

Color Strength Variations in Cotton/Hemp Blends: Influence of Fiber Composition

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Abstract

This study investigated the influence of fiber composition on the color strength of cotton/Hemp blends in textile applications. Cotton and Hemp, two natural fibers with distinct structural and chemical properties, were blended in varying ratios to assess their impact on dye uptake and color strength. Blends were dyed with reactive dye using a direct dyeing method, and color strength (K/S values) was measured using spectrophotometry. The results revealed significant variations in color strength across different blend ratios, with fiber composition playing a crucial role in dye absorption. Higher proportions of Hemp with higher moisture regain were found to increase color strength due to its high water absorbency as compared to cotton. This study provides valuable insights into optimizing cotton/Hemp blends for enhanced color performance, offering practical implications for textile manufacturers seeking sustainable and high-performance fabric solutions.

Index Terms: Calibration curve, Cotton, blend, Hemp, moisture regain,color Strength(K/S)

1. INTRODUCTION

The increasing global awareness and societal concern about the environmental consequences of the textile industry have underscored the urgent requirement to adopt eco-friendly and sustainable practices across the industry's supply chain. In response to escalating population growth and the higher demand for textile fibres, it has become imperative to explore sustainable raw materials and processes to address these challenges(Felgueiras et al., 2021).

Cotton is the most widely used natural fibre due to its comfort properties representing about 90% of all natural fibres and being extensively utilized in apparel, home furnishings, and industrial applications(Yu, 2015). However, other fibres like Hemp are also used to meet the increasing demand. Blending cotton with fibres like Hemp not only enhances the quality of the final product but also helps conserve cotton for other uses. Environmentally, it is important to gradually replace cotton with pulp-based fibres. Among alternative textile materials,Hemp fibre is also known for its versatility, as it can be blended with other fibres to produce fabrics with a range of properties like strength, flexibility, softness, lustre, absorbency, antimicrobial properties(Ramesh &Bhoopathi, 2022). Hemp fiber can be blended with cotton to produce a fabric that is both strong and soft.It has a high absorbency rate, making them useful for products that need to be absorbent, such as towels and cloth diapers. Hemp is more hygroscopic than cotton. The moisture regain of hemp fibre is typically around 10-12%compare to cotton moisture regain of 8% (Sfiligoj et al., 2013).The differing structural and chemical properties of these fibers can influence various characteristics, particularly dye uptake and color strength of textile.

The amount of dye on fabric can be estimated using the well-known Kubelka–Munk model, as shown in equation 1:

$$K/S = \frac{(1-R_{\infty})^2}{2R_{\infty}} \quad (1)$$

Here, K and S represent the absorption and scattering coefficients, respectively, while R_{∞} denotes the reflectance factor from an opaque surface. This model reflects the depth and intensity of color, which are influenced by factors such as fiber type, blend ratio, and dyeing conditions. Additionally, fluctuations in the moisture content of a substrate, caused by changes in the relative humidity of the surrounding environment, can affect how light interacts with the substrate, thereby altering its color (Senthilkumar et al., 2011)

In blended fabrics, achieving uniform and optimal color strength requires a thorough understanding of how the blend ratio influences dye absorption. The blend ratio plays a significant role in determining dye uptake, largely depending on the nature of the fibers in the blend and the type of dyes used (Sule et al., 2014).

Despite the potential of Cotton/Hemp blends, limited research has been conducted on how varying fiber compositions influence color strength in dyed textiles. This study aims to fill this gap by exploring the impact of different Cotton/Hemp blend ratios on the color strength of dyed fabrics. By analysing the dyeing performance of these blends, this research seeks to provide valuable insights into optimizing fiber compositions for enhanced aesthetic and functional textile properties.

II MATERIALS AND METHODS

Fibers

For this study Cotton and Hemp fibres were sourced from Northern India Textile Research Association NITRA.

Dyes, Chemicals, and Auxiliaries

For dyeing commercially available Dimerene Reactive dye-GB Red dye was used due to their excellent fastness and bright coloration. Various chemical like Sodium Hydroxide, Sodium Carbonate, Acetic Acid, Sodium Bicarbonate, Sodium Chloride and Soap solution used for scouring and dyeing process were sourced from the laboratory of the Northern India Textile Research Association (NITRA).

2.1 Identification of Fibres

Fiber identification was carried out in accordance with AATCC 20 guidelines, employing various techniques such as the burning test, solubility test, microscopic analysis, and Fourier Transform Infrared (FTIR) spectroscopy.

Burning Test: To evaluate the burning behaviour of Cotton and Hemp fibres, small samples of each fibre were exposed to a small flame. Observations were made on characteristics like melting, shrinkage, and sustained burning, along with the type of odour emitted during combustion.

Solubility Test: The solubility of Cotton and Hemp fibres was tested by placing 10 mg of each fibre into separate test tubes, followed by the addition of 1 ml of 70% sulfuric acid to each tube.

Microscopic Analysis: The longitudinal and cross-sectional structures of the fibres and their blends were examined using a Zeiss high-resolution projection microscope.

Fourier Transform Infrared (FTIR) Study: The presence of Cotton and Hemp fibres was confirmed using Fourier Transform Infrared Spectroscopy with the ATR technique on a Perkin Elmer UATR TWO instrument. FTIR spectra were recorded over a range of 450 cm^{-1} to 4000 cm^{-1} .

2.2 Dyeing

Scouring of Cotton and Hemp fibers was done to remove surface impurities that may hinder the dye absorption. The scoured Cotton and Hemp fibers were dyed with 3% concentration of dye. Initially the temperature of dye bath kept at 40°C for 10 minutes. Sodium chloride was added for dye exhaustion in three instalments over a period of 30 minutes and temperature raised to 80°C, then sodium carbonate was added in dye bath for color fixation in two instalments in a period of 40 minutes. After dyeing fibers were removed from dye bath and thorough soaping and rinsing was done to remove surface dye. After rinsing fibers were air dried.

2.3 Blending of Dyed Fiber

The dyed fibers were blended in five blend ratios of Cotton and Hemp (80% Cotton:20 %Hemp, 60% Cotton: 40% Hemp, 50% Cotton: 50% Hemp, 40% Cotton:60%Hemp, 20% Cotton:80% Hemp) at the NITRA pilot plant as per weight. Along these blend 100% Cotton and 100% Hemp fibre were also taken for study to observe the change in K/S values with different blend proportions. The blends were prepared manually with hands to ensure uniform mixing of the both the fibers.

2.4 Assessment of Color Strength of Blended Fiber

The Macbeth Computer Color Matching (CCM) system was used to assess the color strength of the dyed fiber blends samples that had been created in different blend ratio. To do this, the samples were put into the Macbeth Color Eye 3100 slot with 100% fiber set as the standard. K/S values were then produced as a result.

2.5 Statistical Analysis

The experimental data obtained from the study were analysed using the statistical software SPSS (version 20). The null hypothesis (H₀) proposed that there is no relationship between the percentage of fibre blend and Color Strength (K/S). Conversely, the alternative hypothesis suggested the existence of a potential relationship between the fibre blend percentage and color strength(K/S). The null hypothesis (H₀) would be rejected if the p-value obtained from the statistical analysis is lower than the predetermined significance level, typically set at 0.05.

III RESULT AND DISCUSSION

3.1 Identification of fibres

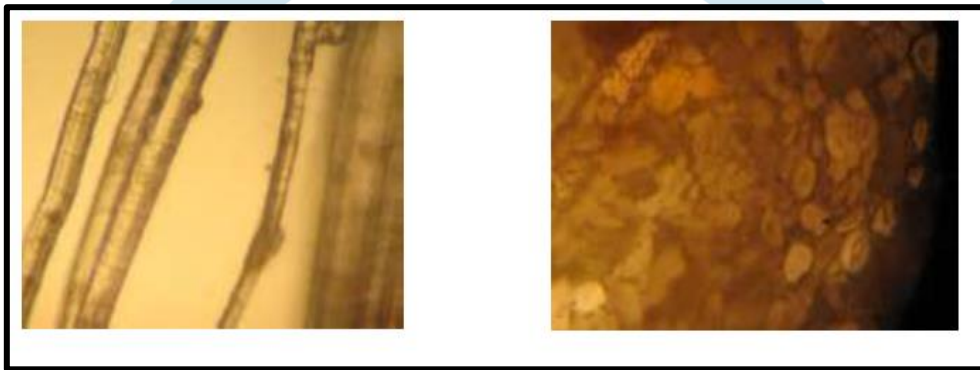
Burning test: The burning test conducted in the study revealed that both Cotton and Hemp fibre did not exhibit melting or shrinking behaviour, resembling the burning characteristics of paper. This experimental test provided evidence that the fibres consisted of cellulosic fibres.

Solubility test: The solubility test demonstrated that both fibres were successfully dissolved when exposed to 70% sulphuric acid. This additional test confirmed that the fibres were indeed of cellulosic nature.

Microscopic test: To further examine the fibres, both the fibers were subjected to microscopic evaluation. Longitudinal and cross-sectional structures of the fibres were observed under the microscope. Cotton fibers were observed longitudinally as twisted ribbons, and cross-sectional views revealed a kidney-shaped structure with a central lumen, a feature unique to cotton fiber (Fig. 1). Hemp fibers showed a smooth yet coarse surface feature when examined longitudinally. in cross-section showed fiber bundles with tiny lumen sizes (Fig. 2) (Kabir, et. al., 2013; Pil, et.al., 2016).



(a) *Longitudinal view of cotton Fibre* (b) *Cross-sectional view of cotton fibre*
Figure 1: Longitudinal and Cross-sectional View of Cotton Fibers



(a) *Longitudinal view of HempFibr*(b) *Cross-sectional view of Hemp fibre*
Figure 2: Longitudinal and Cross-sectional View of Hemp Fibers

Fourier transforms infrared (FTIR) study:

To further support microscopic analysis, FTIR study was carried out of Cotton and Hemp fibre. The result of FTIR study of individual Cotton and Hemp fibres were evaluated. FTIR spectra of Cotton, Hemp are shown in Fig-3,4 respectively. Typical Functional group and their corresponding wavenumbers are given in Table 1.

A peak between 1508 and 1587 cm^{-1} , found in Hemp, suggests lignin presence, which is absent in pure Cotton due to its lack of lignin (Jose et al., 2016) which differentiate Cotton from Hemp fiber.

Table 1: IR Absorbion frequencies of Cotton and Hemp fibers

Wave number (cm^{-1}) of Cotton as per Fig.3	Wave number (cm^{-1}) of hemp as per Fig.4	Peak Characteristics	References
3345	3398	H bounded OH stretch	(da Silva et al., 2016)
2857	2880	C-H stretching (Cellulose, Hemicellulose)	(Cecci et al., 2020)
1635	1646	Adsorbed H ₂ O	Jose et al.,2016

-	1512	Lignin	Jose et al.,2016
1427	1454	HCH and OCH in plane bending variation	Jose et al.,2016
1370	1324	CH bending (deformation stretch)	Jose et al.,2016
1274	1228	CH deformation stretch	Simonassi et al., 2017
1028	1032	C-O strctch	(da Silva et al., 2016)
890	892	COC, CCO, and CCH deformation and Stretching	(Cecci et al., 2020)
663	690	C-OH out-of -plane bending	(Cecci et al., 2020)

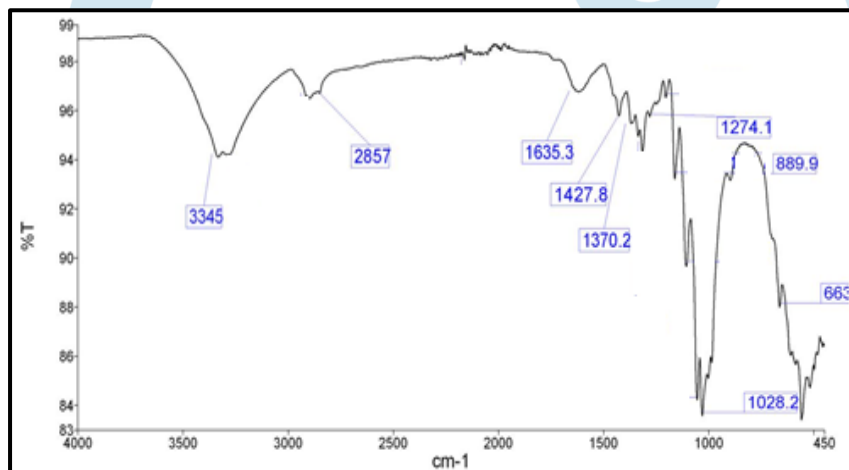


Figure 3: FTIR Spectra of Cotton fiber

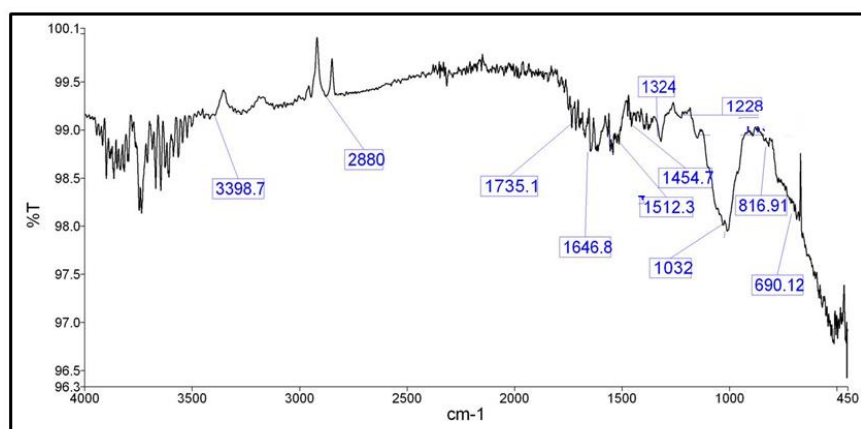


Figure 4: FTIR Spectra of Hemp fiber

3.2 Assessment of Color Strength of Dyed Cotton/Hemp Blend

After dyeing Cotton and Hemp, blends were prepared in different ratio as per fiber weight and their color strength (K/S) values were evaluated. The relationship between the moisture absorption properties of fibers and the resulting color strength of dyed textiles is a well-studied phenomenon in textile science. Result of color strength (table 2) showed that with the increase in percentage of fiber having higher moisture absorption in blend percentage, color strength value also increased. Fiber swells with moisture absorption which leads to spaces in the fiber structure and allow the dye molecules to enter in the fiber (Lee, S. H., & Lee, Y. H., 2002).

In Cotton/Hemp blend (table2), due to higher moisture absorption of Hemp lead to higher color strength of blend with high percentage of Hemp. The Cotton/Hemp blend showed high affinity for dye and better build-up property than cotton, may due to the lower crystallinity (Jieun Lee,2009).

Table 2: Cotton/Hemp blend Ratio and their K/S value

S.No.	Cotton/Hemp Blend Ratio	Color Strength-K/S (Reactive red Dye)
1	100% Cotton	1.81
2	80% Cotton 20% Hemp	1.82
3	60% Cotton 40% Hemp	1.83
4	50% Cotton 50% Hemp	1.84
5	40% Cotton 60% Hemp	1.96
6	20% Cotton 80% Hemp	2.04
7	100% Hemp	2.06

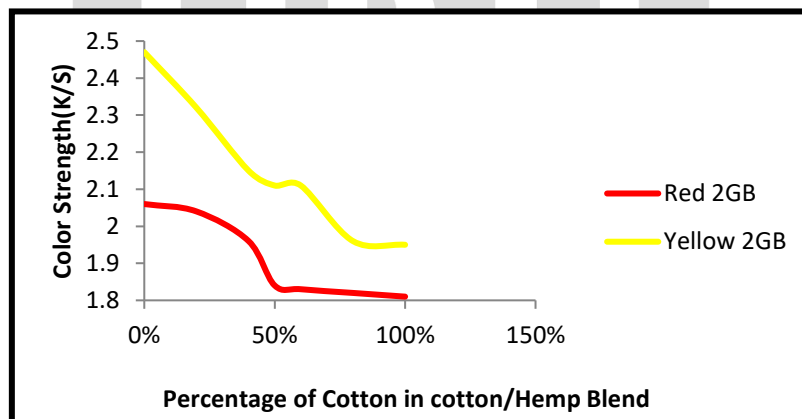


Figure 5: Blend Percentage of Cotton/Hemp Vs K/S

3.3 Statical Analysis

The analysis of the relationship between blend percentage and Color Strength(K/S) in the blend of Cotton and Hemp using the ANOVA test resulted in the rejection of the null hypothesis (H_0)(table 3). This rejection was based on the p-value being lower than the predetermined significance level of 0.05.

**Table 3: Univariate Annova between Blend Percentage (Cotton/Hemp) vs. K/S
Dependent Variable: Color Strength (KS)**

SUMMARY						
Groups	Count	Sum	Average	Variance		
Blend Percentage	6	350	58.33333	816.6667		
K/S	6	11.55	1.925	0.01199		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	9545.7	1	9545.7	23.37688	0.000687	4.964603
Within Groups	4083.393	10	408.3393			
Total	13629.09	11				

5. CONCLUSION

1. Based on the qualitative studies conducted, including burning, solubility,, it was determined that both fibres are of cellulosic nature. The burning test demonstrated that the fibres burned similarly to cellulose, without melting or shrinking. The solubility test further supported this finding, as the fibres dissolved in sulphuric acid, a characteristic of cellulose-based fibres.
2. Microscopic analysis of the fibres longitudinal and cross-sectional views revealed and confirmed the visual identification.
- 3.The Fourier transform infra-red (FTIR) spectra of the Cotton and Hemp fibres exhibited similarities, with the only notable difference in the Hemp fibre spectra being the presence of a peak at 1508cm^{-1} , indicating the presence of lignin which was absent in cotton due to no lignin content.
4. Through the univariate ANOVA analysis of blend percentage versus Color Strength (K/S), the null hypothesis (H_0) was rejected, as the p-value was lower than the predetermined significance level of 0.05, indicated a strong relationship between the blend percentage and color Strength(K/S).
5. Blending ratio of 40% Cotton 60% Hemp was optimum ratio to get significant change in color strength value (K/S)in comparison to 100% Cotton.

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