method of compatibility test, the study has been made using colorimetric method by comparing ΔC *vs* ΔL and *K*/*S* *vs* Δ*L* for two sets of dyed samples, varying time and temperature profile in one set, and dye concentration in second set for dyeing jute fabric with binary pairs of dyes in equal proportion (50:50). In proposed method of compatibility test, the colour difference index (CDI) values are calculated for dyed jute fabrics using different proportions of binary mixture of dyes. Finally, from the difference of maximum CDI and minimum CDI, the relative compatibility rating is judged. In conventional method of compatibility test, Direct Red 12B + Direct Green YG and Direct Green YG + Direct T Blue 2R combinations show better compatibility, while Direct Yellow 5GL + Direct T Blue 2R exhibits worst compatibility amongst total six combinations studied. In case of proposed method, Direct Green YG + Direct Yellow 5GL and Direct Green YG + Direct T Blue 2R combinations show better compatibility ; Direct Red 12B + Direct Green YG combination shows fair compatibility ; and Direct Yellow 5GL + Direct T Blue 2R shows moderate compatibility. Thus, the results of two methods though are not exactly the same but are nearer and acceptable.

Keywords: Colorimetric method, Colour difference index, Direct dye, Dyeing, Jute fabric

1 Introduction

Compatibility of dyes is a relative measure of similarities and dissimilarities in dyeing rate, colour build up, etc. between two dyes used in a combination (binary pair). Compatibility of each dyes can be judged conventionally by different methods[1-6] , such as (i) colorametric method by comparing and plotting ΔC *vs* ΔL or *K*/*S* *vs* Δ*L* values for two sets of progressive shades build up by dyeing with varying dye concentration in one set and with varying profile of dyeing time and temperature in second set[1]; (ii) subjective visual assessment of the degree of on-tone build up by a series of dyeing; (iii) prediction of compatibility[5] by comparison of rates of dyeing (time of half dyeing) and dyeing kinetics (diffusion coefficients) for each individual dye; and (iv) quantitative assessment of change in hue[6] (ΔH) with dye concentrations. Some studies on compatibility of binary and ternary mixture of synthetic dyes[1-6] are available in literature, but such studies for application of binary mixture of direct dyes applied on jute[7-11] are scanty and rare.

Dyeing of a particular fibre , considering a combination of different dyes in the same dye bath for obtaining compound shades and having different chemical structures and functional groups of dyes , is really a challenge for dyers. This becomes further complicated for dyeing of a multi-constituent fibre like jute. Conventional colorimetric method of determining compatibility of dyes is a cumbersome process by comparing ΔC *vs* ΔL and *K*/*S* *vs* ΔL curves for two sets of dyeing , namely by varying dyeing temperature and time profile in one set and varying dye concentration in another set. So, a simpler and easy method needs to be adopted. Following an earlier study[12] , a new method of relative compatibility rating test has been used in the present study for application of direct dyes on jute . The applicability/adoptability of this new method has been checked based on the calculation of colour difference index (CDI) values using different proportions of dyes to obtain desired

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compound shades on jute fabrics. The new method will be beneficial for dyers and researchers for obtaining a predictable and uniform colour shade with maximum reproducibility.

2 Materials and Methods

2.1 Materials

Fine hessian jute fabric , bleached with 3% H_2O_2 and having the specifications 215 tex warp, 285 tex weft, 64 ends/dm, 58 picks/dm, 320 g/m^2 fabric area density and 0.70 mm fabric thickness , was used. The fabric was obtained from M/s Gloster Jute Mills Ltd., Bauria, Howrah, India.

Direct dyestuffs [Atul Ltd(Tuladir)] of four different colours , namely Direct Turquoise blue 2R (CI Direct Blue 199), Direct Red 12B (CI Direct Red 31), Direct Yellow 5GL (CI Direct yellow 44) and Direct Green YG (CI Direct Green 513) along with sodium chloride (NaCl) were used in the present study.

2.2 Methods

2.2.1 Dyeing of Jute

Unless otherwise mentioned, normal dyeing of jute fabric with direct dyes are given below:

The pre-wetted material was put into dyebath at 50^{0}C and then temperature was raised slowly to 95-100^{0}C within 45-50 min. The requisite quantity of common salt was then added in two instalments into the above dye bath. After attaining the temperature 95-100 ^{0}C, dyeing was continued for further 10-30 min[13]. Then the dyed fabric was initially washed with running tap water followed by washing with hot water for 15 min by soaping with 2g/L soap at 50^{0}C followed by normal two repeated washing and drying in air.

2.2.2 Compatibility Test

Following six binary pairs (50:50) of direct dyes ($^4C_2$ nos. =6 only) were applied on the 6% H_2O_2 bleached fine hessian jute fabric:

(i) M1- Direct Red 12B + Direct Green YG
(ii) M2- Direct Red12B + Direct Yellow 5GL
(iii) M3- Direct Red12B + Direct Turquish Blue 2R
(iv) M4- Direct Green YG+ Direct Yellow 5GL
(v) M5- Direct Green YG+ Direct Turquish Blue 2R
(vi) M6- Direct Yellow5GL + Direct Turquish Blue 2R

In compatibility tests of binary pairs, bleached fine hessian jute fabric samples were dyed in two different sets (Set I and Set II) for building progressive depth of shade for each binary pair of dyes.

In Set I, the progressive depth of shade was developed by varying dyeing time and temperature. For each pair of dyes , six jute fabric samples were dyed using EEC make laboratory beaker dyeing machine with temperature controller at different dyeing temperatures (50 - 100^{0}C) and time periods (10-60 min with 10 min interval) , considering 1% (50:50) shade depth for each pair. The samples were taken out from the dye bath at the intervals of 10 min from 50^{0}C onwards, maintaining the heating rate of 1^{0}C/min. The penultimate sample was taken out after 60 min at 100^{0}C and the last one at the end of the dyeing process.

In Set II, the progressive depth of shade was developed by dyeing at 1% shade and by varying total dye concentration (0.20, 0.40, 0.60, 0.80, 0.90 and 1.00%). For each pair of dyes, six separate jute fabrics were dyed at the increments of 0.20% dye concentration for initial 1-4th sample. The remaining two samples were dyed with 0.90% and 1.00% binary dye mixture (M1- M6) at the increments of 0.10% dye at 100^{0}C for 60 min.

For both Set I and Set II dyeing, all the dyed fabrics were subjected to initial washing with running tap water followed by washing with hot water for 15 min using 2g/L soap at 50^{0}C followed by normal two repeated washing and drying in air.

The differences in the CIE Lab coordinates, namely ΔL, Δa, Δb and ΔC for all the dyed fabrics using Set I and Set II methods with respect to the standard undyed (control bleached) fabric sample were obtained from separate measurement of the above-mentioned colorimetric assessment using Macbeth 2020 plus reflectance spectrophotometer and associated software and computer.

2.2.3 Proposed Method

After the application of different proportions (100:0, 75:25, 50:50, 25:75, 100:0) of binary pairs of the selective dyes on the same fabric, the magnitudes of the respective ΔE, ΔC, ΔH, and MI values were utilized to obtain a newer colorimetric index known as colour difference index (CDI) using the following empirical relationship[12]:

$$\text{Colour difference Index (CDI)} = \frac{\Delta C \times MI}{\Delta E \times \Delta H}$$

where ΔC is the change in chroma; ΔE, the Total color difference; ΔH, the change in Hue; and MI, the Metamerism Index

As per the earlier report[12] , the relative compatibility rating (RCR) chart with respect to differences between maximum and minimum CDI values is shown in Table 1 . The closer the CDI values of binary pairs of dyes, the higher is the compatibility ratings between them.

The closer the CDI values of any one set of same and comparable dyeing conditions, the more is the uniformity of colour distribution and better is the dispersion of colour across the plane/surface area of the textile fabric. The higher CDI values thus indicate some lesser uniformity for non-uniform colouration. Moreover, minimum the values of (CDI max –CDI min) for dyeing with different proportions of two dyes in a binary mixture, the better is the compatibility between them.

2.2.4 Measurement of Colour Strength and Related Colour Interaction Parameters

K/S values of dyed jute fabrics were determined by measuring surface reflectance of the dyed samples using a computer aided Macbeth 2020 plus reflectance spectrophotometer followed by calculating the *K/S* values using Kubelka Munk equation[14]. CV % of *K/S* was also determined for estimating dye uniformity using standard statistical formula for calculation of coefficient of variation. Also ΔL, Δa, Δb and chroma values (ΔC), and difference in hue (ΔH) were measured as per CIE Lab formulae[14].

General metameric index (MI) was calculated employing Nimeroff and Yurow's equation[14] , as shown below:

$$MI = \frac{\sum(\Delta RX_o)^2}{X^2} + \frac{\sum(\Delta RY_o)^2}{Y^2} + \frac{\sum(\Delta RZ_o)^2}{Z^2}$$

where X_o, Y_o and Z_o are the tristimulus values of a standard white surface of MgO (or equivalent surface of standard white tile) and *X*, *Y* and *Z* are the tristimulus values of the corresponding samples.

Table 1 — Relative compatibility rating (RCR) values

Compatibility grade	RCR value	Highest values[a]
Excellent	5	>0 but d<=0.05
Very good	4-5	>0.05 but d<=0.10
Good	4	>0.10 but d<=0.20
Moderate	3-4	>0.20 but d<=0.30
Average	3	>0.30 but d<=0.40
Fair	2-3	>0.50 but d<=1.00
Poor	2	>1.0but d<=5.00
Very poor	1-2	>5.0 but d<=10.0
Worst	1	>10.0 but d<=15.0
Non compatible	0	>>15.0

[a]Difference between maximum CDI value and individual CDI value.

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

$$\text{Brightness index} = \frac{\text{Reference value of sample at 457nm}}{\text{Reference value of standard diffuser (white tile) at 457 nm.}} \times 100$$

2.2.5 Measurement of Colour Fastness

The wash fastness of dyed jute fabric was evaluated according to ISO-105-C06/C-10: 2010(E) method. The light fastness of the bleached and dyed jute fabrics was evaluated as per ISO-BO2:2013 method using Shirley MBTF-micro-scale fade-o-meter along with the eight (1 to 8) blue wool standards. Dry and wet rub fastness of the dyed jute fabric was evaluated as per ISO-105-X12:2001(E) method.

3 Results and Discussion

For compatibility test, selective binary pairs of different direct dyes have been applied under two sets of dyeing conditions. In new proposed method, the closer CDI values (differences of CDI $_{max}$ and CDI $_{min}$) for dyeing with different proportions of binary mixture indicate the better or higher compatibility rating performance for that pair of binary mixture. The results of conventional method and newer method of compatibility tests are also compared for adopting the easy and simpler method for dyeing jute with direct dyes.

3.1 Colour Strength, Brightness Index and Related Parameters

Table 2 shows *K*/*S* values and brightness indices along with other important colour parameters (ΔE, ΔC, ΔH and MI) of dyed jute fabrics with respect to bleached jute, after dyeing with single direct dye individually as well as with binary mixture of direct dyes at comparable shade depth and under same conditions of dyeing.

Table 2 interestingly shows lowest and highest *K*/*S* values for Direct Turquoise Blue 2R and Direct Green YG respectively, whereas reverse trend is observed for brightness index values , indicating some negative correlation between these two parameters. Similarly, lowest and highest metameric indices (MI values) are observed for Direct Yellow 5GL and Direct Red 12 B respectively, but reverse trend is observed for ΔC (chroma values), signifying negative correlation between these two parameters. On the contrary, lowest and highest ΔH values and brightness indices are observed for Direct Green YG and Direct Turquoise Blue 2R respectively, pointing positive

Table 2 — Colour strength, brightness index and related colour parameters of jute fabrics dyed with single and binary mixture of selected direct dyes (1% shades) in different proportions

Dye	*K/S* at λ_{max}(420)	CV % of *K/S*	ΔE	ΔC	ΔH	MI	BI	CDI
Single dyes								
Control jute	0.52	-	-	-	-	-	47.34	
Direct Red 12 B	2.93	4.23	13.93	2.44	12.34	967.97	17.80	0.104
Direct Green YG	6.47	4.46	18.47	12.62	10.39	550.31	14.64	0.027
Direct Yellow 5GL	5.78	3054	15.49	13.75	11.42	450.29	20.25	0.028
Direct Turquish Blue 2R	0.86	3.62	23.71	9.82	19.99	501.37	46.97	0.096
For 75:25 proportion								
M1	3.76	6.10	21.03	-0.44	15.12	1150.1	6.69	0.131
M2	2.94	2.72	28.58	11.65	-24.65	403.74	13.12	0.149
M3	3.53	6.21	31.54	16.5	21.58	1119.2	8.48	0.037
M4	10.08	5.13	12.25	3.27	10.34	1194.2	5.02	0.033
M5	4.76	4.67	20.03	4.49	16.74	1159.32	9.43	0.064
M6	5.42	5.14	22.38	13.17	16.17	388.96	10.74	0.071
For 50:50 proportion								
M1	5.76	8.37	20.15	-1.87	13.87	1125.2	9.88	0.589
M2	6.33	3.37	19.51	10.06	-16.53	400.61	10.94	0.080
M3	3.16	7.65	30.76	14.53	21.38	1170.7	9.36	0.408
M4	10.54	6.13	10.53	4.10	8.47	1193.8	4.43	0.018
M5	4.00	6.25	21.99	6.53	18.32	1142.71	11.39	0.054
M6	5.28	4.03	26.24	11.63	23.13	386.46	13.77	0.135
For 25:75 proportion								
M1	5.19	7.13	14.47	-4.33	11.82	1192.3	8.37	0.039
M2	4.33	5.23	12.85	9.38	-8.42	320.04	11.8	0.036
M3	1.98	6.42	31.75	12.18	22.46	1031.9	14.55	0.056
M4	11.58	5.39	11.14	9.61	5.59	1140.8	4.86	0.005
M5	3.18	3.67	22.3	6.68	18.56	1070.8	13.89	0.056
M6	2.83	3.45	29.4	6.59	28.59	373.46	18.99	0.341

M1 – Direct Red 12B + Direct Green YG, M2 – Direct Red 12B + Direct Yellow 5GL, M3 – Direct Red 12B + Direct Turquish Blue 2R, M4 – Direct Green YG + Direct Yellow 5GL, M5– Direct Green YG + Direct Turquish Blue 2R, M6 – Direct Yellow 5GL + Direct Turquish Blue 2R.

correlation between these parameters. It is interesting to observe that for application of any of the direct dyes in each case, there is significant reduction in BI values for most of the dyed fabric as compared to the bleached one, except in case of Direct Turquoise Blue 2R where marginal reduction of BI is observed. It may be due to the fact that reflectance is the common function controlling the parameters, *K/S* value and brightness, in opposite way. Brightness of dyed fabrics also depends on the structure and property of the dye itself as well as its fixation pattern /orientation in the fibre matrix after bonding[7].

Data (Table 2) for total colour difference (ΔE) at comparable shade depth show minimum values for combination M 4 , irrespective of the proportions of the binary mixture of selective dyes (12.25 for 75:25, 10.53 for 50:50 and 11.14 for 25:75 respectively). ΔE values are relatively higher for any other combination of binary mixtures of selective direct dyes, indicating some kind of synergistic interaction of Direct Green YG and Direct Yellow 5GL. However, comparison of ΔC values (change in chroma) shows minimum ΔC values for combination (M1). The maximum ΔC values are obtained for combination M3. For all other combinations of the selective direct dyes used, ΔC values are found to be in between the minimum and maximum . The values for change in hue (ΔH) are found to be positive for all combinations M1, M3, M4, M5 and M6, but it is negative for M2 combination, irrespective of the proportions of the binary mixture selective dyes. Irrespective of negative or positive sign, the increasing order of magnitude of the ΔC and ΔH values for these binary mixtures of direct dyes (50: 50) are as follows:

For ΔC − M1 < M4< M5 < M2 < M6 <M3.

For ΔH − M4 < M1 < M2 < M5 < M3 < M6.

Magnitude of minimum ΔH values further indicates some kind of mutual synergistic interaction of M4 combination (Direct Green YG + Direct Yellow 5GL), which is also fully reflected in ΔE value but not in ΔC values. Direct Red 12 B and Direct Green YG show minimum ΔC values, probably due to their predominating individual views of Direct Red 12 B and Direct Green YG.

The data for MI show relatively lower values for use of any combination of M6 (Direct Yellow 5GL+ Direct T Blue 2R) and M2 (Direct Red 12 B + Direct Yellow 5GL) than those found for other combinations of dyes, irrespective of the dye proportions in binary mixture. The minimum MI values found for both M6 and M2 combinations (being Direct Yellow 5GL is common for both combinations, with Direct Turquoise Blue 2R and Direct Red 12 B respectively) may be viewed for two different reasons, namely some kind of synergistic interaction (may be due to high degree of compatibility) or nearing predominating huge of these dyes in combination.

It is also interesting to observe that CDI values are maximum (0.589 and 0.408) for binary mixture of complimentary colour or colours of opposite hue like M1 (Direct Red 12B + Direct Green YG) and M3 (Direct Red 12B + Direct Turquish Blue 2R) combinations respectively for 50:50 ratio. However, CDI value is lowest in case of M4 (Direct Green YG + Direct Yellow 5GL) combination, showing highest *K*/*S* value in binary mixture of 50:50 ratio, may be due to a synergistic effect. Higher CDI value indicates higher sensitivity with poor compatibility of that binary combination and lower CDI values indicate better compatibility of the same.

The changes in all the above-said colour parameters may be considered as a combined effect of minor or major positive or negative shifts of the predominating hues causing hypso-chromic or batho-chromic shift due to variation in absorption of different concentration / proportions of selective binary mixture of direct dyes.

For different dye proportions in mixture, in most of the cases there is always same reduction in BI value on dyed products than that of bleached and undyed products. BI values for jute dyed with binary mixture may be the combined effects of light absorption properties of mixed dyes, dye-fibre bonding pattern and orientation/conglomeration of both dyes in fibre matrix as well as contribution of specular reflectance pattern of individual dye in specific mixture. Brightness index values for these binary pairs of dyes (50:50) are found to increase in the following order:

For BI − M4 < M3 < M1 < M2 < M5 < M6 .

3.2 Test of Compatibility

As per the selective conventional method, the results of compatibility test for both Set I and Set II are discussed hereunder.

The compatibility of a pair of dyes is judged from the degree of closeness and overlapping of two curves (*K/S vs* ΔL and ΔL *vs* ΔC) for both the sets (Set-I and Set-II). Relevant data given in Table 3 and 4 and corresponding curves in Fig 1 show the plots of *K*/*S vs* ΔL for M1 - M6 and plots of ΔC vs ΔL for M1’ - M6’ respectively for two sets of direct dyed materials having progressive shade build up.

For excellent or highest degree of compatibility, the two curves for each Set I and Set II in plots of ΔL vs *K*/*S* and ΔL *vs* ΔC are expected to almost overlap each other, when the colour build up (*K*/*S* values) with different profile of time-temperature (Set I) and the change in chroma (ΔC) values with increase in dye concentration (Set II) progress similarly. Even, pattern between plots of ΔL *vs* K/S and plots of ΔC *vs* ΔL may be almost the same to show good compatibility of dyes in their binary mixture.

In case of binary mixture of M1 (Direct Red 12B + Direct Green YG), both the curves in plot (M1) of *K/S vs* ΔL run parallel to some extent (Fig. 1) and then run very closely in a similar pattern. However, the curves tend to apart from both the ends with a small gap between them, showing good degree of compatibility albeit with low rate of colour build-up. Small difference may be due to the differences in the rate of dye absorption by these two dyes. This may be owing to the differences in molecular weights and functional group pattern of their colour components. The other two curves for Set I and Set II in plot (M1’) of ΔC vs ΔL show much varied and a complete different pattern of build up, showing a poor degree of compatibility. This

Table 3 — Colour strength and colour parameters required for conventional method of test of compatibility of binary mixture (50:50) of direct dyes (1% shade) for Set I [*K*/*S* of control jute = 0.53]

Parameter	*K*/*S*	ΔL	Δa	Δb	Δc
		M 1			
50 ^{0} C,10 min	1.82	-15.7	13.6	-14.8	7.83
60 ^{0} C,20 min	1.88	-14.4	7.41	-14.4	2.34
70 ^{0} C,30 min	3.81	-15.4	8.72	-13.9	3.15
80 ^{0} C,40 min	3.76	-12.0	-1.20	-12.0	-3.51
90 ^{0} C,50 min	3.87	-12.5	-2.8	-11.8	-3.10
100 ^{0} C,60 min	3.62	-11.6	-3.0	-11.1	-3.59
		M 2			
50 ^{0} C,10 min	5.08	-2.37	17.78	3.29	13.46
60 ^{0} C,20 min	4.25	-3.97	22.48	2.54	17.24
70 ^{0} C,30 min	4.71	-2.56	21.24	3.94	16.78
80 ^{0} C,40 min	4.59	-2.35	20.59	4.17	16.34
90 ^{0} C,50 min	5.86	-5.10	24.33	1.33	18.53
100 ^{0} C,60 min	5.02	-3.33	20.32	3.17	15.62
		M 3			
50 ^{0} C,10 min	3.67	-6.74	7.61	-7.38	-0.60
60 ^{0} C,20 min	3.69	-7.66	-7.77	-8.72	-.39
70 ^{0} C,30 min	4.04	-8.83	-8.83	-9.66	-0.17
80 ^{0} C,40 min	4.45	-8.04	-8.04	-8.21	-0.67
90 ^{0} C,50 min	4.17	-7.72	-7.72	-8.01	-0.62
100 ^{0} C,60 min	4.14	-7.76	-7.76	-7.23	-1.06
		M 4			
50 ^{0} C,10 min	5.61	1.29	-9.97	9.14	11.6
60 ^{0} C,20 min	5.96	0.35	-10.0	7.45	10.2
70 ^{0} C,30 min	6.36	-1.97	-11.2	4.74	8.77
80 ^{0} C,40 min	8.37	-3.76	-10.9	0.99	5.96
90 ^{0} C,50 min	8.53	-4.06	-11.2	-0.39	5.33
100^{o}C,60min	4.47	-6.25	-10.9	-2.87	3.86
		M 5			
50 ^{0} C,10 min	1.4	-8.63	-13.5	-9.65	5.49
60 ^{0} C,20 min	1.75	-8.58	-13.7	-9.30	5.57
70 ^{0} C,30 min	2.06	-9.58	-14.8	-10.4	6.84
80 ^{0} C,40 min	2.62	-9.79	-15.0	-11.1	7.19
90 ^{0} C,50 min	2.72	-9.97	-15.2	-10.7	7.34
100^{o}C,60 min	3.38	-10.1	-15.2	-10.5	7.19
		M 6			
50 ^{0} C,10 min	2.38	5.79	-9.82	11.27	13.34
60 ^{0} C,20 min	2.91	6.31	- 10.1	12.39	14.59
70 ^{0} C,30 min	3.91	6.53	-13.17	12.99	16.59
80 ^{0} C,40 min	3.81	6.34	-13.64	12.76	16.65
90 ^{0} C,50 min	5.05	5.34	-15.26	12.22	17.16
100 ^{0}C,60 min	4.34	4.46	-17.40	9.94	16.78

Table 4 — Colour strength and colour parameters data required for conventional method of test of compatibility of binary mixture (50:50) of direct dyes (1% shade) for Set II [*K*/*S* of control jute = 0.53]

Dye conc. (50:50)	*K*/*S*	ΔL	Δa	Δb	Δc
		M 1			
0.20	1.33	-10.9	-0.57	-11.1	-4.52
0.40	1.73	-12.1	-0.75	-12.8	-2.75
0.60	2.27	-12.5	-0.36	-12.9	-2.71
0.80	3.13	-13.4	0.109	-13.2	-2.36
0.90	3.82	-13.5	1.082	-12.9	-2.47
1.00	3.53	-13.9	3.37	-12.8	-1.56
		M 2			
0.20	5.44	-4.09	22.25	2.25	16.95
0.40	7.41	-4.99	22.69	2.02	17.26
0.60	9.34	-7.69	22.34	-0.62	16.0
0.80	8.89	-5.92	21.79	0.74	15.95
0.90	9.68	-6.45	21.76	0.89	15.97
1.00	10.12	-6.58	21.32	0.23	15.32
		M 3			
0.20	4.49	-7.84	-7.22	-8.61	-0.95
0.40	6.57	-8.15	-6.21	-8.26	-1.98
0.60	7.01	-8.94	-5.60	-8.53	-2.56
0.80	8.02	-10.14	-4.78	-9.34	-3.17
0.90	8.79	-10.72	-4.19	-10.4	-3.25
1.00	9.35	-10.17	-4.56	-9.37	-3.37
		M 4			
0.20	2.68	-1.05	-10.27	3.85	7.47
0.40	3.62	-1.35	-10.96	3.86	7.93
0.60	4.52	-2.08	-11.46	3.43	7.95
0.80	5.56	-3.45	-11.24	1.06	6.19
0.90	6.51	-3.13	-11.29	1.38	6.43
1.00	8.93	-3.80	-10.64	0.04	5.08
		M 5			
0.20	1.22	-8.55	-14.02	-9.51	5.91
0.40	1.75	-9.78	-14.36	-10.3	6.37
0.60	1.98	-9.96	-15.82	-10.9	7.92
0.80	2.53	-9.84	-15.32	-10.6	7.36
0.90	3.48	-9.89	-14.79	-10.3	6.78
1.00	3.63	-10.3	-14.93	-10.9	7.05
		M 6			
0.20	3.26	5.12	-14.55	10.59	15.4
0.40	5.53	4.97	-15.69	10.86	16.32
0.60	5.46	5.27	-15.93	12.13	17.45
0.80	6.78	3.74	-16.35	10.84	16.73
0.90	7.71	5.17	-15.86	12.70	17.87
1.00	7.50	5.45	-15.22	13.17	17.87

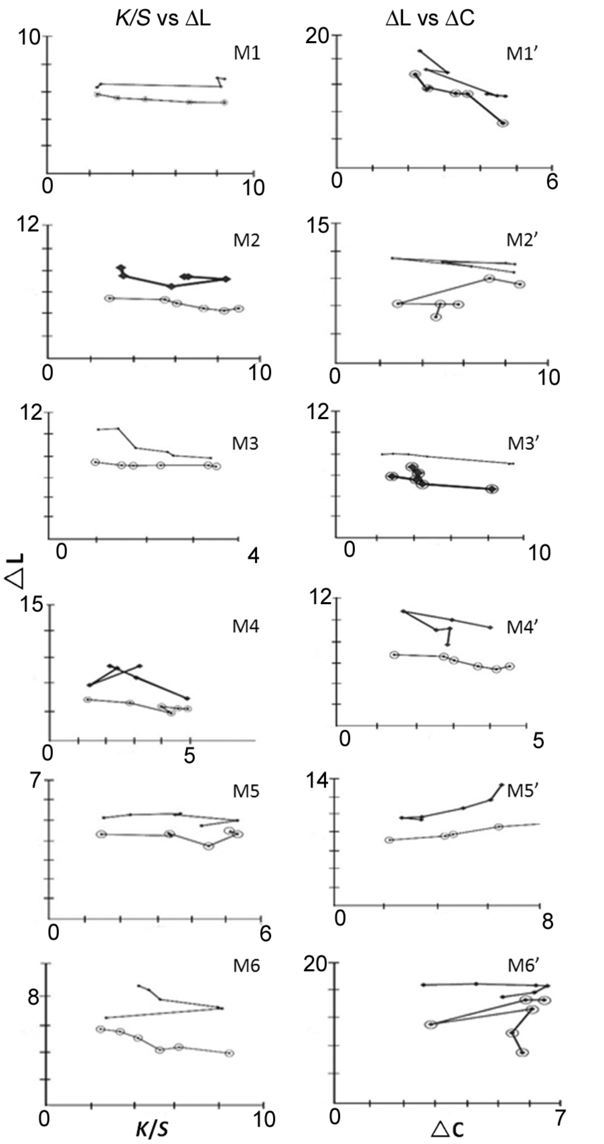

Fig. 1 — Plots showing *K/S vs* ΔL (M1-M6) and ΔL *vs* ΔC (M1' - M6')

may be due to the facts that Direct Red 12B and Direct Green YG are complementary colours of different hues. Moreover, with the increase in dyeing time and temperature (Set I), the change of hue or chroma (ΔC) is much more predominant in Set I than in Set II under the said conditions of dyeing for the above-said reason. Therefore, overall compatibility rating is fair to average.

For determining RCR by the newer method, the CDI and $CDI_{max} - CDI_{min}$ have been calculated and tabulated in Table 5. The binary mixture of direct dyes M1 exhibits RCR grade 2-3 (fair) . Thus, for M1, the compatibility results of both the conventional methods obtained by plots of *K/S vs ΔL*, and the newer RCR system are in well agreement. However, the compatibility results obtained from the observed plots of ΔC vs ΔL do not match well with the observed RCR results. .

For equal proportion (50:50) of dyes used in a binary mixture of M2 (Direct Red 12B + Direct Yellow 5GL), *K/S vs ΔL* curves in Set I and Set II are observed in plots (M2 & M2') (Fig. 1) .The colour build up is moderate to high from the beginning of the dyeing cycle, showing a varying but closer run in similar path (almost parallel but distinct gap in-between throughout the time of dyeing). This variation is assumed to be due to both the differences in initial energy level as well as differences in molecular weights of these two dyes used in M2 (Direct Red 12B + Direct Yellow 5GL). However, as both the dyes hold nearer colour component, both the Set I and Set II curves in plot (M2), with the increase in colour build up and darkness, go a bit parallel with differential phase and hence show a moderate degree of compatibility, while for plot (M2') the two curves for Set-I and Set-II are represented by almost a similar pattern with minor deviations, indicating a moderate

Table 5 — Colour difference index and fastness results for dyed jute fabrics using binary pairs of selective direct dyes

Dye	CDI			$CDI_{max} - CDI_{min}$	RCR	Compatibility grade	Wash fastness		Light fastness	Rub fastness	
	75:25[a]	50:50[a]	25:75[a]				LOD	ST	None	Dry	Wet
M1	0.131	0.589	0.039	0.550	2-3	Fair	3	2-3	3	3-4	2
M2	0.149	0.089	0.036	0.113	4	Good	3-4	4-5	3	4-5	2-3
M3	0.037	0.408	0.056	0.364	3	Average	3	3	3	3-4	2-3
M4	0.033	0.018	0.005	0.028	5	Excellent	4	4	3	4-5	3
M5	0.064	0.054	0.056	0.010	5	Excellent	4	4-5	3	4-5	3
M6	0.071	0.135	0.341	0.270	3-4	Moderate	3-4	3-4	3	4-5	3

[a]Proportion of binary pair of dyes.

to good degree of compatibility. This moderate to good degree of compatibility shown in plot (M2') for Set I and Set II may be due to the combined effects of variation in temperatures, time and dye concentrations on colour build up and increase in darkness at a similar rate in both Set I and Set II with or without minor deviations. Moreover, the linear conjugated structural part of Direct Red 12B facilitates easy dye diffusion and better covering of the compound shade for uniform rate of colour build up; keeping the colour build up rate unaltered. In the new relative compatibility rating (RCR) system, this binary mixture (M2) of dyes exhibits grade 4 (i.e good) relative compatibility rating (Table 5). Thus, this newer RCR method is showing results very much close to the results obtained by both K/S *vs* ΔL plots as well as ΔC *vs* ΔL plots for conventional test of dyes compatibility . This newer method, thus, being much easier practical method to test compatibility between two dyes in a selective pair, is found applicable for different types of natural dyes of varying chemical constitution and structure.

For mixture M3 (plot M3, Fig. 1), the two curves in each case for Set-I and Set-II have a wide and varied gap and thus do not show a systematic build up of colour between two Sets (I & II) . Plot (M3) thus shows that colour strength or depth of shade (K/S) and increase in lightness /darkness (ΔL) does not match for the two curves of Set-I and Set-II though they start running parallel at the beginning. Plot (M3') shows much similar pattern of curves; however have a big phase difference between the two sets. Thus, this binary mixture of dyes (M3) is averagely compatible. Interestingly, the relatively newer method of RCR system also shows that binary mixture of dyes (M3) has average relative compatibility rating as 2 (Table 5). This further proves the efficacy at this newer RCR method of test of compatibility of dyes, applicable for these natural dyes.

In case of mixture M4[plot (M4) Fig. 1], the two curves for Set-I and Set-II run in the same pattern with a phase difference ,although they match in shape, showing similar rate of colour build up for both the sets. The curves come relatively closer as time-temperature profile increases. Moreover, the plot (M4') of ΔC *vs* ΔL for the same mixture of dyes (M4), the two curves for Set-I and Set-II run almost in similar pattern maintaining a reasonable gap between them due to phase difference. There is similar build up of colour with good degree of similarity in lightness or darkness (ΔL) between Set I and Set II, perhaps due to similar dye character with differences in greenish tonal effect of the colour component of Direct Green YG. This may perhaps affect the brighter yellow tone of Direct Yellow 5GL in the Set II by use of increased dye concentration during the whole dyeing cycle .Thus, the plots (M4 & M4') for Set I and Set II indicate good compatibility between the dyes in this particular binary mixture of direct dyes. As per relatively newer RCR method of compatibility test of dyes, M4 mixture exhibits excellent rating, showing a relative compatibility rating of 5 (Table 5). Thus, the results of compatibility test by newer system is more precise and in tune with the results of compatibility test by conventional method as understood by both the plots ΔC vs ΔL (M4**'**) and of K/S vs ΔL (M4) (Fig. 1).

In case of mixture M5 (Direct Green YG + Direct Turquish Blue 2R), the two curves for Set-I and Set-II though show a closer run in similar path at almost all concentrations, they also show some variation in the path at the end showing distance between the two, indicating good degree of compatibility in conventional method. In case of plot (M5**'**) of ΔC vs ΔL, for the same binary mixture of dyes, the two curves for Set-I and Set-II show almost parallel path, showing very low gap initially and at the end tending to differ one another, thus indicating a good to excellent degree of compatibility. In case of plot (M5**'**) , the decrease or increase in hue (ΔH) or chroma values (represented by ΔC) and darkness of the shade (represented by ΔL) between the two Sets also show a similar pattern , indicating either relative increase/decrease of ΔL values with respect to K/S or ΔC in both the set. Thus ,along with the increase in dye concentration as well as with the progress in dyeing time almost up to the end of dyeing cycle, both the set of curves for M5**'** dye mixture run in similar fashion and indicate a good compatibility between these two dyes (M5). In case of K/S *vs* ΔL plot (M5), colour strength or depth of shade (K/S value) and corresponding darkness and lightness of the shade build up (ΔL) are very much similar in both Set-I and Set-II with minor deviation probably due to their differences in molecular weights, and differences in predominating hues between them. However, at higher concentration of dyes and higher temperature of dyeing, these initial differences are reduced and follow a similar pattern in both the set due to higher mobility of the dyes at higher temperature and concentration. Moreover, compatibility testing by the newer RCR method shows that this particular binary mixture (M5) has excellent compatibility (RCR 5). Thus, the results of compatibility test by both the methods are much in tune.

In case of mixture M6 (Direct Yellow 5GL + Direct Turquish Blue 2R), for both the plots (**M6**) and (M6**'**) the two sets of curves maintain a gap at the different stage of dyeing and meet each other at the one end. However, the curves run differently and thus do show systematic build up of colour either with increased concentration of dyes (Set II) or with increased dyeing time- temperature profile (Set I). Plot (M6) thus shows that colour strength or depth of shade (K/S) and increase in lightness /darkness (ΔL) mismatch to some extent for the two curves at the time when complete exhaustion is achieved (dyeing equilibrium point). This may be due to differences in chemical constitution and molecular weight of both the dyes. Plot (M6**'**) shows that the increase in hue and chroma (ΔC) values and increase in lightness /darkness (ΔL) do not match well at any point of dyeing after start and both the curves tend to differ at the later part of dyeing cycle, when the full exhaustion is achieved. Thus, compatibility of this binary mixture (M6) may be considered as moderate to fair as evaluated by this conventional method of test of compatibility. However, the newer RCR method shows that this combination (M6) is compatible with moderate compatibility rating as 3-4 (Table 5). This may due to the fact that they possess some inevitable difference in molecular weight as well as chemical constitution.

It is very interesting to observe overall colour fastness results of compound shades (Table 5) and to find out relation between overall fastness properties and compatibility rating. It is seen that the combinations like M2, M4 and M5 show good compatibility rating and exhibit better overall fastness properties , whereas combinations like M1, M3 and M6 show average or moderate compatibility rating and demonstrate inferior fastness properties as compared to other combinations.

4 Conclusion

4.1 In conventional method of compatibility test, the combinations M1 (Direct Red 12B + Direct Green YG) and M5 (Direct Green YG + Direct Turquish Blue 2R) combinations show better compatibility, while M6 (Direct Yellow 5GL + Direct Turquish Blue 2R) exhibits worst compatibility amongst six combinations (M1 - M6). However, as per newer RCR system of compatibility rating, the order of relative degree of compatibility among the selective binary mixture of dyes is:

M5 > M4 > M2 > M6 > M3 > M1.

This newer method (RCR) is thus found to be simpler and more useful to determine compatibility of binary pairs of selective direct dyes for dyeing jute with binary mixture of direct dyes in various proportions for developing different compound shades on jute fabric. This will help providing the dyer an option for selecting correct and compatible mixture of direct dyes to match a targeted compound shade easily.

4.2 Moreover, binary mixture of direct dyes applied in equal (50:50) proportions, ΔC (change in chroma) values are in the following order for different binary combination , gradually showing more intense colour and higher shade depth in terms of surface colour strength:

M1< M4< M5 < M2 < M6 <M3

4.3 In all cases, the brightness index (BI) values for the selective binary pairs of direct dyes (50:50) are found to increase in the following order:

M4 < M3 < M1 < M2 < M5 < M6

4.4 Also for binary mixture of direct dyes applied in equal (50:50) proportions, ΔH values are found in the following order, indicating the increasing heat of dyeing required for successful dyeing of the selective binary pairs:

M4 < M1 < M2 < M5 < M3 < M6

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