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Comparison of yarn properties of gossypium hirsutum and naturally colored gossypium arboreum cotton

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ABSTRACT

Naturally colored cotton can be a highly sustainable alternative to conventional cotton which entails huge consumption of water, energy, and chemicals in scouring, bleaching and dyeing. The objective of this study was to investigate the yarn properties of one of the most commonly grown Gossypium hirsutum cotton and naturally colored Gossypium arboreum cotton grown in Pakistan. Eighteen different samples of ring-spun yarn were developed using the two cotton types, in three different yarn counts (Ne 16, Ne 20, Ne 24), each with three different twist multipliers (TM: 4.00, 4.25, 4.50). Different yarn properties of all yarn samples were investigated as per standard test methods. Result comparisons show that tenacity and elongation of conventional cotton yarns was about 42% and 10 % higher as compared to that of colored cotton respectively. Similarly, hairiness, CVm and total imperfections of colored cotton yarns were 11%, 25%and 320 % higher as compared to conventional cotton respectively. Comparative analysis reveals that although yarns made from Gossypium hirsutum cotton are superior in terms of strength, elongation and uniformity. However, the properties of naturally colored Gossypium arboreum cotton yarn are good enough for making different textile products which do not require too high mechanical strength and uniformity such as knitwear, woven casuals, and home textiles like bed linen and curtains. It seems that the natural color genes of cotton suppress its strength and fiber length properties which reduced yarn tenacity, and increased yarn unevenness, imperfections, and hairiness.

1. Introduction

Cotton is one of the most widely used fibers in apparel due to its soft hand feel and desirable comfort properties. However, one of the most critical arguments against the use of cotton products is the exorbitant consumption of water during its scouring, bleaching and dyeing, in addition to toxic pesticides and fertilizers used during its production. Gossypium hirsutum is the most commonly grown type of cotton in the world but it has to be scoured, bleached, and dyed as usual for most of the end uses. However, Gossypium arboreum cotton can be grown in a naturally colored shade and may be potentially used in many niche products, without any need of scouring, bleaching and dyeing [1], [2]. This fiber is suitable for applications where fine yarn counts are not essential, as its short length and lower strength makes it challenging to produce finer yarns. No finishing is needed at the fiber stage; instead, finishes can be applied at the fabric stage based on the intended end use. A standout characteristic of this cotton is that it is non-GMO organic cotton.

In the textile industry, sustainability has become a topic of concern. The extensive use of chemical fertilizers and pesticides in conventional cotton farming has a negative impact on our ecosystem. The scouring, bleaching, and dyeing processes of cotton textiles increase environmental pollution, as the pre-

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treatment of the textiles takes 5-500 liters of water per kg of the fabric processed, depending on the processing method used [3-7]. It may take between 10 and 80 liters of water to scour one kg of cotton fabric and between 10 and 130 liters of water to bleach it [3]. Dyeing one kg of cotton fabric might use up to one hundred liters of water [8]. For ecological sustainability, we need textile materials that have a minimum negative environmental impact on our planet. Naturally colored cotton may be a more sustainable alternative to conventional cotton, at least in some niche products.

Palamutcu et al. studied different varieties of white and naturally colored cotton fibers for their physical properties considering the effect of location, climate, and crop year and found that for all the factors, the fineness, strength, and length of white cotton fiber were superior as compared to colored cotton fibers [9]. Gunaydina et al. examined the mechanical properties of woven fabrics using five different types of cotton, including white and naturally colored variants, and discovered that white cotton had superior mechanical properties when compared with the colored cotton of the same species [10, 11]. The mechanical and functional properties of the woven fabrics are enhanced by scouring the naturally colored cotton fabric as compared to unscoured fabric [12]. Wang et al. developed non-woven spunlaced fabrics using various blends of colored cotton along with white cotton and evaluated their anti-bacterial properties and found that the colored cotton blends having a proportion of 70% or more, possessed excellent anti-bacterial properties against Staphylococcus aureus and Escherichia coli while the processes like laundering and sunlight exposure decreased their efficiency [13].

Hidayat et al. investigated the fiber properties of a colored cotton specie and compared it with the superior cotton variety and found that the Bronesian-colored cotton varieties have less strength and fineness properties as compared to the Kanesia white cotton varieties [14]. Xu et al. developed a woven gauze made from naturally colored cotton and it was found that the naturally colored cotton gauze accelerated wound healing when compared with that of commercially available cotton gauze [15]. Soydan et al. adapted three pre-treatment techniques (scouring, bleaching, and a combination process) to investigate the colorimetric and hydrophilic properties of white and naturally colored cotton fibers. The hydrophilic properties of the samples were observed to be improved as a result of the combined treatment. The colorimetric data followed the same pattern, however, white cotton performed better than colored cotton [16].

VanZandt et al. reported that woven fabrics made from naturally colored buffalo-brown cotton had better mechanical properties as compared to those made from coyote-colored cotton [17]. Tsaliki et al. found that there was no significant effect of the wet processing treatments on the color fastness properties of the naturally colored cotton [18]. Ma et al. found that unlike white and green cotton varieties, naturally colored brown cotton showed a significant antibacterial activity due to presence of a natural antibacterial pigment in the fibers [19].

Price et al. investigated the quality parameters of four different naturally colored cotton varieties and found that the micronaire and strength of the fibers was dependent on the shade of the cotton variety. The darker shades demonstrated poor strength properties as compared to the lighter shades of naturally colored cotton [20]. Parmar et al. found that the Limiting Oxygen Index (LOI) of the naturally colored cotton was higher than that of the white cotton [21]. Hinchliffe et al. also reported better flame retardancy of naturally colored cotton as compared to that of white cotton [22]. Aliei et al. investigated the effect of detergents, water type and temperature on the color fastness of the naturally colored cotton and found that the water hardness was the main factor contributing to the change in the color followed by the high temperature during laundering [23].

Properties of cotton fibers not only depend on the cotton species but also on the specific cotton variety, nature of soil on which it is grown as well as the climatic conditions. Pakistan is among the top ten cotton producing countries in the world and to the best of our knowledge, there has been no systematic study that compared in detail the strength and uniformity properties of white and naturally colored Pakistani varieties of cotton.

While it is true that natural color genes in cotton can influence certain fiber properties, it is important to note that the existing studies have primarily focused on comparing conventional and naturally colored cotton in terms of general fiber properties without statistical analysis. However, there is a lack of systematic studies that specifically compare the strength and uniformity properties of yarns produced from different types of Pakistani grown Gossypium hirsutum and naturally colored Gossypium arboretum cotton with varying linear densities and twist levels. The existing studies also lack the robustness of statistical analyses such as analysis of variance (ANOVA). Our study aims to bridge this gap in the literature by providing a detailed analysis of these specific yarn properties at different yarn counts and twist levels.

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By conducting a comprehensive comparison of yarn properties, we aim to investigate whether the potential differences in fiber properties between conventional and naturally colored cotton translate into statistically significant variations in the strength and uniformity properties of the resulting yarns of different linear densities and twist levels. While it is reasonable to expect some impact of fiber properties on yarn properties, the precise extent and significance of these effects are not well understood.

Our research contributes to the existing literature by specifically examining the relationship between fiber properties and yarn properties, filling a gap in the current knowledge. This study will provide valuable insights into the practical implications of using naturally colored cotton in yarn production, aiding manufacturers and researchers in making informed decisions regarding its suitability for specific applications.

2 Materials and Methods

2.1Materials

Eighty (80) kg naturally colored seed cotton, grown at 1-acre area of the agricultural farm of National Textile University (NTU) Pakistan was taken and ginning was done on a Saw ginning machine installed at NTU Spinning lab to separate the seeds and thus 24 kg fiber was obtained for making the yarns. Out of 80 kg, amount of lint or fiber was 30% while the rest was the seed. One bale of conventional saw ginned off-white cotton was obtained from the local Pakistani cotton market. This specific variety of colored cotton was taken for the study because it was an improved local variety having staple length 0.95 inch as compared to 0.75-inch old version in Pakistan along with having improved maturity, strength and micronaire. The properties of off-white cotton and naturally colored cotton fibers were investigated using High Volume Instrument (HVI) calibrated at standard white cotton and are given in Table 1.

Table 1

Properties of cotton fibers

Property	Units	White cotton	Colored cotton
Genus/Species	-	*Gossypium hirsutum*	*Gossypium arboretum*
Spinning Consistency Index (SCI)	-	123.00	67.00
Moisture (Mst)	%	8.00	7.50
Maturity Index (Mat)	-	0.87	0.85
Upper Half Mean Length (UHML)	in	1.06	0.94
Uniformity Index (UI)	%	82.30	80.20
Short Fiber (SF)	%	9.30	10.90
Strength (Str)	g/Tex	30.10	20.80
Elongation (Elg)	%	5.20	6.20
Micronaire (Mic)	µg/in	4.44	3.90
Rd	-	71.00	38.30
(+b)	-	9.60	19.70
Color Grade	-	42-1	85-5

It can be said from the above results that colored cotton has lower quality especially in length and strength which suggests that it can be used to make coarser yarns of Ne 8 to 16.

Eighteen different samples of yarn were developed using the two cotton types given in Table 1, in three different yarn counts, each with three different twist multipliers (TM). Experimental factors and levels are listed in Table 2, and the complete experimental design is given in Table 3.

Table 2

Experimental factors and levels

Experimental Factors	Levels		
	Level 1	Level 2	Level 3
Cotton Type	White	Colored	-
Yarn Count	16/1	20/1	24/1
Yarn TM	4.00	4.25	4.50

Table 3

Design of experiment

S. No.	Cotton Type	Yarn Count	Yarn TM
1	White	16/1	4.00
2	White	16/1	4.25
3	White	16/1	4.50
4	White	20/1	4.00
5	White	20/1	4.25
6	White	20/1	4.50
7	White	24/1	4.00
8	White	24/1	4.25
9	White	24/1	4.50
10	Colored	16/1	4.00
11	Colored	16/1	4.25
12	Colored	16/1	4.50
13	Colored	20/1	4.00
14	Colored	20/1	4.25
15	Colored	20/1	4.50
16	Colored	24/1	4.00
17	Colored	24/1	4.25
18	Colored	24/1	4.50

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2.2 Development of Yarn Samples

Using both white and colored cotton fibers, distinct yarns were spun with varying linear densities and twist multipliers (TM) according to the design of experiment. There were eighteen different yarn samples, nine of them were made from white cotton, and the others from colored cotton. Same spinning machine lines and process parameters were used for the development of both white and colored cotton yarns.

The fibers were first opened and cleaned in the Toyoda Ohara blow room, yielding a lap sheet of Ne 0.00123, the first step in the process of making carded yarn. The lap sheets were then processed through carding machine to make the sliver with count of Ne 0.134. At drawing machine (Rieter RSB D 40), two passages were given to both types of slivers at a speed of 250 m/min and doubling of six slivers to get a final sliver with count of Ne 0.138. These finisher slivers were used to make rovings of Ne 0.7 for both types of cotton at a twist multiplier (TM) of 1.30 at Toyota FL-16 Simplex machine. Finally, the rovings were processed through ring spinning machine (Toyota Ring RY-5), to make 16/1, 20/1, and 24/1 yarns with TM of 4.00, 4.25, and 4.50. Linear densities of intermediate spinning process outputs are given in Table 4.

Table 4

Linear density of intermediate spinning process outputs

Spinning output	Count (Ne)
Carded Sliver	0.134
Drawn Sliver	0.138
Roving	0.70
Yarn	16, 20, 24

2.3 Testing of Yarn Samples

Yarn linear density was determined according to ASTM D1907 standard test method using a wrapping reel (model no. 9230) and weighing balance (model no. TE214S). The lea breaking strength was determined in accordance with ASTM D 1578 standard test method using the lea strength tester (model no. 1477). USTER-5 Tester was used to determine yarn unevenness, yarn imperfections (IPI), and hairiness, according to ASTM D1425. USTER Tensorapid was used to determine the single yarn strength, elongation, and tenacity according to ASTM D 2256, using 500 millimeters gauge length.

3. Results and Discussion

3.1 Yarn Strength

Fig. 1 shows a visual comparison of the yarn tenacity values of colored cotton and white cotton. The analysis of variance (ANOVA) for yarn tenacity shown in Table 5 depicts that the effect of cotton type and twist multiplier on the tenacity of the yarn was statistically significant (p-value = 0.000). Moreover, the interaction between the yarn count and the twist multiplier was also found statistically significant (p-value = 0.047). Fig. 2 gives the main effect plots for yarn tenacity, showing mean results at each level of experimental variables. It is clear from Fig. 2 that the mean yarn tenacity of white cotton is 17.04 g/Tex, which is about 42% higher as compared to that of colored cotton (11.93 g/Tex). The yarn characteristics are mostly determined by the inherent qualities of the constituent fibers [24], so the higher strength of white cotton may be attributed to higher fiber strength, longer fiber length, and lower content of short fibers as compared to those of colored cotton (Table 1).

Fig. 2 gives a decreasing trend in tenacity as the yarn count increased. As the count of yarn is increased, the mean yarn breaking strength falls. Because finer yarns have fewer fibers in their cross-section, resulting in lower strength [25]. Surprisingly, the mean yarn tenacity of different yarn counts was not found statistically significant according to ANOVA results given in Table 5. Fig. 2 shows that TM 4.5 resulted in the highest mean yarn tenacity whereas TM 4.0 in the lowest mean yarn tenacity. Fibers get closer together and have more cohesiveness as the twist multiplier rises and the yarn strength increases as fibers become more uniformly aligned with one another [26].

Table 5

ANOVA Table

Yarn tenacity					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Cotton Type	1	587.318	587.318	317.45	0.000
Yarn Count	2	7.784	3.892	2.10	0.129
Twist Multiplier	2	55.741	27.870	15.06	0.000
Error	76	140.608	1.850		

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Total	89	813.625			
Yarn elongation at break					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Cotton Type	1	6.8614	6.86136	40.16	0.000
Yarn Count	2	15.6796	7.83979	45.89	0.000
Twist Multiplier	2	13.6547	6.82734	39.96	0.000
Error	76	12.9835	0.17084		
Total	89	51.9026			
Coefficient of yarn mass variation (CVm)					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Cotton Type	1	441.383	441.383	1308.75	0.000
Yarn Count	2	45.176	22.588	66.98	0.000
Twist Multiplier	2	0.226	0.113	0.34	0.716
Error	76	25.631	0.337		
Total	89	515.382			
Total yarn imperfection (IPI)					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Cotton Type	1	46908340	46908340	1402.55	0.000
Yarn Count	2	13233789	6616894	197.84	0.000
Twist Multiplier	2	67365	33682	1.01	0.370
Error	76	2541821	33445		
Total	89	66834165			
Yarn hairiness					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Cotton Type	1	12.7841	12.7841	109.80	0.000
Yarn Count	2	34.5209	17.2605	148.25	0.000
Twist Multiplier	2	12.1315	6.0657	52.10	0.000
Error	76	8.8486	0.1164		
Total	89	71.8493			

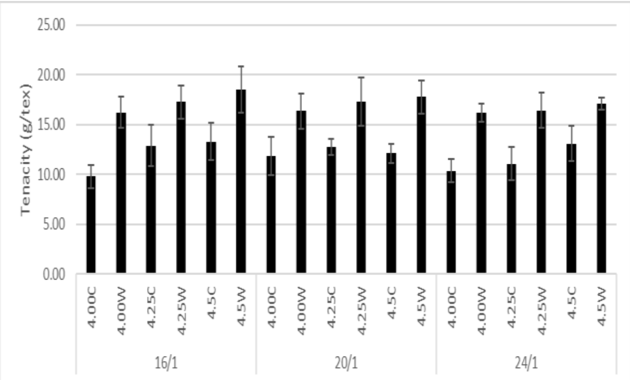

Fig. 1. Effect of Different Factors on Yarn Tenacity

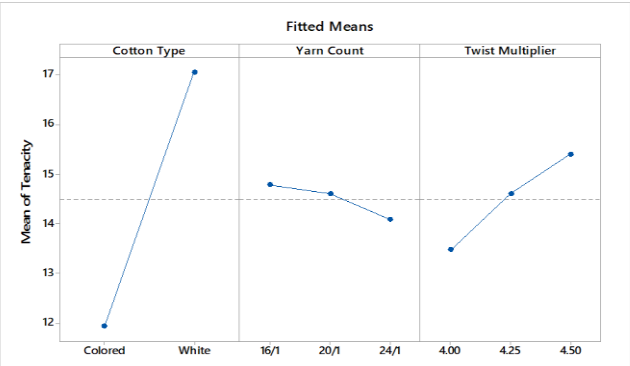

Fig. 2. Main Effect Plots for Yarn Tenacity

3.2 Yarn Elongation at Break

As seen in Fig. 3, the values of the yarn elongation for both the colored and white cotton samples were highest for the 16/1 samples and subsequently declined with increasing yarn count from 16/1 to 20/1 and finally 24/1. This could be because of the finer yarn diameter that arises from a higher yarn count, which in turn reduces the yarn's elongation [27].

Table 5 for an analysis of variance depicts the elongation at break of white and colored cotton yarns with varying yarn counts and twist multipliers. It was found that the elongation at break of the yarn was significantly affected by cotton type, yarn count, and twist multiplier, (p-value = 0.000). When comparing the yarns' elongation at break in Fig. 4, white cotton samples were found to have a greater mean value of elongation than the colored yarns. In terms of fiber composition, colored cotton yarns tend to be slightly less elastic than white. This may be because of weaker and shorter colored cotton fibers which have low inter-fiber interaction as compared to stronger and longer white cotton fibers. As longer fibers can hold the adjacent fibers for a longer period and thus exhibit a

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greater breaking elongation [28]. This is mostly because brown cotton's color genes suppress fiber development. Moreover, research shows that the presence of color reduces the fiber's strength [10]. The elongation behavior of yarns is also affected by the proportion of short fibers present, with more short fibers present in colored yarns compared to white yarns (Table 1) [29].

From the plots in Fig. 4, it is clear that the yarn's elongation significantly reduced as its linear density increased which shows that there exists an inverse relationship between the elongation behavior and the yarn count [30]. When accounting for the influence of the yarn twist multiplier, there existed a direct relation between the yarn TM and the yarn elongation. As the TM was increased from 4.00 to 4.25 and subsequently 4.50, the yarn elongation likewise increased.

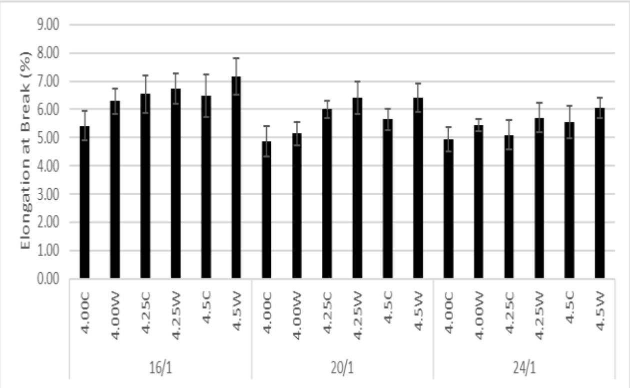

Fig. 3. Effect of Different Factors on Yarn Elongation at Break (%) of Yarn

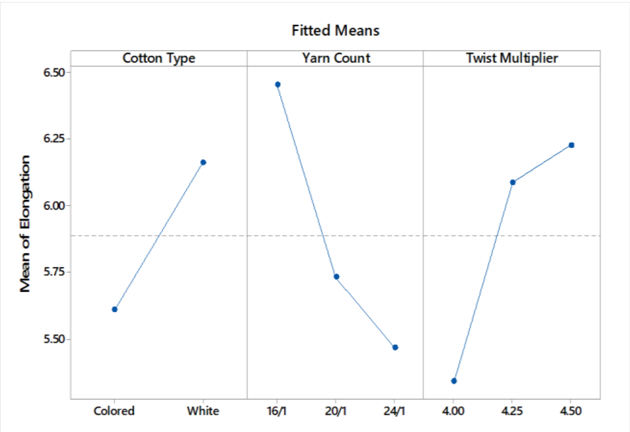

Fig. 4. Main Effect Plots for Yarn Elongation at Break

3.3 Coefficient of Variation in Yarn Mass (CV_m)

A visual representation of the CV_m of both colored and white cotton yarns is provided in Fig. 5. The variability in yarn mass was seen to be affected by both the yarn count and the cotton type. The ANOVA results listed in Table 5 demonstrate that only the cotton type and the yarn count played a significant impact in influencing the CV_m of the yarns (p-value = 0.000). The yarns' CV_m was not noticeably affected by the third element, the twist multiplier. Fig. 6 shows the main effect plot for CV_m of the yarns. The mean CV_m for colored cotton was found to be 21.68, which was higher than the mean CV_m for white cotton (17.25). This is because of the main fiber parameter that decides the unevenness of the yarn i.e., fiber length and SFC. The greater the length of the fiber, the lower the CV_m of the yarn as a result. The short fiber content, inter-fiber cohesion, uniformity index, and fineness are other parameters that may also influence the unevenness of the yarn. [31]. An increase in fiber length decreases the CV_m of the yarn while an increase in the short fiber content increases the CV_m of the yarn [32]. The CV_m of the yarn is proportional to its count, increasing the count of the yarn increased the CV_m [33], which was highest for Ne 24/1 (20.32), followed by Ne 20/1 (19.47) and Ne 16/1 (18.59) but the CV_m of the yarn was unaffected or barely affected by its twist multiplier.

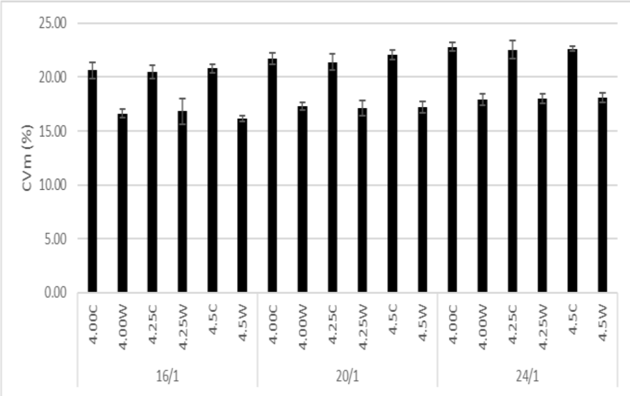

Fig. 5 Effect of different factors on coefficient of yarn mass variation (CV_m)

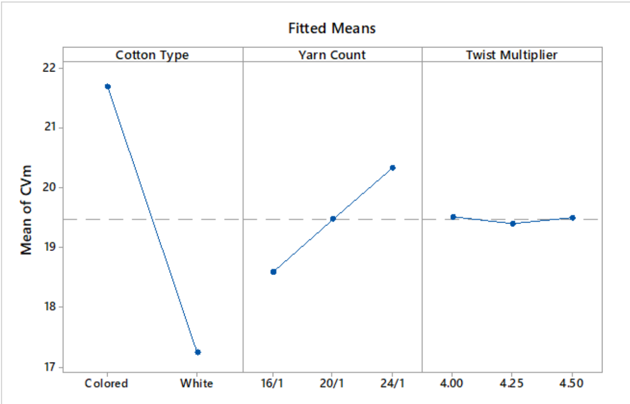

Fig. 6 Main Effect Plot for Coefficient of Yarn Mass Variation (CV_m)

3.4 Total Yarn Imperfections (T IPI)

Fig. 7 depicts a visual representation of the total IPI of the colored and white cotton yarns. Since there was greater variation in the uniformity of the colored yarns than in white cotton, the colored yarns had a higher IPI. As shown in the ANOVA for IPI (Table 5), cotton type and yarn count showed a statistically significant effect (p-value = 0.000). When calculating Total IPI, the twist multiplier did not play a major role.

The main effect plot of Total IPI depicted in Fig. 8 shows that the IPI in colored cotton is significantly higher than in white cotton (1894 vs. 450). As expected, the IPI increased with yarn count [34] from Ne 16/1 to Ne 24/1, going from 701 to 1640. TM variable did not appreciably alter the overall yarn IPI.

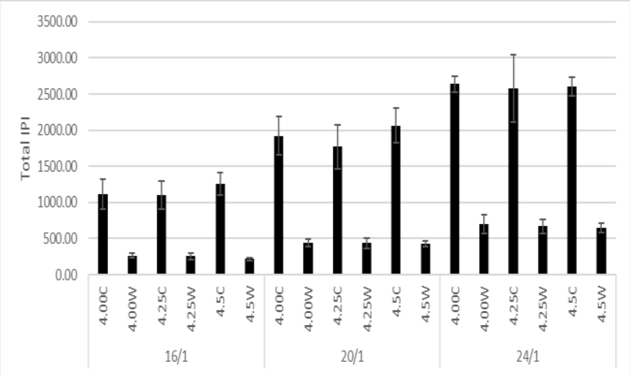

Fig. 7. Effect of Different Factors on Total Yarn Imperfections (IPI)

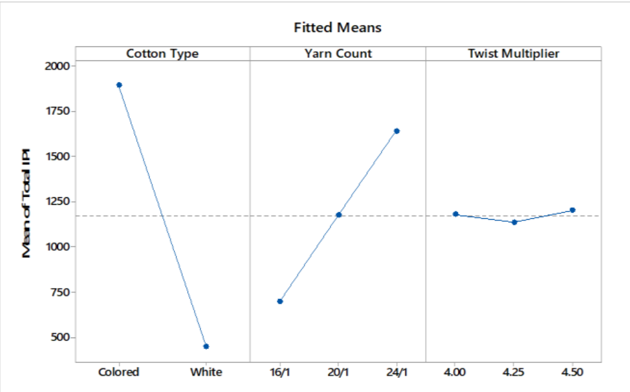

Fig. 8. Main Effect Plot for Total Yarn Imperfections (IPI)

3.5 Yarn Hairiness

The impact of all the variables on the yarn hairiness is depicted graphically in Fig. 9. Table 5 displays the ANOVA results for the level of hairiness in the yarn. The hairiness of the yarn was significantly affected by all the three variables (p-value = 0.000). The main effect plots for hairiness are given in Fig. 10. The colored cotton yarns had a higher level of hairiness, 7.53 when compared with white cotton, 6.78. This is due to the fact that there are more short fibers in the colored cotton which increases the hairiness of the yarn as a result and this was also stated by Mustafa et al in his research to predict the yarn hairiness [35]. Also, the fineness of the yarn possesses an inverse relation. Less the fineness of the yarn, the more its hairiness as stated by Krupincová et al. [36]. When taking yarn count into account, it became clear that a higher yarn count produced less hairy yarn. The hairiness value was 8 for Ne 16/1, 6.9 for Ne 20/1, and 6.5 for Ne 24/1, with a decreasing trend. The same pattern was observed with the twist multiplier. The TM 4.00 had a hairiness value of 7.57, the TM 4.25 got 7.22, and the TM 4.50 counted 6.68.

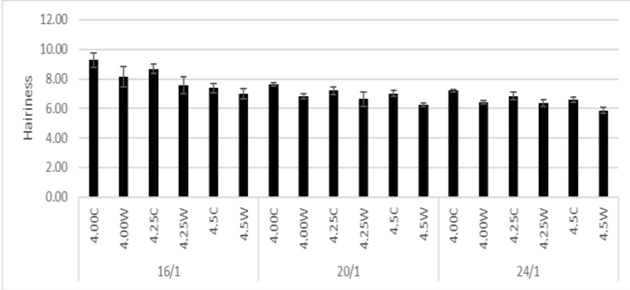

Fig. 9. Effect of Different Factors on Yarn Hairiness

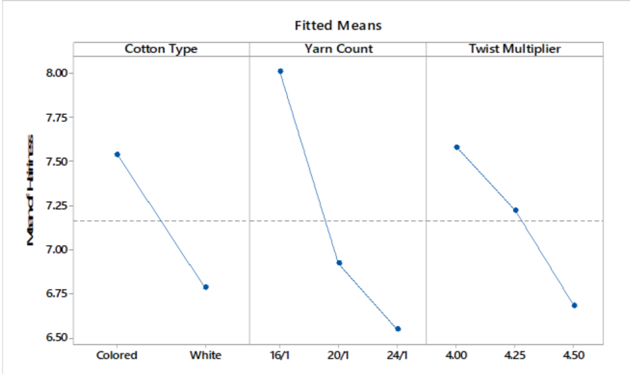

Fig. 10. Main Effect Plot for Yarn Hairiness

4. Conclusion

Eighteen yarns of Ne 16/1, Ne 20/1 and Ne 24/1 with twist multipliers of 4.00, 4.25 and 4.50, were made from conventional Gossypium hirsutum and naturally colored Gossypium arboreum cotton through ring spinning, for comparison of their mechanical and evenness properties. The tenacity of conventional cotton yarns was about 42% higher (17.04 g/Tex) as compared to that of colored cotton (11.93 g/Tex). The hairiness was 11% higher for colored cotton (7.53) as compared to conventional cotton (6.78). Unevenness (CV_m) was 25% higher for colored cotton (21.68%) as compared to conventional cotton (17.25%). Elongation at break was 10% higher for conventional cotton (6.16%) as compared to colored cotton (5.60%). Total IPI value was 320% higher for colored cotton (1894/km) as compared to conventional cotton (450/km). Overall, yarns made from naturally colored Gossypium arboreum showed inferior mechanical and evenness properties as compared to those of conventional Gossypium hirsutum. When considering the effect of yarn count and twist multiplier, it was found that the tenacity and elongation of yarn were decreased as the yarn count was made finer from Ne 16 to Ne 24 while yarn tenacity and elongation were improved with increase in TM. The CV_m and total imperfections were increased with the increase of the yarn count while the TM had little impact on both the parameters. The hairiness of the yarns was decreased by increasing the yarn count and the TM. These results indicate the potential of naturally colored cotton as a more sustainable alternative to conventional cotton for producing niche cotton products with elimination of environmentally devastating scouring, bleaching and dyeing processes.

5. Message for Industry and Customers

Naturally colored cotton may be spun easily on the existing set ups of spinning industry. Keeping in view its lower quality as compared to white, it may be used to make coarser counts. Products of NCC will be of some higher price but environment friendly with better comfort properties.

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