ASSESSMENT OF COLOUR PROPERTIES OF REACTIVE DYED COTTON FABRICS UNDER DIFFERENT ILLUMINANTS BY USING CIELAB AND HUNTER SYSTEMS

REAKTİF BOYARMADDELERLE BOYANMIŞ PAMUKLU KUMAŞLARIN RENK ÖZELLİKLERİNİN CIELAB VE HUNTER SİSTEMLERİ KULLANILARAK FARKLI AYDINLATICILAR ALTINDA DEĞERLENDİRİLMESİ

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ABSTRACT

This paper focuses on the assessment of colour properties of reactive dyed cotton fabrics at four different shades under the illuminants of D65, A and F11 by using CIELAB and Hunter systems in computing. The fabric samples were dyed with four reactive dyes (black, yellow, red and navy) at ten different dyeing concentrations (% owf) and the colour coordinates of the dyed samples were measured by a reflectance spectrophotometer. Colour coordinates and colour differences of the resultant dyeings were calculated according to CIELAB and Hunter systems and the results were discussed in accordance with the shades obtained. The colour results which were calculated according to CIELAB and Hunter systems were found sensitive to the shade variations. Black, yellow, red, and navy shades were found sensitive to illuminant choice when the colour coordinates were calculated according to the Hunter system. The highest differences between the calculated colour coordinates were obtained at yellow shade.

Key Words: CIELAB, Hunter, Colour coordinates, Cotton, Reactive dyeing.

ÖZET

Bu çalışmada reaktif boyarmaddeler ile boyanmış pamuklu kumaşların renk özellikleri D65, A ve F11 aydınlatıcıları altında CIELAB ve Hunter sistemleri ile hesaplanarak değerlendirilmiştir. Kumaş numuneleri dört farklı reaktif boyarmadde (siyah, sarı, kırmızı ve mavi) ile on ayrı boyama konsantrasyonunda boyanmış ve boyanmış numunelerin renk koordinatları bir reflektans spektrofotometresi ile ölçülmüştür. Sonuç boyamaların renk koordinatları ve renk farklılıkları CIELAB ve Hunter sistemlerine göre hesaplanmış ve elde edilen sonuçlar boyamaların renkleri ile ilişkili olarak tartışılmıştır. CIELAB ve Hunter sistemlerine göre hesaplanan renk sonuçlarının elde edilen renklerin farklılıklarına göre hassas olduğu bulunmuştur. Renk koordinatları Hunter sistemine göre hesaplandığında siyah, sarı, kırmızı ve mavi renklerin aydınlatıcı seçimine hassas olduğu görülmüştür. Hesaplanan en yüksek renk koordinatları farkı sarı renkte elde edilmiştir.

Anahtar Kelimeler: CIELAB, Hunter, Renk koordinatları, Pamuk, Reaktif boyama.

1. INTRODUCTION

Colour is the result of the physical modification of light by colorants as detected by the human eye (called a response process) and interpreted in the brain (called a perceptual process, which induces psychology) (1). The existence of colour requires a source of light, an object, and an observer to see the light. The reflectance of light by an opaque object as a function of wavelength describes the colour of the object (2). The colour of a textile material is often one of its most important features. Colour is a subjective (individual/personal) perception and in a colour-using industrial environment, objectivity is of great importance (3, 4).

Numerous colour appearance models have emerged over the years, along with various sets of colour measurement terms. Although the CIELAB system is widely accepted in the field of textiles, some practitioners use other models. CIELAB and Hunter are based on established theory and are well documented (1,5,6). However, the practical differences between the vari-

ous systems can be confusing to a dyer (5).

The CIE (Commission Internationale de l'Eclairage) colour order system is numerical. CIE recommended CIEL*a*b* colour space (also known as CIELAB system) and colour-difference formula in 1976 (7). CIELAB colour space was developed from attempts to transform the X, Y, Z system (tristimulus values) to a visually uniform colour-system through experiments which correlate trisitimulus values with visual perceptions of colour (2).

CIELAB colour space is an opponent-type colour space. The a* axis represents the red-green opponent pair, the b* axis represents the yellow-blue opponent pair, and the L* axis represents the white-black opponent pair. The a* and b* coordinates define a chromaticity plane. The third axis, L*, is perpendicular to the chromaticity plane and runs from 0 for black to 100 for white (2). The L*, a* and b* colour coordinates are the numerical results obtained according to established formulations and they represent the location of a colour (shade) in the CIELAB colour space (8). Hunter system (Hunter L, a, b scale) is a uniform colour scale devised by Hunter in 1958 for use in colour difference meter, e.g. a reflectance spectrophotometer. It is based on Hering's opponent-colour theory of vision and it uses the CIELAB colour space for the presentation of colour coordinates and colour differences which were calculated according to the Hunter Lab scale.

Colour difference is the magnitude and character of the difference between two object colours under specified conditions. In the textile industry, effective colour control and communication between designer, dyer, and retailer are critical to obtaining high product quality and cost efficiency. Commonly, colour control is achieved both via visual assessment and colour measurement. One of the fundamental attributes that defines visual colour perception is the spectral power distribution (SPD) (or Spectral Energy Distribution – SED) of the light source used to observe and specify the object colour (9). In textiles, lighting and illuminating conditions must be carefully specified in order to assess the colour of an object in case of change in light sources (the lamp) and illuminating.

It is important to differentiate between a light source and an illuminant. A light source is a physical emitter of light whilst essentially an illuminant is a table of relative energies (SPD) at each wavelength in the visible or near u.v. spectra. Consequently it has a theoretical output which may not always be realisable by an actual source (7).

CIE advised the usage of different illuminants which were derived basically from the spectral energies of different sources of light through the years. CIE illuminant D65, with an approximate correlated colour temperature (CCT) of 6500 K (Kelvin),

contains a spectral energy distribution (SED) which is a good approximation of average daylight. D65 is the primary illuminant of colour measurement applications. CIE illuminant A, with an approximate correlated colour temperature of 2856 K, was devised as a means of defining light typical to that from a gas-filled tungsten filament lamp. The amount of energy emitted at the longer wavelengths is far greater than that emitted at the shorter wavelengths. CIE illuminant F11 (fluorescent illuminant), with an approximate correlated colour temperature of 4000 K, is commercially known as TL84 and contains a spectral energy distribution which is a good approximation of store lighting. Fluorescent illuminants have very high SED(s) at narrow bandwidths (7).

When illuminants having different spectral power distributions are used with object colours, two different effects can take place. First, the tristimulus values of the colours can change (illuminant colorimetric shift); second, the observer's state of chromatic adaptation can change (adaptic colour shift). If a single object colour is viewed first under one illuminant, and then under an illuminant having a different chromaticity, its appearance in the second illuminant will be combined result of both the illuminant colour shift and the adaptive colour shift taking place (7, 10). Under different illuminating conditions, because of the possible changes in the calculated tristimulus values, the colour coordinates may be computed into different results when different colour systems (CIELAB and Hunter) are used.

Epps et al. investigated the effects of the changes of liquor-to-goods ratios on colour coordinates and compared the resultant colours according to different colour systems (5). Hinks et al. focused on the lighting variability in stores and its effect on the resultant colour differences according to changes in illumination (9). Luo and Hunt investigated chromatic adaptation transform in an adopted colour appearance model and derived a

colour inconstancy index under different illuminants (10). Kuehni discussed the possibility of using new colour order systems and colour difference calculations which might be alternatives to CIELAB system and its related equations (11).

Reactive dyes are coloured compounds which have suitable groups capable of forming covalent bonds (12). They are the most important dyes in dyeing of cellulosic materials. Their colouring properties on cotton fabrics in accordance with colour measurements were investigated by researchers (13,14).

A common objective in colour technology is to control and reproduce a colour under a set of specified conditions. In this paper, the colour coordinates calculated according to the CIELAB and Hunter systems under different illuminants were compared according to the shades and dyeing concentrations. The aim of this research was to consider the colour properties of reactive dyed cellulosic samples under two sets of specified conditions and to correlate the results in terms of colour coordinates and differences in order to establish the differences between the two systems for the further practical uses. The colour values differentiated from each other in respect to the illuminant chosen, the shades and dyeing concentrations.

2. MATERIALS AND METHOD

The reactive dyeings were performed on cotton plain knitted (single jersey) fabric (148.8 g/m^2) made from Ne30/1 cotton yarns. The fabric was scoured under controlled mill conditions and prepared for dyeing in the laboratory.

Reactive dyes used in the experimental part are given in Table 1.

Dye concentrations (% owf) and the amounts of chemicals used in dyeings are presented in Table 2.

Dyes of different hues were selected to see the results of the two colour systems under increasing dye concentrations at different areas of a*-b* colour

Table 1. Reactive dyes and their properties

Dye	C.I. No.	Explanation	λ_{max}(nm)	Chemical Structure
I	Reactive Red 180	Warm Reactive Dye	550 nm	Vinylsulphone (VS)
II	Reactive Yellow 176	Warm Reactive Dye	430 nm	Vinylsulphone (VS)
III	Reactive Blue 171	Hot Reactive Dye	620 nm	Monochlorotriazine (MCT)
IV	Reactive Black	Warm Reactive Dye	600 nm	Mix Dye

Table 2. Chemicals and their amounts used in the dyeing processes

Dye Concentration (% owf)	Salt (g/l)		Sodium Carbonate (g/l)
	Warm (Dyes I, II, IV)	Hot (Dye III)	
0.1	20	20	10
0.2	20	20	10
0.4	30	20	10
0.8	45	30	15
1.2	60	40	15
1.6	60	40	15
2.0	60	40	15
2.4	80	60	20
3.2	80	60	20
4.0	80	60	20
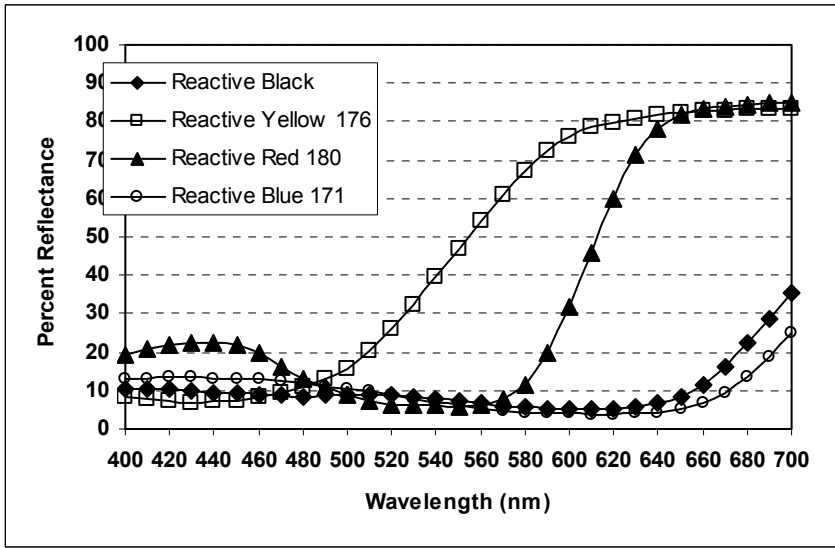
Figure 1. Percent reflectances of the shades (at 1.2% owf)

plane. The black reactive dye was chosen because at high dye concentrations, the reflectance of the black dyed substrates reaches to a minimum value which is close to zero and this enables us to assess the values very near the gray point.

The dyeing of the fabric samples were carried out in a laboratory-type dyeing machine (Roaches) under laboratory conditions. All the chemicals used were in commercial grade.

Dyeing with reactive dyes (Dyes I, II and IV) at warm temperatures began at 40°C. After 10 minutes the temperature was raised to 60°C by 1°C/min. The dyeing continued for 90 minutes at this temperature and then the temperature was decreased to 45 °C and

the fabric samples were taken out from the dyeing machine. Dyeing with reactive dye (Dye III) at hot temperatures began at 60°C. After 15 minutes the temperature was raised to 95°C by 2°C/min. The dyeings continued at this temperature for 20 minutes. Later the temperature was decreased to 82°C and soda was added to the dyebaths. Dyeings continued at 82°C for 90 minutes and then the temperature was decreased to 45°C. The dyed samples were taken out from the dyeing machine. All the dyeings were made under 15:1 liquor-to-goods ratio. All the dye baths contained 1 ml/l anionic wetting agent and 1ml/l sequestering agent. All the chemical additions were made according to the instructions of

the dyestuff manufacturer (Everlight Chem.).

The dyed samples were cold (tap water) and hot (60°C) rinsed. After that, the samples were soaped at 95°C for 30 minutes in the presence of an anionic soaping agent (2 g/L). After soaping, the samples were hot (60°C) and cold (tap water) rinsed and left to dry under laboratory conditions.

Evaluation of the Results of the Dyeing Experiments

The results were obtained according to the colour measurements of the samples with a Macbeth reflectance spectrophotometer (MS 2020+) coupled to a PC and with 10° observer under the illuminants D65, A and F11 at SCI (specular component included mode) between 400-700 nm from which corresponding CIELAB (L*, a*, b*, C*) and Hunter (L, a, b, C) coordinates were calculated. Each fabric sample was folded twice to realize a total of four thickness of fabric. When calculating the colour differences (ΔE) in Figures 18-21, the dyeings made at the lowest concentrations (0.1% owf) were taken as the reference (standard) and the ones made at the higher dye concentration were taken as the samples.

The calculation of the colour differences according to CIELAB and Hunter colour difference equations can be summarized as follows:

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

$$\Delta E_{Hunter} = [(\Delta L_H)^2 + (\Delta a_H)^2 + (\Delta b_H)^2]^{1/2}$$

where;

ΔL^* and ΔL_H: difference between the sample and reference in lightness axis.

Δa^* and Δa_H: difference between the sample and reference in red-green axis.

Δb^* and Δb_H: difference between the sample and reference in yellow-blue axis.

all the differences are calculated as Δ = sample – reference.

3. RESULTS AND DISCUSSIONS

3.1. Percent Reflectances

The percent reflectances according to wavelength were presented in Figure 1. The percent reflectances which were measured at the maximum absorption wavelengths of each dye (600 nm for black, 430 nm for yellow, 550 nm for red, and 620 nm for navy dye) were presented for 1.2 % owf dyeing concentration. The percent reflectances showed the characteristic % reflectance-wavelength presentation of the dyes in visible spectrum (400-700 nm).

3.2. Lightness Coordinates

The lightness coordinates (CIELAB L* and Hunter L) under the three different illuminants were presented in Figures 2-5 for the black, yellow, red and navy dyes respectively. Lightness value is a measure of black-white scale in CIELAB colour space and it is closely related with the dye amount in the fibres. The lightness values decreased gradually as the dyeing concentrations increased under all the illuminants in Figures 2-5.

When the lightness values were considered for the two systems (CIELAB and Hunter), the CIELAB L* values were slightly higher than the Hunter L values except the yellow dye and except the lowest dyeing concentration (0.1% owf) (black, red, and navy dyes).

When the lightness values were considered for the different illuminants (D65, A, and F11), the values were
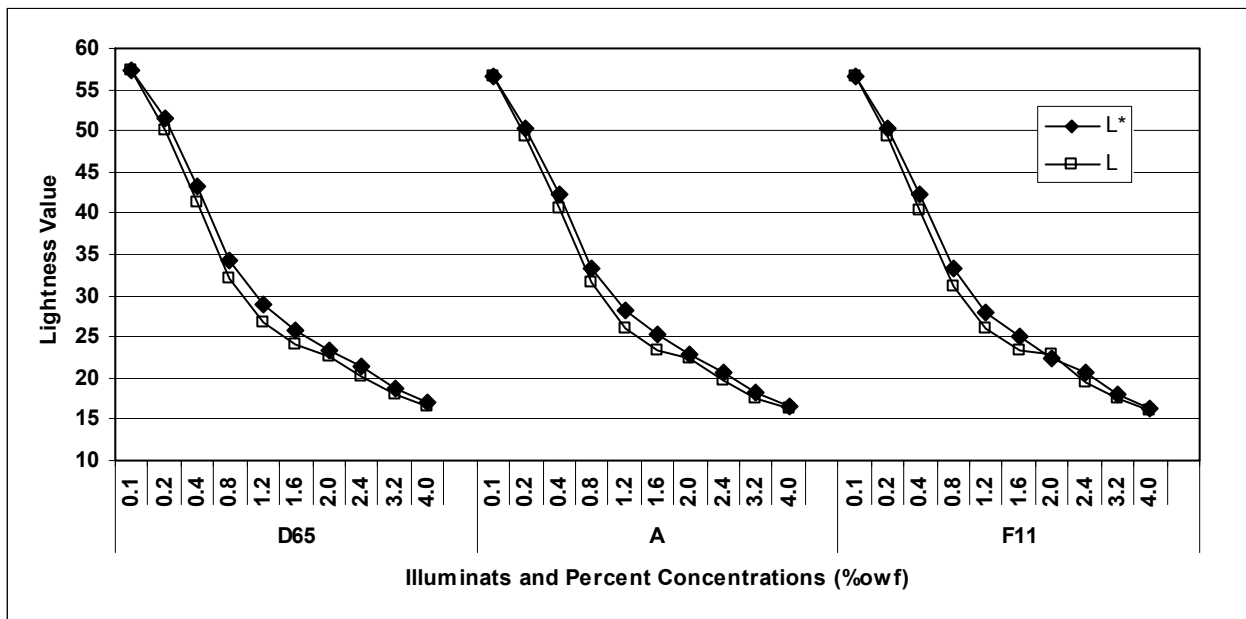
Figure 2. Lightness coordinates of the black dye
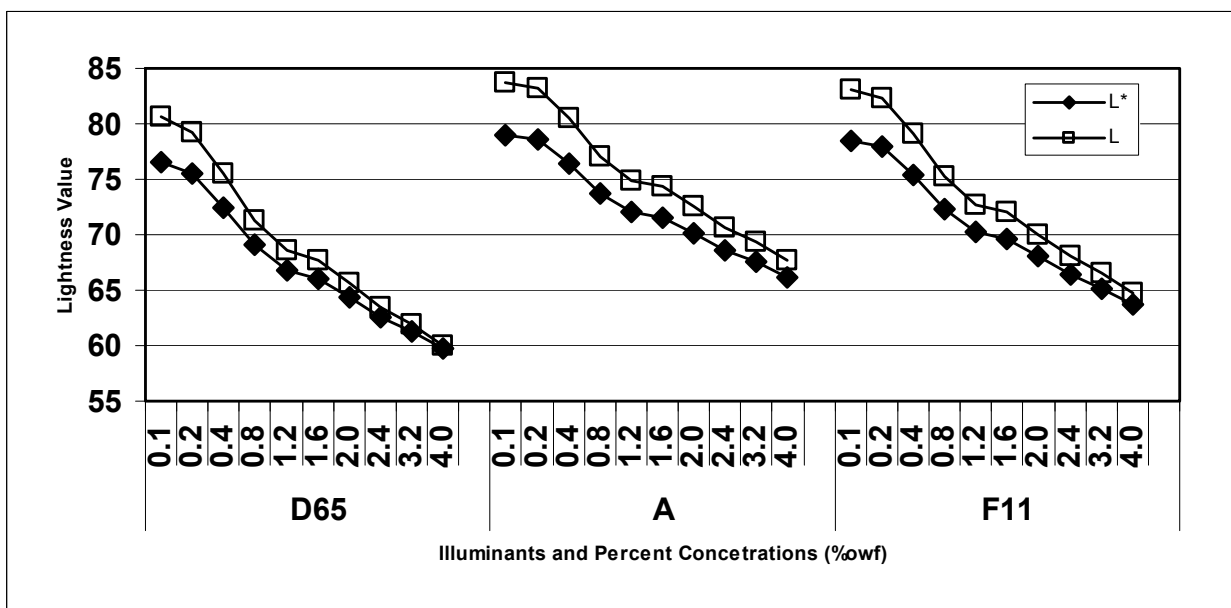
Figure 3. Lightness coordinates of the yellow dye
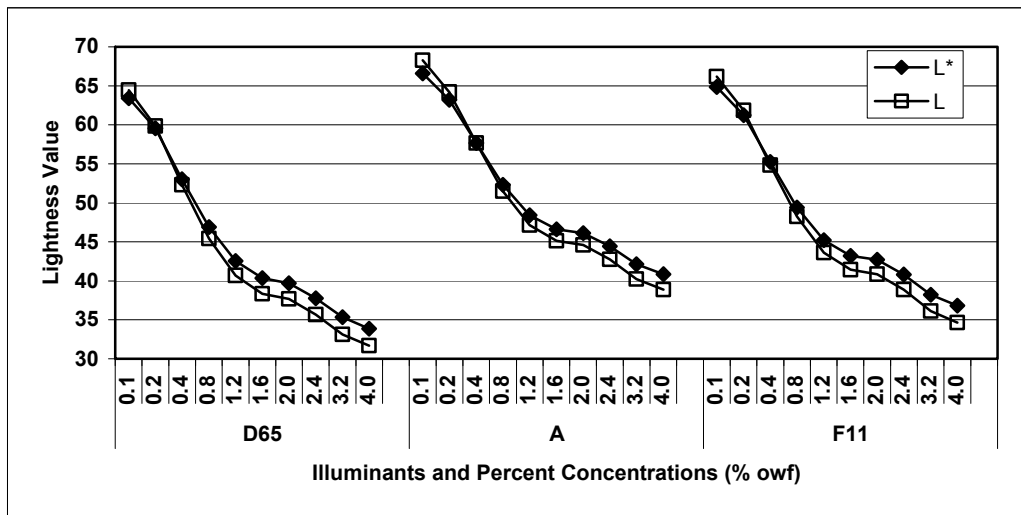
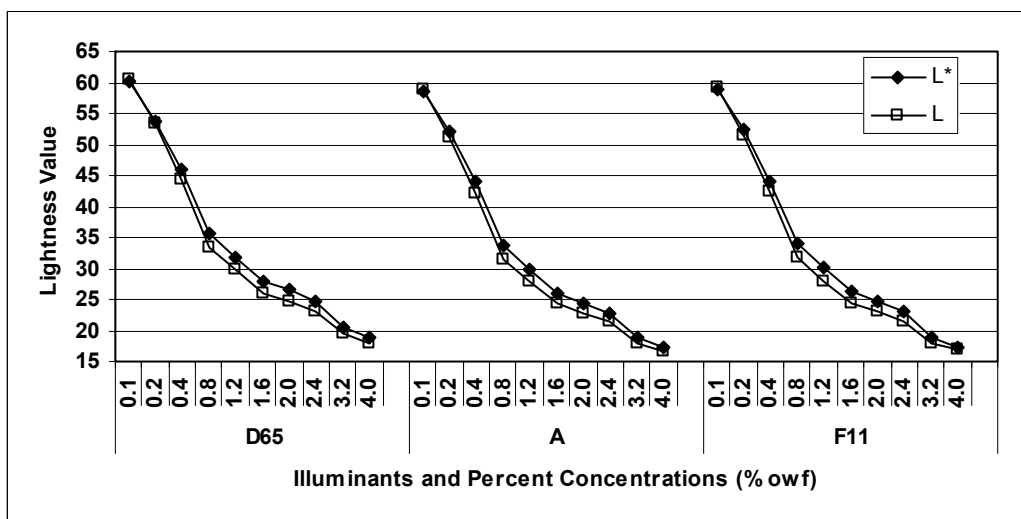**Figure 4.** Lightness coordinates of the red dye

Figure 5. Lightness coordinates of the navy dye

almost the same at black and navy dyes (Figs. 2 and 5). But the lightness values obtained under A and F11 were higher than the values obtained under D65 for yellow and red dyes (Figs. 3 and 4). Yellow and red dyeings appeared lighter in colour when they were viewed under A and F11. Also Hunter L values of the yellow dye were very much different from CIELAB L* values. The yellow shade was found to be the most sensitive one to the calculation differences of the lightness values (L* and L) and to the different illuminants under which the measurements were made. Yellow shade has much of its reflectance in the yellow part of the spectrum which comprises

longer wavelengths. Also illuminant A has much of its energy in the same region while F11 has high energy bands. The high energy output of these illuminants in the longer wavelength of the spectrum might cause the very different lightness values to be obtained for the both systems.

3.3. Red-Green Coordinates

The red-green coordinates (CIELAB a* and Hunter a) under the three different illuminants were presented in Figures 6-9 for the black, yellow red, and navy dyes respectively. Red-green value is a measure of the coordinate of colour on the red-green axis in CIELAB colour space. Positive coordinates repre-

sent red shade and negative coordinates represent green shade in colour terms. The red-green values changed in different manners for the four dyes in Figures 6-9. The highest red-green values were obtained for the red and yellow shades and the lowest values were obtained for the black shade. The red-green values changed considerably as the dyeing concentrations increased. The red-green values of the black and navy dyes moved gradually to zero (which represents the gray-point of the CIELAB a*-b* colour plane) and red-green values of red and yellow dyes increased, as it would be expected.
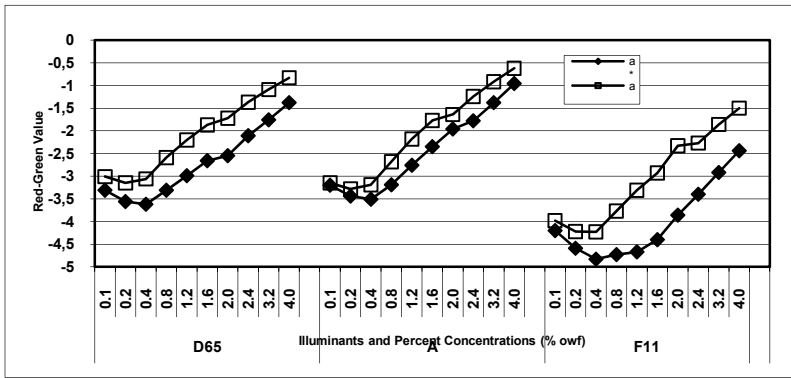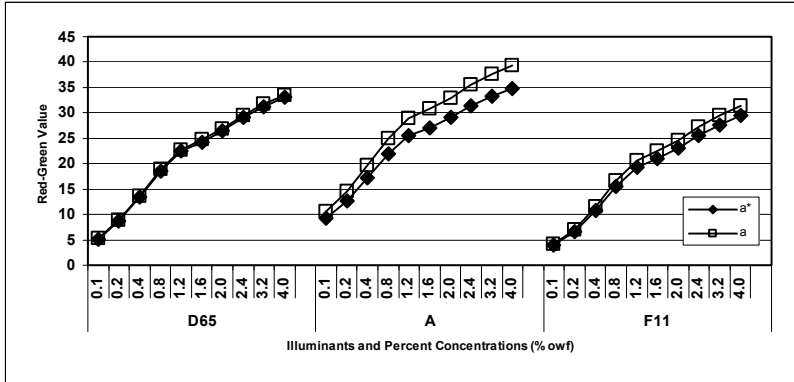
Figure 6. Red-Green coordinates of the black dye

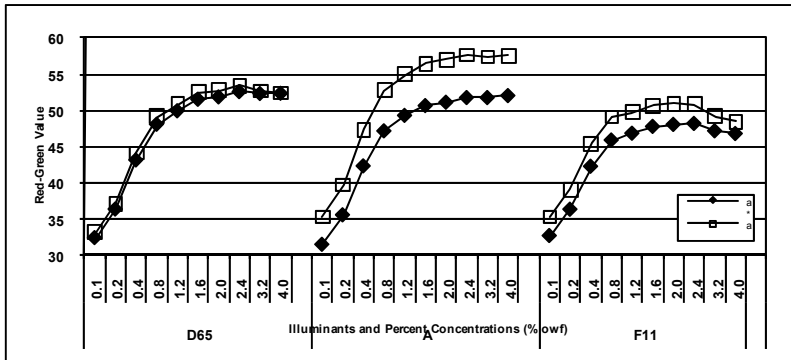**Figure 7.** Red-Green coordinates of the yellow dye

Figure 8. Red-Green coordinates of the red dye
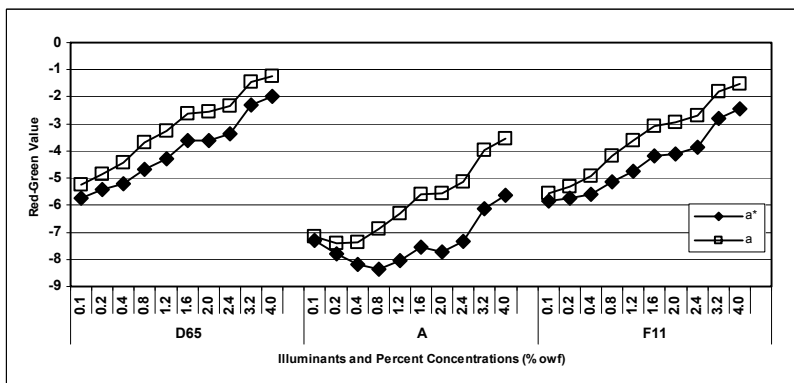

Figure 9. Red-Green coordinates of the navy dye

When the red-green values were considered for the two systems (CIELAB and Hunter), greener readings were obtained for the black and navy shades with CIELAB a* but redder readings were obtained for the yellow and red shades with Hunter a.

When the red-green values were considered for the different illuminants (D65, A, and F11), the navy shade appeared much greener under illuminant A while the black shade appeared much greener under illuminant F11. The red-green values of yellow and red shades under D65 were almost the same for CIELAB and Hunter systems. But Hunter system gave much redder readings under the illuminants A and F11. The red-green values obtained under illuminant A were the highest ones when compared with the others because illuminant A has high energy outputs in the yellow and red parts of the visible spectrum. Hunter system gave the highest readings of red-green values (in the red part of the axis which was shown with positive readings) especially under illuminant A for red and yellow shades.

3.4. Yellow-Blue Coordinates

The yellow-blue coordinates (CIELAB b* and Hunter b) under the three different illuminants were presented in Figures 10-13 for the black, yellow red, and navy dyes respectively. Yellow-blue value is a measure of the coordinate of colour on the yellow-blue axis in CIELAB colour space. Positive co-ordinates represent yellow shade and negative coordinates represent blue shade in colour terms. The yellow-blue values changed in different manners for the four dyes in Figures 10-13. The highest yellow-blue values were obtained for the yellow (positive values) and navy (negative values) and the lowest values were obtained for the black shade. The yellow-blue values changed considerably as the dyeing concentrations increased, similar to the changes obtained in lightness and red-green coordinates. The yellow-blue values of the black dye moved to zero (which represents the gray-point of the CIELAB a*-b* colour plane), as it would be expected. The yellow-blue values of the navy shade in Figure 13 together with its red-green values in Figure 9 confirmed that navy shade formed an arc on the a*-b* plane of the CIELAB colour space. The coordinates
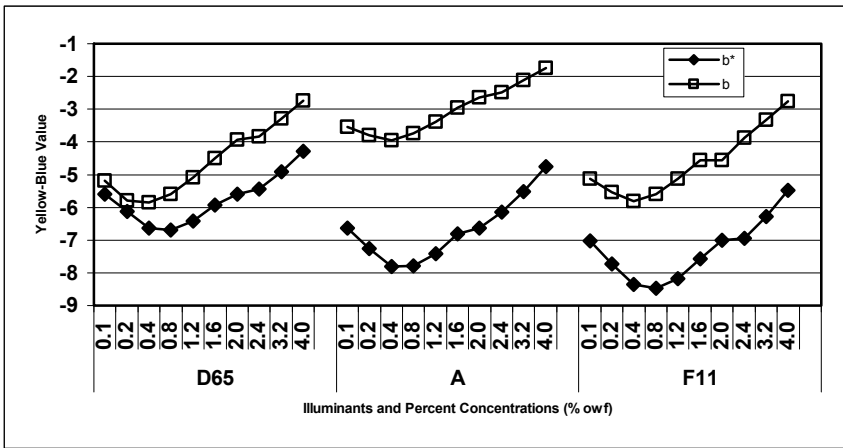
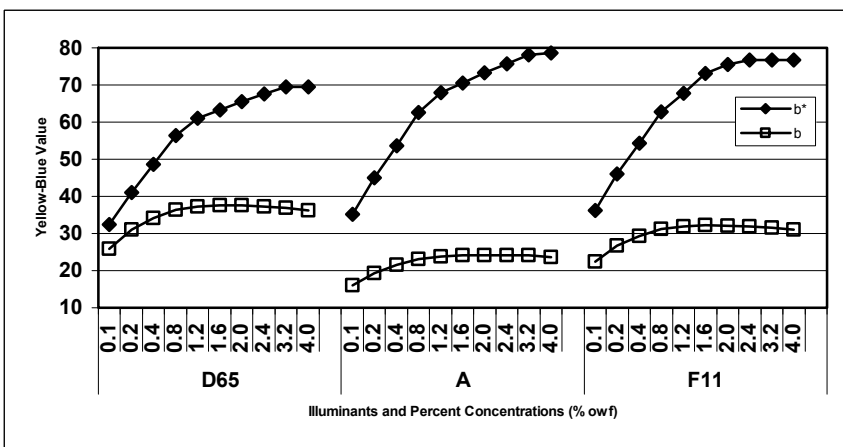**Figure 10.** Yellow-Blue coordinates of the black dye

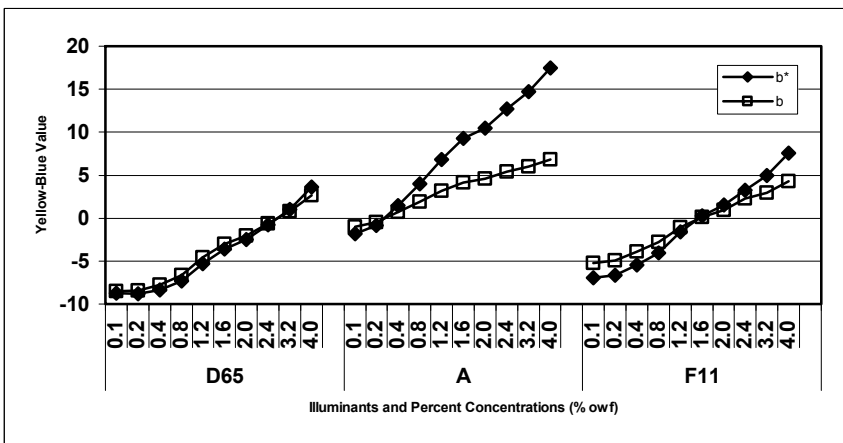**Figure 11.** Yellow-Blue coordinates of the yellow dye

Figure 12. Yellow-Blue coordinates of the red dye

of the navy shade first increased and then decreased which corresponded to a formation of and arc on a*-b* plane with respond to increasing dyeing concentrations. The yellow-blue values of yellow and red shades gradually increased as the dyeing concentrations increased.

When the yellow-blue values were considered for the two systems (CIELAB and Hunter), bluer readings were obtained for the black and navy shades and yellower readings were obtained for yellow and red shades with CIELAB b*. Especially the differences in numerical readings between

CIELAB b* and Hunter b were very high at the yellow shade.

When the yellow-blue values were considered for the different illuminants (D65, A, and F11), the black and navy shades appeared bluer and yellow and red shades appeared yellower under A and F11. The Hunter system seemed insensitive to dyeing concentration increases at the yellow shade. Almost the same L* and L readings were obtained for the red dye under D65, similar to the results obtained for red-green coordinates of the same dye in Figure 8. The colour coordinates under A differed very much for CIELAB b* and Hunter b.

3.5. Chroma Values

The chroma values (CIELAB C* and Hunter C) under the three different illuminants were presented in Figures 14-17 for the black, yellow red, and navy dyes respectively. Chroma value is a measure of the saturation of the colour on the a*-b* plane in CIELAB colour space which is calculated as the distance from the intercept point where a*=b*=0 and L*=50. High values of chroma represent saturated shades far from the gray point while low values represent dull shades near the gray point in colour terms. The chroma values are calculated from a* (a) and b* (b) values and they resemble these values in shape when the values are plotted against concentration (% owf).The chroma values changed in different manners for the four dyes in Figures 14-17. The highest chroma values were obtained for the yellow and red shades similar to the results obtained for red-green and yellow-blue coordinates. The lowest chroma values were obtained for the black shade, as it would be expected. The change of the chroma values against dyeing concentrations for black (Figure 14) and for navy (Figure 17) shades pointed that the colour coordinates of these dyes form an arc on the a*-b* plane as the dyeing concentrations increased.

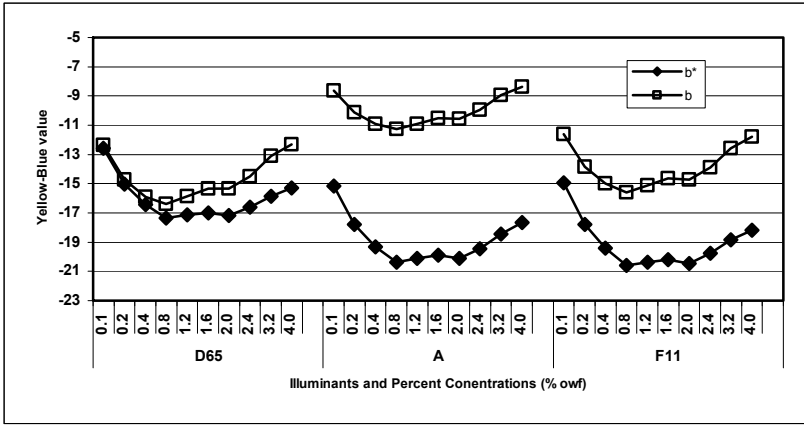When the chroma values were considered for the two systems (CIELAB and

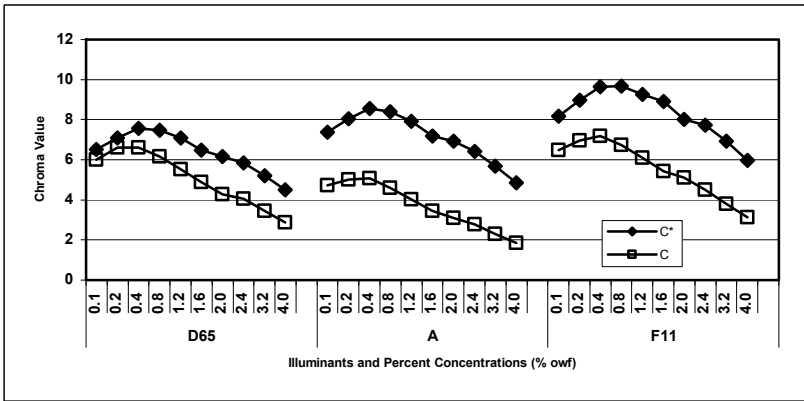**Figure 13.** Yellow-Blue coordinates of the navy dye

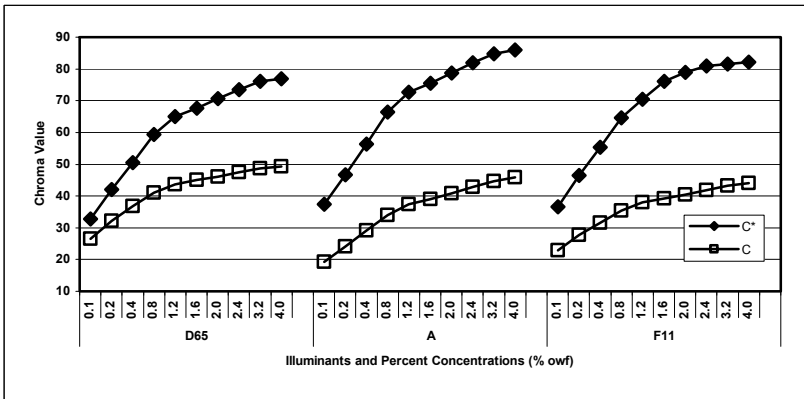**Figure 14.** Chroma values of the black dye

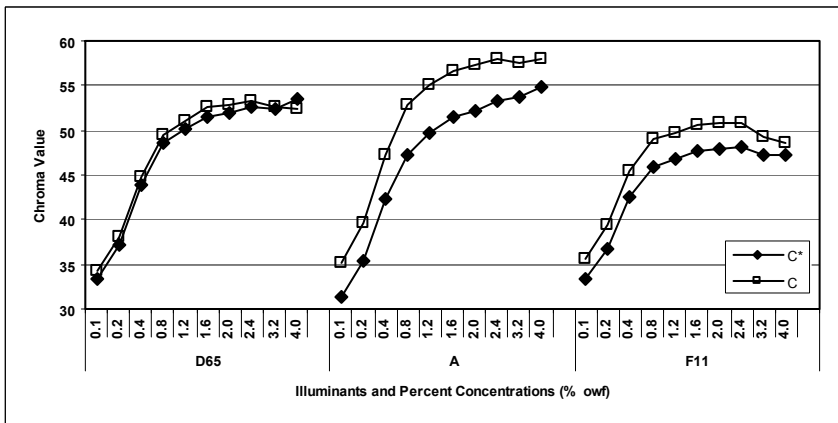**Figure 15.** Chroma values of the yellow dye

Figure 16. Chroma values of the red dye

Hunter), saturated readings were obtained in black, yellow and navy shades with CIELAB C*. The chroma readings with the Hunter system were higher than the ones with CIELAB system in the red shade.

When the chroma values were considered for the different illuminants (D65, A, and F11), the values changed according to the hues of the shades and according to the calculation systems (CIELAB and Hunter). Almost all the lowest chroma values (C*) with the CIELAB system were obtained under D65. The lowest chroma values (C) with the Hunter system were obtained under illuminant A for the black, yellow and navy shades. The highest chroma values with the Hunter system were obtained under illuminant A for the red shade.

3.6. Colour Differences

The colour differences (CIELAB ΔE^* and Hunter ΔE) under the three different illuminants were presented in Figures 18-21 for the black, yellow red, and navy dyes respectively. Colour differences are obtained from the colour difference formulations which use the colour coordinates for calculation. Colour difference corresponds to the distance between the reference colour and sample colour in the CIELAB colour space. Colour difference results are always positive and high colour difference values (>1.2 CIELAB ΔE^*) indicate visible colour difference between the reference (standard or target colour) and sample (the sample colour). The colour difference values given in Figures 18-21 were calculated by taking the 0.1 % owf dyeing as the reference (standard or reference colour) and the remaining ones as the samples (sample colours). The colour difference values increased as the dyeing concentrations increased, as it would be expected.

When the colour differences were considered for the two systems (CIELAB and Hunter), almost the same colour differences were obtained in the shades except the yellow shade. The Hunter colour differences obtained
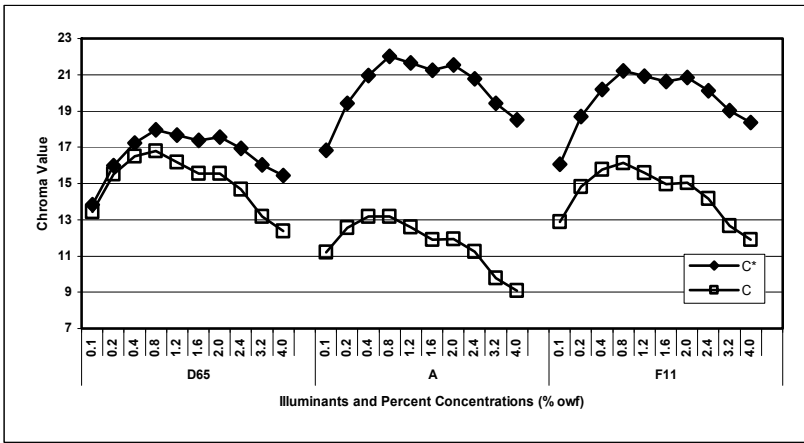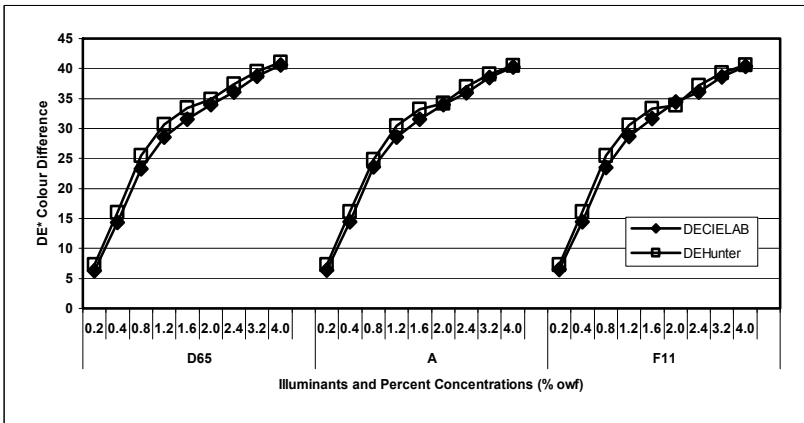
Figure 17. Chroma values of the navy dye

Figure 18. Colour difference values of the black dye
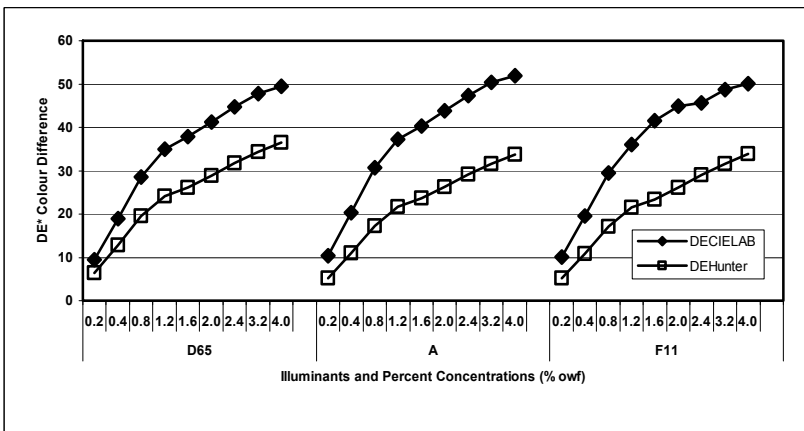

Figure 19. Colour difference values of the yellow dye
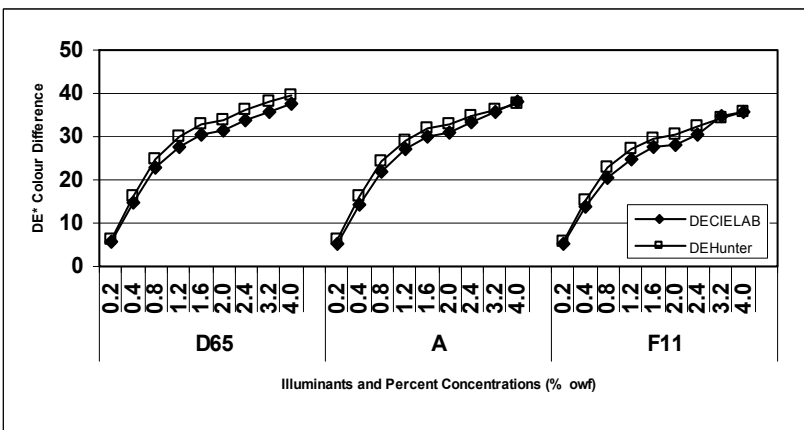

Figure 20. Colour difference values of the red dye

in black, red, and navy shades were slightly higher than the corresponding CIELAB ones. But CIELAB colour differences were considerably higher than that of Hunter in the yellow shade. The reason of that was the great difference between the yellow-blue values of the two systems obtained in Figure 11. Although the lightness, red-green and yellow-blue coordinates of the four dyes differed considerably from each other when calculated according to the CIELAB and Hunter systems, the colour differences obtained were almost the same except the yellow shade. The CIELAB colour difference formulation (ΔE^*) was more sensitive to the changes in colour coordinates in the yellow shade than the Hunter system.

When the colour differences were considered for the different illuminants (D65, A, and F11), almost the same values were obtained for the both systems (CIELAB ΔE^* and Hunter ΔE). The two systems were both sensitive to the illuminants under which the measurements were made but their sensitivity depended on the shades of the dyed material.

An overall consideration of the Figures 2 – 21 pointed that yellow shades differed from the others in terms of colour coordinates computed according to CIELAB and Hunter systems. Hunter readings of the yellow shades were observed insensitive to the increases in dyeing concentrations which could be the result of the non-uniform colour spacing of the Hunter system. CIELAB and Hunter systems use the same tristimulus values in computation but the two systems differ in their mathematical derivations from tristimulus values. CIELAB results in a more uniform colour space than the older Hunter system. The differences obtained in colour coordinates could have resulted from the differences in uniformity of the two systems; Hunter system being less sensitive to dye concentration increases in the yellow part of the a*-b-* colour plane.

4. CONCLUSIONS

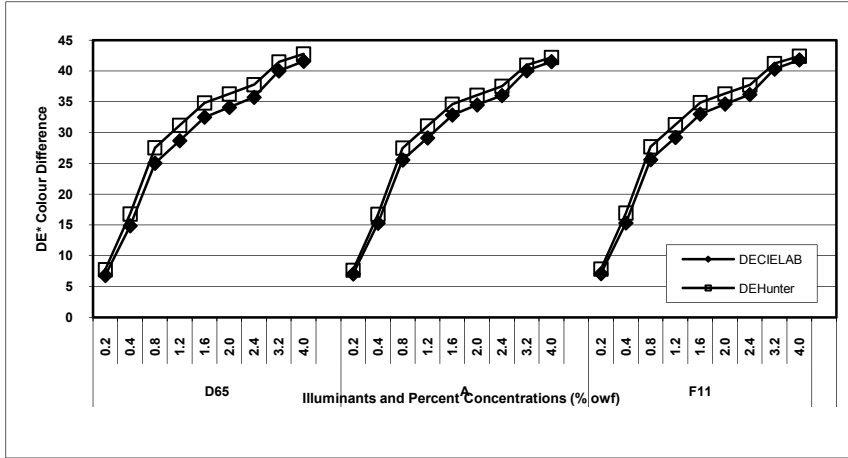The differences between the colour properties of reactive dyed cotton

Figure 21. Colour difference values of the navy dye

the illuminant, and to the system of computing. The colour coordinates and colour differences changed with the changes in dyeing concentrations. The colour coordinates of yellow, red and navy shades appeared more sensitive to the calculation according to the Hunter system than calculation according to the CIELAB system. Colour coordinates calculated according to the Hunter system were sensitive to the illuminant choice, especially they were characteristically different under A and F11. Yellow and red shades appeared redder according to the Hunter system while they appeared yellower according to the CIELAB system.

fabrics according to comparison with CIELAB and Hunter systems were presented in this paper.

The calculation and the results of the colour properties were sensitive to the hues of the dyeings, to the choice of

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