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Effect of Material-to-Liquor Ratio on Fastness Performance and Color Strength of Polyester/Cotton Blended Knitted Fabric Dyed by One-Bath Two-Stage Dyeing

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Abstract: This study investigated the effect of the material-to-liquor (M:L) ratio on the dyeing performance of a 65/35 polyester/cotton blended single jersey knitted fabric using a one-bath, two-stage dyeing process under laboratory conditions. The polyester component was dyed with disperse dyes at high temperature under acidic conditions, followed by reactive dyeing of the cotton component under alkaline conditions. Three different material-to-liquor ratios (1:8, 1:9, and 1:10) were evaluated to assess their influence on color fastness and shade characteristics.

The washing fastness results showed good to excellent resistance to color change (rating 4–5) for all investigated dyeing conditions, indicating stable shade retention after laundering. Excellent staining resistance (4–5 rating) was observed against acetate, nylon, polyester, acrylic, and wool adjacent fabrics, while staining on cotton improved from 2–3 at 1:8 and 1:9 M:L to 3–4 at 1:10 M:L, suggesting reduced dye transfer at a higher liquor ratio. Dry rubbing fastness remained consistently good to excellent (4–5) across all dyeing conditions, whereas wet rubbing fastness improved from 2 at 1:8 M:L to 3 at 1:10 M: L.

Reflectance and color strength (K/S) analysis of selected samples indicated a slight inverse relationship between the two. The 1:8 M:L sample exhibited 51.86% reflectance and a K/S value of 0.223, while the 1:10 M:L sample showed 52.00% reflectance and a K/S value of 0.222, indicating only a marginal difference in shade depth.

Overall, the findings suggest that material-to-liquor ratio influences dyeing performance in one-bath two-stage polyester/cotton blend dyeing, with higher liquor ratio improving washing and wet rubbing fastness, while lower liquor ratio showing slightly higher Color strength.

Keywords: One-Bath Two-Stage Dyeing, Polyester/Cotton Blended Fabric, Material-to-Liquor Ratio, Color Fastness, Color Strength (K/S).

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I. INTRODUCTION

Blended fabrics have gained significant popularity among consumers owing to their improved qualities, lower cost, and wide range of applications [1].

However, double-bath blend dyeing requires a longer processing time, thereby increasing overall costs. In addition, from an environmental perspective, this method is less favourable because it consumes nearly twice as much energy and chemicals as single-bath dyeing [2, 3].

Therefore, researchers have devoted considerable effort over the years to achieving union dyeing through a single-bath, single-stage exhaust method. Consequently, increasing interest in single-bath blend dyeing has been reflected in recent studies, including those on polyester/cotton [3-6], wool/polyester [7, 8], and wool/acrylic blends.

For example, Islam et al. developed a single-bath, single-stage dyeing method for cotton/acrylic-blended fabric using indigo dye as an alternative to conventional multi-bath processing. Their experimental findings demonstrated that process simplification could significantly reduce dyeing time, chemical consumption, and operational complexity while maintaining acceptable color fastness performance [9].

Focusing specifically on polyester/cotton blends, conventional polyester/cotton blend dyeing typically requires separate dyeing stages for the polyester and cotton components, resulting in high water, energy, and chemical consumption.

The complexity of polyester/cotton blend dyeing has encouraged the development of sustainable one-bath dyeing approaches. Riaz et al. proposed a sustainable one-bath dyeing approach for polyester/cotton blends by chemically modifying the cotton component to enable disperse dyeing, demonstrating improved color depth and acceptable fastness performance [10].

In a further development, Zhou et al. successfully achieved one-bath dyeing of a 65/35 polyester/cotton fabric using reactive disperse dyes in supercritical CO_2, reporting satisfactory color strength and fastness performance while eliminating the need for conventional water-intensive processing [11].

Despite continued progress in one-bath polyester/cotton dyeing technologies, studies focusing on the process optimisation of conventional aqueous one-bath two-stage dyeing remain relatively limited, particularly regarding the influence of the material-to-liquor ratio on dyeing quality. As the M:L ratio plays an important role in dye distribution, fixation behaviour, fastness performance, and color yield, understanding its effects is relevant for both laboratory optimisation and industrial applications. Accordingly, this study evaluates the effect of different material-to-liquor ratios on the dyeing performance of a 65/35 polyester/cotton blended knitted fabric, including washing fastness, rubbing fastness, and color strength.

II. EXPERIMENTS

➤ *Materials*

The materials employed for fabric pretreatment, dyeing, and subsequent evaluation are summarized in Table 1.

Table 1 Materials Used in the Experiment.

Material Category	Material Name	Specification / Trade Name	Function
Fabric	Polyester/cotton blended single jersey knitted fabric	65/35 P/C blend	Substrate for dyeing
Disperse dye	Disperse Red	Foron Red SWF	Dyeing of polyester component
Disperse dye	Disperse Yellow	Foron Brilliant Yellow SWF	Dyeing of polyester component
Disperse dye	Disperse Blue	Foron Carbon SE-WF	Dyeing of polyester component
Reactive dye	Reactive Red	Drimaren Ultimate Crimson HD	Dyeing of cotton component
Reactive dye	Reactive Yellow	Drimaren Ultimate Yellow HD	Dyeing of cotton component
Reactive dye	Reactive Blue	Drimaren Ultimate Blue HD	Dyeing of cotton component
Chemical	Glauber salt	Laboratory grade	Electrolyte for reactive dyeing
Chemical	Soda ash	Na_2CO_3	Alkali for dye fixation
Chemical	Sodium hydroxide	NaOH	Scouring agent
Chemical	Hydrogen peroxide	H_2O_2	Bleaching agent
Chemical	Wetting agent	Kieralon CDP	Improves wetting and penetration
Chemical	Sequestering agent	Lufibrol 2UD	Controls metal ions in dye bath
Chemical	Leveling agent	Dekol SN Liquid	Promotes uniform dyeing

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Chemical	Acetic acid	Invatex	pH adjustment in disperse dyeing
Chemical	Carrier	Delatin POE	Assists polyester dye diffusion
Chemical	Hydrose	Commercial grade	Reduction clearing agent
Chemical	Detergent	Laboratory grade	Washing and pretreatment

➢ *Equipment*

The equipment used for pretreatment, dyeing, and testing of the fabric samples are summarized in Table 2.

Table 2 Equipment Used in the Study Experiment.

Equipment Category	Equipment Name	Specification / Model	Function
Dyeing Equipment	Sample Dyeing Machine	Laboratory scale	Used for fabric pretreatment and dyeing processes
Drying Equipment	Sample Dryer	Laboratory scale	Used for drying treated and dyed fabric samples
Testing Equipment	SDL Atlas Rotawash Machine	ISO compatible	Used for color fastness to washing test
Testing Equipment	Crock Meter (Crock Master)	ISO compatible	Used for dry and wet rubbing fastness test
Testing Equipment	Spectrophotometer	Datacolor 800TM	Used for reflectance (%) and color strength (K/S) measurement
Measuring Equipment	Electronic Balance	Laboratory grade	Used for accurate weighing of fabric, dyes, and chemicals
Assessment Equipment	Grey Scale	ISO standard	Used for evaluating color change and staining

➢ *Fabric Pretreatment*

Before dyeing, the 65/35 polyester-cotton blended single jersey knitted fabric was subjected to combined scouring and bleaching in a single bath to remove natural impurities, surface contaminants, waxes, and other non-fibrous substances, thereby improving fabric absorbency and promoting uniform dye uptake during subsequent dyeing. The pretreatment was carried out under controlled laboratory conditions using a sample dyeing machine. The pretreatment recipe and operating conditions used in this study are presented in Table 3.

Table 3 Recipe for Combined Scouring and Bleaching of Polyester/Cotton Blended Fabric.

Chemical / Parameter	Amount	Function
Sodium Hydroxide (NaOH)	2.5 g/L	Scouring agent
Hydrogen Peroxide (H_2O_2)	2.5 g/L	Bleaching agent
Wetting Agent	1.0 g/L	Improves wetting and penetration
Sequestering Agent	1.0 g/L	Controls metal ions
Detergent	1.0 g/L	Removes impurities
Acetic Acid	0.5 g/L	Neutralizing agent
pH	11.5	Process condition
Temperature	95 °C	Process condition
Time	60 min	Process duration
Material-to-Liquor Ratio	1:8	Process condition

The temperature profile followed during the combined scouring and bleaching process is illustrated in Fig.1.

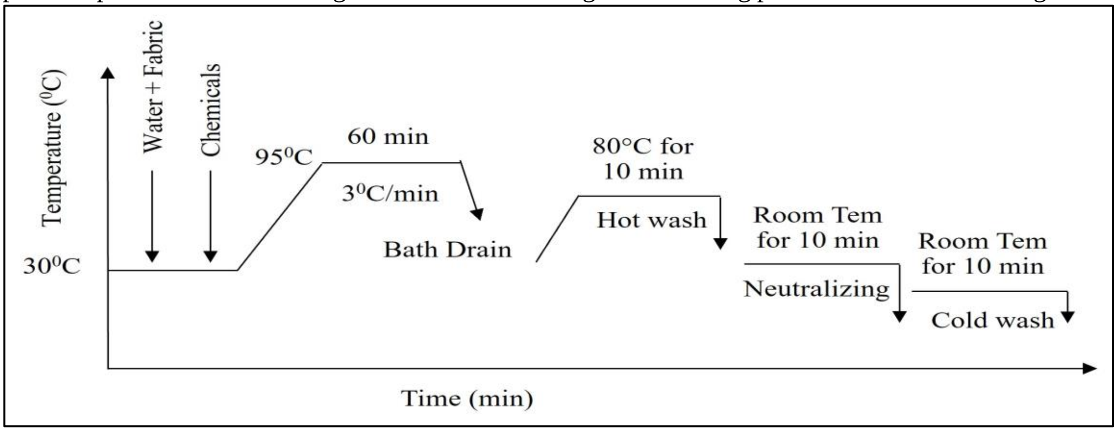

Fig 1 Temperature Profile for Combined Scouring and Bleaching of Polyester/Cotton Blended Fabric.

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Fabric samples were cut to the required experimental dimensions and placed in the pretreatment bath containing the specified amount of water and auxiliary chemicals. The combined scouring and bleaching process was conducted at 95 ℃ for 60 minutes under alkaline conditions. After pretreatment, the fabric samples were subjected to hot washing at 80 ℃ for 10 minutes, followed by neutralisation with 0.5 g/L acetic acid at room temperature, cold rinsing for 10 minutes, and subsequent drying under laboratory conditions before dyeing.

➢ *One-Bath Two-Stage Dyeing Procedure*

Following fabric pretreatment, the 65/35 polyester-cotton blended single jersey knitted fabric was dyed using a one-bath two-stage dyeing method under controlled laboratory conditions. In this process, the polyester component was first dyed with disperse dyes under high-temperature, acidic conditions, followed by dyeing the cotton component with reactive dyes under alkaline conditions within the same experimental framework. Three different material-to-liquor (M:L) ratios, namely 1:8, 1:9, and 1:10, were investigated to evaluate their influence on dyeing performance.

- *Polyester Dyeing Stage*

The polyester portion of the blended fabric was dyed with disperse dyes at high temperatures. The dyeing recipe for the polyester stage is presented in Table 4, and the corresponding dyeing temperature profile is shown in Fig.2.

Table 4 Dyeing Recipe for Polyester Component of Polyester/Cotton Blended Fabric.

Component	**1:8 M:L**	**1:9 M:L**	**1:10 M:L**
Disperse Yellow (Foron Brilliant Yellow SWF)	0.25%	0.25%	0.25%
Disperse Red (Foron Red SWF)	1.0%	1.0%	1.0%
Disperse Blue (Foron Carbon SE-WF)	0.10%	0.10%	0.10%
Sequestering Agent	1.0 g/L	1.0 g/L	1.0 g/L
Leveling Agent	1.0 g/L	1.0 g/L	1.0 g/L
Acetic Acid	0.5 g/L	0.5 g/L	0.5 g/L
pH	4–5	4–5	4–5
Time	60 min	60 min	60 min
Temperature	130 ℃	130 ℃	130 ℃

The temperature profile used for polyester dyeing is illustrated in Fig.2.

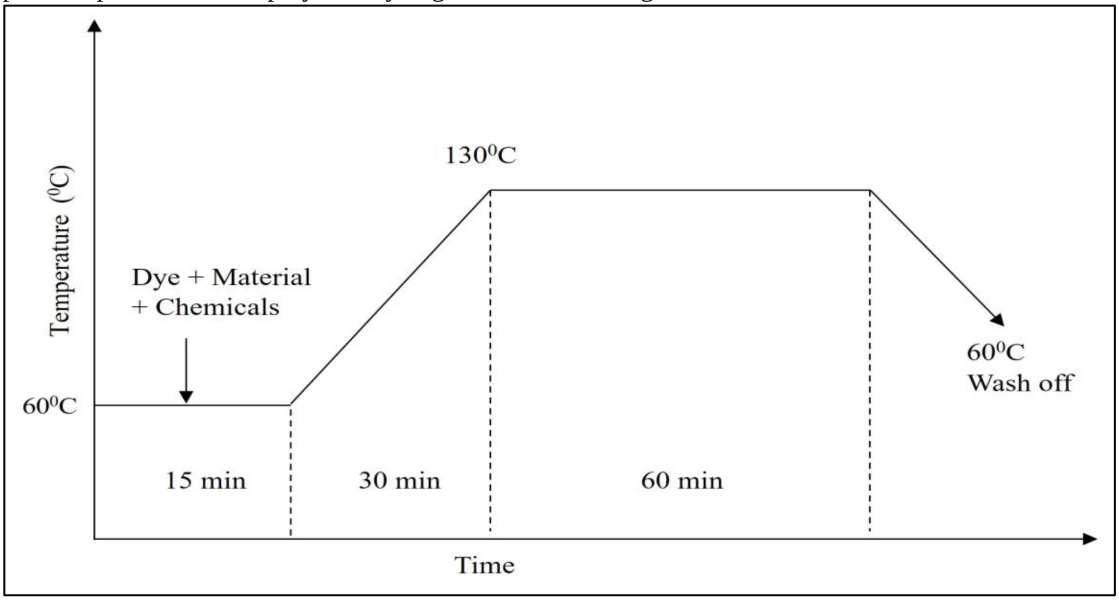

Fig 2 Temperature Profile for Polyester Dyeing Stage in One-Bath Two-Stage Dyeing Process.

For polyester dyeing, the required amounts of water, disperse dyes, auxiliary chemicals, and fabric samples were added to the dye bath. The bath pH was adjusted to 4–5 with acetic acid. The dye bath was initially maintained at 60 ℃ for 15 minutes, after which the temperature was gradually increased to 130 ℃ and maintained for 60 minutes to facilitate effective diffusion and adsorption of disperse dye molecules into the polyester component. Upon completion of dyeing, the bath was cooled to 60 ℃, followed by hot rinsing, reduction clearing, and washing before proceeding to the subsequent cotton dyeing stage.

- *Cotton Dyeing Stage*

After polyester dyeing, the cotton component of the blended fabric was dyed with reactive dyes under alkaline conditions. The dyeing recipe used for the cotton stage is presented in Table 5, and the process temperature profile is shown in Fig.3.

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Table 5 Dyeing Recipe for Cotton Component of Polyester/Cotton Blended Fabric.

Component	1:8 M:L	1:9 M:L	1:10 M:L
Reactive Yellow (Drimaren Ultimate Yellow HD)	0.5%	0.5%	0.5%
Reactive Red (Drimaren Ultimate Crimson HD)	1.0%	1.0%	1.0%
Reactive Blue (Drimaren Ultimate Blue HD)	0.2%	0.2%	0.2%
Wetting Agent	1.0 g/L	1.0 g/L	1.0 g/L
Glauber Salt	30 g/L	30 g/L	30 g/L
Soda Ash	12 g/L	12 g/L	12 g/L
pH	10–11	10–11	10–11
Time	60 min	60 min	60 min
Temperature	60 °C	60 °C	60 °C

The temperature profile used for cotton dyeing is illustrated in Fig.3.

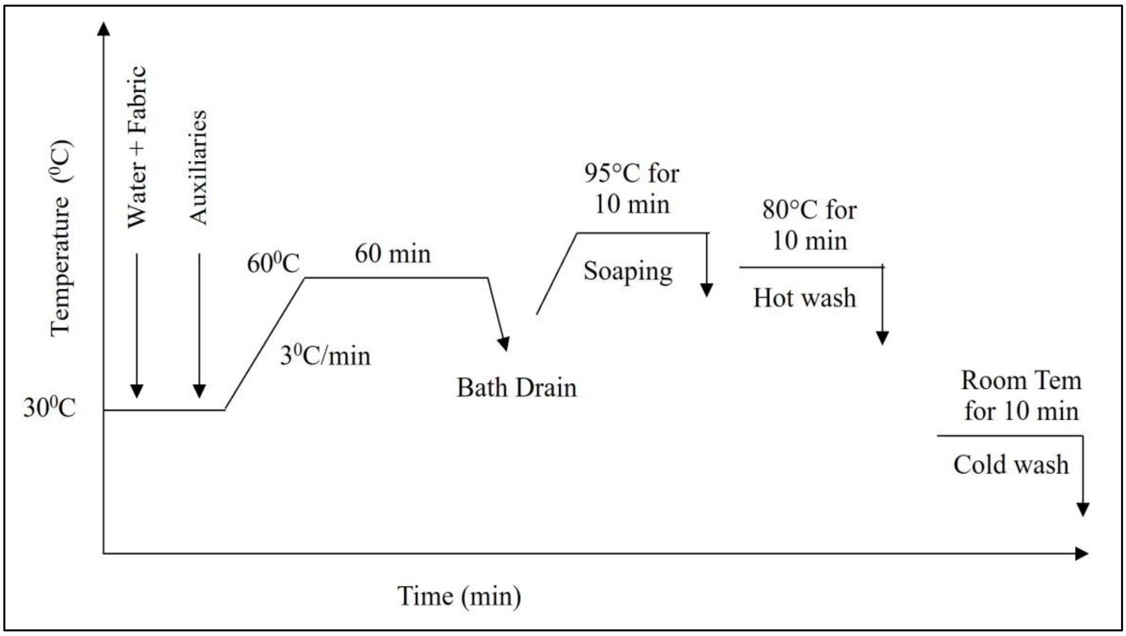

Fig 3 Temperature Profile for Cotton Dyeing Stage in One-Bath Two-Stage Dyeing Process.

For the cotton dyeing stage, fabric samples were prepared in rectangular form with an individual sample weight of 10 g. The required amounts of water, reactive dyes, and auxiliary chemicals (excluding soda ash) were added to the dye bath along with the fabric samples. Dyeing was carried out at 60 °C for 60 minutes. After the initial 20 minutes, the required amount of soda ash was introduced to establish alkaline conditions and promote fixation of the reactive dyes onto the cotton component. Upon completion of dyeing, the dye bath was drained, followed by soaping at 95 °C for 20 minutes, hot washing at 80 °C for 10 minutes, cold washing at room temperature for 10 minutes, and final drying under laboratory conditions.

➢ *Testing Methods*

- *Color Fastness to Washing*

Color fastness to washing of the dyed polyester/cotton blended fabric samples was evaluated according to BS EN ISO 105-C06:2010 (B2S) using an SDL Atlas Rotawash machine. Dyed fabric specimens measuring 10 cm × 4 cm were stitched with adjacent multifiber fabric and conditioned before testing. The washing solution consisted of 4 g/L ECE detergent and 1 g/L sodium perborate prepared in distilled water.

For each test, 150 mL of washing solution and 25 stainless steel balls were placed in the test container to simulate the washing action. The specimens were tested at 50 °C for 30 minutes, then rinsed with cold water and dried under laboratory conditions. The washed specimens were evaluated for color change and staining using the standard grey-scale rating system.

- *Color Fastness to Rubbing*

Color fastness to rubbing (dry and wet) of the dyed polyester/cotton blended fabric samples was evaluated according to BS EN ISO 105-X12:2001 using a James H. Heal Crockmaster rubbing fastness tester. Dyed fabric specimens measuring 15 cm × 5 cm were tested against standard white cotton rubbing cloth measuring 5 cm × 5 cm.

The rubbing test was carried out using a 16 mm diameter rubbing finger with a stroke length of 104 ± 3 mm under an applied downward force of 9 N. Each specimen was subjected to 10 rubbing cycles under both dry and wet conditions. For wet rubbing assessment, the rubbing cloth

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was wetted with distilled water before testing. After completion of the test, the degree of color staining on the rubbing cloth was evaluated using the standard grey-scale for staining.

- *Color Strength (K/S) Measurement*

The color strength (K/S) of the dyed polyester/cotton-blended fabric samples was evaluated by reflectance measurement using a Datacolor 800TM spectrophotometer. Reflectance values of the dyed samples were recorded, and the corresponding color strength was calculated using the Kubelka–Munk equation:

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

Where R represents the reflectance value, K is the absorption coefficient, and S is the scattering coefficient. Higher K/S values indicate greater color strength and deeper shade development.

III. RESULTS AND DISCUSSIONS

➢ *Color Fastness to Washing*

The washing fastness performance of the dyed polyester/cotton blended fabric samples produced at different material-to-liquor (M:L) ratios was evaluated in terms of color change and color staining, and the results are presented in Table 6, Fig.4, and Fig.5.

Table 6 Color Fastness to Washing of Dyed Polyester/Cotton Blended Fabric at Different Material-to-Liquor Ratios.

M:L Ratio	Color Change	Color Staining					
		Di-acetate	Cotton	Nylon	Polyester	Acrylic	Wool
1:8	4-5	4-5	2-3	4-5	4-5	4-5	4-5
1:9	4-5	4-5	2-3	4-5	4-5	4-5	4-5
1:10	4-5	4-5	3-4	4-5	4-5	4-5	4-5

The color fastness to washing results indicate that all dyed samples exhibited good to excellent resistance to color change, with a consistent rating of 4–5 across all investigated material-to-liquor ratios. This suggests that variation in the M:L ratio within the selected experimental range had little effect on the overall shade retention of the dyed polyester/cotton-blended fabric after washing.

In terms of color staining, the dyed samples demonstrated excellent resistance to staining on acetate, nylon, polyester, acrylic, and wool adjacent fabrics, all showing ratings of 4–5 irrespective of the material-to-liquor ratio. However, staining behaviour on the cotton adjacent fabric showed noticeable variation. At 1:8 and 1:9 M:L, the staining rating remained 2–3, indicating greater dye transfer, whereas at 1:10 M:L, the rating improved to 3–4, reflecting reduced staining behaviour.

This improvement in cotton staining fastness at a higher liquor ratio may be attributed to improved dye dispersion and more controlled dye exhaustion during the one-bath two-stage dyeing process. A higher liquor ratio provides greater bath volume, which may reduce localised dye concentration and minimise the presence of loosely bound, unfixed dye molecules on the cotton component, thereby reducing dye bleeding during washing.

Overall, the washing fastness results suggest that all investigated dyeing conditions produced acceptable washing durability. At the same time, the 1:10 material-to-liquor ratio showed better staining resistance on cotton fabric, indicating improved wash fastness under this condition.

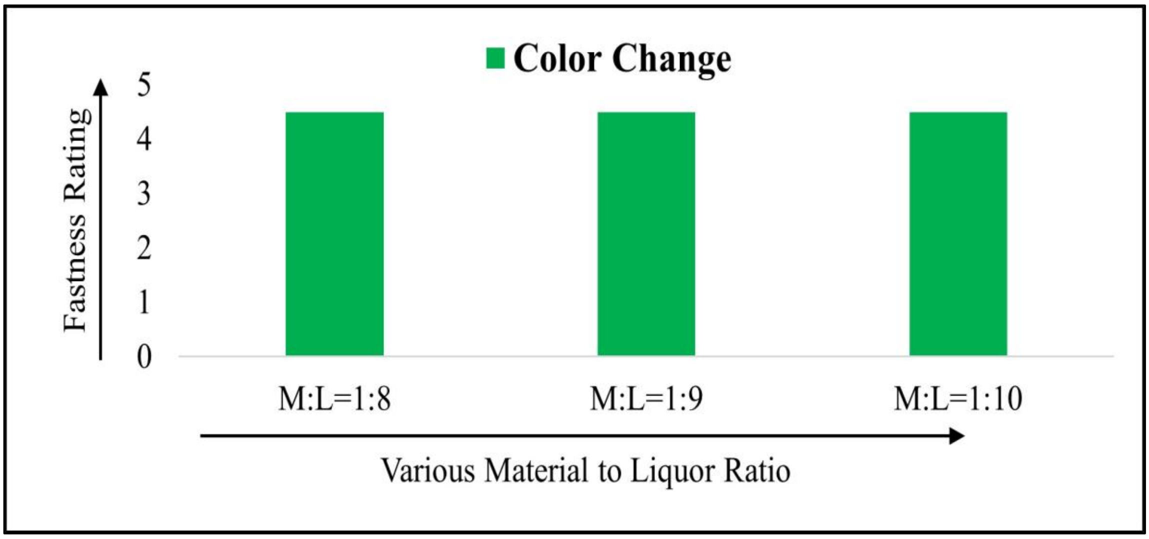

Fig 4 Color Fastness to Washing (Color Change) of Dyed Polyester/Cotton Blended Fabric at Different Material-to-Liquor Ratios.

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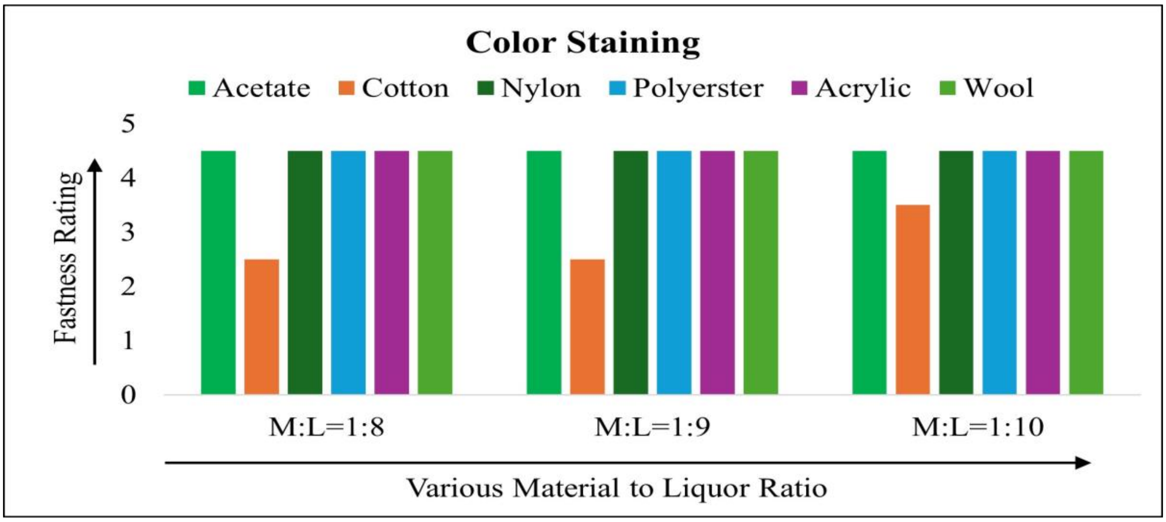

Fig 5 Color Fastness to Washing (Color Staining) of Dyed Polyester/Cotton Blended Fabric at Different Material-to-Liquor Ratios.

➢ *Color Fastness to Rubbing*

The rubbing fastness performance of the dyed polyester/cotton blended fabric samples produced at different material-to-liquor (M:L) ratios was evaluated under both dry and wet rubbing conditions, and the results are presented in Table 7 and Fig.6.

Table 7 Color Fastness to Rubbing of Dyed Polyester/Cotton Blended Fabric at Different Material-to-Liquor Ratios.

M:L Ratio	Dry Rubbing	Performance	Wet Rubbing	Performance
1:8	4–5	Good to excellent	2	Moderate
1:9	4–5	Good to excellent	2–3	Moderate to average
1:10	4–5	Good to excellent	3	Average

The results indicate that all dyed fabric samples exhibited good to excellent dry rubbing fastness, with a consistent rating of 4–5 across all investigated material-to-liquor ratios. This suggests that variation in the M:L ratio had minimal influence on dry rubbing performance, and the dye molecules remained adequately fixed within the fibre structure under dry mechanical friction conditions.

However, noticeable variation was observed in wet rubbing fastness. The wet rubbing fastness rating improved progressively from 2 at 1:8 M:L to 2–3 at 1:9 M:L, and then to 3 at 1:10 M: L. This indicates that increasing the material-to-liquor ratio reduced color transfer during wet rubbing.

The comparatively lower wet rubbing fastness at lower liquor ratios may be attributed to the presence of loosely bound or unfixed dye molecules on the fabric surface, which become more susceptible to migration during wet friction. At higher liquor ratios, improved dye dispersion and more controlled dye uptake may reduce surface dye accumulation, thereby enhancing wet-rubbing fastness.

Overall, the results demonstrate that while dry rubbing fastness remained consistently satisfactory across all dyeing conditions, the 1:10 material-to-liquor ratio provided better wet rubbing fastness, indicating improved resistance to color transfer under wet rubbing conditions.

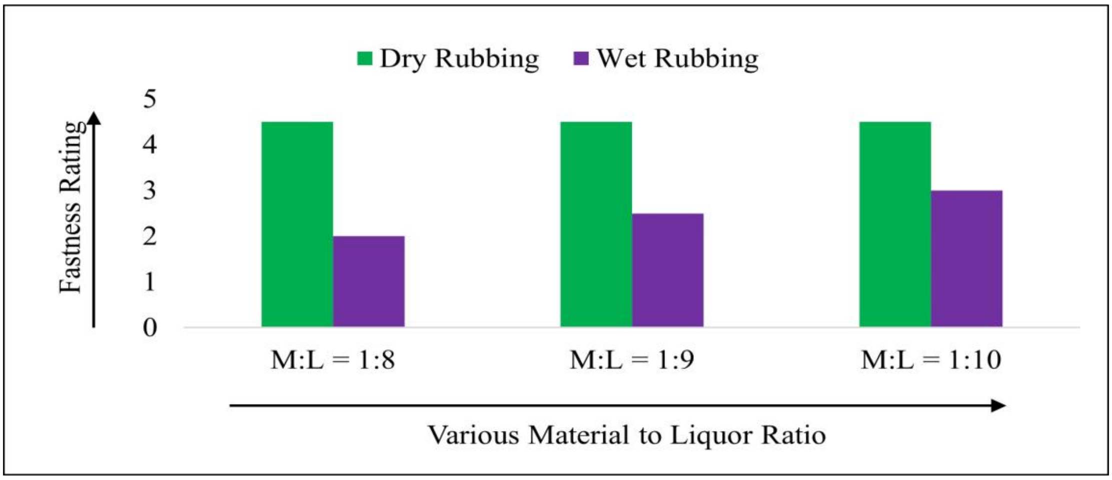

Fig 6 Color Fastness to Rubbing of Dyed Polyester/Cotton Blended Fabric at Different Material-to-Liquor Ratios.

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➢ *Color Strength (K/S) Analysis*

The reflectance and color strength characteristics of selected dyed polyester/cotton blended fabric samples at different material-to-liquor ratios were evaluated using a Datacolor 800TM spectrophotometer, and the results are presented in Table 8 and Fig.7.

Table 8 Comparative Reflectance (%) and Color Strength (K/S) Values of Selected Dyed Polyester/Cotton Blended Fabric Samples at Different Material-to-Liquor Ratios.

Fabric Type	M:L Ratio	Reflectance (%)	Color Strength (K/S)
65/35 Polyester/Cotton blended single jersey fabric	1:8	51.86	0.223
65/35 Polyester/Cotton blended single jersey fabric	1:10	52.00	0.222

Due to experimental measurement constraints, comparative reflectance and color strength (K/S) analysis was conducted for the 1:8 and 1:10 M:L dyed samples, while the 1:9 M:L condition served as the reference sample during spectrophotometric assessment.

The reflectance values increased slightly with increasing material-to-liquor ratio. The fabric dyed at 1:8 M:L exhibited a reflectance value of 51.86%, whereas the sample dyed at 1:10 M:L showed a slightly higher reflectance value of 52.00%. This increase in reflectance indicates comparatively lower dye absorption by the fabric substrate at higher liquor ratio.

The corresponding color strength (K/S) values were calculated using the Kubelka–Munk equation and showed a slight decreasing trend with increasing material-to-liquor ratio. The fabric dyed at 1:8 M:L exhibited a K/S value of 0.223, whereas the sample dyed at 1:10 M:L showed a slightly lower K/S value of 0.222. This suggests that the lower material-to-liquor ratio produced marginally deeper shade development due to relatively higher dye concentration in the dye bath.

The inverse relationship between reflectance and color strength observed in this study is scientifically consistent, as higher dye uptake generally reduces reflectance while increasing color strength. The results suggest that lower liquor ratio promotes greater dye absorption, resulting in improved shade depth and enhanced color yield on the polyester/cotton blended fabric.

Overall, the findings indicate only a marginal difference in color strength between the investigated liquor ratios, with the 1:8 M:L condition showing slightly higher K/S value.

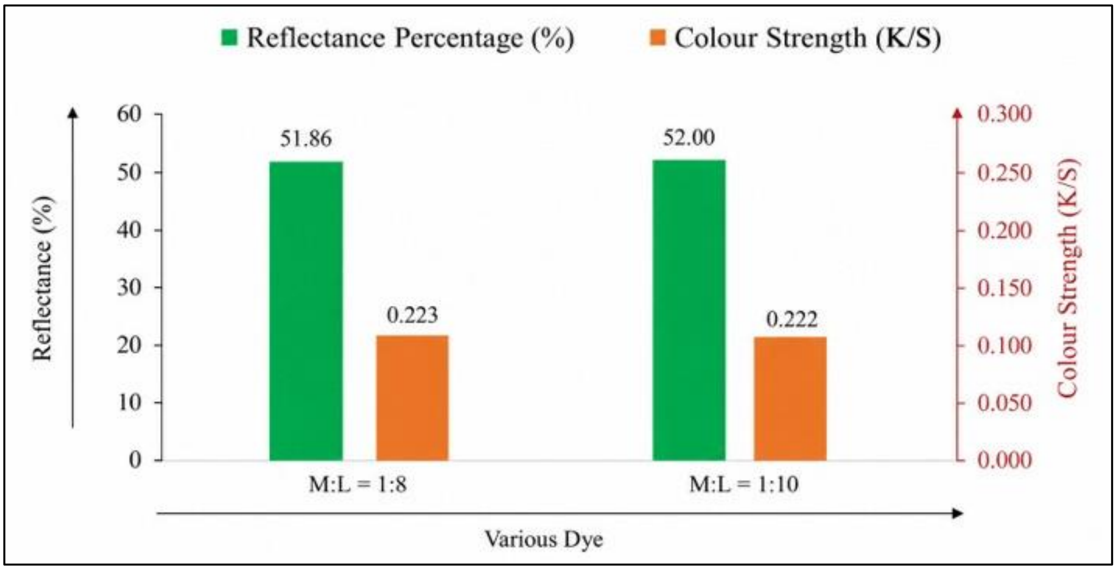

Fig 7 Reflectance (%) and Color Strength (K/S) of Selected Dyed Polyester/Cotton Blended Fabric Samples at Different Material-to-Liquor Ratios.

IV. CONCLUSIONS

This study investigated the influence of the material-to-liquor (M:L) ratio on the dyeing performance of a 65/35 polyester/cotton blended single jersey knitted fabric using a one-bath, two-stage dyeing process combining disperse and reactive dyeing techniques.

The experimental findings demonstrated that washing fastness performance remained satisfactory across all investigated dyeing conditions. All dyed samples exhibited good to excellent resistance to color change (rating 4–5), while excellent staining resistance (4–5 rating) was observed against acetate, nylon, polyester, acrylic, and wool adjacent fabrics. However, staining on cotton improved from 2–3 at lower liquor ratios (1:8 and 1:9) to 3–4 at 1:10 M:L, indicating reduced dye bleeding at higher liquor ratios.

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Dry rubbing fastness remained consistently good to excellent (4–5) for all dyeing conditions, demonstrating stable dye fixation under dry friction. In contrast, wet rubbing fastness showed noticeable improvement with increasing liquor ratio, rising from 2 at 1:8 M:L to 3 at 1:10 M:L, suggesting reduced color transfer due to improved dye dispersion and lower surface dye accumulation.

Color strength analysis revealed that the 1:8 M:L ratio produced slightly higher color strength (K/S = 0.223) than the 1:10 M:L ratio (K/S = 0.222). At the same time, reflectance increased slightly from 51.86% to 52.00%, indicating comparatively deeper shade formation at a lower liquor ratio due to increased dye concentration and improved dye uptake.

Overall, the study confirms that the material-to-liquor ratio plays an important role in balancing fastness performance and color yield in one-bath, two-stage dyeing of a polyester/cotton blended fabric. Among the investigated conditions, 1:10 M:L demonstrated better washing and wet-rubbing fastness, whereas 1:8 M:L provided comparatively superior color strength, indicating a practical trade-off between fastness durability and shade depth.

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