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REGULAR ARTICLE

Effect of Different Energy Level Disperse Dyes in Dyeability of Polyester/Cotton Blend Fabrics Using PEG-Based Reverse Micelle as Disperse/Reactive Dye Carrier

Yanming Wang[1] · Cheng Hao Lee[1] · Alan Yiu Lun Tang[1] · Chi-wai Kan[1]

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Abstract

Disperse dyes are categorized based on their energy levels and are utilized in conjunction with reactive dyes for the dyeing of polyester/cotton fibres in two distinct compositional ratios. The dyeing conditions and the colour fastness properties of the dyed materials are intrinsically linked to this classification. The application of reverse micelles as dye carriers is advantageous when dyeing below 100 °C as it facilitates the levelling of disperse dyes. The presence of reverse micelles in the dye bath may render the dyeing behaviour of disperse dyes, categorized by varying energy levels, sensitive to fluctuations in dyeing temperature and dye bath concentration. The combination of medium energy disperse dyes and reactive dyes exhibited the highest colour yield and well facilitated at dyeing temperature of 98 °C. Higher percentage of cotton in (T40/C60) blend illustrated lower reflectance compared to (T65/C35) blend fabric with lower cotton percentage. Dyed polyester/cotton fabrics with a higher polyester content (T65/C35), demonstrate slightly greater resistance to colour fastness to crocking, laundering and light compared to those with a lower polyester content (T40/C60). Disperse dyes with low-to-medium energy levels may exhibit unique dyeing characteristics when combined with reactive dyes. A dyeing process conducted at a temperature of 98 °C is deemed appropriate for both polyester and cotton fibres, utilizing PEG-based reverse micelles as dye carriers in an octane solvent. The quality of the dyed fabric, employing disperse dyes of various energy levels, was systematically evaluated.

Keywords Polyester · Cotton · Disperse dye · Reactive dye · Reverse micelle · Non-aqueous dyeing

1 Introduction

Owing to wicking and quick-dry properties of polyester and air breathable properties of cotton, polyester/cotton fabrics are commonly utilized in apparel and other technical textile application sectors [1–3]. The blending of polyester and cotton fibres offer sufficient comfort level and improved sweat-resistant due to different properties. The combination of polyester and cotton are significant for user-friendly functionality and aesthetic value and eventually achieves a reasonable balance between their respective limitations [3, 4], however, the issue of effective dyeing of polyester/cotton blend fabrics still needs to be addressed [4].

Cotton fibre is hydrophilic, soft, and have more anti-static qualities than polyester fibres, which is dyed by employing alkaline conditions at 60 °C or 80 °C and using reactive, direct or vat dyes. Polyester fibre exhibits a highly hydrophobic nature and possesses a densely packed, crystalline structure [5]. Consequently, the dyeing of polyester is conducted using disperse dyes at elevated temperatures. During the polyester dyeing process, disperse dyes migrate from bulk solutions to the fibre surface through adsorption, followed by diffusion into the subsurface region of the fibre. To mitigate effluent discharge and improve the environmental sustainability of textile manufacturing, modifications to the dyeing processes are imperative.

Traditional water dyeing method often require the additives and prolonged dyeing times, resulting in more serious water pollution and energy consumption [6–8]. Considerable efforts have been devoted to PET/cotton blend to enhance dyeability by developing various fillers such as cellulose, clay nano-adsorbent, calcium carbonate, carbon, metal oxides and various forms of silica [9–14].

✉ Chi-wai Kan
tccwk@polyu.edu.hk

1 School of Fashion and Textiles, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong SAR, China

One such modification involves the implementation of contemporary techniques that render the dyeing process more cost-effective, rapid, and labour-efficient, while simultaneously promoting sustainability. To optimize colour yield while conserving time and energy, alternative energy sources such as gamma radiation, ultrasound, microwave and ultraviolet radiation have been integrated into the dyeing process [5, 15–17]. Other approaches using various dye carriers including oxide-based nano-powder, nanomicelle, o- and p-vanillin and anionic agent [18–21]. Polyester takes a substantial amount of energy during aqueous dyeing for better absorption of disperse dyes. Microwave heating has evolved as more efficient approach than the traditional heating method as heat transfer can be reduced and all dye particles can be heated up within short period of time.

Disperse dyes are used which are very sensitive to time, temperature, electrolyte, concentration, etc. This sensitivity is quite alternative to correctness which is produced by the colour difference of one unit between the correct recipe and incorrect recipe. The appropriate duration for dyeing is critical for the disintegration of dye dispersion, the opening and swelling of the polyester structure, and the transfer of solubilized dye from the dye solution to the fibre surface. Initially, the dye adheres to the fibre surface, followed by molecular diffusion of the dye into the fibre structure. Temperature plays a pivotal role in the application of disperse dyes, as it significantly influences the dyeing process. In instances where a high-temperature dyeing method is employed, temperatures exceeding 100 °C are required to facilitate fibre swelling. This swelling phenomenon, akin to that observed in carrier dyeing, occurs within the temperature range of 85 °C to 90 °C [21].

In terms of the energy level of disperse dyes, small molecular size and low polarity are defined as low energy dyes, providing better levelling and excellent dyeing rates with poor thermal resistance. On the contrary, large molecular size with high polarity is categorized as higher energy-level dyes and results as low dyeing rates and good colour fastness under various thermal environmental conditions [22, 23]. At sufficiently high temperature range (100–130 °C), thermal agitation brings the polyester structure to become swell and less crystalline, generating opening gaps for penetration of dye molecules via van der Waal's and dipole forces [24].

Fabrics made of a polyester/cotton combination are commonly dyed using a two bath or one bath, two-stage procedure. Many efforts are being made to create an effective method for dyeing polyester/cotton blend fabrics via various types of pretreatments on blend fabric. Najafi et al. introduced one bath method dyeing of blend fabric with sulphatoethylsulphonyl disperse/reactive dyes pretreatment by chitin biopolymer [25]. Oliveria et al. applied both natural and synthetic electrolytes for surface functionalization of polyester/cotton fabric [26]. This functionalized surface can be dyed at relatively lower temperature than conventional process. Muralidharan et al. [27] introduced an innovative methodology that employs an azeotropic ternary mixture of organic solvents for the pretreatment of polyester/cotton blends, facilitating the simultaneous dyeing process with disperse and reactive dyes in a single-bath application. The dimensional, surface, colourfastness, and wrinkle qualities of the surface pretreated polyester/cotton blended fabrics can be improved significantly. Bana et al. [28] studied one-bath one-step aqueous dyeing of polyester/cotton (T/C) blends fabric with disperse dyes after acetylation of cotton.

Two-bath or one-bath two-step dyeing methods with the proper dyes and agents for each fibre have frequently been used for colouring polyester/cotton blends [27]. On the other hand, these methods of dyeing are time consuming and complicated process control. Shorter than the two-bath approach, the one-bath two-step dyeing procedure has the drawbacks of reduced dyeability from migration and poor shade reproducibility because two different types of dyes are used in an equivalent bath [29, 30]. In two bath dyeing process, dyeing of cotton by reactive dyes is normally carried out under alkaline condition at around 80 °C, however, this is entirely different scenario from that of polyester dyeing, which is carried out under acidic conditions over 120 °C. For selection of appropriate combination of disperse dye-reactive dye mixture, the energy level of disperse dye with similar dyeing process condition with reactive dye should be considered in order to obtain acceptable dyeability. Numerous studies have been achieved recently in the dyeing of polyester/cotton blend fabric through introduction of disperse and reactive dyes in a single bath simultaneously after surface modification of fabrics and adjustment of process parameters [29–35]. When compared to traditional dyeing methods, the one-bath, one-step dyeing of polyester/cotton blends with disperse/reactive dyes has the advantage of a shorter dyeing cycle and less energy consumption [28–33].

Our series of systematic investigations has concentrated on exploring the utilization of reverse micelle-based dye carriers as an alternative technology for fabric coloration in nonaqueous organic solvent media, specifically employing polyethylene glycol (PEG) as a nonionic surfactant [36–40]. Unlike the two-step method, the majority of our prior research predominantly utilized the Levafix CA series and other vinyl sulfone (VS)-based warm type reactive dyes [39]. This study examines the application of disperse dyes with varying energy levels in conjunction with reactive dyes to assess the viability of a PEG-based reverse micellar approach for the efficient dyeing of polyester/cotton fabrics at a moderate temperature of 98 °C. The dyeing performance is evaluated based on several criteria: (a) colour yield (K/S_{sum} value); (b) colour space coordinates (CIE L*a*b* values); (c) colour levelness (Relative Unlevelness Indices); (d) colour reflectance (Reflectance curves); (e) washing and crocking colourfastness (Greyscale); and (f) fibre morphology post-dyeing as observed from scanning electron microscope.

2 Experimental

2.1 Materials

In this investigation, polyester/cotton blend woven fabrics (T/C fabrics) (40% polyester / 60% cotton (T40/C60) 3/1 “S” twill and 65% polyester/35% cotton (T65/C35) 3/1 "S" twill) were employed that were ready for dyeing commercially. They were initially cleaned for 45 min in a washing machine set at 49 °C. Prior to the next experiment, the materials were washed, tumble dried, and condition for at least 24 h at relative humidity of 65 ± 2% and 20 ± 2 °C.

Polyoxyethylene glycol (12) tridecylether ($C_{13}H_{27}(OCH_2CH_2)_nOH$) (n ~ 12) (PEG-12), n-octanol and octane were utilized as non-ionic surfactants, co-surfactants and solvent respectively in the dyeing process. The colour fixation agent was sodium carbonate. Both belonged to the reagent grade. Without further purification, the experiments used three reactive dyes (RD) (Levafix CA Red, Levafix CA Blue, and Levafix CA Yellow) and nine disperse dyes with low energy levels (LEDD: Dianix Red AC-E 01, Dianix Yellow AC-E new and Dianix Blue AC-E); medium energy levels (MEDD: Dianix Red CC, Dianix Yellow Brown CC and Dianix Blue Plus); high energy levels (HEDD: Dianix Rubine S-2G, Dianix Yellow Brown S-4R and Dianix Blue S-2G.

2.2 Preparation of PEG-Based Dye-Encapsulated Reverse Micelle

A straightforward injection technique was used to create PEG-based reverse micelles at room temperature. Co-surfactant and non-ionic surfactants were initially combined while being stirred. To help the mixture self-assemble into a PEG-based reverse micelle, the mixture was then dispersed in octane. The reverse micellar system was then separately applied reactive dye and disperse dye aqueous solution dropwise and vigorously swirled to generate a well-dispersed solution with reactive dyes and disperse dyes encapsulated in the interior of reverse micelle. Table 1 provides an illustration of the preparation conditions for dye-encapsulated reverse micelles.

2.3 Reverse Micellar Dyeing of T/C Fabrics Using PEG-Based Reverse Micellar Approach (Without Salt)

Figure 1 depicts the reverse micellar dyeing processes for T/C fabric using a one-bath, one-step method. Typically, the T/C fabric was submerged in reverse micelle dye liquid for 10 min at 30 °C while the water bath was shaking. Then, with 170 shakes per minute at a pace of 1 °C/min, the bath temperature was raised to 98 °C. The fabric was dyed and fixed for 100 min at 98 °C. The dyed cloth was then drip-dried and condition for 24 h at 65 ± 2% RH and 20 ± 2 °C before being washed with detergent (2 g/L) and rinsed at 50 °C.

2.4 Colour Yield Measurement

The DataColor International, USA, SF650 Spectrophotometer was used to evaluate the colour yield of the dyed T/C fabrics. The specimen face was measured, and the measurement parameters were selected to incorporate specular light using a medium aperture (20 mm). The standard observer was 10° and the illumination was D65. The same parameters were used to average four measurements. Equation (1) was used to determine the colour yield represented as K/S value from the visible spectrum at wavelengths between 400 and 700 nm with 10 nm intervals. The amount of dye-uptake increases with increasing K/S value, improving colour yield.

$$K/S = (1 - R)^2/2R \tag{1}$$

where K = absorption coefficient, depending on the concentration of colourant, S = scattering coefficient, caused by the dyed substrate, R = reflectance of the coloured sample.

Table 1 The parameters used for reverse micellar polyester/cotton blend dyeing and fixation using octane

Solvent volume to cotton weight ratio (v/w)			8:1		
Surfactant to co-surfactant mole ratio			1:8		
Surfactant to water mole ratio			0.04:1		
Volume of water-pool for dye (mL)			0.5		
Volume of water-pool for soda ash (mL)			0.3		
Dyeing and fixation time (min)			100		
Dyeing and fixation temperature (°C)			98		
Dye concentration (% owf)	0.1	0.5	1.5	2.5	3.5
Soda ash to liquor (g/L)	6	6	8	8.5	9.5
Soda ash to cotton weight ratio (g/g)	0.06	0.06	0.08	0.085	0.095

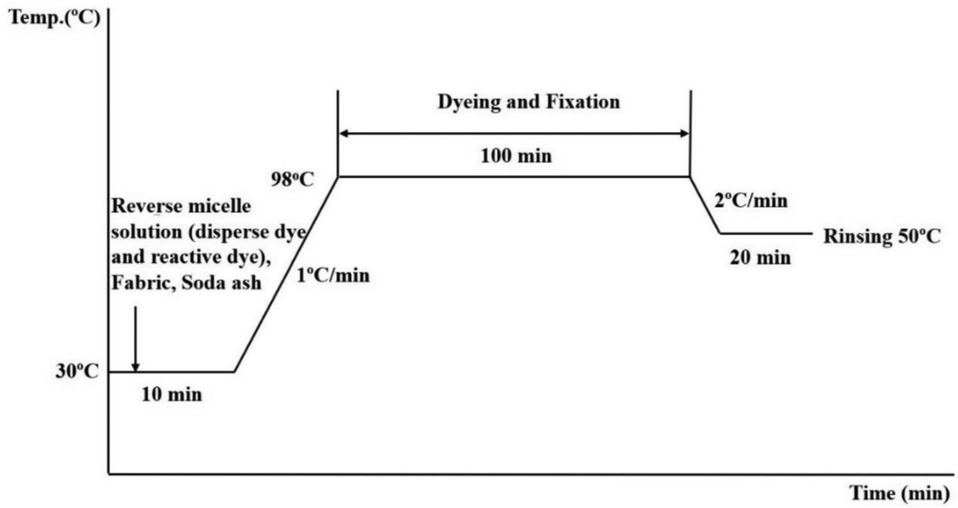

Fig. 1. The dyeing profile of one-bath one-step polyester/cotton blend fabric dyeing with incorporation of disperse dye and reactive dye using reverse micellar approach

Table 2 Suggested interpretation of RUI values [34]

RUI	Visual appearance of levelness
< 0.2	Excellent levelness (unlevelness not detectable)
0.2–0.49	Good levelness (noticeable unlevelness under close examination)
0.5–1.0	Poor levelness (apparent unlevelness)
> 1.0	Bad levelness (conspicuous unlevelness)

2.5 Levelness Measurement

The reflectance readings of four randomly chosen areas on dyed standard and batch samples were used to calculate the relative unlevelness indices (RUI) over the visible spectrum (400–700 nm) at intervals of 10 nm. DataColor International's SF650 Spectrophotometer (U.S.) was used to obtain the measurements. Illuminant D65 was used under specular illumination, and a standard observer with a field of view of 10° and a medium aperture (20 mm) were used. The RUI was calculated using Eq. (2), where s is the standard deviation of reflectance values measured at a particular wavelength, R is the mean of reflectance values across all measurements for each wavelength, and V is the coefficient of variation of reflectance by the photopic relative luminous efficiency function. Table 2 provides the suggested RUI value interpretation.

$$\mathrm{RUI} = \sum_{\lambda=400}^{700} (s_\lambda/\overline{R})V_\lambda \tag{2}$$

2.6 Optical Microscopy

The cross-sectional photographs of the fibre content of the fabrics were captured and examined using optical light material microscopy (Leica DM2700M, Germany). AATCC Test Method 20–2010 (Fibre Analysis: Qualitative) was used to analyze the fibres qualitatively.

2.7 Scanning Electron Microscopy

The morphology of the fabric surface was examined using a tungsten thermionic emission scanning electron microscope (SEM) (JEOL Model JSM-6490, Tokyo, Japan) that is outfitted with an EDS (energy dispersive X-ray spectroscopy) system. The coloured textiles were placed on a sample holder, covered with a layer of gold using ion sputtering in a vacuum coating equipment, and then inspected in a SEM with a 20 kV accelerating voltage. All SEM photos were produced at a 1000 X magnification.

2.8 Evaluation of Colour Fastness

The colour fastness properties of conventional micellar and water-dyed T/C fabrics have been evaluated: (a) colour fastness to washing (AATCC Test Method 61, Test No. 2A),(b) colour fastness to crocking (AATCC Test Method 8) and (c) colour fastness to light (AATCC 16.3).

3 Results and Discussion

3.1 Colour Yield (K/S$_{sum}$ Value)

Low energy disperse dyes have poor colour production due to their use and operating temperature. Low energy disperse dyes are primarily created for traditional polyester carrier dyeing at reduced working temperatures. Because of this, low energy disperse dyes should not be used to dye polyester at high temperatures because the dyeing efficiency and colour yield are reduced. With a greater operating temperature, high energy disperse dyes are generally utilized for thermo-fixation. The optimal temperature for medium energy disperse dyes to be utilized in high temperature polyester dyeing is around 130 °C, resulting in outstanding dyeing effectiveness and colour output.

In terms of K/S_{sum} value, it has been found that blue-dyed samples consistently outperformed red-dyed and yellow-dyed samples among the dyestuff's three primary colours. When compared to blue dyes, red and yellow dyes are more vulnerable to high temperature dyeing, which results in dye degradation. The molecular structure of dye may be the cause of this vulnerability.

According to various colours and energy levels of the disperse dyestuff in Table 3, T/C (40%/60%) lend fabric exhibits higher mean K/S_{sum} value (8.42 to 197.05) compared with K/S_{sum} value (4.19 to 96.70) measured from (T65/C35) blend fabric in octane.

According to Table 3, mixture of reactive dye and disperse dye with medium energy level have the highest colour yield (4.19 to 96.7) for the majority of dye concentrations and fabrics, followed by disperse dyes with a low energy level (4.05 to 85.17) and disperse dyes with high energy level have the lowest colour yield (4.18 to 76). The dyeing temperature used in octane-based systems may be the major factor for the lowest colour yield using high energy disperse dyes. The process temperature of this reverse micellar dyeing system in octane is maintained at 98 °C, which is 32 °C lower than the working temperature of water-based dyeing system (130 °C). Poor colour yield is attained because high energy disperse dyes are typically used for thermo-fixation at sufficiently higher operating temperatures. The colour output of the dyed fabrics is thus larger than that of high energy disperse dye since low energy disperse dyes are created primarily for carrier dyeing at lower working temperatures. The largest colour yield may be obtained from the stable dye fixation on fibre surface, making medium energy level

Table 3 The K/S_{sum} values of octane-dyed T65/C35 and T40/C60 fabrics with disperse dyes and reactive dyes

Fabric	Dye	Dye conc	RD + LEDD	RD + MEDD	RD + HEDD
T65/C35	Red	0.1	4.05	4.19	4.18
		0.5	17.76	18.28	18.22
		1.5	43.08	46.94	42.17
		2.5	53.18	64.72	60.44
		3.5	67.04	73.88	71.29
	Yellow	0.1	2.94	2.96	2.65
		0.5	10.68	10.96	10.50
		1.5	24.58	25.56	23.65
		2.5	32.23	34.16	34.11
		3.5	42.58	42.40	42.04
	Blue	0.1	3.87	4.37	3.29
		0.5	17.54	18.45	15.46
		1.5	41.29	47.72	40.46
		2.5	57.07	69.58	61.87
		3.5	85.17	96.70	76.00
T40/C60	Red	0.1	7.52	8.42	7.82
		0.5	36.90	37.10	40.12
		1.5	117.55	111.79	110.31
		2.5	148.43	163.31	158.18
		3.5	171.72	180.59	184.51
	Yellow	0.1	5.51	5.59	5.11
		0.5	21.63	22.11	21.60
		1.5	59.16	59.97	58.04
		2.5	75.27	90.23	84.86
		3.5	100.86	107.38	102.54
	Blue	0.1	6.64	7.21	6.56
		0.5	31.15	32.37	31.26
		1.5	98.17	100.53	99.60
		2.5	121.73	170.54	158.48
		3.5	169.94	197.05	185.75

disperse dyes the most suitable dyestuff for efficient dyeing in octane-based reverse micellar systems.

For the three core colours of the dyestuff, blue octane disperse-dyed samples consistently perform better than red octane reactive-dyed samples and yellow octane reactive-dyed samples.

When compared to other energy level combinations in T40/C60 fabric, low energy disperse dyes and reactive dyes (7.52 to 169.94) and high energy disperse dyes and reactive dyes (7.82 to 185.75), under the same dye concentration, the combination of medium energy disperse dyes and reactive dyes can, to a large extent, achieve the highest colour yield (8.42 to 197.05). This is because both reactive dye and selected disperse dye are well facilitated at dyeing temperature of 98 °C.

3.2 Colour Reflectance

Figures 2, 3, 4 depict the reflectance curves of octane reverse micellar-dyed T/C fabric with disperse dye. The lower the reflectance (%), the less light is reflected or scattered by the materials surface and darker in terms of shade of the surface. When dye concentration increases, the reflectance (%) of the dyed fabrics, within the visible light spectrum (from 400 to 700 nm), generally decreases and the reflectance curves thus move downward, maintaining identical in shape with no peak shift are observed.

As illustrated from Figs. 2, 3, 4, the more light is reflected or scattered by the object and the lighter the substrate's shade, the higher the reflectance (%). With the introduction of both reactive dyes and disperse dyes, higher percentage of cotton in T40/C60 illustrates slightly darker shade when the dyeing temperature in reverse micellar dyeing system is set at 98 °C, it is speculated that the lowering of reflectance is due to the contribution of more reactive dye in cotton and less disperse dye in polyester component. On the contrary, T65/C35 blend fabric with higher polyester composition (65%) helps to explain the lighter shade in terms of reflectance to a considerable extent. It is common knowledge that polyester has a glass transition temperature of around 70 °C. 70 °C is the onset temperature at which polyester starts to soften. The polyester is partially softened if the dyeing temperature is well below 130 °C, which makes it difficult for penetration of disperse dye into the fibre matrix and results in relatively higher reflectance (%).

3.3 CIE L*a*b* Values

The CIE L*a*b* values of two types of T/C fabrics that have been dyed with mixture of disperse dyes and reactive dyes in octane are shown in Table 4. The L* value typically falls as dye concentration rises from 0.1% to 3.5%, indicating that the fabric surface is lighter, and the colour strength is stronger. The features of the fabrics and dyestuffs determined whether the a* and b* values, which represent the red–green axis and yellow–blue axis, increase to an optimum limit and then gradually fall or simply increase continuously when dye concentration increases, as shown in Tables 4.

Based on the results of reflectance spectrophotometry (Table 4), the L (lightness) value decreases (increase in colour strength) as dye concentration increased from 0.1% to 3.5%. The lowest L value according to the tested standard using D65 at 10° observer indicating that the sample bound the greatest amount of dye. For T/C fabric with higher polyester percentage, i.e. T65/C35, a* values (the green–red axis on the CIE L*a*b* coordinate colour system) showed a more positive value for low energy disperse dye compared to medium and high energy disperse dyes, which means that T65/C35 blend treated with medium energy disperse dyes are redder compared to samples treated with high energy level disperse dyes samples. b* values (the blue–yellow axis on the CIE L*a*b* colour coordinate system) were decreased more in low energy disperse dyed samples (Table 4) compared to the same parameter for samples treated with higher energy level disperse dyes. This means that the colours of the lower energy level disperse dye (LEDD + RD and MEDD + RD) dyed fabric samples were bluer compared to the (HEDD + RD) dyed T/C fabric. On the other hand, b* values were observed to be increased with respect to dye concentration in yellow-dyed fabric. Low energy disperse dyed samples (Table 4) exhibit higher yellow colour shift compared to the same parameter for samples treated with higher energy level disperse dyes. A similar study presented CIE L*a*b* colour coordinates for T40/C60 blend fabric was observed that LEDD + RD dyes showed a higher positive a* value compared to fabrics treated with (MEDD + RD) and (HEDD + RD) dyes, which indicates (LEDD + RD) dyed samples were redder than that of (MEDD + RD) and (HEDD + RD) dyes which was especially noticeable in the use of low energy dyes at temperature of 98 °C. For b* values (the blue–yellow axis on the CIE L*a*b* colour coordinate system), (LEDD + RD) dyes showed more negative value compared to both (MEDD + RD) and (HEDD + RD) dyes, more negative b* values mean the blue colour strength is correspondingly higher. In this case, the yellow colour shift was observed to be increased significantly in (LEDD + RD) dyed fabric, followed by (MEDD + RD) and (HEDD + RD) dyes.

Figures 5 and 6 express visually that octane-assisted reverse micellar dyeing on T40/C60 can produce better dyeability than dyeing on T65/C35 with good levelness and there is no shade change in the final colour strength, which is in good agreement with the reflectance curves.

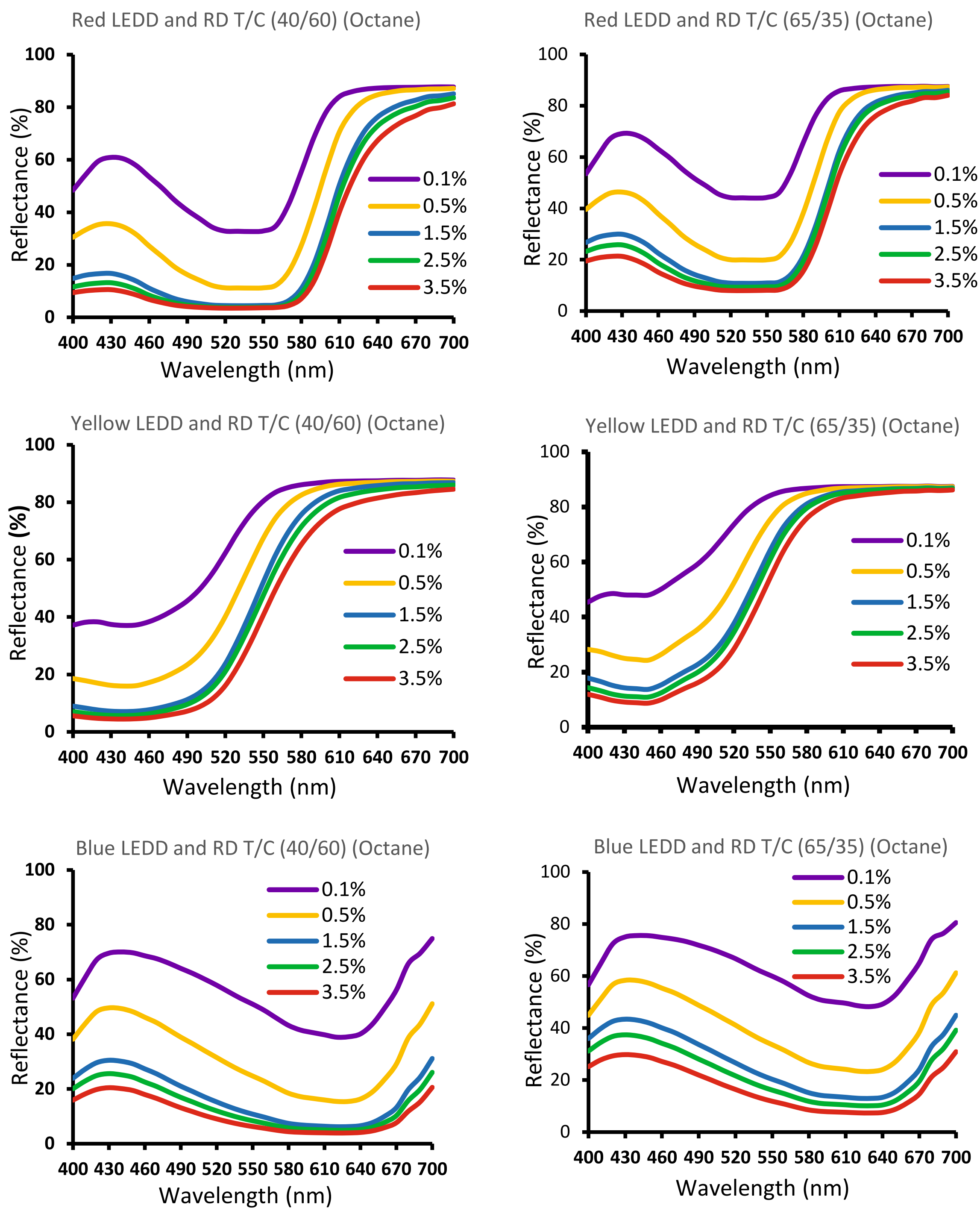

Fig. 2. The reflectance curves of octane-dyed T/C (40% polyester / 60% cotton) and T/C (65% polyester / 35% cotton) T/C fabrics with low energy disperse dye-reactive dye mixture: **a** red dye; **b** yellow dye and **c** blue dye

3.4 Levelness (Relative Unlevelness Index)

The Relative Unlevelness Index (RUI), as established by Chong et al. (1992), serves as a widely recognized metric for assessing the colour uniformity of dyed textiles [41]. According to this methodology, a lower RUI value indicates superior colour uniformity. Specifically, an RUI value of less than 0.2 signifies excellent visual uniformity; values ranging from 0.2 to 0.49 are classified as good; an RUI between 0.5 and 1.0 is considered to reflect poor visual uniformity; and an RUI value exceeding 1.0 is indicative of very poor visual uniformity.

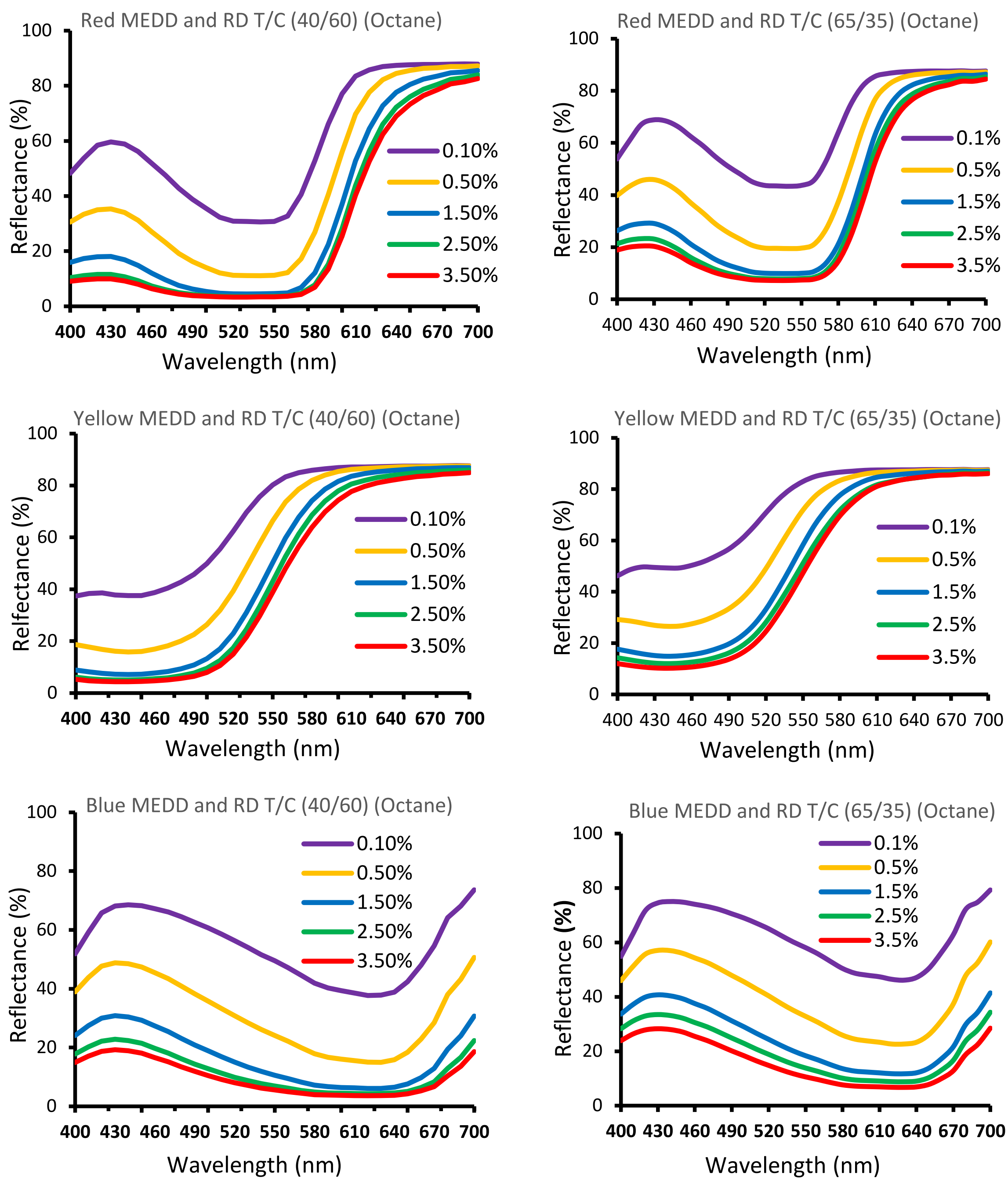

Fig. 3. The reflectance curves of octane-dyed T/C (40% polyester / 60% cotton) and T/C (65% polyester / 35% cotton) T/C fabrics with medium energy disperse dye-reactive dye mixture: **a** red dye; **b** yellow dye and **c** blue dye

The levelness, in terms of relative unlevelness indices (RUI), of reverse micellar octane-dyed T/C textures by either scatter or receptive colours, or in combination, is delineated in Table 5. Dyed T/C textures (RD + LEDD) and (RD + HEDD) can accomplish good to excellent visual levelness as illustrated in Table 5. All the medium vitality coloured (RD + MEDD) T/C textures can pick up fabulous levelness with RUI values within the range from 0.032 to 0.477. Reactive-dyed with MEDD dyed T/C textures can accomplish great to amazing levelness with RUI extended from 0.032 to 0.477. With respect to Table 5, when diverse vitality levels of scatter colours are utilized in companion with responsive colours, both can too pick up great to amazing levelness with RUI values less than 0.5. This validates that the colour atoms are equitably disseminated inside the T/C textures without the arrangement

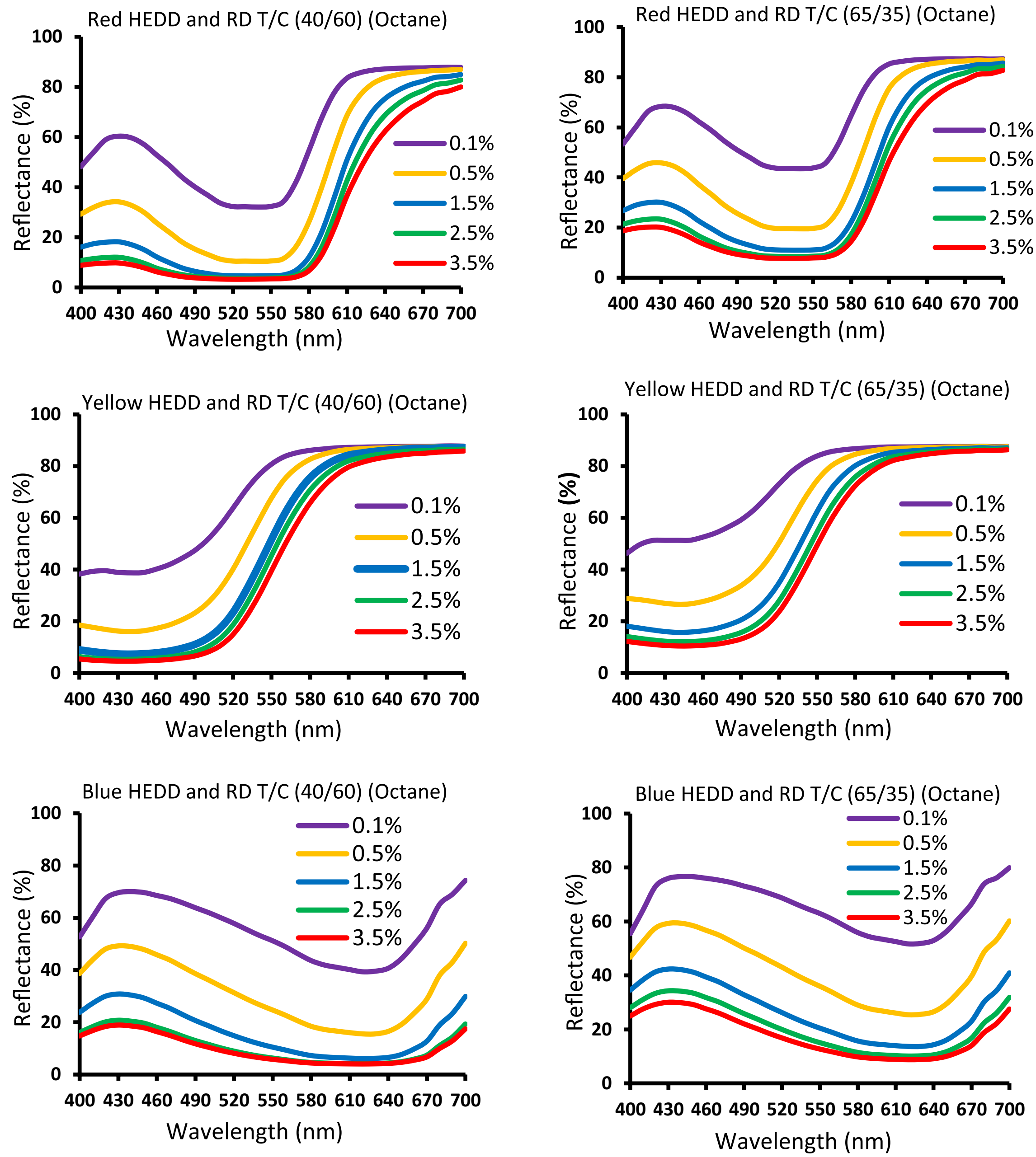

Fig. 4. The reflectance curves of octane-dyed T/C (40% polyester / 60% cotton) and T/C (65% polyester / 35% cotton) T/C fabrics with high energy disperse dye-reactive dye mixture: **a** red dye; **b** yellow dye and **c** blue dye

of expansive totals when octane medium is utilized for colouring of T/C textures.

3.5 Cross-Sectional Fibre Analysis

A 1000X optical light microscope is used to analyze the cross section of the red-dyed fabrics. The cross section of T40/C60 warp yarn is depicted in Fig. 7. It attested to the properties of polyester fibres with reference to Appendix I of AATCC Test Method 20 [42]. This indicated that the warp and weft yarn of T40/C60 were made of different fibres and explained that the warp yarn of T40/C60 was dull in appearance while the weft yarn of the fabric was luster in appearance.

The image revealed the yarn of these two fabrics constituted of both cotton (kidney-shape with lumen) and polyester (round shape) fibres. The warp and weft yarns are both manufactured from mixed fibres that have been combined and twisted into yarn before being woven.

Table 4 The CIE L*a*b* values of reverse micellar octane-dyed polyester/cotton blend fabrics (mixture of reactive dyes and various energy level of disperse dyes)

CIE L*a*b* (Octane Solvent)			HEDD (mixed with RD)			MEDD (mixed with RD)			LEDD (mixed with RD))		
Fabric	Dye	Dye conc	L*	a*	b*	L*	a*	b*	L*	a*	b*
T65/C35	Red	0.1	80.03	36.53	− 0.86	66.09	41.19	− 2.89	77.67	32.34	− 5.93
		0.5	65.49	45.85	1.55	52.24	51.07	1.22	64.28	51.13	− 3.98
		1.5	55.44	47.52	4.50	42.97	54.76	6.59	52.74	61.83	0.54
		2.5	51.16	48.17	6.84	39.30	55.28	9.31	47.77	63.84	3.96
		3.5	48.49	46.31	7.94	35.12	52.04	10.49	44.17	63.51	6.86
	Yellow	0.1	91.18	18.34	32.42	78.14	19.68	33.28	90.58	− 4.02	40.65
		0.5	85.71	28.70	48.63	65.41	30.86	47.17	84.99	4.42	66.61
		1.5	80.75	36.75	59.19	56.89	35.87	55.66	79.77	15.20	81.17
		2.5	77.67	38.69	59.81	52.66	38.06	56.31	77.28	21.49	86.68
		3.5	75.48	39.90	58.73	47.54	38.72	52.37	75.53	25.24	88.54
	Blue	0.1	83.27	− 9.77	− 20.04	66.73	− 6.49	− 23.22	73.05	− 6.19	− 21.97
		0.5	67.17	− 9.87	− 26.12	49.32	− 4.38	− 30.07	55.97	− 3.67	− 31.20
		1.5	53.92	− 6.14	− 28.86	34.35	0.24	− 31.38	40.05	0.09	− 36.24
		2.5	47.64	− 3.24	− 27.83	28.73	2.40	− 30.33	35.56	2.14	− 37.20
		3.5	44.38	− 0.30	− 26.34	24.91	3.75	− 28.54	29.66	5.05	− 36.19
T40/T60	Red	0.1	74.46	30.36	− 2.57	72.13	31.69	− 2.51	76.99	30.35	− 3.71
		0.5	57.41	42.80	− 2.63	55.99	50.06	− 0.93	64.35	47.84	− 3.37
		1.5	46.38	51.18	0.02	44.91	58.48	4.88	51.74	60.47	0.61
		2.5	42.15	52.06	3.06	42.14	57.19	6.64	46.41	62.56	4.50
		3.5	39.56	51.04	4.91	38.06	57.67	10.39	43.19	62.66	7.51
	Yellow	0.1	89.03	14.19	26.21	81.01	13.93	28.02	87.48	3.65	40.56
		0.5	82.65	24.43	53.07	69.73	25.91	55.50	81.94	13.07	67.06
		1.5	76.24	33.10	68.57	61.08	33.29	65.62	75.66	24.07	81.85
		2.5	73.46	34.78	68.29	57.66	34.08	64.57	72.61	28.69	85.37
		3.5	70.84	41.23	59.75	53.67	36.62	63.67	70.78	31.22	86.15
	Blue	0.1	76.91	− 7.94	− 15.96	71.39	− 5.08	− 18.34	75.68	− 5.66	− 17.26
		0.5	57.90	− 7.57	− 26.56	50.38	− 4.29	− 28.65	54.41	− 4.36	− 29.75
		1.5	41.09	− 3.21	− 30.84	33.99	0.77	− 32.71	39.40	− 0.47	− 34.41
		2.5	32.86	− 0.32	− 30.03	29.91	2.03	− 31.20	33.33	1.75	− 34.63
		3.5	31.46	2.48	− 28.75	24.11	4.31	− 28.95	27.30	4.77	− 33.52

3.6 Scanning Electron Microscopic Observation of Fibre Structure

Surface morphology is a key characteristic that indicates the dyeability of composite fabric. Therefore, the surface structures of polyester/cotton blend fabrics that were dyed in octane with various disperse dyes were examined using scanning electron microscope. The SEM pictures of the samples clearly show that dyed fabrics exhibit characteristic convoluted and wrinkle-like fibrous structure because of the longitudinal fibril structure, as seen in Figs. 8, 9, 10. Higher cotton percentage (60% cotton) resulted in a somewhat rougher and more inflated fabric surface compared to lower cotton percentage (35% cotton). Among all energy level disperse dyes, there were no appreciable variations in the morphology of the fibre surface.

3.7 Colour Fastness

3.7.1 Colour Fastness to Crocking (AATCC Test Method 8)

The colour staining results of dry crocking and wet crocking of the dyed T/C fabrics are revealed in Table 6, respectively. Generally speaking, fabrics tested by dry crocking can achieve better crocking fastness and smaller variation of rating relatively to wet crocking since wet crocking involves the use of wet cotton cloth which may increase the possibility of colour staining.

From the findings of both crocking tests, octane reverse micellar-dyed fabrics can achieve excellent dry crocking fastness with the rating of 5 and good to excellent wet crocking fastness with the rating of 4 to 5 in Table 6.

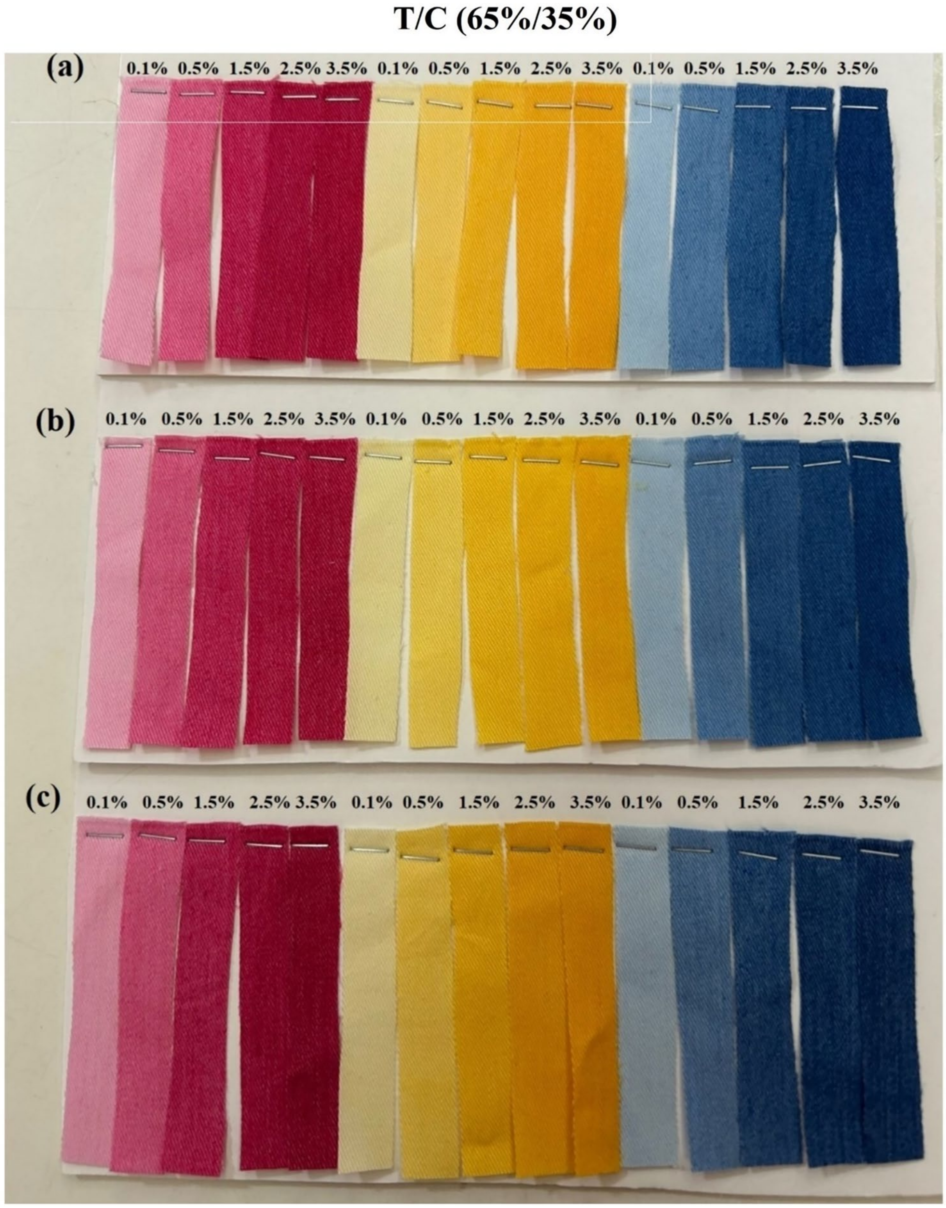

Fig. 5. Visual images of dyed T/C fabric (65% polyester / 35% cotton) using mixture of reactive dye and **a** low energy disperse dye; **b** medium energy disperse dye and **c** high energy disperse dye

The colour fastness to wet rubbing of dyed cotton fabrics is influenced by the depth of dyeing. When the concentration of the dye is relatively high, an excess of reactive dye particles may not effectively interact with the fibre surface, resulting in accumulation on the fibre surface, which manifests as a floating colour. Consequently, unfixed dyes are prone to detachment from the dyed fabric, and during the wet crocking process, lightly dyed fibres may be abraded and stained. This phenomenon complicates the achievement of a wet rubbing fastness rating of 5, ultimately leading to significant staining issues. In contrast, polyester fibres exhibit low water absorption properties, whereby water serves a lubricating function during the wet crocking colourfastness test. Therefore, fabrics with a higher polyester content, such as T65/C35, demonstrate slightly greater resistance to wet rubbing fastness compared to those with a lower polyester content, such as T40/C60.

3.7.2 Colour Fastness to Laundering (AATCC Test Method 61)

The colour change findings of colour fastness to laundering of reverse micellar-dyed T/C fabrics in octane medium are illustrated in Table 7. Generally speaking, octane-dyed specimens can acquire excellent washing fastness against colour change with a rating of 5. Table 7 exhibits the colour staining results of colour fastness to laundering of octane-dyed T/C fabrics. It is evident that specimen dyed with low energy and medium energy disperse dyes can acquire similar washing fastness against colour staining with rating 5 when

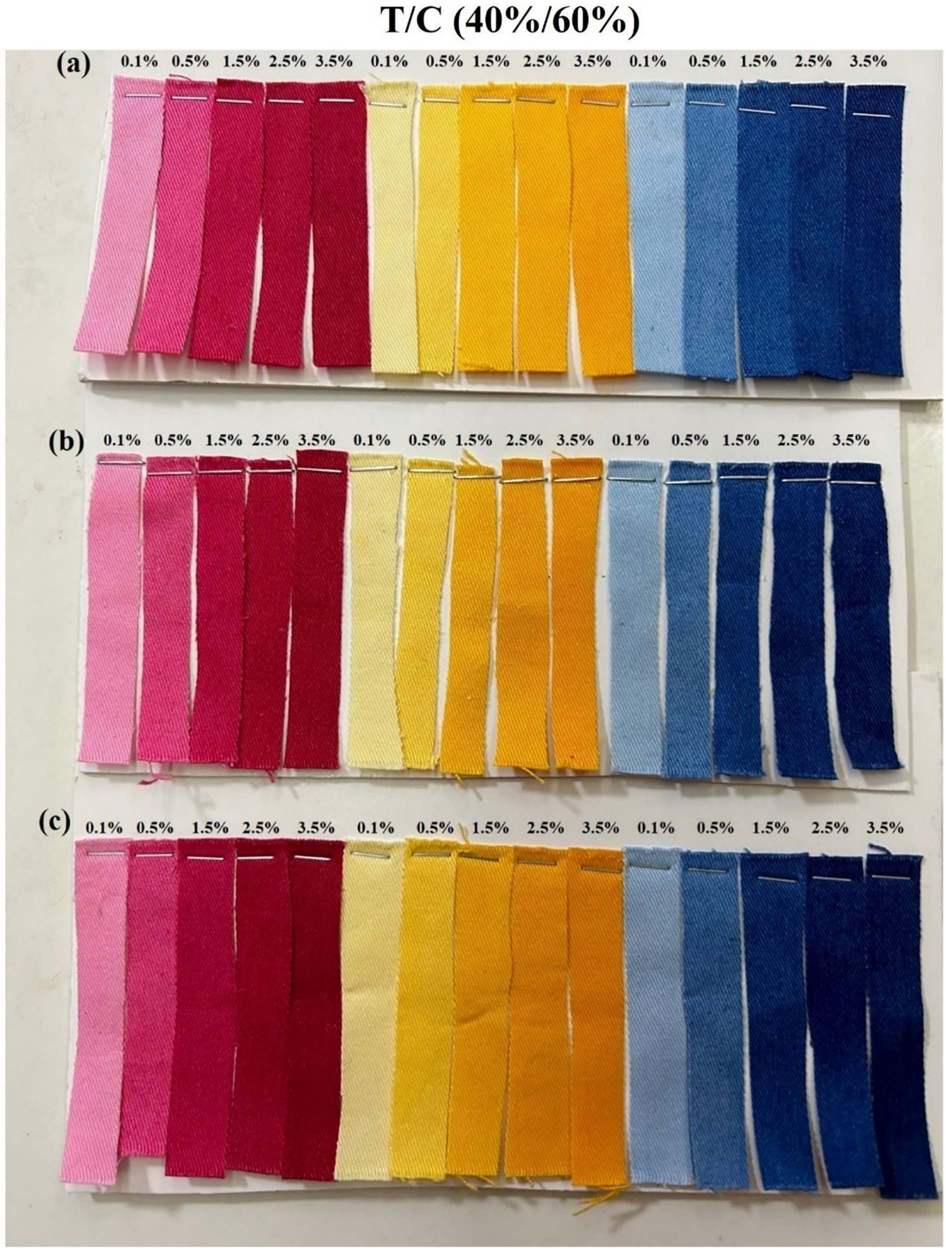

Fig. 6. Visual images of dyed T/C fabric (40% polyester / 60% cotton) using mixture of reactive dye and **a** low energy disperse dye; **b** medium energy disperse dye and **c** high energy disperse dye

compared to fabrics using high energy disperse dyes with rating ranged from 4 to 5. Good to excellent washing fastness results of fabrics dyed by different methods attest that the dyed specimens are thoroughly rinsed without unfixed and hydrolyzed dyes remaining in the fabrics.

3.7.3 Colour Fastness to Light (AATCC Test Method 16E)

The colour change results of light fastness of the dyed Tc fabrics are depicted in Table 8. Generally, octane reverse micellar-dyed fabrics can achieve good to excellent light fastness with the score between L6 and L8. Conventional water-dyed fabrics can also obtain good to excellent light fastness, but with a slightly lower score between L5 and L7 when compared with reverse micellar fabrics dyed with all energy-level disperse dyes.

4 Conclusion

The analysis of K/S values indicates that the combination of reactive dyes and disperse dyes with various energy levels results in differing colour strength responses as dye bath concentrations increase. The application of a mixture of reactive and disperse dyes at a temperature of 98 °C enhances the dyeability of polyester-cotton blends. However, the introduction of a carrier alters the colour values, which is contingent upon several factors including the hue of

Table 5 The RUI values and visual interpretations of octane-dyed polyester/cotton blend fabrics (disperse dye and reactive dye)

RUI (Octane Solvent)			RD + DD					
Fabric	Dye	Dye conc (%)	HEDD	Visual	MEDD	Visual	LEDD	Visual
T65/C35	Red	0.1	0.112	Excellent	0.045	Excellent	0.153	Excellent
		0.5	0.206	Good	0.165	Excellent	0.065	Excellent
		1.5	0.298	Good	0.265	Good	0.363	Good
		2.5	0.298	Good	0.271	Good	0.316	Good
		3.5	0.203	Good	0.260	Good	0.163	Excellent
	Yellow	0.1	0.040	Excellent	0.060	Excellent	0.038	Excellent
		0.5	0.046	Excellent	0.052	Excellent	0.033	Excellent
		1.5	0.046	Excellent	0.042	Excellent	0.076	Excellent
		2.5	0.074	Excellent	0.044	Excellent	0.061	Excellent
		3.5	0.095	Excellent	0.131	Excellent	0.079	Excellent
	Blue	0.1	0.027	Excellent	0.122	Excellent	0.032	Excellent
		0.5	0.123	Excellent	0.427	Good	0.358	Good
		1.5	0.458	Good	0.295	Good	0.141	Excellent
		2.5	0.310	Good	0.269	Good	0.197	Excellent
		3.5	0.373	Good	0.477	Good	0.303	Good
T40/C60	Red	0.1	0.129	Excellent	0.116	Excellent	0.056	Excellent
		0.5	0.300	Good	0.288	Good	0.289	Good
		1.5	0.267	Good	0.328	Good	0.257	Good
		2.5	0.164	Excellent	0.131	Excellent	0.097	Excellent
		3.5	0.182	Excellent	0.245	Good	0.226	Good
	Yellow	0.1	0.038	Excellent	0.032	Excellent	0.024	Excellent
		0.5	0.183	Excellent	0.092	Excellent	0.057	Excellent
		1.5	0.175	Excellent	0.141	Excellent	0.162	Excellent
		2.5	0.176	Excellent	0.193	Excellent	0.088	Excellent
		3.5	0.079	Excellent	0.215	Good	0.079	Excellent
	Blue	0.1	0.180	Excellent	0.109	Excellent	0.247	Good
		0.5	0.447	Good	0.122	Excellent	0.300	Good
		1.5	0.420	Good	0.097	Excellent	0.470	Good
		2.5	0.322	Good	0.302	Good	0.190	Excellent
		3.5	0.246	Good	0.408	Good	0.128	Excellent

the dye, the energy level, the concentration of the dye bath, and the dyeing temperature. Consequently, making informed decisions regarding these variables can be complex. It is uncommon for single dyes to be utilized in the dyeing of textile materials; rather, combination dyeing, which employs at least two dyes, is typically conducted to achieve the desired colour. In the context of combination dyeing on polyester-cotton blend fabrics, it is essential to utilize disperse dyes that share the same energy level to ensure uniform dyeing and to achieve the target colour on the initial attempt. It is widely recognized that dyes within the same energy level can be combined with a higher degree of safety compared to those from differing energy levels. The findings of the current study suggest that disperse dyes, despite being classified within the same energy level, may exhibit varied and distinct colouring behaviours during reverse micellar dyeing of polyester-cotton fibres.

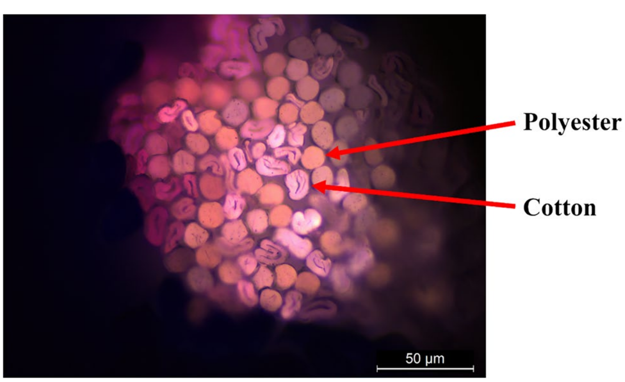

Fig. 7. Microscopic cross section analysis of fibre composition of dyed T/C (40% cotton / 60% polyester) fabrics with 1000X magnification

T/C blend fabrics were successfully dyed using a one-bath, one-step dyeing procedure that used a physical mixing of disperse/reactive dye. The novel aspect of the study is the successful blending of commercially available

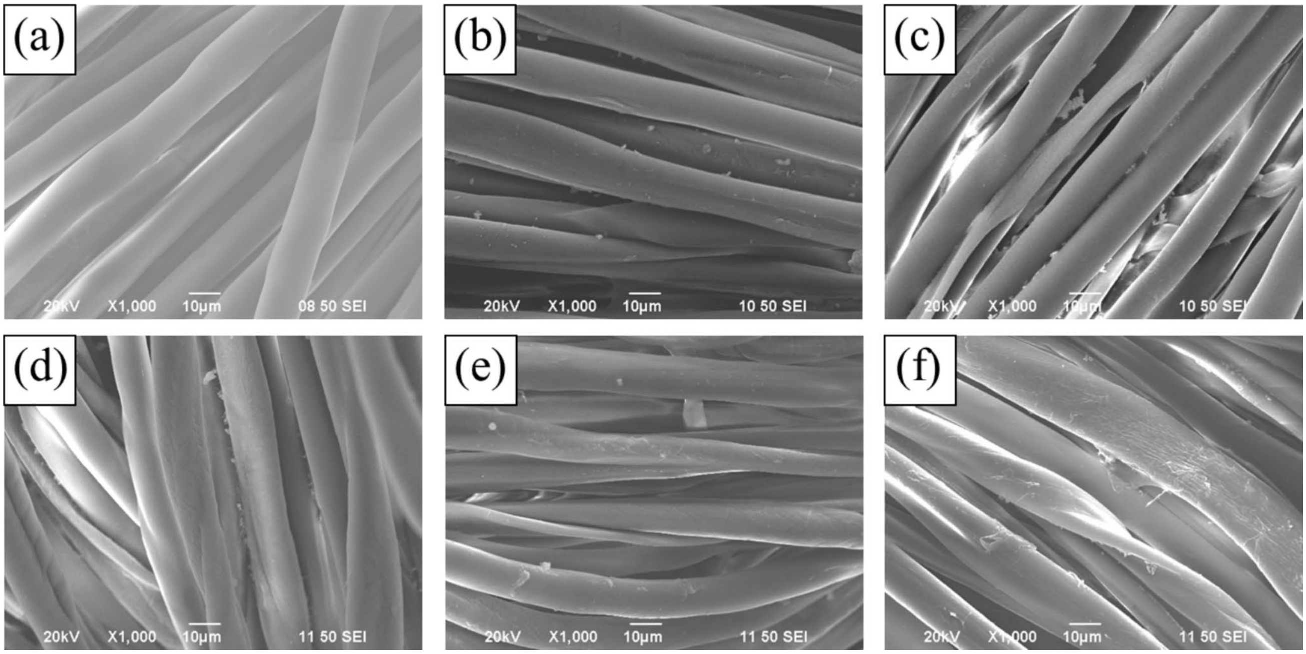

Fig. 8. SEM micrographs of T/C (65% polyester / 35% cotton) fabric dyed with **a** low energy red, **b** low energy yellow, **c** low energy blue disperse dyes and T/C (40% polyester / 60% cotton) fabric dyed with **d** low energy red, **e** low energy yellow and **f** low energy blue disperse dyes

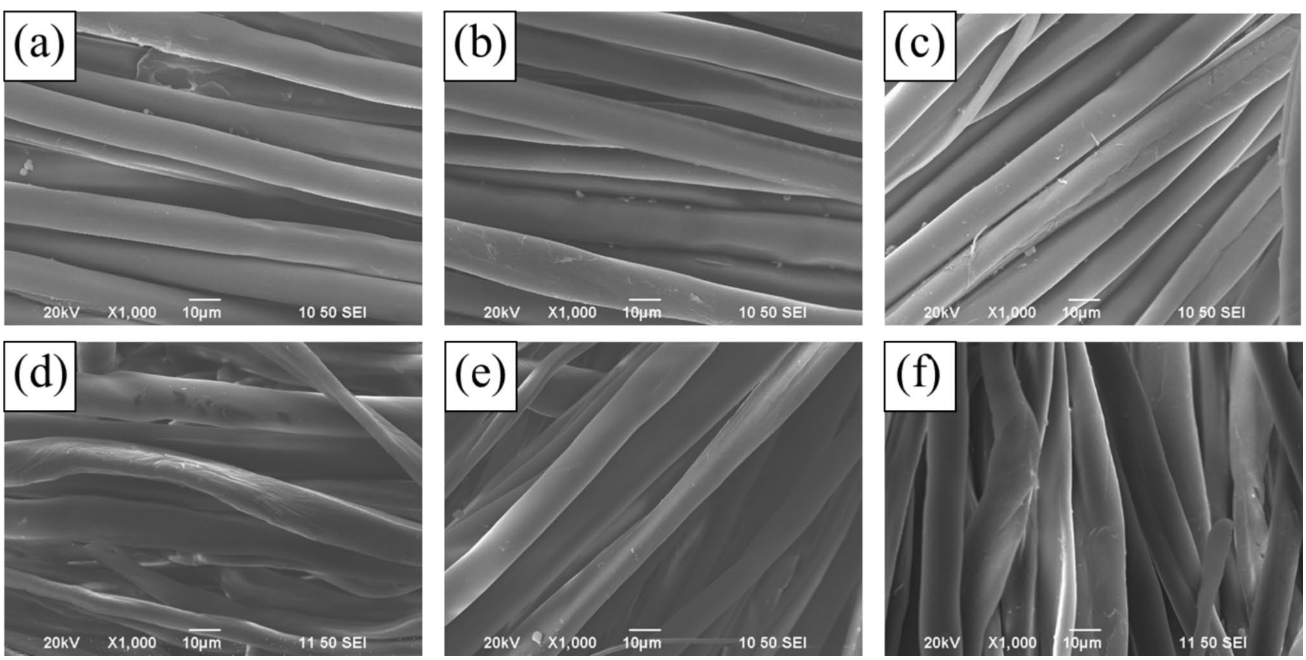

Fig. 9. SEM micrographs of T/C (65% polyester / 35% cotton) fabric dyed with **a** medium energy red, **b** medium energy yellow, **c** medium energy blue disperse dyes and T/C (40% polyester / 60% cotton) fabric dyed with **d** medium energy red, **e** medium energy yellow and **f** medium energy blue disperse dyes

dyes in powder form in order to generate the whole shade spectrum, which will provide new opportunities for dyestuff producers to meet the needs of textile processors for blend dyeing. Colour strength due to dye fixation is closely related to their energy level of dyes in this study, the medium-energy azo-based disperse dyes had the highest K/S values and dye uptake. The work is based on the well-known dyeing technique, but ready-made dyes will

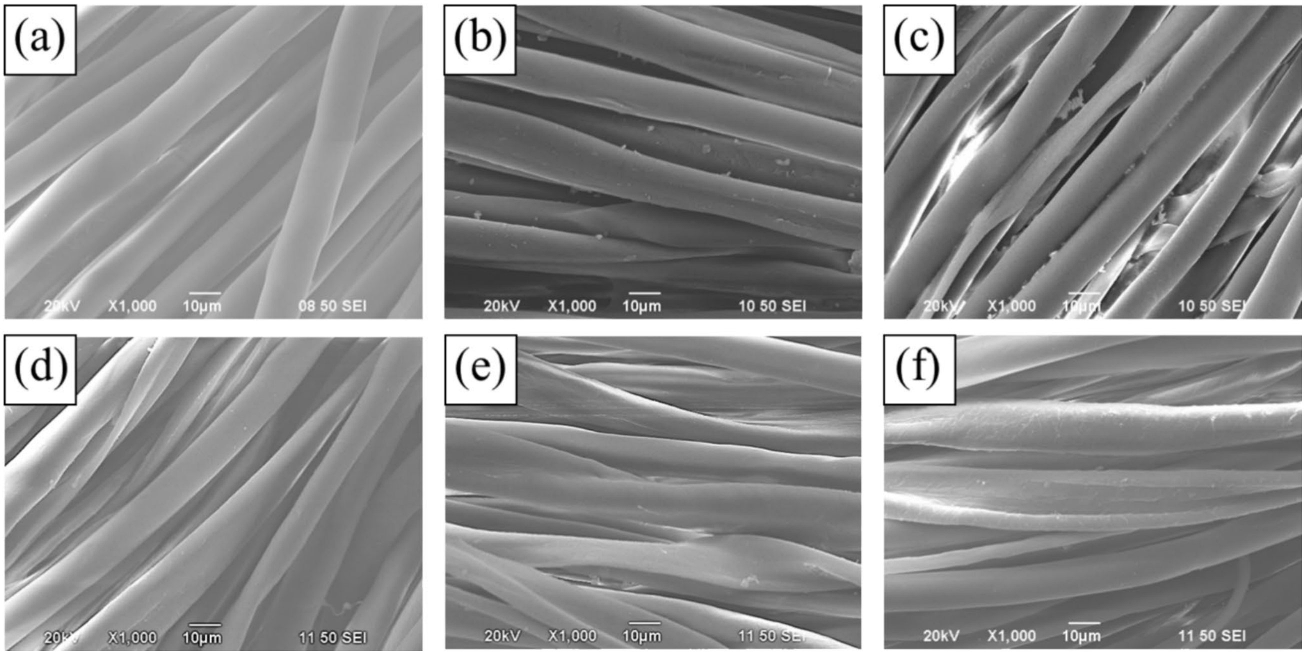

Fig. 10. SEM micrographs of T/C (65% polyester / 35% cotton) fabric dyed with **a** high energy red, **b** high energy yellow, **c** high energy blue disperse dyes and T/C (40% polyester / 60% cotton) fabric dyed with **d** high energy red, **e** high energy yellow and **f** high energy blue disperse dyes

Table 6 Various colour staining rating of octane-assisted dyed specimens for colour fastness to dry crocking and wet crocking

Octane			Dry crocking	Wet crocking
Specimen	Colour	Depth (%)	Rating	Rating
T65/C35 High energy disperse dye	Red	1.5	5	4
	Blue	1.5	5	4–5
	Yellow	1.5	5	4–5
T65/C35 Medium energy disperse dye	Red	1.5	5	4
	Blue	1.5	5	4–5
	Yellow	1.5	5	4–5
T65/C35 Low energy disperse dye	Red	1.5	5	5
	Blue	1.5	5	4
	Yellow	1.5	5	4–5
T40/C60 High energy disperse dye	Red	1.5	5	4
	Blue	1.5	5	4
	Yellow	1.5	5	4–5
T40/C60 Medium energy disperse dye	Red	1.5	5	4–5
	Blue	1.5	5	4–5
	Yellow	1.5	5	4–5
T40/C60 Low energy disperse dye	Red	1.5	5	4–5
	Blue	1.5	5	4–5
	Yellow	1.5	5	4–5

Where rating: 5 = Excellent washing fastness; 1 = Poorest washing fastness

become an option for dyers to do away with laborious hue matching at their end. Additionally, this one-bath, one-step dyeing method has the potential to result in time, energy, water, and labour savings. This study illustrates the precise possibilities of a T/C blend dyeing method that is commercially viable by utilizing a physical mixing of disperse/reactive dye.

Table 7 Colour change and staining rating of octane-dyed specimens for colour fastness to laundering

Specimen	Colour	Depth (%)	Colour change Rating	Colour staining Rating of multifibre strips
T65/C35 High energy disperse dye	Red	1.5	5	5/5/5/4–5/4–5/4–5
	Blue	1.5	5	4–5/5/4–5/4–5/5/4–5
	Yellow	1.5	5	5/5/5/5/5/5
T65/C35 Medium energy disperse dye	Red	1.5	5	4/5/4–5/4–5/4–5/4–5
	Blue	1.5	5	5/5/5/4–5/5/5
	Yellow	1.5	5	5/5/5/5/5/5
T65/C35 Low energy disperse dye	Red	1.5	5	5/5/5/5/5/5
	Blue	1.5	5	5/5/5/4–5/5/5
	Yellow	1.5	5	5/5/5/4–5/5/5
T40/C60 High energy disperse dye	Red	1.5	5	5/5/4–5/4–5/4–5/4–5
	Blue	1.5	5	5/5/5/4–5/4–5/5
	Yellow	1.5	5	5/5/5/5/4–5/5
T40/C60 Medium energy disperse dye	Red	1.5	5	4–5/5/4–5/4–5/4–5/4–5
	Blue	1.5	5	5/5/5/4–5/4–5/5
	Yellow	1.5	5	5/5/5/5/4–5/4–5
T40/C60 Low energy disperse dye	Red	1.5	5	5/5/5/4–5/4–5/5
	Blue	1.5	5	5/5/5/4–5/4–5/4–5
	Yellow	1.5	5	5/5/5/4–5/5/5

Where rating: 5 = Excellent washing fastness; 1 = Poorest washing fastness

The order of multifibre strips is wool/Acrylic/Polyester/Nylon/Cotton/Acetate

Table 8 Colour change rating of water-dyed and octane-dyed specimens for colorfastness to light

Colour change			Water	Octane
Specimen	Colour	Depth (%)	Rating	Rating
T65/C35 High energy	Red	1.5	L 5	L 7
	Blue	1.5	L 6	L 7
	Yellow	1.5	L 5	L 5
T65/C35 Medium energy	Red	1.5	L 6	L 7
	Blue	1.5	L 6	L 7
	Yellow	1.5	L 6	L 7
T65/C35 Low energy	Red	1.5	L 7	L 8
	Blue	1.5	L 8	L 8
	Yellow	1.5	L6	L 7
T40/C60 High energy	Red	1.5	L 5	L 7
	Blue	1.5	L 5	L 7
	Yellow	1.5	L 6	L6
T40/C60 Medium energy	Red	1.5	L 6	L 7
	Blue	1.5	L 7	L 8
	Yellow	1.5	L 6	L 7
T40/C60 Low energy	Red	1.5	L 6	L 8
	Blue	1.5	L 7	L 8
	Yellow	1.5	L 6	L 7

Where rating: L8 = Excellent light fastness; L2 = Poorest light fastness

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Data Availability All data generated and analyzed during this study are included in this published article.

Declarations

Conflict of interest None.

Ethical Approval The authors confirm that there were no ethical issues in preparing this manuscript.

Consent to Participate All authors consent to participate in this work.

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