

Comfort properties and dyeing behaviour of cotton/milkweed blended rotor yarn fabrics

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Milkweed (M) fibres have been blended with cotton (C) fibres at three different proportions and the rotor-spun yarn fabrics are produced. The comfort properties of 100% cotton and C/M blended fabrics are analysed. The fabrics have been dyed with two types of reactive dyes, namely CI Reactive Yellow 3RS and CI Reactive Red 120, and the colour strength and other calorimetric parameters of the dyeing are analysed. From the comfort properties of the fabrics, it is noticed that the air and water vapour permeabilities of C/M blended fabrics are lower than the 100% cotton fabric and decrease with the increase in milkweed proportion. The thermal conductivity of C/M blended fabrics is lower than 100% cotton fabric and decreases with the increase in milkweed proportion. The reduction in inter-yarn space and higher yarn hairiness leads to reduction in air, water and thermal conductivity values with the increase in milkweed proportion. The wickability of C/M blended fabrics increases with milkweed proportion due to the open yarn structure and hollowness of milkweed fibres. From the dyeing behaviour of fibres, it is observed that the colour strength of C/M 80/20 is higher than 100% cotton and it decreases with the further increase in milkweed blend proportion. The low cellulose percentage, higher crystalline orientation index of milkweed fibres compared to cotton results in lower colour strength values with milkweed percentage greater than 20%.

Keywords: Air permeability, Comfort properties, Cotton-milkweed fabric, Dyeing behaviour, Thermal conductivity, Water vapour permeability, Wickability

1 Introduction

In textiles due to continuous changing preference, product diversification becomes one of the crucial issues for a visible economic activity. The evolution of synthetic fibres, which have many advantages over cotton in certain aspects like durability and elasticity, has revolutionized the textile production¹. As a result of this change in raw material utilization, combined with an enormous increase in energy and chemical demand, the world is now facing an ecological crisis. Further, the ever decreasing petroleum reserves all over the globe have compelled the textile manufacturers to look for alternate sources for raw materials, which are friendly to environment and biodegradable.

One such hitherto less investigated ligno-cellulosic fibre is the seed fibre obtained from *Pergularia daemia*, naturally growing drought and pest resistance tree of Indian origin², well known for its medicinal values³. The plant *Pergularia daemia* belongs to the family of *Asclepiadacea* and genus of *Pergularia* and comes under the milkweed fibres. The milkweed flowers are grown as milkweed pod which contains

the seed attached with the fibre or floss which is filled with tiny hollow tube like structures that act as insulators⁴⁻⁸. Like cotton, it is a single cell fibre, but unlike cotton, it is free from convolutions and has low cellulose content⁹⁻¹⁰. Due to its very smooth surface, spinning of 100% milkweed fibre is difficult. Because of its short length, milkweed floss has been blended with cotton and processed to develop yarns in ring and rotor spinning systems¹⁰⁻¹². The studies conducted on spinning of milkweed fibre blends showed that spinning of pure milkweed fibres is not practically possible due to the inherent characteristics of the fibre and could be able to spun with other fibres after suitable chemical modification of fibres. Further, the properties of milkweed blended yarns are found to be inferior to 100% cotton yarn¹³⁻¹⁵. This study explores the dyeability of cotton/milkweed rotor yarn fabrics with reactive and natural dyes and comfort properties of cotton/milkweed blended yarn fabrics.

2 Materials and Methods

2.1 Materials

The seed fibre from *Pergularia daemia* plant was obtained from its fully matured bolls, and the medium grade S-6 variety of cotton fibre was procured from

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the spinning mills. Sodium hydroxide pellet (analytical grade, Merck, India, purity >99.5 %) for scouring, hydrogen peroxide (pure, 50 % w/v, Merck, India) for bleaching, sodium carbonate (analytical, Merck), sodium silicate (technical, Merck) a stabilizer for hydrogen peroxide, hydrochloric acid (pure, 35 % solution, Merck, India) for washing the scoured fibre to remove the last traces of alkali were used. Two Reactive dyes, namely C.I Reactive Yellow 3 and C.I Reactive Red 120 were obtained from commercial sources. All other chemicals used were of analytical grade. The physical properties of cotton and milkweed fibres are given in Table 1.

2.2 Yarn Production

The spinning trials were conducted on a lab model spinning line (Trytex, India)¹¹. Since 100% milkweed fibres cannot be processed on the machine due to its lack of cohesiveness and low elongation at break, it was blended with the cotton fibres using three different blend ratios, namely C/M 80/20, 60/40 and 40/60. The process parameters were kept constant for all the three blend ratios (sliver weight 3.9 ktex, opening roller speed 8000 rpm, opening roller wire type OS21, rotor speed 40000 rpm, rotor diameter 43 mm) for the production of 20^s Ne rotor-spun blended yarns.

2.3 Fabric Production

The particulars of woven fabric produced from the handloom are given in Table 2.

2.4 Pre-treatment of Fabrics

Desized cotton and C/M blended fabrics were scoured prior to use by treatment at 95–100 °C for 60 min in an aqueous solution comprising 3% NaOH solution and 1 g/L scouring agent with a liquor ratio of 30:1. Then bleaching was carried out with hydrogen peroxide as per standard procedure.

2.5 Dyeing of Fabrics

For analyzing the dyeability of milkweed blended fabrics, the reactive dyes which are popular for dyeing cellulosic fabrics are used. Two types of reactive dyes, namely Reactive Yellow 3RS ($\lambda_{\max} = 432$) and Reactive Red 120 ($\lambda_{\max} = 542$) were used and the dyeing process is shown in Fig. 1.

2.6 Comfort Properties of Fabrics

Air permeability of the samples was measured via standard TS 391 EN ISO 9237 method, using the Textest FX 3300 air permeability tester. The measurements were performed on 10 samples at a constant pressure drop of 100 Pa (20 cm² test area).

Evaporative dish method based on the British Standard BS 7209 was used to determine the moisture water vapor permeability (MVTR) through a known area of a fabric in a controlled atmosphere. The wickability of fabrics was determined by the vertical wicking test as per AATCC TM 197-2011 standard. The vertical wickability, expressed as the wicking height in cm, was then noted after a time interval of 15 min. The thermal conductivity of the fabrics was determined using Lee's disc method.

2.7 Testing of Dyed Fabrics

The reflectance value (R) of the dyed materials was measured at different wavelengths in the visible region (400-700 nm). The *K/S* value at a λ_{\max} was calculated using the Kubelka-Munk equation. The corresponding CIE *L**, *a**, *b**, *C**, and *h₀* of the dyed samples were measured, employing a Macbeth Color-eye 7000 spectrophotometer under illuminant D65, and using a 100 standard observer. The calorimetric parameters such as *L**, *a**, *b**, *c** and *h* were also

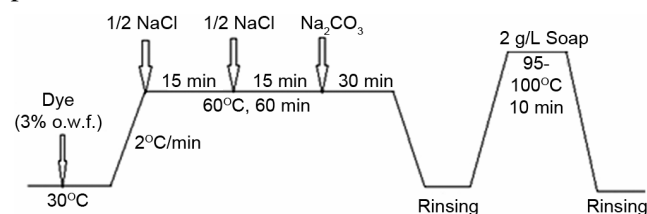


Fig. 1 — Dyeing process

Table 1 — Physical properties of cotton and milkweed fibre

Sample	Cotton	Milkweed
2.5% Span length, mm	28.3 (5.34)	29.09 (9.56)
50% Span length, mm	13.67 (8.49)	12.68 (9.6)
Uniformity ratio, %	45.2 (7.41)	41.6 (6.26)
Strength, g/tex	21.3 (4.7)	20.5 (7.99)
Elongation, %	6.3 (1.51)	3.9 (2.7)
Moisture regain, %	8.2 (2.3)	10.5 (1.5)
Micronaire, μ g/inch	3.5 (1.42)	< 2.4

Values in parentheses represent CV%.

Table 2 — Woven fabric particulars of cotton and cotton/milkweed blended fabrics

Parameters	100% Cotton	C/M (80/20)	C/M (60/40)	C/M (40/60)
Weave	Plain	Plain	Plain	Plain
Warp count	20s	19.0s	20.5s	21s
Weft count	19.5s	20s	19.5s	19s
EPI	54	53	54	52
PPI	52	52	51	50
GSM	154	138	131	118
Cover factor	18.77	18.51	18.55	18.29

noted from the spectrophotometer to analyse the colour differences between the fabrics.

3 Results and Discussion

3.1 Comfort Properties of Fabrics

One of the parameters influencing the comfort characteristics of fabric is cloth cover. The theoretical cover factor (Table 2) is found almost the same for both types of fabrics. It is meaningful to understand the differences in practical cover factor of the fabrics since the milkweed fibres tend to give bulk to the fabrics, which, in turn, influences other comfort attributes of the fabrics. The fractional cover factor is known to represent the both groups of yarns, defined as the total area of the fabric covered by the component yarns. It is calculated by assuming the

yarns to have a circular cross-section. If the yarn diameter is ' d ' and the adjacent yarn is displaced by a distance ' s ', then the fractional cover factor is expressed as ' d/s '. If C_1 and C_2 are the fractional cover for the warp and weft respectively, then the total fabric cover will be given by $C_1 + C_2 - C_1C_2$.

The images of 100% cotton and C/M 60/40 fabrics, as shown in Fig. 2, indicate the yarn diameter and inter-yarn space in the fabric. The warp, weft and total fractional cover are given in Table 3. From Fig. 2 and Table 3, it is clear that the C/M 60/40 blended yarn fabric have better fractional cover as compared to 100% cotton fabric due to increased yarn diameter. Higher hairiness in C/M 60/40 yarns could have reduced inter-yarn spacing.

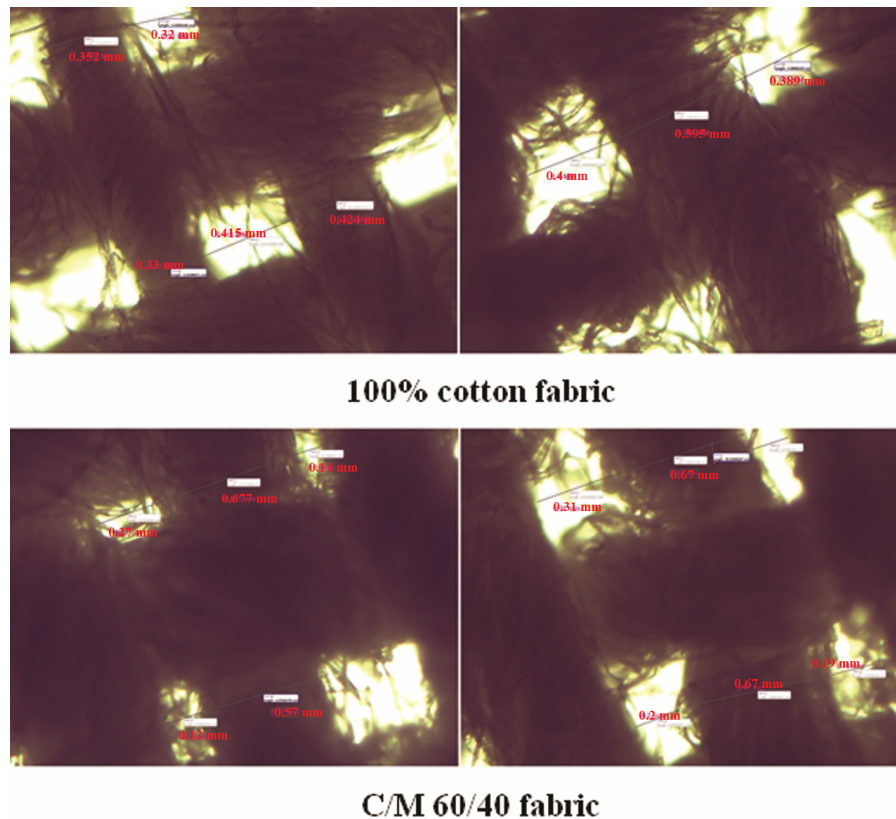


Fig. 2 — Measurement of yarn diameter and spacing in woven fabric

Table 3 — Fractional cover for 100% cotton and C/M 60/40 fabrics

Fabric	Warp			Weft			Total cover factor
	Yarn diam. (d) mm	Yarn spacing (s) mm	C_1	Yarn diam. (d) mm	Yarn spacing (s) mm	C_2	
100% Cotton	0.42	0.77	0.545	0.591	0.971	0.61	0.822
C/M 60/40	0.47	0.76	0.618	0.599	0.965	0.62	0.854
C/M 60/40	0.587	0.767	0.765	0.642	0.802	0.80	0.953
C/M 60/40	0.599	0.752	0.796	0.651	0.778	0.837	0.967

The comfort properties of the cotton and cotton/milkweed blended fabrics are shown in Table 4.

From Table 4, it is observed that the air permeability of C/M blended fabrics is decreasing with the increase in milkweed proportion in the blend and is lower than 100% cotton fabrics. The air permeability of fabrics depends on the yarn structure and fabric geometry. The porosity in fabric plays an important role in transmission of air through the fabrics. The poor packing density and higher yarn diameter of C/M blended yarns compared to 100% cotton yarn results in reduced thread spacing in fabric, which is the reason for poor air permeability in C/M blended fabrics. In C/M blended yarn fabrics, the higher yarn diameter with the increase in milkweed proportion reduces the inter-yarn space, and the higher yarn hairiness leads to reduction of air permeability in milkweed blended fabrics. The higher yarn hairiness in C/M blended yarns could overlaps the inter-yarn pore area significantly, and reducing the air permeability of fabrics.

The yarn property and fibre content play a vital role in water vapour transmission. The water vapour permeability of C/M blended fabrics is significantly lower than 100% cotton fabrics. The water vapour diffusion through the inter-yarn space in the fabric is instantaneous, whereas the diffusion through a fabric is limited due to lower water vapour diffusivity of the textile material. The increased yarn diameter of C/M blended yarns results in lesser inter-yarn spaces in the fabric, thus showing the lower water vapour transmission as compared to 100% cotton fabrics.

The thermal conductivity of C/M blended fabric is significantly lower than 100% cotton fabrics, which indicates better thermal resistivity or thermal insulation property as compared to cotton fabrics. With the increase in milkweed blend proportion, a larger number of hollow milkweed fibres is present in the blend, which acts as an insulating medium preventing the thermal transmission through the

fabric. Further, the lesser the inter-yarn and larger inter-fibre gap in the yarn due to poor yarn packing helps in storage of air pockets, resulting in lower thermal conductivity of blended yarn fabrics.

The wickability of a fabric denotes the ability to transport the liquid moisture in the form of sweat from inner to outer surface of a body. The wicking height of 100% cotton and C/M blended yarn fabrics after the time interval of 15 min is given in Table 3. The wicking property of C/M blended fabric is significantly higher than 100% cotton fabric. Wicking will occur only when the fibres, assembled with capillary spaces between them, are wetted by a liquid. The fibre surface properties and pore structure are the main factors influencing the wicking. The higher wicking height of C/M blended fabrics shows better capillary effect due to hollow nature of milkweed fibres and less packing of fibres inside the yarn. The availability of more pore space within the C/M yarn structure leads to creation of larger capillary size and higher interconnectivity between the capillaries within the yarn structure and results in higher wickability as compared to 100% cotton fabrics.

3.2 Colour Strength of Dyed Fabric

For analyzing the dyeability of C/M blends of different proportions, fabrics are dyed using reactive dyes of two different colors yellow and red at 3% shade. The colour strength and other calorimetric parameters of undyed and dyed fabrics are shown in Table 5. The comparison of colour strength values of undyed cotton and C/M blended fabrics are shown in Fig. 3. It is clear that the colour strength of C/M is higher than that of 100% cotton fabric and it increases with the increase in proportion of milkweed fibres.

By observing the calorimetric values of undyed fabrics (Table 4), it is noticed that the ΔL (the difference between 100% cotton and C/M blended fabrics) is '-ve', indicating that the C/M blended fabrics are on darker side compared to 100% cotton and the darkness increases with milkweed proportion in the blend. Further by observing the 'b*' values, it is clear that the C/M blended fabrics are in yellow shade compared to 100% cotton even after the bleaching of fabrics. The higher lignin content in milkweed fibres leads to yellowish colour on the fabrics compared to pure cotton fabric, which is further noticed in C^* and h° values.

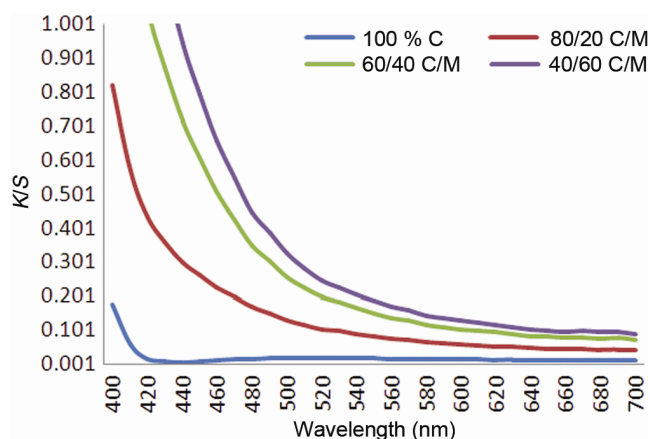
The amount of dye uptake on the fabric depends on the structural feature of both the dyes and the fibres. The milkweed fibres are having lower degree of crystallinity but higher crystalline orientation index

Table 4 — Comfort properties of fabrics

Properties	100% Cotton	C/M 80/20	C/M 60/40	C/M 40/60
Air permeability $\text{cm}^3/\text{cm}^2/\text{s}$	156.61	155.68	148.94	124.55
Moisture vapour permeability, $\text{g}/\text{m}^2/\text{day}$	1434.38	1424.03	1389.27	1321.26
Wicking height, cm	9.6	11.8	13.5	14.3
Thermal conductivity w/mk	0.038	0.033	0.029	0.017

Table 5 — Calorimetric parameters and colour strength of different fabrics

Dye	Fibre	L*	a*	b*	c*	h ⁰	ΔL*	Δa*	Δb*	Δc*	Δh ⁰	ΔE*	K/S
Before dyeing	100% Cotton	93.14	1.43	-1.38	1.99	316.2	-	-	-	-	-	-	0.176
	C/M 80/20	86.43	-0.30	17.48	17.48	91.02	-6.70	-1.74	18.85	15.49	-10.9	20.08	0.647
	C/M 60/40	85.92	-1.10	17.79	17.84	92.89	-7.22	-2.53	19.16	15.85	-12.9	19.71	0.674
	C/M 40/60	89.44	-1.31	21.92	21.95	94.27	-3.69	-2.75	23.30	19.96	-11.1	24.52	0.907
Reactive Yellow 3RS	100% Cotton	69.25	31.29	79.09	85.05	68.39	-	-	-	-	-	-	15.34
	C/M 80/20	65.79	32.31	79.14	85.48	67.77	-3.46	1.01	0.05	0.422	-0.92	3.61	20.66
	C/M 60/40	66.44	29.17	74.20	79.73	68.51	-2.81	-2.12	-4.89	-5.33	0.18	6.02	15.18
	C/M 40/60	66.14	30.07	73.62	79.52	67.76	-3.11	-1.22	-5.47	-5.53	-0.90	6.41	14.74
Reactive Red 120	100% Cotton	51.70	45.95	-6.85	46.46	351.5	-	-	-	-	-	-	4.46
	C/M 80/20	50.05	45.27	-3.41	45.40	355.7	-1.65	-0.68	3.44	-1.05	3.35	3.88	4.91
	C/M 60/40	51.20	44.76	-3.95	44.93	354.9	-0.50	-1.19	2.91	-1.53	2.75	3.18	4.37
	C/M 40/60	51.91	41.65	-2.41	41.71	356.7	0.21	-4.30	4.45	-4.74	3.90	6.19	3.92

Fig. 3 — Comparison of *K/S* values of fabrics before dyeing

(COI) than cotton fibres^{5,16}. The higher COI leads to poorer flexibility and rigid structure of milkweed fibres. This low flexibility along with the low concentration of accessible sites in milkweed fibres could lead to the lower diffusion and reaction for bulky dyes. The dye strength of 100% cotton and C/M blended fabric are compared using yellow and red colour dyes, as shown in Fig. 4.

It is clearly evident that the colour strength (*K/S*) of C/M 80/20 fabric is the highest, followed by 100% fabric, C/M 60/40 and 40/60 fabrics. The crystallinity of cotton is the higher, while the COI of cotton is lower than milkweed fibres. The higher crystallinity of cotton fibres could result in smaller amorphous region in the fibre, which might affect dye accessibility to the fibres; higher COI means that the molecular chains are aligned more closely with each other and more molecular chains are parallel to

the long axis of the fibre, thus making it difficult for the dyes to gain access to the fibres.

In case of C/M 80/20 blended fabrics, the combination of higher amorphous region of milkweed fibres and lower COI of cotton fibres results in higher colour strength both in yellow and red colour dyes. But with further increase in milkweed proportion, the colour strength of fabric decreases. This could be attributed by two reasons. As the milkweed proportion increases, the higher COI of milkweed fibre increases in the blend, which affects the dye accessibility and hence reduces the colour strength of fabrics. Another reason could be due to lower cellulose percentage in the fabrics. The cellulose which has good affinity with reactive dyes is lower in milkweed fibres compared to that in cotton fibres⁵. As a reactive dye usually contains a reactive group that could form a chemical bond with cellulose fibre, fabric containing more cellulose would have a higher dye uptake and dye fixation. The existence of lignin in milkweed blended fabrics has a negative effect on their colour strength, irrespective of dye colour.

Figure 4 shows that the colour strength of fabrics is higher in yellow dyes compared to that in red dye. The bulky molecular size of C.I. Reactive Red 120 leads to poor migration properties and thereby the *K/S* value belonging to the fabrics dyed with the above-mentioned dye is lower than those dyed with C.I. Reactive Yellow 3RS which has smaller molecular size.

In the case of calorimetric parameters, namely lightness (*L**) and chroma (*C**), although the values for fibres dyed with C.I. Reactive Yellow 3RS is a little higher than those dyed with C.I. Reactive Red 120,

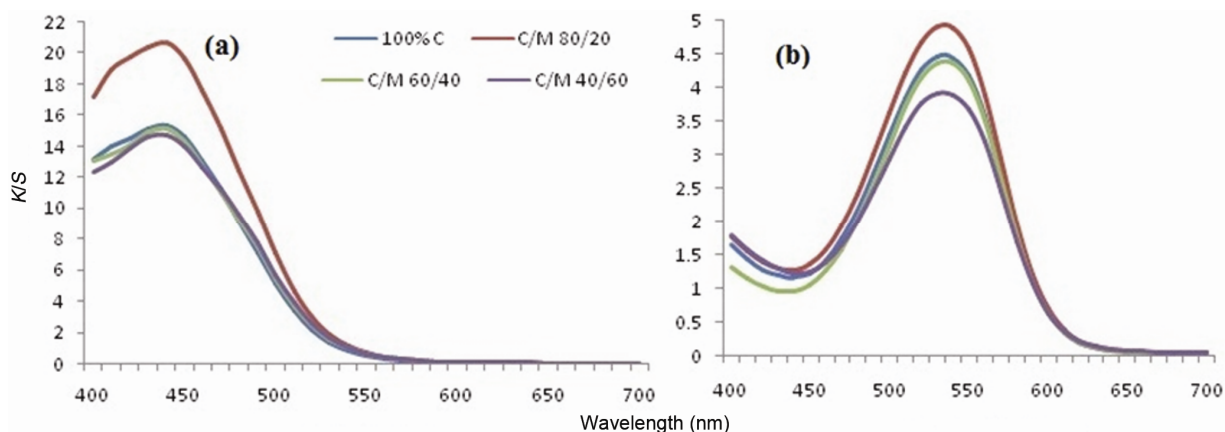


Fig. 4 — Comparison of K/S values of fabrics dyed using (a) reactive yellow dye and (b) reactive red dye

it appears that L^* and C^* values are almost independent of the fibre type and mostly are dependent to the dyes used. Other colorimetric parameters such as a^* , b^* and h° obtained for the different fabrics are in proper agreement with the expected hue characters of the applied dyes.

4 Conclusion

4.1 It is found that as the milkweed proportion increases in the blend, the air permeability and water permeability of fabrics decrease. The reduction of inter-yarn spaces in the fabric due to increase in yarn diameter and yarn hairiness with increase in milkweed blend proportion reduces the air and water vapour permeability of C/M blended fabrics.

4.2 The thermal conductivity value for C/M blended fabrics is found lower than the 100% cotton fabric. The reduction of inter-yarn space in the fabric and hollow nature of milkweed fibres enable storage of air-pockets both between and within yarn structure, leading to lower thermal conductivity and better thermal insulation compared to 100% cotton fabrics, which determines its potential application as thermal wears like winter jacket.

4.3 The colour strength of 100% cotton and C/M blended yarn fabrics were analysed. From the results, it is observed that C/M 80/20 blended yarn fabrics show higher color strength as compared to 100% cotton and C/M blends of 60/40 and 40/60 proportions for both the dyes used.

4.4 The combination of higher amorphous content in milkweed fibres and lower crystalline orientation index of cotton shows higher colour strength in C/M 80/20 fabrics. Further increase in milkweed proportion in the fabric leads to reduction of colour strength as compared to 100% cotton. The higher COI and lower cellulose percentage in milkweed fibres compared to cotton results in lower colour strength values at milkweed proportions greater than 20%.

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