EFFECTS OF LIGHT SOURCES ON ILLUMINANCE DIFFERENCE AND COLOR DIFFERENCE FOR DYED FABRICS

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ABSTRACT

Under various light sources, the color of dyed fabrics could be observed in different ways. In this study, the red (R), green (G) and blue (B) dyed fabrics were evaluated through color difference (ΔE) and illuminance difference (ΔI) under daylight (D65), fluorescence (F, TL84, CWF), and ultraviolet (UV) lights. It was found that when D65, a standard daylight illuminant, is used as the reference, ΔE value under TL84 and CWF light sources was not significantly different. Therefore, D65 can be complemented by TL84 and CWF for color evaluation to enhance accuracy. The study also highlighted that using a 45-degree viewing angle yielded the most objective color evaluation results. This angle provides optimal conditions for observing light reflection, contributing to more reliable color evaluation. Additionally, dye concentration had a significant impact on color evaluation. An incorrect dye concentration can alter the ability of fabric to absorb light, leading to inaccurate evaluations. Furthermore, washing cycles also affect the colorfastness of dyed fabrics, with increased washing leading to a brighter appearance and higher light reflection.

KEYWORDS

Light source; Color Fabric; Color difference (ΔE); Illuminance Difference (ΔI); RGB Histogram.

INTRODUCTION

In textile production, color consistency is a crucial factor in ensuring product quality and meeting consumer expectations [1,2]. Color plays a significant role in influencing customer perception, particularly in sectors such as apparel, home furnishings, and technical textiles [3-5]. With the growing demands of global markets, ensuring consistent color standards during manufacturing has become more critical than ever [6]. Color evaluation is essential in industries such as textiles, fashion, automotive, and paint manufacturing, where accurate color representation is critical for quality control, product consistency, and customer satisfaction

In general, color evaluation is carried out through a range of methods, from simple visual assessments to advanced instrumental techniques. Modern tools like spectrophotometers and colorimeters provide precise measurements, yet optical methods continue to hold value in ensuring color consistency across various production stages [7-13]. In fact, factors like light sources, observation angles, dye concentration, and washing cycles can significantly influence color evaluation results [14,15].

Despite technological advancements, ensuring uniformity remains a challenge in textile color evaluation, particularly under varying lighting and observation conditions [16,17]. Inconsistent results can lead to products that fail to meet customer expectations, negatively impacting a brand's reputation [1,18,19]. Understanding the effects of external factors like light source, dye concentration, and washing is critical for manufacturers aiming to improve production quality.

Light sources, especially LED light, play an important role in determining the appearance of colors and ensuring color consistency across various fabrics and products [20,21]. The perception of color can change drastically depending on the type of light used, making it important to choose the right lighting conditions for accurate color evaluation. Furthermore, textile evaluation under different lighting also helps assess the color fastness properties of dyed fabrics, particularly their resistance to fading or changing color by washing and ultraviolet exposing conditions [22,23].

Light sources have different color temperatures (measured in Kelvin), which impact the way colors are perceived [24]. Daylight (D65) provides a balanced light source for color evaluation, while cool white fluorescent (CWF) light can make colors appear cooler, often with a bluish tint. Fluorescent light, commonly used in retail stores, typically has a color

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Received October 17, 2024; accepted January 21, 2025

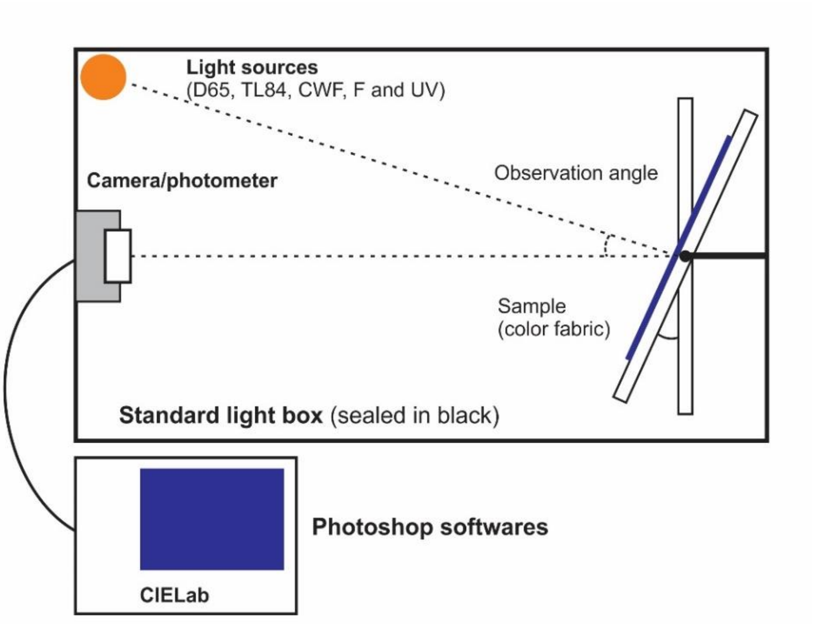


Figure 1. Standard light box setup with five light sources (D65, TL84, CWF, F and UV).

temperature of around 4,000K. Fabrics with fluorescent dyes or finishes may appear brighter or change color under ultraviolet (UV) light due to their ability to absorb UV radiation and re-emit it as visible light. The intensity of the light source, or illuminance (measured in lux), can also influence color perception [25,26]. The brightness and clarity of colors improve with high illuminance, but this may amplify the contrast between subtle shades. Conversely, low illuminance can cause colors to appear darker and less vibrant, making it harder to differentiate between various shades.

This research examines key factors influencing the optical evaluation of dyed fabrics, including light sources, observation angles, dye concentrations, and washing conditions. By analyzing their interactions and effects on illuminance and color differences, the study proposes optimized conditions to reduce discrepancies in color assessments. It also explores how repeated washing cycles impact fabric appearance. The findings aim to offer practical recommendations for textile manufacturers to enhance color consistency and reliability, while minimizing waste and resource consumption. Additionally, these insights can guide future research on dyeing techniques and color evaluation.

MATERIALS AND METHODS

This study used three types of woven fabrics, each dyed with specific colorants and characterized by their respective color indices in the CIE color space, to achieve consistent and uniform red, green, and blue colors. Each fabric sample was cut into squares of equal size (10 cm×10 cm). The fabric samples were conditioned under standard conditions (23°C, 65% RH) for 24 hours prior to testing to ensure stable measurements. Each sample was placed under a light source in the light box for a fixed period to simulate real-world viewing conditions. In this study, five following light sources were used including 1) **D65** (daylight) - a standard daylight illuminant used to simulate natural sunlight which it serves as the reference light source for accurate color evaluation, 2) **TL84** (fluorescent) - commonly used in retail environments, 3) **CWF** (cool white fluorescent) - primarily used in retail spaces, 4) **F** (fluorescent) - widely used in settings where color evaluation and visual consistency are important in textile and fashion showrooms, and 5) **UV** (ultraviolet) - invisible to the human eye but has a significant impact on certain materials (e.g., textiles).

A standard light box with different light sources (D65, TL84, CWF, F and UV) was used to simulate the lighting conditions for color evaluation (as illustrated in Figure 1). A photometer (Reed Instrument, R8130 light meter) was used to measure the illuminance in lux and the difference in illuminance (ΔI) was determined as follows:

$$\Delta \boldsymbol{I} = |\boldsymbol{I_D} - \boldsymbol{I_S}| \tag{1}$$

where I_D is the illuminance of the sample under D65 light, and I_S is the illuminance of the samples under other lights.

A camera is installed in the light box and connected with a computer. The photoshop CS2 software is used to determine the three coordinates (L^*, a^*, b^*) of captured photos according to the CIELab color space under lighting conditions. The color difference (ΔE^*) represents the color distance between samples and is calculated as follows:

$$\Delta \boldsymbol{E}^* = \sqrt{(\Delta \boldsymbol{L}^*)^2 + (\Delta \boldsymbol{a}^*)^2 + (\Delta \boldsymbol{b}^*)^2} \tag{2}$$

Table 1. Illuminance difference (*ΔI*) and color difference (*ΔE*) of red, green, blue fabrics under D65, F, TL84, UV and CWF lights.

Light source	Red		Green		Blue	
	ΔI	**ΔE**	**ΔI**	**ΔE**	**ΔI**	**ΔE**
D65	-	-	-	-	-	-
F	5.5	33.5	2.8	36.3	20.6	67.1
TL84	**23.1**	17.8	0.7	28.1	8.9	36.4
UV	**94.4**	58.0	74.9	12.3	87.3	28.6
CWF	6.0	15.8	7.6	15.8	17.3	32.3

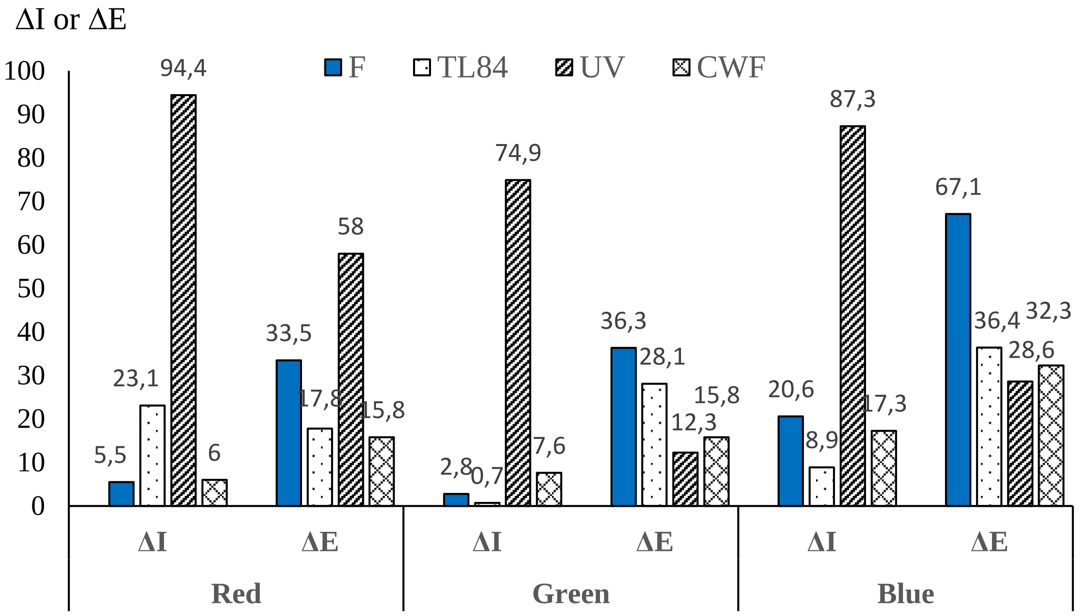


Figure 2. Comparison of illuminance and color difference between red, green and blue fabrics under F, TL84, UV and CWF lights.

where *ΔL**, *Δa**, and *Δb** are the differences in lightness, the green-red axis, the blue-yellow axis between two colors, respectively.

MATLAB software was also utilized to display the spectral reflectance curves, enabling comparisons of sample photos captured at different observation angles under various light sources. Finally, the blue-dyed twill denim fabric was tested using a Miele washing machine (in accordance with ISO 105-C06) to simulate real-world evaluations of color differences under different lighting conditions.

RESULTS AND DISCUSSION

Effects of light source on illuminance difference and color difference

Light sources remarkably impact on the perception of color in dyed fabrics which is a critical aspect of color evaluation in textile industry. Different light sources can change the fabric appearances, leading to varying degrees of illuminance and color difference, as displayed in Figure 2 and Table 1.

The illuminance of dyed fabrics varied with different light sources. D65, which mimics natural daylight, provided the most accurate reflection of the fabric colors, offering the highest illuminance values for all fabric samples. This is because D65 provides a full spectrum of light, allowing true colors of fabrics to be revealed. Under TL84 and CWF lights, *Δ*I value decreased slightly, especially for red fabrics (i.e., 23.1 and 6.0) and blue fabrics (i.e., 8.9 and 32.3). This demonstrates that these artificial light sources do not offer the same color-rendering capability as natural daylight, leading to a reduced perception of luminous intensity. However, the reduction was not large enough to significantly affect the overall visual quality of the fabrics under typical retail lighting conditions.

The *ΔE* values, which measure the color difference between a standard sample (under D65 light) and the sample under various light conditions, were also influenced by the type of light source. It showed that while TL84 and CWF light sources led to measurable color differences, the *ΔE* values remained within acceptable limits for retail and general use in the textiles and fashion (*ΔE* ≤ 3.0 - 5.0, according to ASTM D3136). Red fabrics showed the highest ΔE values, particularly under CWF lighting, indicating that red colors are more sensitive to changes in light sources. Blue fabrics, on the other hand, exhibited relatively lower *ΔE* values, suggesting that blue colors are more stable across different lighting conditions. The green fabric showed moderate *ΔE* values under both TL84 and CWF light sources, indicating that while there is a noticeable shift in color, it is not as significant as the shift of red fabric.

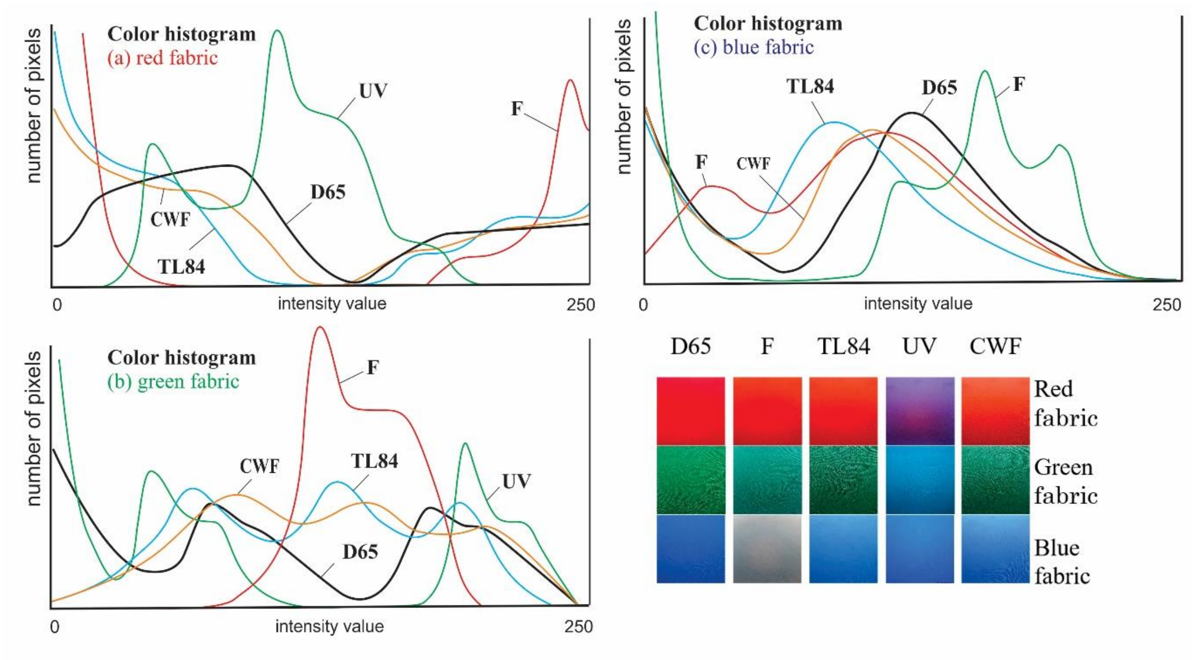
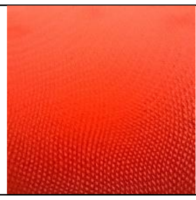
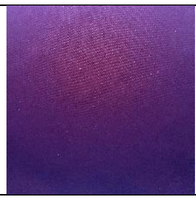
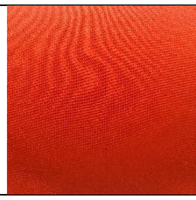


Figure 3. Color histogram of red, green, and blue fabrics (RGB images) under D65, F, TL84, UV and CWF lights.

Table 2. Illuminance difference (*ΔI*) and color difference (*ΔE*) of red fabrics with observation angles of 45°, 60° and 75° under D65, F, TL84, UV and CWF lights.

Observed angle	**D65**	**F**	**TL84**	**UV**	**CWF**
45°					
ΔI	-	5.5	23.1	94.4	6.0
ΔE	-	33.5	17.8	58.0	15.8
60°					
ΔI	-	3.7	16.2	72.6	13.8
ΔE	-	46.5	37.6	42.0	31.5
75°					
ΔI	-	0.9	2.0	39.3	15.5
ΔE	-	33.8	26.6	61.8	13.1

Based on color histogram (as shown in Figure 3), the energy distribution curves can reveal the effect of light sources on color perception. Accordingly, different light sources can change the color perception for dyed fabrics. Light sources with uneven energy distribution, such as F and TL84, can distort color perception, while the D65 light source is the ideal reference as it simulates natural sunlight, providing more accurate color reproduction.

It can see that F curves present strong emission in short and long wavelength region but no emission in middle wavelength region (yellow and green), making them appear "cooler" or "harsher" compared to natural daylight.

Effects of observation angles on color accuracy of dyed fabrics

The results in Table 2 indicated that the observation angle had a noticeable effect on the accuracy of color evaluation for red, green, and blue fabrics. Specifically, as the observation angle shifted from 45° to 60° and 75°, there was a corresponding change in both *ΔI* and *ΔE*. For all three fabric colors, the optimal viewing angle for achieving the most accurate and reliable color evaluation was found to be 45°. At this angle, the fabrics reflected light in a manner that provided the most consistent and true representation of their actual colors.

As shown in Figure 4, the spectral reflectance curves of red fabrics depict their reflectance behavior under various light sources (D65, F, UV, CWF, and TL84) and observation angles (45°, 60°, and 75°). The curves are analyzed across the blue region (400–500 nm), green region (500–600 nm), and red region (600–700 nm), with the highest reflectance observed in the red region, consistent with the red appearance of fabrics.

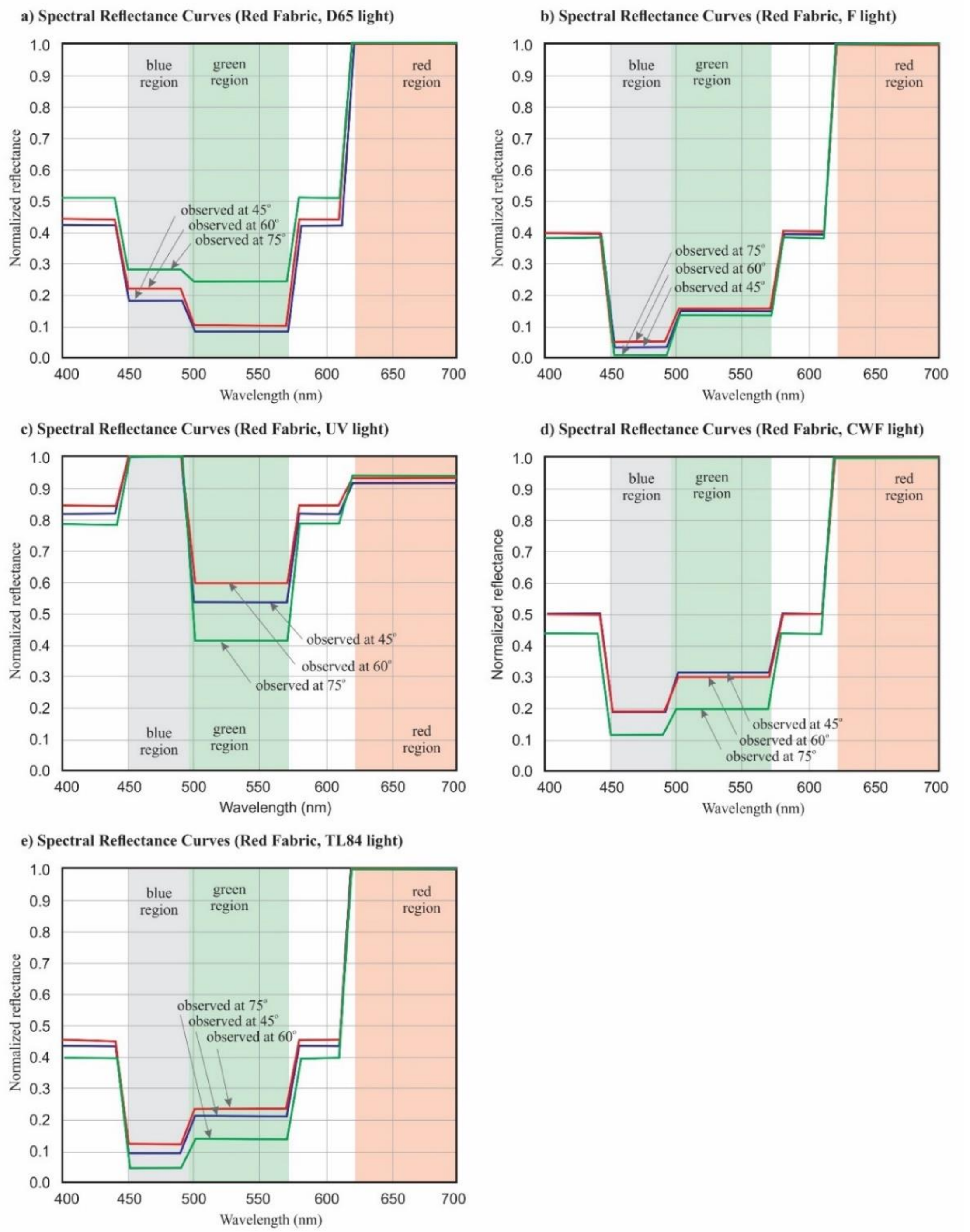


Figure 4. Spectral reflectance curves of red fabrics under a) D65, b) F, c) UV, d) CWF, and e) TLT84 light sources at 45, 60 and 75° of observation angle.

Table 3. Photos of fabrics dyed with 1, 3, and 6wt% of indigo pigment under D65, F, TL84, UV and CWF lights.

Sample	D65	F	TL84	UV	CWF
SP01 (1%)					
SP03 (3%)					
SP06 (6%)					

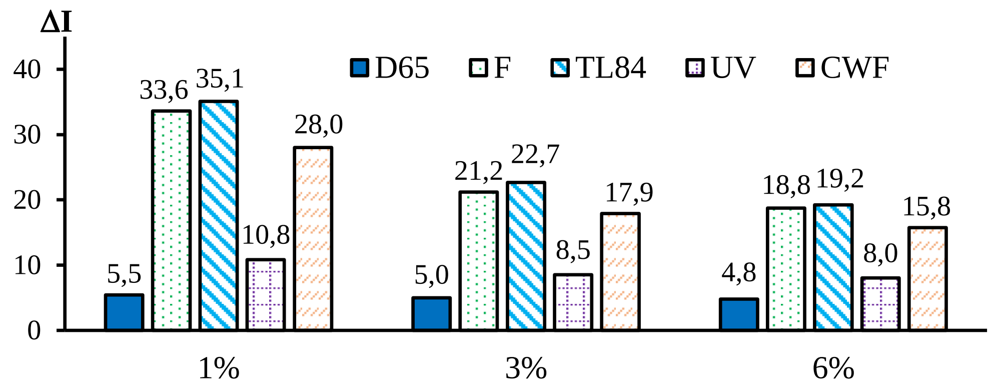


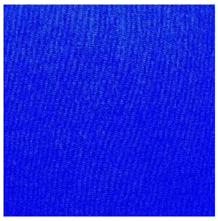
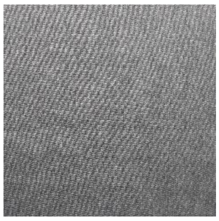
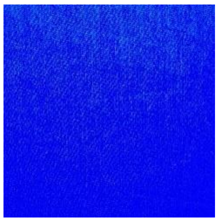
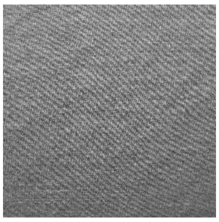
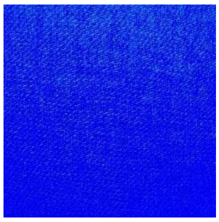
Figure 5. Difference in illuminance of fabrics dyed with 1, 3, and 6 % of indigo dyes under D65, F, TL84, UV and CWF lights.

Across all light sources, slight variations in reflectance are observed with changes in observation angles, indicating minor angular dependence. Under D65 light, reflectance is highest in the red region but decreases slightly at larger observation angles. For F light, red reflectance remains dominant, but the green and blue regions exhibit a sharper decline, with noticeable angular variations in the green region. In UV light, a peak appears in the blue region due to UV sensitivity, accompanied by slight spectral shifts across angles. CWF light shows a similar pattern to F light but with smoother transitions between the green and red regions, and less pronounced angular effects. Finally, TL84 light demonstrates smoother reflectance transitions, with dominant red reflectance and minimal angular dependence. Obviously, the observation angle has a minor but noticeable impact on the spectral reflectance of dyed fabric under different light sources.

Effects of observation angles on color accuracy of dyed fabrics

Table 3 and Figure 5 indicate that the dye concentration significantly influences the color intensity of blue fabrics. Accordingly, increasing dye concentration consistently led to a decrease in the *ΔI* value across all light sources (D65, F, TL84, UV, and CWF), suggesting that more dye particles are absorbed by the fibers, resulting in deeper and more intense colors. It reflects the basic principle that higher dye concentrations allow for greater dye uptake, thereby enhancing color intensity. Nevertheless, beyond a certain threshold, the increase in *ΔI* value begins to plateau, indicating a saturation point, where occurs when the fiber has absorbed as much dye as it can, and additional dye in the solution no longer contributes to significantly deeper colors. This plateau suggests a maximum dye absorption limit, after which the *ΔI* value remains relatively stable despite further increases in dye concentration. The results align with the theory of equilibrium dyeing, where the dye-fiber interaction reaches its peak, and the fabric can no longer take up more dye molecules.

Table 4. The ΔE values of blue denim fabrics after 0, 3, 6 and 9 washing cycles under D65, F, TL84, UV and CWF lights.

Washing cycle	**D65**	**F**	**TL84**	**UV**	**CWF**
0					
ΔE	-	45.3	42.8	86.9	43.4
3					
ΔE	-	46.5	43.7	78.2	44.6
6					
ΔE	-	45.8	44.0	95.7	43.9
9					
ΔE	-	42.8	40.2	100.4	40.4

As shown in Table 4, the *ΔE* values decreased with each washing cycle, indicating a loss in color intensity and the leaching of dye molecules from the fabric. Notably, higher *ΔE* values were more pronounced under UV light, measuring 86.9, 78.2, 95.7, and 100.4 after 0, 3, 6, and 9 washing cycles, respectively. This can be attributed to repeated exposure to washing, particularly under alkaline conditions, which causes dye molecules to desorb from the fibers, leading to color fading. Fabrics dyed with lower dye concentrations were more susceptible to fading during washing, likely due to weaker dye-fiber interactions. In contrast, fabrics dyed with higher dye concentrations exhibited better color retention after multiple washing cycles, possibly because of stronger or more abundant dye-fiber bonds.

CONCLUSION

This research highlights the significant impact of light sources on the color measurements of dyed fabrics, with particular emphasis on illuminance color and color difference under different lighting conditions. The study demonstrated that D65 and TL84 offer the most consistent and accurate color rendering, especially for green fabrics, while F and UV lights tend to distort color perception, particularly in the red and blue channels. Moreover, the stability of perceived color with varying observation angles is affected by the light source, with D65 and F lights showing more noticeable changes, while TL84 exhibits the most consistent reflectance across angles. These findings are essential for textile manufacturers aiming to maintain color consistency in their products, particularly when viewed under different lighting environments such as retail stores, homes, and outdoor settings. By optimizing evaluation conditions and considering the influence of light sources, manufacturers can improve quality control, reduce color discrepancies, and ensure that products meet consumer expectations. This research provides a foundation for future studies on textile color evaluation and its practical applications.

Acknowledgement: *This work belongs to the project in 2025 funded by Ho Chi Minh City University of Technology and Education, Vietnam.*

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