

Evaluation of Fastness Performance and Colour Strength of Reactive Dyed Cotton Single Jersey Knitted Fabric at Different Shade Depths

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Abstract: Reactive dyes are widely used for cotton dyeing due to their broad shade range, ease of application, and good wet-fastness properties. However, dye fixation behavior and fastness performance may vary depending on dye concentration and processing conditions. In this study, 100% cotton single jersey knitted fabric was pretreated through combined scouring and bleaching and subsequently dyed with reactive dyes at three different shade depths representing light (0.55%), medium (1.55%), and deep (2.05%) shades under controlled laboratory conditions. The dyed samples were evaluated for color fastness to washing, color fastness to rubbing (dry and wet), and color strength (K/S) using standard textile testing methods. The washing fastness results demonstrated excellent resistance to color change, with grey scale ratings of 4–5 for all shade levels, while staining on adjacent multifiber fabrics remained minimal except for slight staining on adjacent cotton fabric at higher shade depths. Dry rubbing fastness showed excellent performance with ratings of 4–5, whereas wet rubbing fastness was comparatively poor, indicating greater dye transfer under moist friction conditions. Reflectance values decreased from 74.01% to 69.48% with increasing shade depth, while calculated color strength (K/S) increased from 0.046 to 0.067, confirming greater color depth at higher dye concentrations. A comparison with industrial reactive dyeing practices in Bangladesh indicated consistency between laboratory findings and practical textile dyeing behavior. The results suggest that the selected reactive dyeing conditions provide satisfactory washing durability and color strength for cotton knitted fabric. However, wet-rubbing fastness remains an area requiring further process optimization.

Keywords: Reactive Dyeing, Cotton Single Jersey Fabric, Colour Fastness, Rubbing Fastness, Colour Strength (K/S), Textile Dyeing, Reactive Dyes.

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I. INTRODUCTION

Reactive dyes are among the most widely used synthetic dyes in textile colouration because of their straightforward application process, strong wet fastness performance, cost-effectiveness, and ability to produce bright and vivid shades [1]. Among synthetic dyes, reactive dyes are widely used

because of their comparatively superior fastness properties and straightforward application process [2, 3]. They have gained significant popularity because of their superior wet fastness, bright colouration, and broad spectrum of achievable hues [4].

The good fastness characteristics of reactive dyes arise from the covalent bond formed between the reactive functional groups of the dye molecules and the cellulosic fiber. Reactive dyes containing different reactive moieties may exhibit varying fixation efficiencies depending on their bonding mechanisms with the fiber [5].

Reactive dyes are extensively applied to cellulosic fibers, particularly cotton, through exhaust dyeing processes. In this method, dye uptake initially occurs through the exhaustion stage, where the presence of electrolyte enhances the attraction between dye molecules and the fiber surface. Subsequently, alkali is introduced to promote fixation by enabling covalent bond formation between the reactive dye molecules and the hydroxyl groups of cellulose. After dyeing, thorough rinsing and washing are required to remove unfixated or hydrolyzed dye and to improve the final fastness properties [6, 7].

Reactive dyes represent the second largest class of synthetic dyes, with nearly 50% of the world's textile fibers and fabrics being coloured using this dye class [8-10]. Reactive dyes account for one of the highest annual expenditures among dyes used in the textile industry, reflecting their significant industrial importance. However, challenges such as low dye fixation, high salt consumption, and the generation of large volumes of wastewater remain major limitations in their application [7, 10, 11].

There is increasing interest in developing and applying new synthetic dye analogues to improve dye exhaustion and achieve the desired colour strength (K/S), thereby minimizing dye loss caused by poor fixation.

Despite the widespread industrial use of reactive dyes for cotton colouration, the influence of shade depth on washing fastness, rubbing fastness, and colour strength performance of reactive dyed cotton knitted fabric remains an important practical consideration. Although reactive dyeing has been extensively studied, comparative evaluation of these performance characteristics under controlled laboratory conditions with reference to practical industrial observations remains valuable for process understanding and optimization.

Therefore, the present study investigates the dyeing performance of reactive dyes on 100% cotton single jersey knitted fabric at different shade depths, with particular emphasis on washing fastness, rubbing fastness, colour strength (K/S), and industrial relevance to textile dyeing practice in Bangladesh.

II. EXPERIMENTS

➤ *Materials*

The materials used for cotton pretreatment and reactive dyeing experiments included knitted cotton fabric, reactive dyes, and textile auxiliary chemicals. Details of the materials used are presented in Table 1.

Table 1 Materials Used in the Study

Category	Material Name	Commercial Name / Specification	Function
Fabric	100% Cotton Single Jersey Knit Fabric	Scoured/Bleached Cotton Fabric	Dyeing Substrate
Reactive Dye	Reactive Red	Drimaren Ultimate Crimson HD	Dyeing
Reactive Dye	Reactive Yellow	Drimaren Ultimate Yellow HD	Dyeing
Reactive Dye	Reactive Blue	Drimaren Ultimate Blue HD	Dyeing
Chemical	Acetic Acid	Invatex	pH Control / Neutralization
Chemical	Caustic Soda	NaOH	Pretreatment / Alkalinity Control
Chemical	Sodium Carbonate	Na ₂ CO ₃	Dye Fixation
Chemical	Glauber Salt / Sodium Sulfate	Industrial Grade	Electrolyte
Chemical	Levelling Agent	Dikol SN Liquid	Uniform Dye Distribution
Chemical	Wetting Agent	Kieralon CDP	Improved Wetting
Chemical	Sequestering Agent	Lufibrol 2UD	Metal Ion Control
Chemical	Soaping Agent / Detergent	---	Post-Dye Washing

➤ *Equipment*

The laboratory equipment used for dyeing, drying, colour measurement, and fastness evaluation are listed in Table 2.

Table 2 Equipment Used in the Study

Equipment	Purpose
Sample Dyeing Machine	Reactive Dyeing of Cotton Samples
Dryer	Drying Treated/Dyed Fabric Samples
Electronic Balance	Accurate Weighing of Dyes and Chemicals
Rotawash Machine	Washing Fastness Evaluation
Combined Laboratory Oven and Incubator	Controlled Heating/Drying During Sample Preparation
Crock Meter (Crockmaster)	Dry and Wet Rubbing Fastness Testing
Datacolour 800 TM Spectrophotometer	Colour Measurement / Colour Strength Evaluation

➤ *Fabric Pretreatment*

Before dyeing, the 100% cotton single jersey knitted fabric was subjected to combined scouring and bleaching in a single bath to remove natural impurities, waxes, and non-cellulosic substances, thereby improving absorbency and enhancing dye affinity. The pretreatment recipe and operating conditions used in this study are presented in Table 3. The

fabric was treated in a laboratory sample processing system at 95 °C for 60 minutes with a material-to-liquor ratio of 1:8, following the temperature profile illustrated in Fig.1. After completion of the pretreatment process, the samples were subjected to hot washing at 80 °C for 10 minutes, followed by cold rinsing at room temperature for 10 minutes, and finally dried under laboratory conditions before dyeing.

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

Chemical / Parameter	Amount
Caustic Soda (NaOH)	2.5 g/L
Hydrogen Peroxide (H ₂ O ₂)	2.5 g/L
Wetting Agent	1.0 g/L
Sequestering Agent	1.0 g/L
Detergent	1.0 g/L
pH	11.5
Temperature	95 °C
Time	60 min
Material-to-Liquor Ratio	1:8

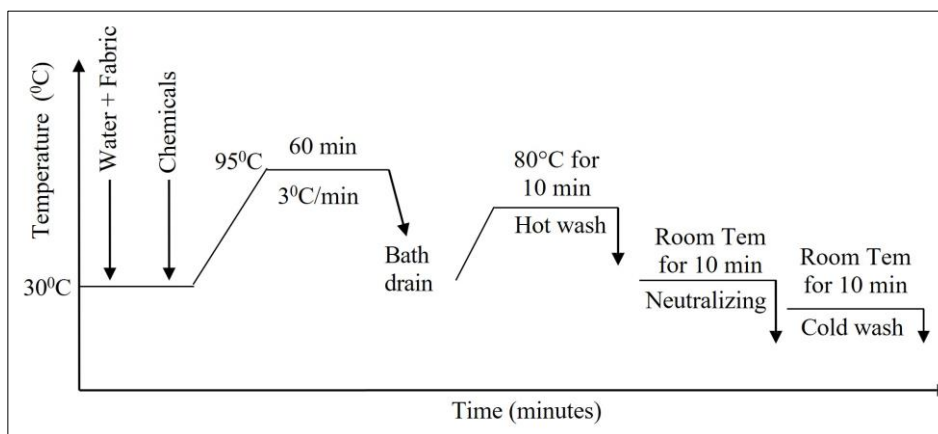


Fig 1 Temperature Profile for Combined Scouring and Bleaching of Cotton Fabric

➤ *Reactive Dyeing Procedure*

Following pretreatment, reactive dyeing of the cotton fabric was performed using a laboratory dyeing machine under controlled conditions. Pretreated fabric samples were cut into rectangular specimens with an individual sample weight of 10 g. Three different shade depths, namely light, medium, and deep shades, were prepared using combinations of reactive yellow, reactive red, and reactive blue dyes. The detailed dyeing recipe for each shade level is shown in Table 4, and the dyeing temperature profile is presented in Fig.2.

The dye bath was prepared by adding the required amount of water, reactive dyes, and auxiliary chemicals,

excluding alkali. The dyeing process was conducted at 60 °C for 60 minutes with a material-to-liquor ratio of 1:10. After the initial 20 minutes, the required amount of sodium carbonate was added to initiate dye fixation under alkaline conditions, and the process continued for the remaining dyeing period. Upon completion, the dye bath was drained.

Post-dye treatment was carried out to remove unfixed dye and improve fastness properties. Soaping was performed at 95 °C for 10 minutes, followed by hot washing at 80 °C for 10 minutes, cold washing at room temperature for 10 minutes, and final drying under laboratory conditions.

Table 4 Reactive Dyeing Recipe for Cotton Fabric at Different Shade Depths.

Component	Light Shade	Medium Shade	Deep Shade
Reactive Yellow (Drimaren Ultimate Yellow HD)	0.30%	0.75%	1.00%
Reactive Red (Drimaren Ultimate Crimson HD)	0.20%	0.72%	0.95%
Reactive Blue (Drimaren Ultimate Blue HD)	0.05%	0.08%	0.10%
Glauber Salt	30 g/L	40 g/L	50 g/L
Sodium Carbonate (Na ₂ CO ₃)	12 g/L	15 g/L	18 g/L
Sequestering Agent	1.0 g/L	1.0 g/L	1.0 g/L
Wetting Agent	0.5 g/L	0.5 g/L	0.5 g/L

Levelling Agent	1.0 g/L	1.0 g/L	1.0 g/L
Time	60 min	60 min	60 min
Temperature	60 °C	60 °C	60 °C
Material-to-Liquor Ratio	1:10	1:10	1:10
Sample Weight	10 g	10 g	10 g

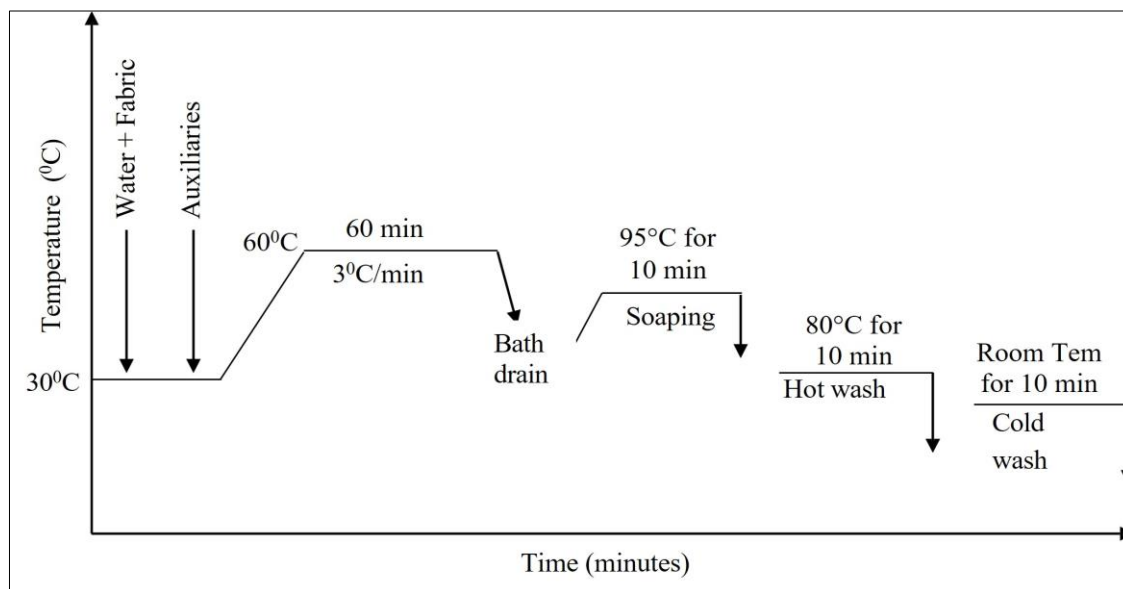


Fig 2 Process Temperature Profile for Reactive Dyeing of Cotton Fabric

➤ *Testing Methods*

• *Colour Fastness to Washing*

Color fastness to washing of the dyed cotton 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 multifiber adjacent 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 samples 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.

• *Colour Fastness to Rubbing*

Color fastness to rubbing (dry and wet) 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 a 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 in both dry and wet conditions. For wet rubbing assessment, the rubbing cloth 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.

• *Colour Strength (K/S) Measurement*

The color strength (K/S) of the dyed cotton samples was evaluated through reflectance measurement using a Datacolour 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 colour strength and deeper shade development.

➤ *Industrial Data Collection*

To understand the practical industrial application of reactive dyeing in Bangladesh’s textile sector, supplementary industrial information was collected during undergraduate industrial training conducted in early 2021. Data were obtained through direct observation and informal discussions with dyeing personnel, including machine operators, supervisors, dyeing officers, and production managers from several textile dyeing industries.

The collected information included commonly used reactive dyes, processing practices, and industrial preferences related to cotton dyeing. These observations were used to provide a practical industrial context for interpreting the experimental findings of this study.




III. RESULTS AND DISCUSSIONS

➤ Visual Characteristics of Dyed Cotton Fabric Samples

The visual appearance and physical characteristics of the reactive dyed cotton fabric samples at different shade depths are presented in Table 5. Distinct color variations were

observed among the light, medium, and deep shade samples, confirming the successful application of reactive dyes under the selected laboratory dyeing conditions. The gradual increase in shade intensity with increasing dye concentration indicates effective color development and dye fixation on the cotton knitted substrate.

Table 5 Visual Appearance and Physical Characteristics of Reactive Dyed Cotton Fabric Samples at Different Shade Depths

Swatch no.: 01 (Light Shade)	Swatch no.: 02 (Medium Shade)	Swatch no.: 03 (Dark Shade)
Fabric type: 100% scoured and bleached cotton knitted fabric. Structure: Single Jersey. GSM of the fabric: 166 Stitch length: 2.66 cm Shade%: 0.55%	Fabric type: 100% scoured and bleached cotton knitted fabric. Structure: Single Jersey. GSM of the fabric: 166 Stitch length: 2.66 cm Shade%: 1.55%	Fabric type: 100% scoured and bleached cotton knitted fabric. Structure: Single Jersey. GSM of the fabric: 167 Stitch length: 2.66 cm Shade%: 2.05%
		

➤ Colour Fastness to Washing

The washing fastness performance of reactive-dyed cotton fabric at different shade depths is presented in Table 6 and Fig. 3. The results demonstrate excellent resistance to color change for all dyed samples, with a consistent grey-scale rating of 4–5, indicating very good to excellent washing fastness performance.

The staining behavior of adjacent multifiber fabrics also showed satisfactory performance. Di-acetate, nylon, polyester, acrylic, and wool adjacent fabrics exhibited fastness ratings of 4–5 for all shade levels, indicating minimal dye transfer during the washing test. However, slightly lower staining resistance was observed for the adjacent cotton fabric in the medium- and deep-shade samples, where the fastness rating decreased to 3–4, indicating good washing fastness performance.

The superior washing fastness observed in this study can be attributed to the effective covalent bonding formed between reactive dye molecules and the hydroxyl groups of the cotton cellulose during the fixation process. This chemical bonding enhances dye retention within the fiber structure and reduces dye loss during washing. The slight reduction in staining resistance on adjacent cotton fabric at higher shade depths may be associated with a small amount of unfixed or hydrolyzed dye remaining after dyeing, which could migrate during washing.

Overall, the results indicate that the reactive dyeing process achieved satisfactory fixation and produced cotton fabrics with strong washing durability across light, medium, and deep shade conditions.

Table 6 Colour Fastness to Washing Results of Reactive Dyed Cotton Fabric

Shade Level	Colour Change	Diacetate	Cotton	Nylon	Polyester	Acrylic	Wool
Light (0.55%)	4–5	4–5	4–5	4–5	4–5	4–5	4–5
Medium (1.55%)	4–5	4–5	3–4	4–5	4–5	4–5	4–5
Deep (2.05%)	4–5	4–5	3–4	4–5	4–5	4–5	4–5

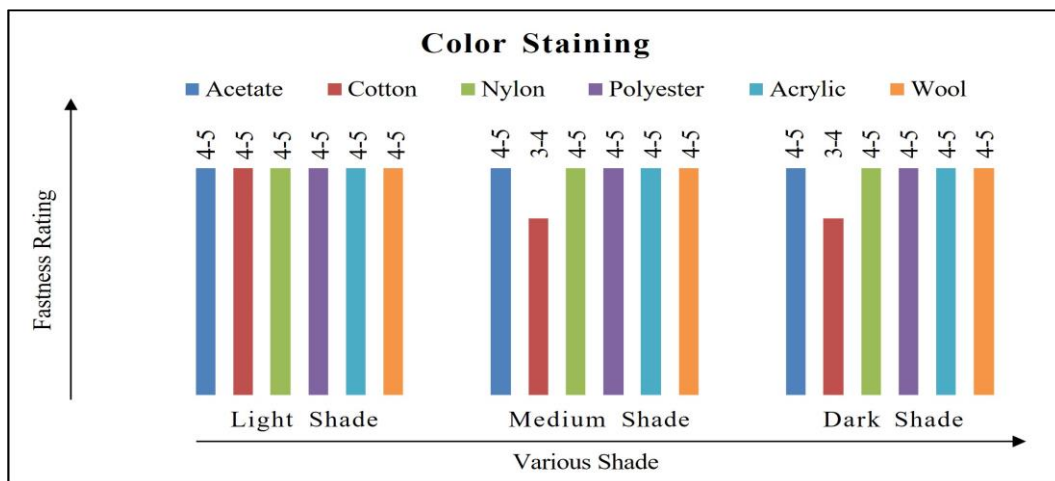


Fig 3 Comparison of Colour Staining Fastness Ratings of Reactive Dyed Cotton Fabric at Different Shade Depths after Washing

➤ *Colour Fastness to Rubbing*

The rubbing fastness performance of reactive dyed cotton fabric at different shade depths is presented in Table 7 and Fig.4. The results revealed excellent dry rubbing fastness for all dyed samples, with consistent grey scale ratings of 4–5 in both lengthwise and widthwise rubbing directions, indicating very good to excellent resistance to color transfer under dry friction conditions.

In contrast, wet rubbing fastness was significantly lower across all shade levels. The light shade sample exhibited ratings of 2 in the lengthwise direction and 1–2 in the widthwise direction, indicating moderate to poor wet rubbing resistance. Medium- and deep-shade samples showed even lower wet-rubbing fastness, with ratings ranging from 1 to 1–2, suggesting substantial dye transfer under wet-friction conditions.

The superior dry rubbing fastness indicates that the dyed fabric surface retained color effectively under dry mechanical action. However, the poor wet rubbing fastness may be attributed to loosely bound or unfixed dye molecules on the fabric surface, which become more susceptible to migration when exposed to moisture and friction. This behavior is commonly observed in reactive dyed cotton fabrics, particularly at higher shade depths where dye concentration increases.

Overall, the results indicate that the reactive dyed cotton fabric demonstrated satisfactory dry rubbing fastness but comparatively poor wet rubbing fastness, highlighting the influence of moisture on dye transfer behavior.

Table 7 Colour Fastness to Rubbing Results of Reactive Dyed Cotton Fabric

Shade Level	Lengthwise Dry Rub	Lengthwise Wet Rub	Widthwise Dry Rub	Widthwise Wet Rub
Light (0.55%)	4–5	2	4–5	1–2
Medium (1.55%)	4–5	1	4–5	1
Deep (2.05%)	4–5	1–2	4–5	1

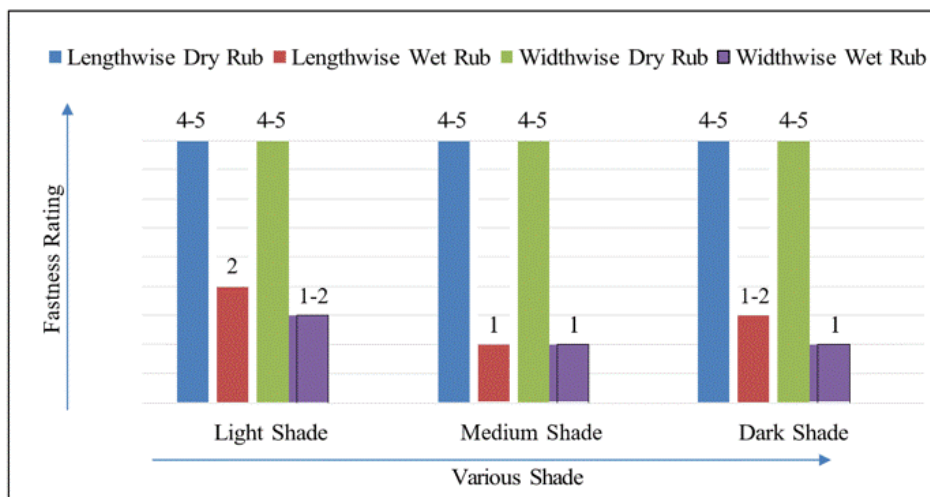


Fig 4 Colour Staining on Rubbing Cloth after Dry and Wet Rubbing Fastness Testing

➤ *Colour Strength (K/S) Analysis*

The reflectance and color strength characteristics of reactive-dyed cotton fabric at different shade depths were evaluated using a Datacolour 800TM spectrophotometer, and the results are presented in Table 8 and Fig. 5. Reflectance values decreased progressively with increasing shade depth, indicating greater dye absorption by the cotton substrate.

The light shade sample (0.55%) exhibited the highest reflectance value of 74.01%, whereas the medium (1.55%) and deep (2.05%) shade samples showed lower reflectance values of 71.03% and 69.48%, respectively. This decreasing reflectance trend confirms that darker shades absorb more

incident light due to increased dye concentration on the fabric surface.

Color strength (K/S) values were calculated using the Kubelka–Munk equation and showed an increasing trend with increasing shade depth. The calculated K/S values were 0.046, 0.059, and 0.067 for light, medium, and deep shades, respectively. Higher K/S values indicate greater color strength and improved dye fixation on the fabric.

Overall, the results demonstrate that increasing dye concentration enhanced color depth and color strength while reducing reflectance, confirming effective reactive dye uptake by the cotton fabric.

Table 8 Reflectance and Colour Strength (K/S) Values of Reactive Dyed Cotton Fabric at Different Shade Depths

Shade Level	Total Shade (%)	Reflectance (%)	Colour Strength (K/S)
Light Shade	0.55	74.01	0.046
Medium Shade	1.55	71.03	0.059
Deep Shade	2.05	69.48	0.067

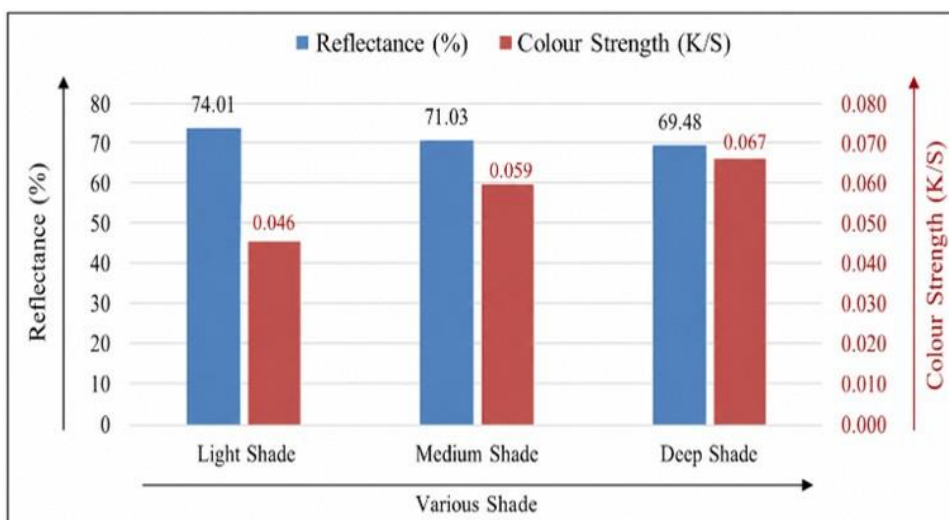


Fig 5 Reflectance and Colour Strength (K/S) of Reactive Dyed Cotton Fabric at Different Shade Depths

➤ *Industrial Relevance of Experimental Findings*

To assess the industrial relevance of the present experimental work, a comparison was made between the laboratory findings and commonly observed reactive dyeing practices in selected textile manufacturing facilities in Bangladesh. The comparative industrial observations and experimental findings are presented in Table 9.

The collected industrial information indicated that reactive dyes are widely used for cotton knitted fabrics due to their broad shade range, acceptable fastness performance, and suitability for commercial dyeing operations. Industrial practice generally involves shade depths of approximately 1.5–2.0%, which are comparable to those investigated in the present study.

As shown in Table 9, industrial observations indicate that typical reactive dye uptake ranges from 60–70%, while

hydrolysis losses may account for approximately 40–60%, depending on the dye type and processing conditions. Although hydrolysis was not directly quantified in the present laboratory work, the obtained washing and rubbing fastness results indicate satisfactory dye fixation.

The experimental results demonstrated good to excellent washing fastness, excellent dry rubbing fastness, and comparatively lower wet rubbing fastness, consistent with the practical industrial dyeing behavior of reactive dyes on cotton substrates. The lower wet rubbing performance may be associated with residual unfixd dye on the fabric surface, leading to increased dye transfer under wet friction conditions.

Overall, the comparison confirms that the experimental dyeing performance observed in this study is relevant to practical industrial textile dyeing applications.

Table 9 Comparison of Laboratory Findings with Industrial Reactive Dyeing Practices in Selected Bangladeshi Textile Factories

Parameter	Industrial Observation	Present Study
Fabric type	Cotton knitted fabric	100% cotton single jersey
Common shade depth	1.5–2.0%	0.55–2.05%
Reactive dye usage	Predominant	Used
Typical dye take-up	60–70%	Experimental colour strength evaluated
Hydrolysis	40–60%	Not directly measured
Washing fastness	Generally good	Good to excellent
Dry rubbing fastness	Good	Very good to excellent
Wet rubbing fastness	Moderate to poor	Poor to moderate

IV. CONCLUSIONS

This study investigated the dyeing performance of reactive dyes on 100% cotton single jersey knitted fabric at different shade depths under controlled laboratory conditions. The experimental findings demonstrated that reactive dyeing provided satisfactory color performance and fastness characteristics for cotton fabric.

The washing fastness results showed excellent resistance to color change and minimal staining on most adjacent multifiber fabrics, indicating effective dye fixation during dyeing. Dry rubbing fastness also exhibited very good to excellent performance across all shade levels. However, wet rubbing fastness was comparatively lower, suggesting increased dye transfer under moist friction conditions, which may be associated with residual unfixed dye on the fabric surface.

Color strength analysis further confirmed that increasing shade depth reduced reflectance while increasing K/S values, indicating greater color depth and improved dye absorption by the cotton substrate. In addition, comparison with industrial reactive dyeing practices in Bangladesh showed that the laboratory findings are generally consistent with practical textile dyeing behavior.

Overall, the study confirms that reactive dyeing is an effective and industrially relevant method for the coloration of cotton knitted fabric, providing satisfactory washing durability and color strength. Further process optimization may improve wet rubbing fastness and overall dyeing performance.

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