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The effect of humidity, fabric surface geometry and dye type on the colour of cotton fabrics dyed with a select range of anionic dyes

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ABSTRACT

Twill and plain woven bleached cotton fabrics were dyed with a trichromatic set of dyes, C.I. Direct Red 243, C.I. Direct Yellow 106, C.I. Direct Blue 85 individually, with different combinations of these dyes and also with C.I. Reactive Red 24. Dyed fabrics were subsequently conditioned at 0, 25, 45, 65 and 85% relative humidity levels to study the effect of various atmospheric humidity levels, expressed by moisture content, on the colour of substrates. A mass balance was performed and dye uptake by the fabric was normalized based on the mass and size of the substrate to minimise error when determining the effect of moisture and fabric surface geometry on colour. Variations in colour between conditioned samples were assessed using two methods: the ΔE^{*}_{cmc} colour difference equation and the summative Kubelka–Munk function. For the same amount of dye present on fabrics, due to increased effective surface area, twill structures exhibited higher increases in their depth of colour than plain woven substrates for any of the relative humidity levels examined. The findings reveal that the moisture absorbed by the fabric from the environment, and fabric geometry, significantly affect fabrics apparent colour and the effect is more pronounced at higher humidity levels.

1. Introduction

Surface colour measurement and colour matching are of great importance for a wide range of coloured goods and various industries. Care in colour matching has to be exercised to limit overall production costs while satisfying a stringent set of quality measures. The stimuli perceived as colour is the result of a complex interaction of incident light with an object, determined by the optical characteristics of the object, and the human visual system. Such interactions not only depend on the amount of colorant present but are also influenced by other foreign matters such as moisture, and chemical additives present within the medium. In the case of textile materials, the moisture content varies in conjunction with the atmospheric humidity. This in turn leads to variations in the interaction of light with the substrate, which affects its colour.

When light falls on a textile material scattering takes place at the surface. The extent of scattering depends on the surface characteristics of the material. Some of the light, however, diffuses into the medium and is subsequently absorbed or scattered internally [1,2]. Internal scattering of light within textile materials depends on a number of factors which include the concentration of dye/coloured molecules, as well as the presence of foreign constituents such as water or chemical compounds. In addition, the transformation of dyed textile substrates from the dry to wet state results in a reduction in total reflectance due to reduced light scattering [3]. Allen and Goldfinger [4] noted that a decrease in scattering efficiency would provide an opportunity for the increased absorption of light. The earlier research reports indicate that changes in reflectance properties of a fabric, due to the influence of moisture, are physically attributable to changes in its surface properties [5,6].

In practice the moisture content of a substrate may fluctuate due to variations in the relative humidity of the surrounding environment. Such variations influence the interaction of light with the substrate and its colour [7,8]. Inadequate assessment of the role of relative humidity on the colour of substrates can complicate colour communication throughout the supply chain and adversely affect the (re)production of colour. The geometry of the reflecting surface also directly influences the amount of scattered light which in textiles can vary widely. Recently a potential model was reported which included the effect of fabric structure on the predicted colour of textile substrates [9]. The influence of relative humidity (RH) and

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Table 1
Fabric specifications.

Parameters	Fabric Type			
	T1	T2	P1	P2
Warp yarn Count/Ne	24	24	24	24
Weft yarn Count/Ne	20	20	20	20
Ends/inch	74	74	74	74
Picks/inch	72	60	52	40
Warp yarn diameter/mm	0.185	0.185	0.185	0.185
Weft yarn diameter/mm	0.203	0.203	0.203	0.203
End spacing/mm	0.343	0.343	0.343	0.343
Pick spacing/mm	0.353	0.423	0.488	0.635
Warp crimp/%	4.8	4.9	5.1	4.8
Weft crimp/%	7.1	6.9	7.0	6.9
g/m^2	181	153	140	113

surface geometry on the colour of textile substrates, however, needs to be clearly elucidated and this merits further investigation. In this study an attempt was made to determine how the change in colour of the dyed substrate is influenced by variations in the RH.

The amount of dye on fabric can be predicted using the well-known Kubelka–Munk model [10], shown in Equation (1).

$$K/S = \frac{(1-R_\infty)^2}{2R_\infty} \tag{1}$$

where K and S represent absorption and scattering coefficients respectively, and R_∞ denotes reflectance factor from an opaque object. Many approaches to modelling reflectance of opaque and translucent materials have been attempted which include modifications to the Kubleka–Munk model [11–19]. In the case of opaque and light absorbing/scattering materials, single-constant Kubelka–Munk theory is used to describe the complex-subtractive colour mixing in the medium. However, the theory does not take into account the surface scattering phenomena and therefore surface correction must be carried out to improve the accuracy of predictions. While myriad research has been conducted in modelling light reflectance from fabric surfaces over the last 40 years, a very limited amount of work has been reported on the development of a colour prediction model that includes variables such as fabric surface geometry, moisture content as well as dye type and concentration and opportunities for further work exist for researchers in the field. The study reported here examines the effect of humid conditions, determined by the moisture content of the substrate, and fabric geometry on the colour of cotton fabrics dyed with three direct dyes as well as one reactive dye. The results can be used to develop new colour prediction models or improve the performance of the existing systems.

2. Materials

In order to determine the effect of fabric surface characteristics on the colour of the substrate two different woven structures namely plain (P) and twill (T) were examined. In both structures pick density was varied to obtain different levels of effective surface area. Specifications of fabrics used are given in Table 1.

Three commercial grade Direct dyes namely C.I. Direct Red 243 (R), C.I. Direct Yellow 106 (Y), C.I. Direct Blue 85 (B) and one commercial grade Reactive dye namely C.I. Reactive Red 24 (RR) supplied by DyStar, USA as well as laboratory grade sodium chloride (NaCl) and sodium carbonate (Na_2CO_3) were used as received for dyeing. The structures of dyes used for this study are given in Figs. 1–4.

3. Experimental procedure

3.1. Preparation of dyed samples

Direct Dyes were applied individually and as a mixture in different proportions to dye the fabric samples as shown in Table 2. The bleached unmercerised cotton fabric samples were dyed at 0.5, 2.0, 3.5 and 5.0% depth of shade based on mass of fabric (omf) in presence of 5, 10, 15 and 20 gL^{-1} NaCl respectively. The material was introduced to a bath containing the required quantity of dye and 0.1 gL^{-1} Na_2CO_3 at 50 °C. Liquor to goods ratio was set at 40:1. Temperature of the bath was gradually raised to 90 °C and the dyeing was continued for 30 min. Electrolyte additions were made in three steps at 5th, 10th and 15th min during dyeing.

In the case of reactive dye the bleached samples were also dyed at 0.5, 2.0, 3.5 and 5.0% depth of shade based on mass of fabric (omf) in presence of 10, 15, 20 and 25 gL^{-1} NaCl respectively and 20 gL^{-1} Na_2CO_3. The sample was introduced in a bath containing the dye and the temperature was gradually raised to 90 °C and the dyeing was continued for 30 min. Electrolyte additions were made at 5th, 10th and 15th min after the bath reached 90 °C. The required amount of alkali was then added and dyeing was continued for another 30 min to fix the dye.

Immediately after completion of dyeing i.e., before washing, a small piece of fabric was cut from the dyed sample and its reflectance was measured. The remaining portion of dyed samples were washed using cold water for 5 min followed by wash-off with a non-ionic detergent (2 ml L^{-1}) at 30 °C for 5 min and finally the samples were thoroughly washed with running tap water until clear. After drying, the samples were checked for the presence of unfixed surface deposited dye molecules by means of washing. To ensure the repeatability of results triplicate samples under every set of conditions were produced.

3.2. Determination of dye uptake

The absorbance of blank solution containing all auxiliaries except dye (A_1) and the solution after dyeing (A_2) at their respective λ_{max}, shown in Table 2, was measured using a UV–Visible spectrophotometer (Cary 3E, USA). The percentage exhaustion (%E) of dye solution was calculated using Equation (2).

$$\%E = \left[1 - \frac{A_2}{A_1}\right] \times 100 \tag{2}$$

The reflectance value of dyed samples immediately after removal from dyebath and also after washing was measured separately in the range of 400–700 nm at an interval of 10 nm using a DataColor SF600X spectrophotometer. UV light was excluded and specular

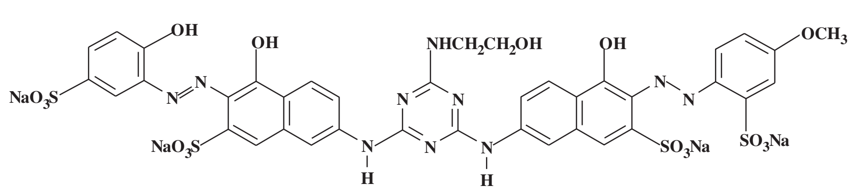

Fig. 1. C.I. Direct Red 243 (R).

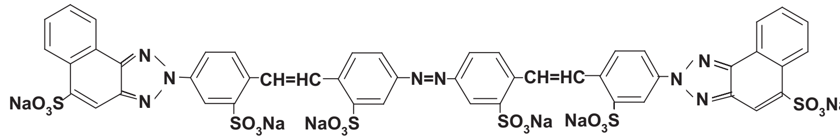

Fig. 2. C.I. Direct Yellow 106 (Y).

light was included. Samples were folded twice and an average of 3 readings using a 30 mm aperture was obtained. The colour strength of dyed samples over the visible region was obtained based on integrated sum of K/S ratios over the visible range according to the summative form of Kubelka–Munk function shown in Equation (3).

$$\sum K/S = \sum_{\lambda=400}^{700} \frac{(1-R_\infty)^2}{2R_\infty} \tag{3}$$

The $\sum K/S$ values of fabrics immediately after removal from dyebath and after washing, denoted K_1 and K_2 respectively, were separately calculated. Finally, the percentage dye uptake (D) of fabrics was calculated using Equation (4) [20,21]. The values are given in Table 3.

$$D = \left[\frac{K_2}{K_1}\right] \times \%E \tag{4}$$

3.3. Determination of colour of conditioned samples

A humidification chamber (PGC, USA) was used to generate various humid conditions and alter the RH in order to condition the dyed substrates. The RH levels examined were 25%, 45%, 65% and 85%. A set of dyed samples were also bone dried to 0% relative humidity level. All dyed samples were conditioned until they reached equilibrium state. Samples were placed inside a desiccator to minimise variations in RH after conditioning and immediately prior to colour measurement. The colour strength of conditioned samples, expressed in $\sum K/S$, was determined according to the method explained in experimental section 3.2. The change in colour of undyed conditioned fabrics at various relative humidity levels was also obtained for all fabrics by measuring the $\sum K/S$ values as shown in Table 4.

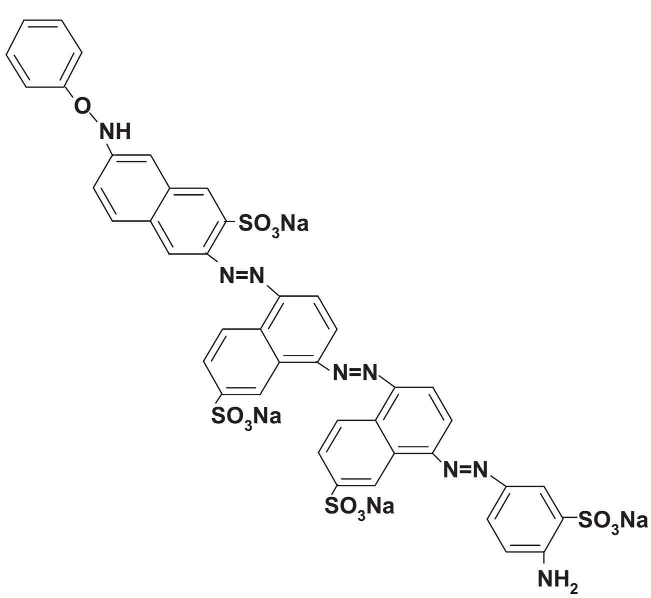

Fig. 3. C.I. Direct Blue 85 (B).

3.4. Calculation of the effective surface area utilised for colour measurement

In order to analyse the effect of RH on colour of fabrics with different surface characteristics, i.e. different weave patterns, a model was developed to calculate the area utilised for colour measurement for all fabrics. The schematic diagram of the model used for this study is given in Fig. 5. In this model the yarn is considered to be cylindrical in shape and it is assumed that only the front side of the fabric comprising roughly 50% of the total area is exposed to incident light during the colour measurement. The increase in dimension of the fibres present in the yarn/fabric exposed to different RH levels, due to swelling, is accommodated within the voids in the yarn. It is also assumed that the spacing between yarns is uniform. The fabric particulars used for the calculation are given in Table 1. The area (A) of one repeat unit for plain (A_P) and 1/3 twill fabrics (A_T), as shown in Fig. 5, was calculated using Equations (5) and (6) respectively.

$$A_P = 2[(\pi R_1 H_{P1})C_{P1} + (\pi R_2 H_{P2})C_{P2}] \tag{5}$$

$$A_T = 4[(\pi R_1 H_{T1})C_{T1} + (\pi R_2 H_{T2})C_{T2}] \tag{6}$$

P and T denote plain and twill structures; C_{P1}, C_{T1} represent warp crimp for plain and twill structures and C_{P2}, C_{T2} denote weft crimp for plain and twill structures respectively. In addition, H_{P1}, H_{P2} and H_{T1}, H_{T2} are calculated using the radius of warp yarn (R_1), weft yarn (R_2), Pick (P_s) and End (E_s) spacing for plain and twill weave respectively as shown in Equations (7)–(10).

$$H_{P1} = 2(P_s - R_2) \tag{7}$$

$$H_{P2} = 2(E_s - R_1) \tag{8}$$

$$H_{T1} = 4P_s - 6R_1 \tag{9}$$

$$H_{T2} = 4E_s - 2R_2 \tag{10}$$

The total number of repeats within the area employed for colour measurement, T, can be calculated using Equation (11).

$$T = \frac{\text{Area of measuring aperture employed}}{\text{Total area of one repeat}} \tag{11}$$

The total area of one repeat is ($l \times b$) where: $l = 2E_s$ for plain, and $l = 4E_s$ for twill structures and; $b = 2P_s$ for plain, $b = 4P_s$ for twill structures.

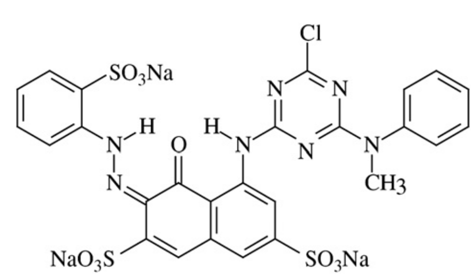

Fig. 4. C.I. Reactive Red 24 (RR).

Table 2
Parts by mass of dyes used for dyeing.

Dye Combinations	C.I. Direct Red 243 (R)	C.I. Direct Yellow 106 (Y)	C.I. Direct Blue 85 (B)	λ_{max}
R	1	0	0	516 nm
Y	0	1	0	415 nm
B	0	0	1	568 nm
RY	1	1	0	506 nm
YB	0	1	1	570 nm
RB	1	0	1	545 nm
RYB	1	1	1	556 nm
C.I. Reactive Red 24 (RR)	–	–	–	553 nm

Thus the effective area used for colour measurement is $A \times T$ where A is calculated for either plain or twill structures using Equations (5) and (6).

4. Results and discussions

4.1. Effect of humidity on colour

Fibres carry moisture in the form of bound and unbound water content. The bound water content in the cotton fibre can be as high as 19% [22]. However, studies pertaining to the effect of bound water on colour measurement of substrates have not been reported. The increase in moisture content within a substrate may effectively change the refractive index at the fibre-air interface to a higher value. Previous researchers have examined the role of wet pick up ranging between 50 to 120% on the colour measurement of wet textile fabrics [3–8,23–27]. Efforts have also been extended to measure the colour of wet substrates after drying the fabrics to a moisture content level of around 20% [24]. In the study reported here, dyed and undyed samples were conditioned at various RH levels in order to obtain different levels of bound water. The bound water content of samples was estimated by assessing the change in mass of conditioned fabrics until no change in mass was noted with increasing the conditioning period. The bound water contents obtained for undyed substrates conditioned at 25%, 45%, 65% and 85% RH levels, determined at equilibrium, were 2.7%, 4.8%, 7.2% and 10.8% respectively. The change in $\sum K/S$ values at various humidity levels, for undyed fabrics, is given in Table 4.

Fig. 6 shows the $\Sigma K/S$ values of the twill fabric, $T1$, dyed to different depths of shade and conditioned at various RH levels. It is shown that the colour strength of the fabrics, for all dye combinations and all depths of shade, increases with an increase in

Table 3
Calculated percentage dye uptake of fabrics examined.

Dye	% omf	Twill		Plain	
		T 1	T 2	P 1	P 2
C.I. Direct Red 243 (R)	0.5	82.7	83.3	81.6	82.1
	2.0	72.7	74.9	79.1	78.0
	3.5	70.3	70.3	72.3	71.4
	5.0	67.3	66.9	70.8	69.1
C.I. Direct Yellow 106 (Y)	0.5	75.5	77.5	80.1	79.5
	2.0	70.3	70.6	70.4	72.3
	3.5	69.3	68.6	67.5	67.7
	5.0	67.3	65.2	64.8	64.9
C.I. Direct Blue 85 (B)	0.5	71.2	74.0	79.3	78.3
	2.0	64.8	63.2	63.1	63.7
	3.5	61.2	60.0	62.3	61.1
	5.0	51.4	55.5	56.9	56.4
RY	0.5	78.8	80.5	81.3	81.0
	2.0	71.7	72.9	74.8	76.5
	3.5	70.9	69.1	68.8	69.8
	5.0	66.3	65.6	67.1	66.3
YB	0.5	72.7	76.4	80.1	79.1
	2.0	68.4	66.1	68.3	64.8
	3.5	62.8	64.5	63.7	63.1
	5.0	61.5	62.1	63.6	63.9
RB	0.5	74.1	77.5	81.3	79.2
	2.0	66.5	68.2	67.5	66.9
	3.5	64.5	64.8	66.1	65.9
	5.0	58.1	57.1	59.3	59.2
RYB	0.5	77.8	76.8	80.8	81.0
	2.0	68.6	70.3	73.4	70.5
	3.5	64.2	65.9	66.2	65.8
	5.0	59.5	60.5	61.2	62.7
C.I. Reactive Red 24 (RR)	0.5	89.3	88.9	87.6	88.2
	2.0	82.2	80.9	81.2	81.2
	3.5	75.3	74.2	75.2	76.3
	5.0	71.2	69.8	71.2	70.2

Table 4
Effect of RH % on $\Sigma K/S$ value of bleached fabrics with different surface characteristics.

Fabric type	$\Sigma K/S$ Value				
	RH %				
	0%	25%	45%	65%	85%
T1	0.37	0.41	0.46	0.60	0.82
T2	0.29	0.34	0.39	0.57	0.81
P1	0.39	0.45	0.51	0.64	0.83
P2	0.56	0.63	0.75	0.88	1.02

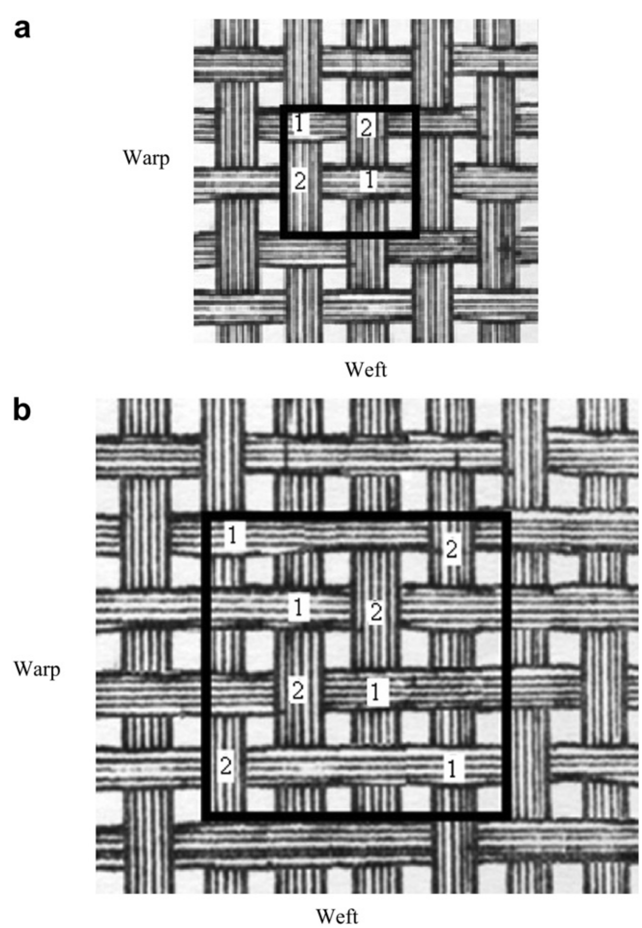

Fig. 5. Repeating unit for (a) plain and (b) twill fabrics.

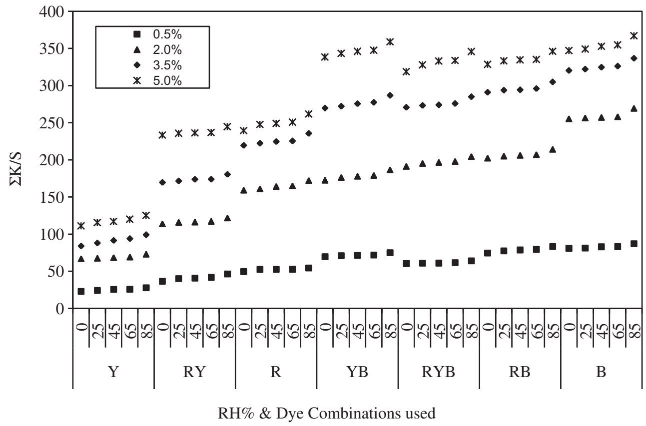

Fig. 6. Effect of humidity on the depth of colour of Twill Fabric, T1.

relative humidity. This is due to the decrease in scattering of light at a boundary across which a small refractive index difference between fibre and its embedded medium exists [22]. The decrease in scattering efficiency will provide more opportunity for absorption of light in the sample and thus contribute to an increase in its colour strength [4]. The increase in colour strength is more pronounced for dark shades compared to the light shades when bound water content increases. The same trend in results was obtained for the *T*1 fabric dyed with C.I. Reactive Red 24 for all shades, as shown in Fig. 7. The Σ*K*/*S* value and depth of colour of other fabrics examined, i.e. *T*2, *P*1 and *P*2, also follow the same trend.

The practical significance of the change in colour with respect to RH was analysed by calculating the colour difference (ΔE^{*}_{cmc}) of the dyed fabrics conditioned at various RH levels compared to a standard substrate conditioned at 0% RH. A summary of results for T1 fabric is given in Table 5. It is shown that colour differences between the standard and fabrics conditioned at 25% R.H. are not appreciable for any of the dye combinations with the exception of the samples dyed with C.I. Direct Yellow 106 which is reported as

Table 5
Effect of change in humidity on ΔE^{*}_{cmc} among T1 Twill fabric samples based on bone dry samples as standard.

Dye	% omf	ΔE^{*}_{cmc} based on change in %RH Levels			
		0 to 25	0 to 45	0 to 65	0 to 85
C.I. Direct Red 243 (R)	0.5	0.6	1.1	1.9	2.5
	2.0	0.7	1.2	1.9	2.9
	3.5	0.6	1.2	2.0	3.1
	5.0	0.7	1.3	2.0	3.2
C.I. Direct Yellow 106 (Y)	0.5	1.1	2.2	3.6	5.1
	2.0	1.2	2.3	4.1	5.0
	3.5	1.2	2.3	4.1	5.3
	5.0	1.3	2.4	4.2	5.2
C.I. Direct Blue 85 (B)	0.5	0.4	0.8	1.6	2.1
	2.0	0.4	0.9	1.5	2.2
	3.5	0.5	1.0	1.6	2.2
	5.0	0.5	1.1	1.6	2.7
RY	0.5	0.9	1.6	2.4	3.9
	2.0	1.0	1.9	2.8	4.1
	3.5	1.1	1.8	3.4	4.2
	5.0	1.2	2.0	3.3	4.2
YB	0.5	0.6	1.1	2.1	2.6
	2.0	0.7	1.4	2.2	2.9
	3.5	0.8	1.5	2.3	3.1
	5.0	1.0	1.6	2.3	3.5
RB	0.5	0.4	0.9	1.4	2.1
	2.0	0.4	1.0	1.5	2.2
	3.5	0.6	1.1	1.7	2.6
	5.0	0.6	1.1	2.0	2.6
RYB	0.5	0.7	1.2	2.0	2.6
	2.0	0.8	1.3	2.1	3.0
	3.5	0.9	1.9	2.2	3.4
	5.0	1.1	1.9	2.2	3.9
C.I. Reactive Red 24 (RR)	0.5	0.5	1.0	1.5	2.1
	2.0	0.6	1.1	1.4	2.2
	3.5	0.6	1.0	1.8	2.3
	5.0	0.8	1.0	1.6	2.7

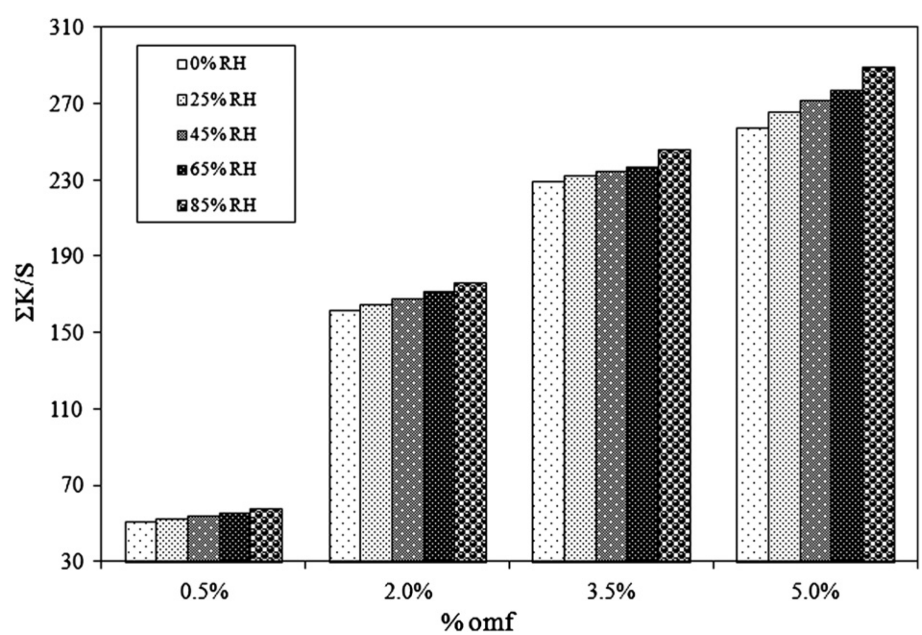

Fig. 7. Effect of humidity on the depth of colour of Twill Fabric, T1dyed with C.I Reactive Red 24 (RR).

Table 6
Effect of change in humidity on ΔE^*_{cmc} among T1 Twill fabric samples based on standard samples conditioned at 65% RH.

Dye	% omf	ΔE^*_{cmc} based on change in %RH Levels			
		65 to 0	65 to 25	65 to 45	65 to 85
C.I. Direct Red 243 (R)	0.5	2.0	1.1	0.6	0.9
	2.0	2.0	1.2	0.6	1.1
	3.5	2.1	1.2	0.8	1.2
	5.0	2.1	1.2	0.9	1.2
C.I. Direct Yellow 106 (Y)	0.5	3.6	2.1	1.1	1.6
	2.0	4.0	2.4	1.2	2.2
	3.5	4.1	2.9	1.3	2.3
	5.0	4.1	2.9	1.3	2.5
C.I. Direct Blue 85 (B)	0.5	1.4	0.8	0.3	0.7
	2.0	1.5	0.9	0.4	0.8
	3.5	1.7	1.0	0.4	0.8
	5.0	1.7	1.1	0.5	1.1
RY	0.5	2.2	1.7	0.8	1.5
	2.0	2.6	1.8	0.9	1.5
	3.5	3.1	1.9	0.9	1.6
	5.0	3.2	1.7	1.2	1.6
YB	0.5	2.0	1.1	0.6	0.7
	2.0	2.2	1.2	0.7	1.1
	3.5	2.2	1.3	0.7	1.2
	5.0	2.3	1.3	0.9	1.2
RB	0.5	1.6	0.7	0.4	0.9
	2.0	1.6	0.7	0.5	0.7
	3.5	1.9	1.0	0.5	0.7
	5.0	2.0	1.2	0.6	1.0
RYB	0.5	2.1	1.3	0.6	0.6
	2.0	2.2	1.3	0.8	1.1
	3.5	2.2	1.5	0.9	1.2
	5.0	2.3	1.6	0.9	1.5
C.I. Reactive Red 24 (RR)	0.5	1.6	0.8	0.6	0.8
	2.0	1.5	0.9	0.8	0.8
	3.5	1.4	1.1	0.8	1.1
	5.0	1.5	1.2	0.9	1.1

a dye with a high luminosity factor [28]. In comparison to all the dyes used C.I. Direct Yellow 106 has the largest number of sulphonated groups. In fact all dyed fabrics with dyes containing a larger number of sulphonated groups show larger increases in colour when compared to those dyed with a fewer number of sulphonated groups. It is not yet clear though whether a direct correlation could be established between the number of sulphonated groups on a dye molecule and the bound water content of dyed substrates and this warrants further investigation.

Results in Table 5 also show that colour differences, expressed in ΔE^*_{cmc}, between the standard and samples conditioned at RH $\geq$ 45%, for the majority of dye combinations, were greater than 1.5. Samples dyed with C.I. Direct Blue 85, or combinations of R and B and C.I. Reactive Red 24 at 45% RH, however, exhibit slightly lower ΔE^*_{cmc} values compared to fabrics dyed with other dyes, although the values are still greater than one. Dyed fabrics which have low reflectance values at certain depths of shade generally exhibit slight changes in measured depth of shade due to variations in moisture content [24]. Differences were also obtained among samples conditioned at 65% RH and those under other RH levels in order to assess the significance of moisture content in relation to standard conditions. Results are shown in Table 6. It can be seen that colour differences between the fabrics conditioned at 65% and 45% R.H. are not appreciable for any of the dye combinations with the exception of the samples dyed with Yellow 106 as well as a combination of R and Y. However, results also show that colour differences between the samples conditioned at 65% and 0%, 25% and 85% RH, for the majority of dye combinations, were greater than 1.5. Figs. 8 and 9 show the L^* and C^* values of fabrics decrease and increase

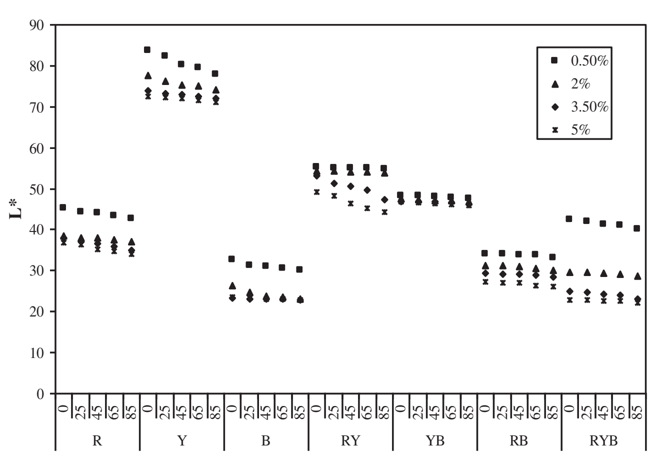

Fig. 8. Effect of humidity on the Lightness value of Twill Fabric, T1.

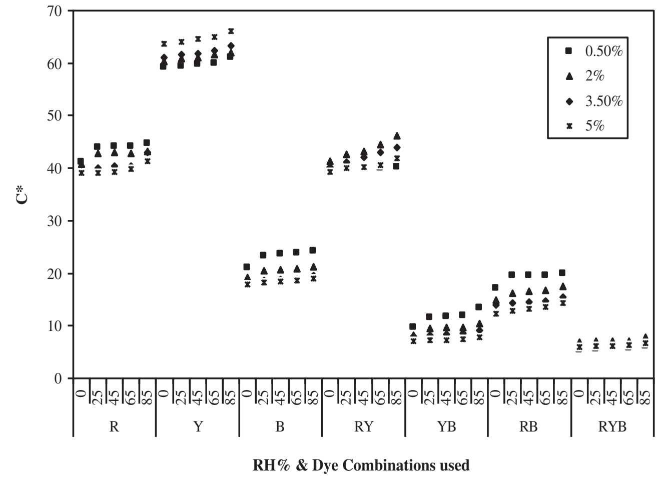

Fig. 9. Effect of humidity on the Chroma of Twill Fabric, T1.

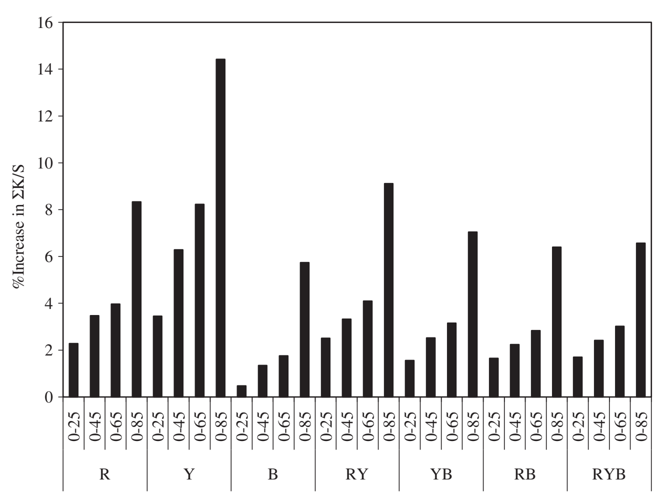

Fig. 10. Effect of increased humidity on the depth of colour of Twill fabric, T1 containing 2 g dye per 100 g of fabric.

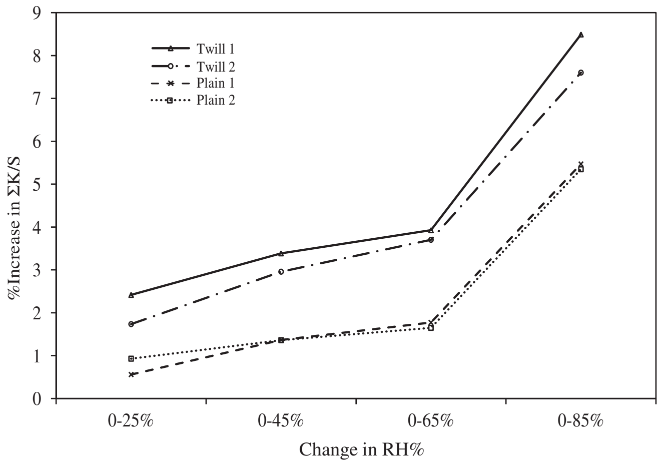

Fig. 11. Effect of increased humidity on the depth of colour of various fabrics containing a normalized amount (3 g/m^2) of C.I. Direct Red 243.

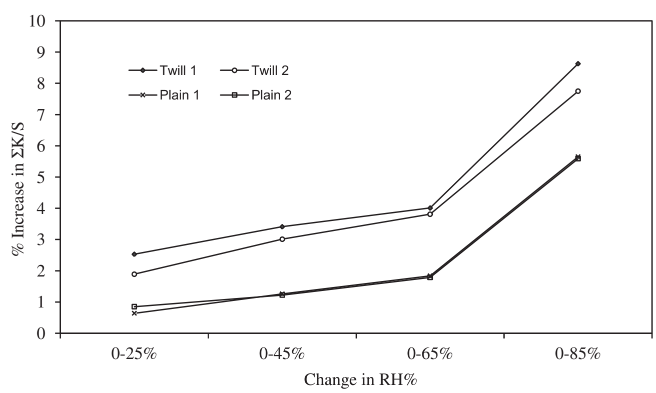

Fig. 12. Effect of increased humidity on the depth of colour of various fabrics containing a normalized amount (3 g/m^2) of C.I. Reactive Red 24.

respectively as the RH increases for all dye combinations and depths of shade as the RH increases.

Although colour difference tolerances are specific to industries, in the majority of cases where critical evaluations of colour are important, ΔE^*_{cmc} is confined to <1. It is shown that variations in the moisture content of the dyed fabrics can cause a significant shift in the measurement of colour and therefore reported values should either indicate the moisture content of the substrate or be based on standardized conditions that include the standard relative humidity level.

4.2. Role of humidity on the colour of fabrics with identical dye uptake

In order to analyse the effect of the increase in RH on the colour of the fabrics dyed with various combinations of dyes the $\sum K/S$ values were calculated by performing a mass balance based on 2 g of dye in 100 g of fabric. For that purpose a best fit line was drawn between the $\sum K/S$ values of the dyed samples and their dye content and $\sum K/S$ values were thus calculated based on 2 g of dye per 100 g of fabric. The percentage increase in $\sum K/S$ value, when the RH is increased from 0% to different levels, for all combinations of dyes for fabric T1 is demonstrated in Fig. 10. The figure shows that the increase in $\sum K/S$ value is gradual up to 65% RH and then increases drastically. At higher RH levels moisture migrates towards the surface of the fibre due to capillary condensation, which in turn results in reduced scattering of light and increased depth of colour. The moisture migration in cotton fibre at high RH levels was also reported by Marsh [29]. Other fabrics examined were also found to follow the reported trend.

Table 7
Effective exposed area of fabrics utilised for colour measurement in spectrophotometer.

Fabric	Total exposed area/mm^2
T1	658.84
T2	622.05
P1	591.36
P2	555.88

The effect of fabric structure on change in colour of dyed samples exposed to different RH levels was also analysed by determining the $\sum K/S$ value for normalized dye uptake on 3 g/m^2 of fabric. This value was used to project dye uptake and $\sum K/S$ for 1 m^2 of fabric. Results are shown in Figs. 11 and 12 for the fabrics dyed with direct and reactive dyes respectively. The increase in $\sum K/S$ value with respect to RH for all fabrics and based on the use of C.I Direct Red 243 was between 28% and 76.9% while for C.I. Reactive Red 24 it was between 26% and 78.2%. The increase in $\sum K/S$ was higher for twill fabrics than that for the plain fabrics. This is due to the higher *effective* surface area of the twill fabrics exposed to incident light during colour measurement. The effective area utilised for colour measurement of fabrics examined is given in Table 7. Clearly the geometry of fabrics in conjunction with variations in relative humidity influences the measurement of colour and thus care should be exercised with respect to both parameters while measuring and reporting the colour of dyed substrates.

5. Conclusions

It was shown here that not only wetting, but also moisture absorbed by dyed fabrics from the humid atmosphere has an appreciable effect on the measured depth of colour. The difference, expressed by both $\sum K/S$ and ΔE^*_{cmc}, between conditioned samples at 0% RH and those at other humidity levels is larger when the RH is raised to above 45%. The study also reveals that the difference in colour due to moisture absorption is gradual up to 65% RH and drastic above this level. With respect to standard conditions the difference between samples at 65% RH and those at other humidity levels is also highly pronounced when the RH% is increased.

Although the amount of dye on fabrics was normalized for various woven structures examined, it was shown that fabric geometry affects the measured depth of shade. Indeed the two twill fabrics studied exhibited higher increases in their depth of colour than plain woven substrates for any of the relative humidity levels examined. Therefore, due importance should be given to the relative humidity of the atmosphere while measuring the colour of dyed hydrophilic substrates. Finally, additional studies are required to examine whether the number of sulphonated groups on dyes employed for the coloration of the substrate result in variations in colour change due to variations in the relative humidity.

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