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Evaluation of Cotton Fibre Properties in Compact Yarn Spinning Processes and Investigation of Fibre and Yarn Properties

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Abstract
Fibre properties are influential factors for yarn properties. Cotton, whose physical properties vary depending on the cultivation region, is still a very common fibre used in the textile industry. Properties such as fibre length, fineness, strength and maturity affect yarn tensility, evenness, imperfections and hairiness. Four different 100% cotton blends were used as raw material (American cotton, Aegean cotton, Urfa cotton, Greek cotton) to be converted into 20 tex compact yarns separately. HVI parameters of each blend type starting from the bale until the 2nd drawing passage machine revealed that yarn processing stages and machinery are influential factors for fibre the properties of fibres that are produced on a spinning line. Additionally ANOVA tests supported the idea that the evenness, tensility, yarn imperfections, and hairiness parameter of yarns produced from various cotton blends were statistically different. Principal Component Analyses (PCA) and the Correlation Matrix were also applied in order to analyse the relationship between fibre properties and compact yarn properties of different blends.

Key words: *cotton fibre property, compact spun yarn property, HVI, spinning consistency index (SCI), spinning process.*

Introduction

Cotton is still one of the most important fibres, with its high consumption rate, despite its share of the global fibre market decrement. It is a global raw material traded in fibre, yarn, fabric or finished goods form. The main cotton fibre issues to be addressed, mostly by cotton producers, are the maturity, fineness, contamination, stickiness, short-fibre content (SFC), seed-coat fragment (SCFs) and nep values, which determine the quality of fibre [1]. The Uster News Bulletin implied that the nep value is the most important parameter for cotton fibre quality, which is additionally used for judging ginning, carding and combing quality, and even fabric quality [2].

HVI and AFIS instruments are commonly used for evaluating the quality of cotton fibres in a bale. HVI was designed to measure fibre properties from a bundle of fibres, while the AFIS instrument was created to measure single fibre. Typical HVI measurements include fibre length, length uniformity, bundle tenacity, elongation, micronaire, colour, and trash content, while the AFIS instrument measures length, fineness, maturity, circularity, short fibre content, immature fibre content, nep/g and percentage of dust and trash [3-5[. There is a high correlation between the quality of raw materials and the final products. A high quality of cotton provides a high quality of yarn, neglecting the process conditions. Cotton is exposed to numerous processes, starting from harvesting until the final product. All these processes influence the fibre as well as yarn properties [6].

There are many studies in the literature related to the analysis of fibre properties to estimate the relative contribution of each fibre property to the overall yarn properties. Ureyen and Kadoglu made a study of the prediction of yarn quality characteristics derived from cotton fibre properties that were measured by means of an HVI system. Linear multiple regression methods were used for the estimation of yarn quality characteristics. Yarn count, twist and roving properties all had considerable effects on the yarn properties [6]. Another work of Ureyen and Kadoglu was related to certain regression equations used for interpretation of the fibre effect on yarn quality. It was concluded that AFIS fibre properties could be used for the prediction of yarn properties successfully [7]. Ozcelik and Kırtay examined the changes in nep count for 11 different cotton blends. They also investigated nep count changes in the different blends in dependence on the carded cotton yarn processing stages. They utilised regression equations to predict yarn nep counts from fibre properties, measured by HVI and AFIS instruments. As result of the study, they established correlation formulas between fibre and yarn properties [8] Faulkner et al. focused on the relationship between ring spun yarn quality and five different groups of high plain cotton fibre properties. In the study, fibre properties were measured by HVI and AFIS instruments, and yarn properties by an USTER tester [3] and USTER Tensorapid. Fibre and yarn properties were evaluated using statistical approaches of principal component analysis and partial least squares regression to determine relationships between fibre and yarn properties. They concluded that there is an urgent need for a new calibrated method for efficient measurement of fibre elongation [9]. Frydrych and Matusiak made an investigation of predicting nep numbers and size in cotton yarn. They considered and elaborated a theoretical model of critical nep size as a function of the linear density of cotton ring spun and OE rotor yarns. In the end they calculated the critical nep size for different yarn linear densities. The results measured confirmed those of the theoretical models that were established within the framework of their research [10]. Hequet et al. tried to determine the cotton stickiness effect on ring and OE rotor yarn quality parameters. Seventeen different cotton blend samples were prepared by blending sticky and non-sticky cottons at different ratios. The stickiness level of seventeen different blends were adjusted in a range of a less to moderate amount of contamination. They used a High Speed Stickiness Detector (H2SD), which was an improvement on the Sticky Cotton Thermodetector. Their results revealed that in the short term, less than 12 H2SD spots within a mix of cotton did not influence spinning productivity for either ring or OE rotor yarn samples [11-12]. Ethridge et al. tried to estimate the func-

Table 1. Cotton blends used in the study.

Blend number	Blend composition
1	100% American cotton
2	100% Aegean cotton
3	100% Greek cotton
4	100% Urfa cotton

tional relationships between fibre properties and the strength of OE rotor yarns. They used samples from 96 bales of Texas High Plain cotton to determine the best functional expression for the impacts of High-Volume-Instrument-measured fibre properties on the strength of OE rotor yarns. According to the results, the most important fibre properties determined were strength, fineness, and length uniformity [13]. A report of the International Textile Manufacturers Federation's International Committee on Cotton Testing Methods (ITMF, ICCTM) implied that neps, SFC, dust/trash, maturity and stickiness are influential fibre parameters in an orderly manner. The influence of neps on fibre quality is specially mentioned as the highest influential (negatively) fibre property [14].

In this study, it is aimed to examine the influence of combed yarn processing machinery on the fibre blend and its influence on the compact yarn properties of yarn evenness, tensility, yarn imperfections, and hairiness. The first part of the study includes analysis of the changes in HVI values during the yarn processing stages, and the second part consists of statistical evaluations of fibre and yarn properties.

Material method

Four different 100% cotton blends were used as raw material (American cotton, Aegean cotton, Urfa cotton, Greek cotton) in the study. All the samples were tested under laboratory conditions of 65 ± 4% relative humidity and 20 ± 2 °C temperature [15].

Table 1 shows a description of the codes used for the cotton blends during the study.

Yarn production was conducted using the processing stages of the combed yarn production line, where cotton fibres were firstly opened and cleaned in a blowroom with the machine park of Rieter UNIfloc A11, UNIclean B12 & UNImix B72. After the blowroom, a carding machine – Rieter C70 (Switzerland) was used to produce carding slivers, which were then subjected to the 1st drawing machine (Rieter SBD-45, Switzerland). For improved fibre alignment and sliver evenness, the slivers underwent combing preparation (Rieter E35 Omegalab, Switzerland) and were then directed to a combing machine (Rieter E76, Switzerland), 2nd drawing machine (Rieter RSB-D45, Switzerland), then to a roving machine (Marzoli FT6-D, Switzerland), and finally toa compact spinning machine – Rieter K45 (Switzerland). All the samples were converted into 20 tex compact yarn with the same twist coefficient under identical spinning conditions, as is mentioned in ***Table 2***.

Table 2. Production line starting from the blow room up to spinning.

1st Draw machine	Rieter SBD-45 1st passage draw frame machine output, tex	4922
	Doubling, D	6
	Total draft	7.2
	Pre-draft	1.4
Omegalab	Omegalab E35 output, m/gr	0.78
	Doubling	24
	Omegalab drafting	1.492
Combing machine	Rieter E76 combing machine output, tex	4922
	Doubling, D	8
	Total draft	15.2
	Pre-draft	71.9
2nd Draw machine	Rieter SBD-45 2nd passage draw frame machine output, tex	0.12
	Doubling, D	6
	Total draft	6
	Pre-draft	1.15
Roving machine	Rieter FT6-D roving machine output, tex	590.5
	Total draft in roving machine	8.3
	Roving twist coefficient, α_{tex}	1215
	Roving twist, TPM	50
Compact spinning machine	Yarn twist, α_{tex}	3447
	Yarn count, tex	20
	Compact spinning machine, TPM	775

Measurement of fibre and yarn properties

The individual measurement of each blend of raw cotton samples was conducted using an HVI instrument. To examine the changes in fibre properties (such as micronaire. SCI values. tenacity... etc.), HVI measurement was also applied during all the yarn preparation stages. Tensile properties of the yarns were evaluated on an Uster Tensorapid 4 testing machine (Switzerland). Five bobbins were chosen for efficient assessment of each yarn sample and five measurements were completed for each bobbin. Unevenness and hairiness tests were performed on an Uster Tester 5 (Switzerland). All the measurements were conducted under standard test conditions: 65 ± 4% relative humidity and 20 ± 2 °C temperature.

The spinning consistency index (SCI) is a very important parameter obtained from the HVI instrument, which gives information about the quality and spinnability of the fibre. [17-18]:

SCI is defined as a regression equation, given in ***Equation (1)*** as follows:

$$SCI = -414.67 + 2.9 \times Str - 9.32 \times Mic + 49.17 \times UHML + 4.74 \times UI + 0.65 \times Rd + 0.36 \times (+b) \quad (1)$$

Where, *SCI* – spinning consistency index, *Str* – tenacity, *Mic* – micronaire, *UHML* – upper half mean length in inches, *UI* – Uniformity Index, *RD* – reflectance degree, (+*b*) – yellowness of cotton fibre.

The short fibre index (SFI) is another useful equation to predict yarn quality. SFI is estimated using HVI measurement values for the length and uniformity index as revealed in ***Equation (2)***. Previously SFI has been calculated with the help of fibrogram data using first-order mechanisms in terms of 2.5% SL and 50% SL and the uniformity index as independent variables [19].

$$Z = 384.3966 - 120.379X - 6.7003Y + 12.4901X^2 + 0.02957Y^2 + 1.0306XY \quad (2)$$

According to ***Equation (2)***: Z – short fibre index predicted (SFI), X – HVI length, Y – uniformity index.

Neps are one of the undesired cotton fibre properties that occur as result of foreign matter and entangled short fibre in the cotton blend. Nep presence in the cotton fibre blend cause short, thick places in yarns, resulting in uneven fabric appearance [8]. The weak places in the yarn are generally observed in the areas with bad fibre orientation, originating from the high nep number. Uster Technologies briefly classifies the nep content as medium staple raw cotton lint measured on an AFIS instrument, as shown in ***Table 3*** [20].

Statistical method

Standardised principal component analysis (PCA) was performed using all fibre data from HVI and yarn quality results from Uster Tensorapid 4 and Uster Tester 5. Correlation analysis was performed separately among the fibre parameters and yarn parameters of each cotton blend. In order to analyse the cotton blend influence on yarn properties, randomised one-factor analysis of variance (one way-ANOVA) was used for determination of the statistical significance of the cotton blend type. The means were compared by means of TUKEY (HSD) tests. The value of the significance level (α) selected for all statistical tests in the study was 0.05. The treatment levels were marked in accordance with the mean values, and levels marked by a different letter (a. b. c) indicate that they were significantly different. All statistical procedures were conducted using the SPSS 23.0 Statistical software package.

Results and discussion

Examination of HVI values during process stages

Yarn processing stages and machinery have an influence on fibre the properties of fibre produced on the spinning line defined above. In order to examine the changes in fibre properties during processing, cotton samples were taken after each machine of the spinning preparation line (UNIfloc, UNIclean, UNImix, UNIstore, condenser 1, card, 1st draw frame, combing machine, 2nd draw frame, roving machine). Each cotton sample was then tested on the HVI in order to evaluate the influence of the machine on every fibre blend.

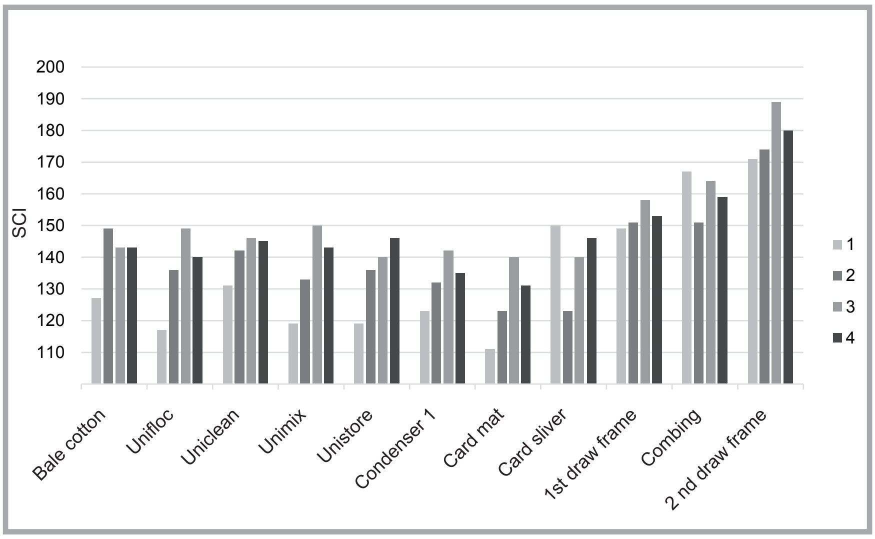


Figure 1. *Changes in spinning consistency index (SCI) values during the process.*

Fibre samples were randomly taken from 15 different bales of each blend, and average HVI results are given in ***Table 4***.

Regarding the results of SCI values, the highest value was obtained for blend No. 2 and the lowest for blend No. 1. It can be anticipated that blend No. 2 will exhibit better yarn quality compared to the other cotton blends. When it comes to the micronaire values, blend No. 4 had the highest micronaire value, which was classified as a considerably thicker class according to the Uster Standards [22], whereas the other blends were classified as a thicker class. When the UHML values were compared, blend No. 2 had the highest value, while blend No. 4 had the minimum UHML values.

Considering SFI values, which reveal the ratio of fibres with a staple length of 0.5 inches (12.7 mm), the maximum was for blend No. 1, whereas the minimum SFI value was obtained for blend No. 2. It was noted that typical SFI values vary from 4-12% for ginned lint, which was observed as lower for un-ginned lint (18). Our SFI results for each blend are found in-between the SFI interval declared above.

The highest fibre tenacity value was obtained for blend No. 2, with blends No. 3, No. 4, and No. 1 following in neat order. The highest fibre elongation at break value was obtained for blend No. 3, with blends No. 2, No. 1, and No. 4 following in neat order. Regarding the number of neps, the highest nep/gr value belonged to blend No. 1, with blends No. 3, No. 2, and No. 4 following in neat order.

The degree of reflectance (Rd), indicating the brightness-dullness value of cotton colour and the yellowness (+b) , indicating the degree of colour pigmentation, were also measured on the HVI. They are used to clarify the visual differences of the blends, where blend No. 1 has the highest Rd and blend No. 1 has the lowest yellowness. The results indicate that the colour of blend No. 1 is the most desired colour compared to the other blends.

Table 3. *Classification of nep content according to Uster Technologies [21].*

Total neps/g	Seed-coat neps/g	Classification
<100	<10	Very low
101-200	11-20	low
201-300	21-30	Medium
301-450	31-45	High
>451	>46	Very high

Table 4. *Fibre parameters of cotton blends.*

Blend type	SCI	Micronaire	UHML, mm	SFI, %	Tenacity, cN/tex	Elg., %	Neps/gr	Rd	(+b)	%RH
1	127	4.11	28.85	10.1	29.90	6.93	354	76.62	8.41	5.38
2	149	4.93	30.22	6.45	33.50	7.28	118	71.66	8.46	7.42
3	143	4.79	29.71	7.10	32.94	7.5	157	70.8	9.3	7.3
4	143	5.05	29.49	6.9	32.84	6.4	96	72.0	8.7	6.3

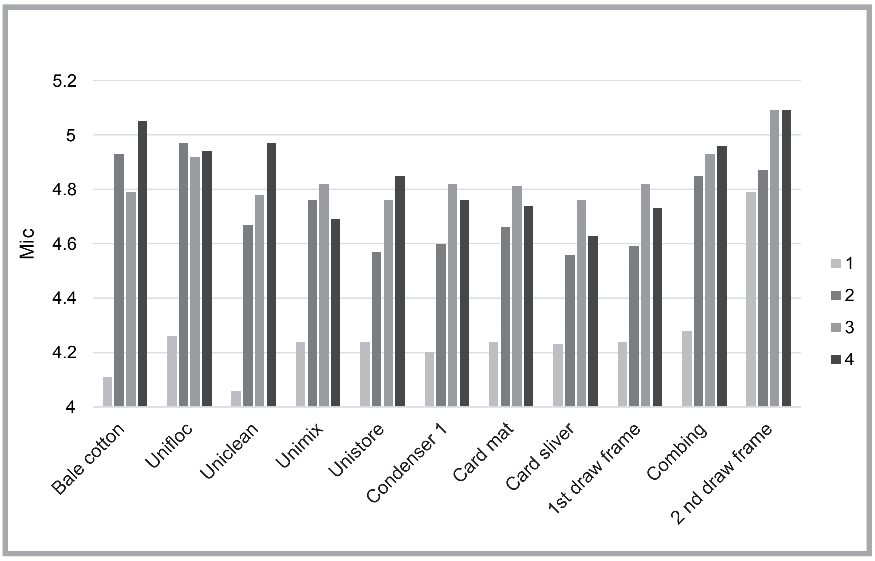


Figure 2. *Changes in micronaire (Mic) during the process.*

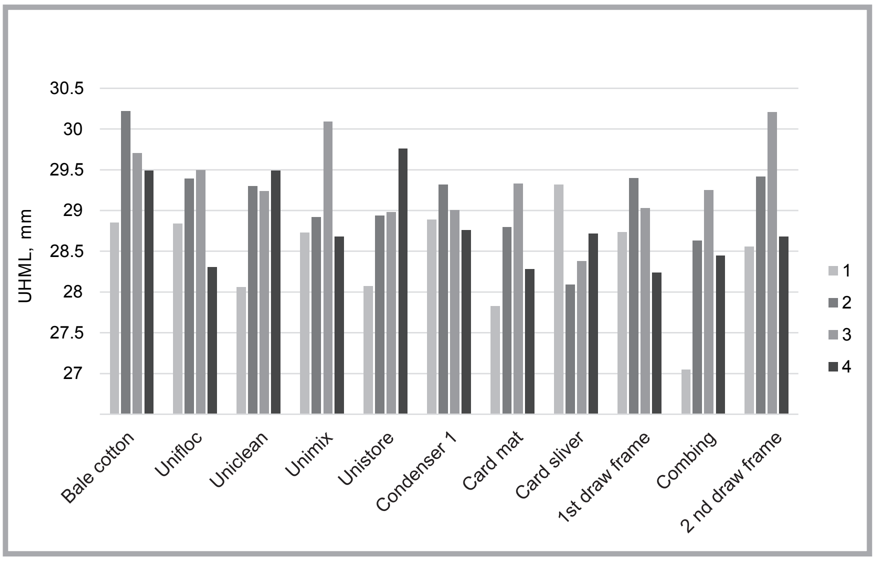


Figure 3. *Changes in upper half mean length (u HML) during the process.*

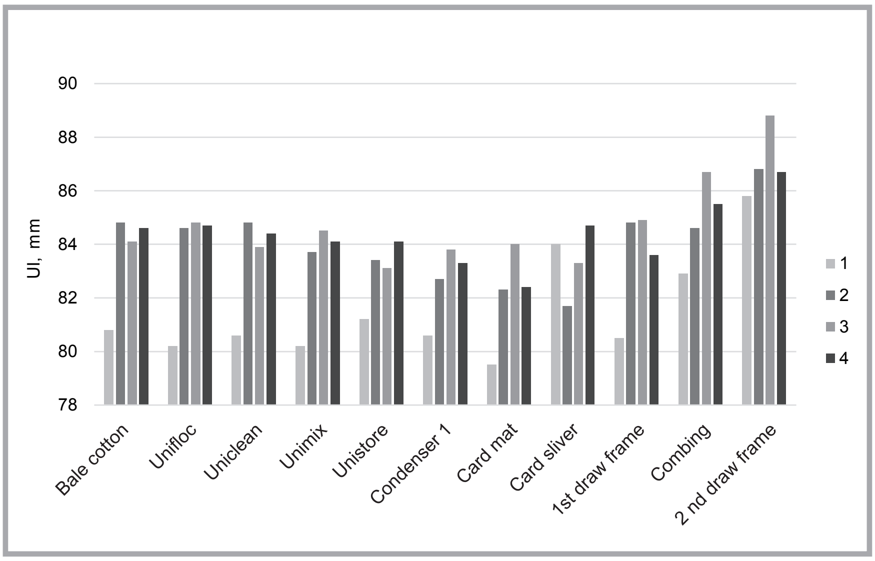


Figure 4. *Changes in uniformity index (UI) during the process.*

The RH % value indicates the average relative humidity of each blend. Measurements were conducted after 24 hours of conditioning under laboratory conditions of 65 ± 4% relative humidity and 20 ± 2 °C temperature. All four cotton blends exhibit different percentages of humidity, which can be explained with their inherent fibre properties.

In order to examine the changes in the following fibre properties of cotton: SCI, micronaire, UHML, uniformity index (UI), SFI, tenacity, elongation at break, Rd, trash content, and nep count values, during processing stages, cotton samples were taken from the blends after each machine, starting from the bale. The following ***Figures 1-11*** exhibit the changes in each of the above-mentioned fibre properties for all cotton blends.

Figure 1 reveals SCI values of all cotton blend types, starting from the bale. SCI values fluctuate between a certain interval for each cotton blend and do not show any dramatic changes up to the carding machine. The carding process, where the card sliver is processed, causes a clear improvement in cotton blend No. 1. The SCI value of blend No. 1 increases from 110 to 150, and blend No. 4 from 131 to 146 right after the carding machine, whereas the other two blends do not show such an increase. Improvement of the SCI value became possible as a result of intensive short fibre elimination in the cotton blends. After carding, the rest of the processing machinery helps to improve the SCI value of each of the four blends in general. At the end of the processing line, for the 2nd passage draw-frame slivers, the highest SCI value was observed in blend Nr.3, with blends No. 4, No. 2 and No. 1 following in neat order.

Figure 2 shows micronaire values of all cotton blend types, starting from the bale. Micronaire is one of the most important characteristics for fibre, as this parameter directly influences the yarn spinning limit and yarn tenacity as well as the fabric properties produced from these yarns. Finer fibre help to increase yarn tenacity, resulting in a lower number of yarn breaks and enabling lower yarn twist. Micronaire values of fibre samples fluctuate between a certain interval for each cotton blend and do not show any dramatic changes up to the combing machine. The combing process causes a clear improvement in cotton blend No. 1, which has the lowest micronaire value among all four cotton blends. Micronaire values of blends No. 2, No. 3 and No. 4 fluctuate in a relatively narrow interval compared to blend No. 1. The micronaire value of blend No. 1 shows the highest increase as result of the intensive short fibre elimination of the combing machine. The highest micronaire value was obtained in blends No. 3 and No. 4, with blends No. 2, and Nr.1 following in neat order.

Figure 3 shows the changes in upper half mean length (UHML) values during the spinning preparation. UHML is one of the parameters derived from the fibrogram, which is defined as the average length (mm) of the 50% longest fibres by weight, used for staple classification. Considering the changes in UHML values of cotton blends in dependence on the yarn processing stages, they show inconsistency in general. UHML values increased after the combing process for the four cotton blends, where the highest improvement was shown in blend No. 1, as result of intensive short fibre elimination in the combing process.

The uniformity index (UI) is the ratio between the mean length and upper half mean length of the fibres, expressed as a percentage. UI affects yarn evenness and tenacity as well as the efficiency of the spinning process. It is also related to short fibre content (content of fibres shorter than 1/2 inch). Cotton with a low uniformity index is likely to have a high percentage of short fibres. Such cotton may be difficult to process and is likely to produce low-quality yarn [23]. ***Figure 4*** reveals UI values of all cotton blend types, starting from bale cotton.

UI values exhibit some fluctuation until the 1^{st} passage of the draw frame machine, where there is an overall upward trend for UI values thereafter. The combing process causes a clear improvement in cotton blend No. 1, which has the lowest UI (mm) value among all four cotton blends. UI values of blends No. 2, No. 3, and No. 4 fluctuate in a relatively narrow interval compared to blend No. 1.

Figure 5 reveals SFI values of all cotton blend types starting from the bale. Blend No. 1 has the highest SFI values during all processes. The combing process causes a clear improvement for SFI values for cotton blend No. 1. At the end of the 2^{nd} passage of the draw machine, the highest SFI value was obtained for blend Nr.1, with blends No. 4, No. 3 and No. 2 following in neat order.

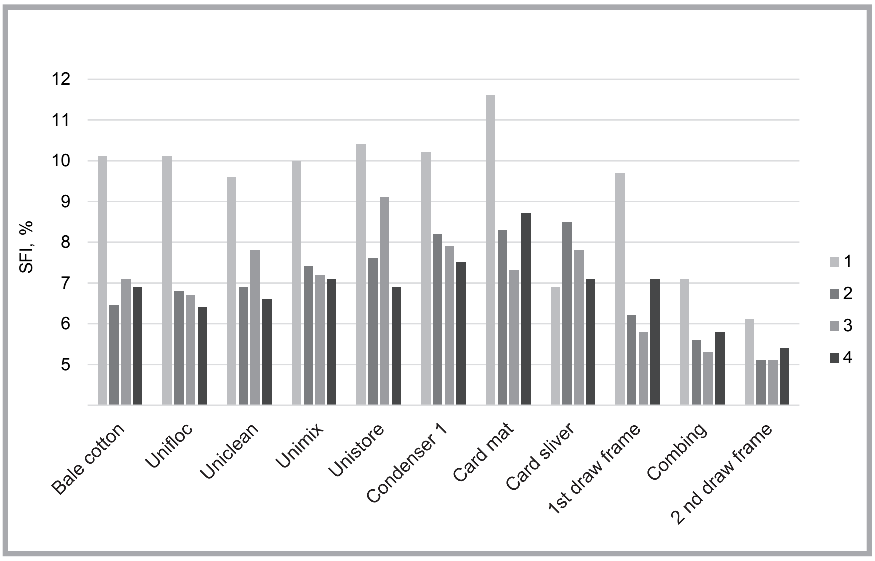


Figure 5. *Changes in short fiber index (SFI) during the process.*

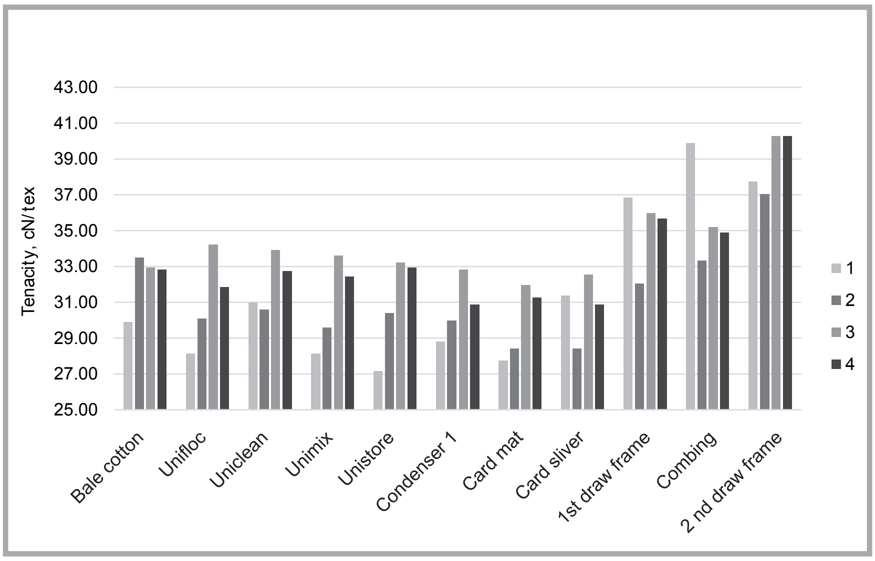


Figure 6. *Changes in fibre bundle tenacity during the processes.*

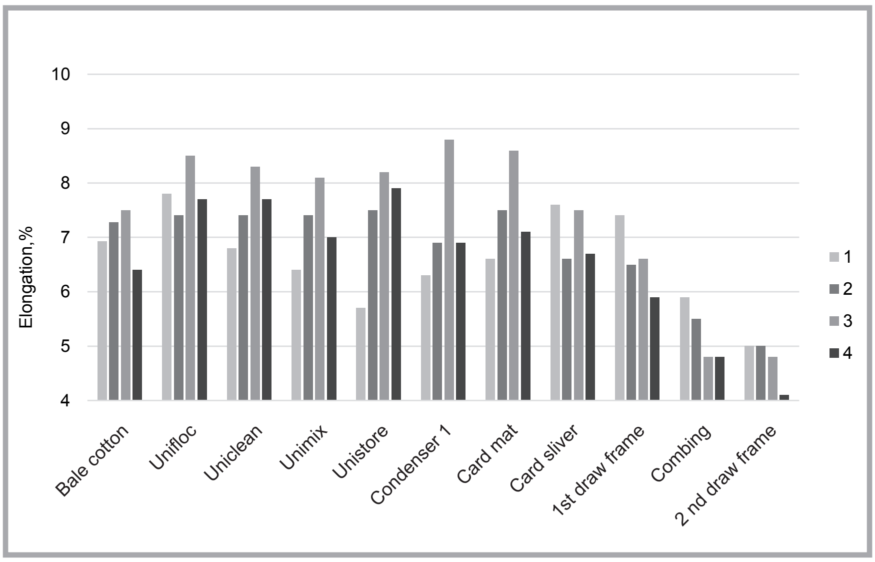


Figure 7. *Changes in fibre elongation at break during the processes.*

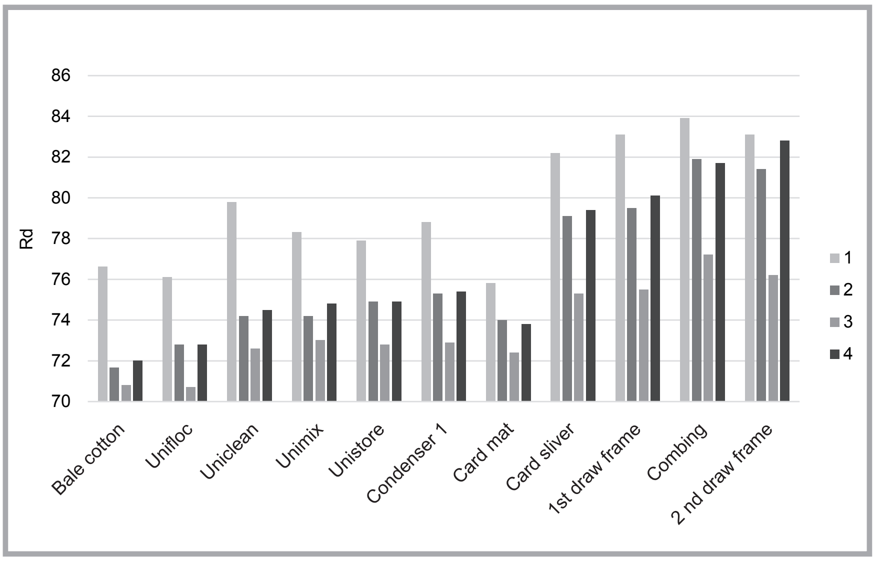


Figure 8. *Changes in the fibre reflectance degree (Rd) during the processes.*

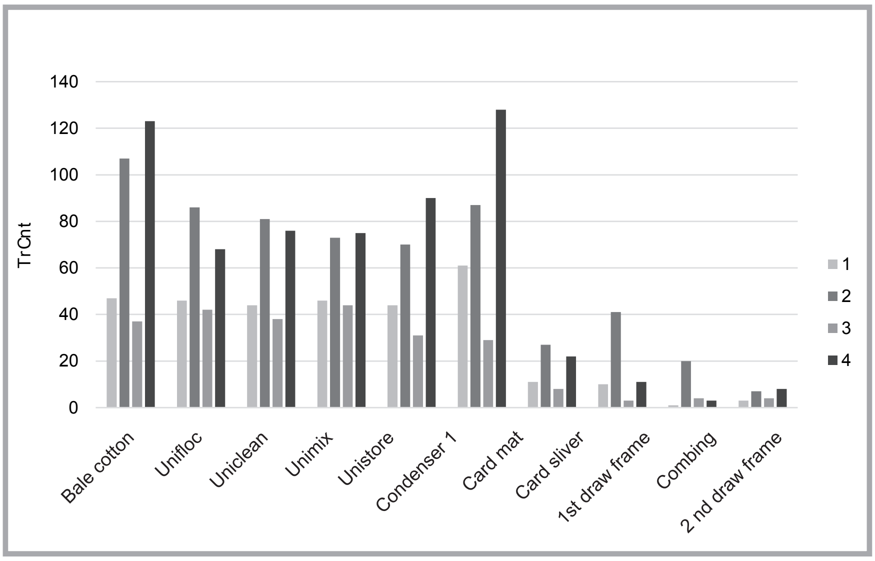


Figure 9. *Changes in fibre trash content (TrCht) during the processes.*

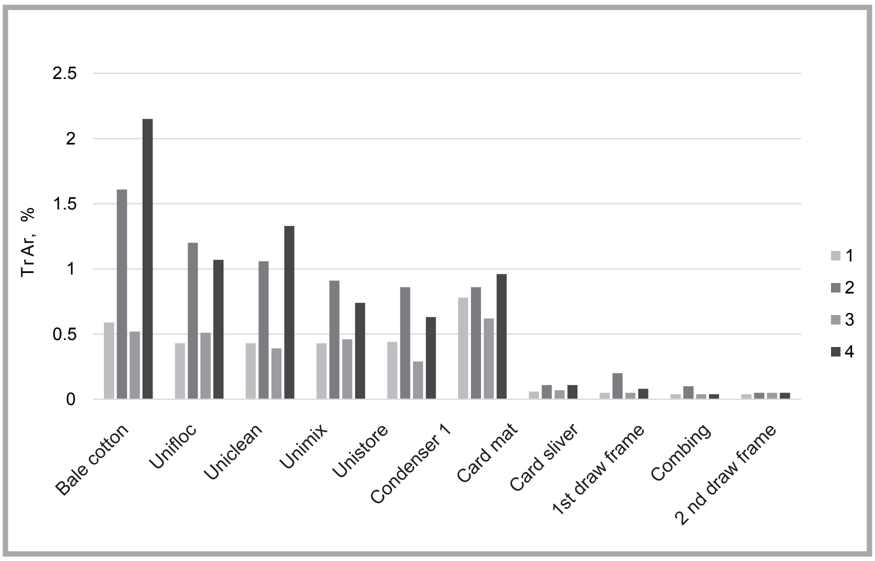


Figure 10. *Changes in the fibre trash content area (TrAr) during the processes.*

It should be emphasised that there is a strong relationship between ***Figure 1***, which indicates the SCI of the cotton blends, and ***Figure 5***, which indicates SFI values. The processes where there is a higher amount of short fibre content (SFI) in the cotton blend reveal lower SCI values, and those where there is lower SFI values lead to better SCI values.

The fibre tenacity of each cotton blend was measured on the HVI in bundle form and is given in ***Figure 6***, which reveals the changes in fibre bundle tenacity during the processes starting from bale cotton. According to ***Figure 6***, after the carding, 1st passage drawing and combing processes, the increase in the fully-opened fibre ratio, which is related to the effective fibre length, led to an increment in the fibre bundle tenacity. There was also a partial contribution of the drawing and combing processes, resulting in an improvement in bundle tenacity with the removal of short and immature fibre as well as in the fibre to fibre friction surface area inside the fibre bundle.

Cotton fibre elongation at break is generally measured with cotton in a bundle form at 3.2 mm (1/8 inch) gauge. ***Figure 7*** reveals the changes in fibre elongation at break during the processes, starting from the bale. Elongation (%) values exhibit some fluctuation until the carding sliver, where there is an overall downward trend for elongation at break values (%), starting from the 1st passage draw frame machine for all cotton blends. This result may be explained by short fibre elimination in the combing process, where the resulting combed sliver contains fewer fibres with free-ends between the test device clamps, leading to lower bundle fibre elongation at break.

The reflectance degree (Rd) of cotton gives information about the reflection of cotton. A higher Rd value is interpreted as the cotton having a better class. ***Figure 8*** reveals the changes in fibre-Rd during the processes. According to ***Figure 8***, an increment is observed for all cotton blends' Rd after the carding process, which can be attributed to higher light reflection in relation to fibre parallelisation.

Figures 9 and ***10*** display the changes in fibre trash content and fibre trash content area [TrAr (%)] during the processes, starting from UNIfloc, respectively. According to the figures, the carding process provides a clear improvement for

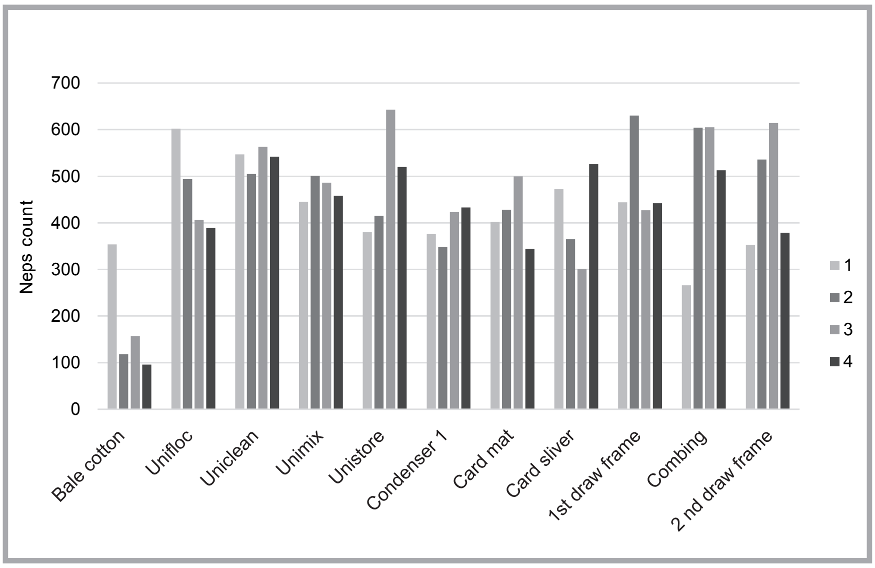


Figure 11. *Changes in fibre neps count during the processes.*

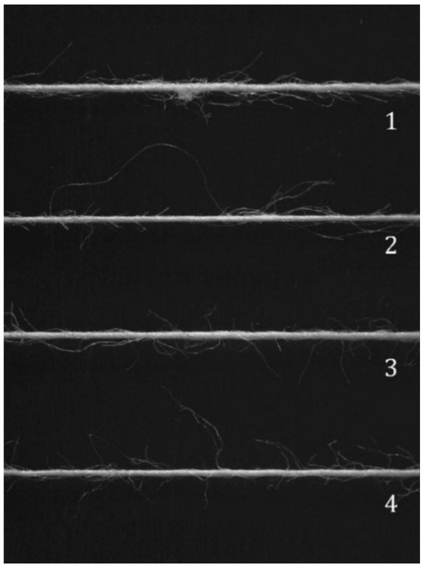


Figure 12. *Compact yarn photos produced from 4 different cotton types (1: Blend No. 1, 2: Blend No. 2, 3: Blend No. 3, 4: Blend No. 4).*

all cotton blends. The fibre trash content and fibre trash content area exhibit some fluctuation until the carding process, where there is an overall downward trend after carding. Additionally, considering ***Figure 8***, efficient trash removal of the cotton blends after the carding process results in a better reflectance degree.

Preliminary treatment of cotton in the opening and cleaning lines causes an increment in the nep number, which can be attributed to external mechanical factors connected with the machine's working parts influencing the fibre and as well as to the pneumatic transport of fibres between the machinery [8]. According to ***Figure 11***, considering the bale cottons, the minimum nep content belongs to blend Nr.4, whereas the maximum nep count is shown by blend Nr.1. However, at the end of the 2nd passage draw frame machine, the highest nep count was obtained in blend No. 3, with blends No. 2, No. 4 and No. 1 following in neat order. It can be stated that the mechanical enforcement of each machine influences the nep count of the blends.

Yarn production and ANOVA results of yarn properties

Slivers from the four different cotton blends were exposed to a total draft of 8.3 with a twist coefficient of 1215 (α_{tex}) on a roving machine – Rieter FT6-D after preliminary preparation processes. Roving slivers of 590 tex were spun into 20 tex yarns with a twist multiplier of 3447 (α_{tex}) on a compact spinning machine – Rieter K45. Ten bobbins of yarn were made from each sample under identical conditions. Compact spun yarn photos of each blend are presented in ***Figure 12***, which were captured on a Leica EZ4 HD stereo microscope at a magnification ratio of 8x.

Yarn properties are evaluated in terms of tensility, unevenness, imperfections,

Table 5. *Tukey HSD test results for compact yarns.*

B-force, cN			
Blend	1	2	3
3	309.31		
1	318.79		
4		334.53	
2			350.95
Sig.	0.116	1.00	1.00

B-work, cN.cm			
Blend	1	2	3
1	390.34		
3	403.73		
4		431.84	
2			553.74
Sig.	0.569	1.00	1.00

Tenacity, cN/tex				
Blend	1	2	3	4
3	15.71			
1		16.20		
4			16.99	
2				17.82
Sig.	1.00	1.00	1.00	1.00

Elongation, %			
Blend	1	2	3
1	4.274		
4		4.532	
3		4.586	
2			6.142
Sig.	1.00	0.823	1.00

U, %			
Blend	1	2	3
1	8.819		
3		8.964	
4			9.180
2			9.197
Sig.	1.00	1.00	0.979

CVm, %		
Blend	1	2
1	11.212	
3	11.337	
4		11.554
2		11.631
Sig.	0.054	0.389

Thin, -50%/km		
Blend	1	2
2	0.0	
3	0.0	
4	0.0	
1		1.0
Sig.	1.00	1.00

Thick, +50%/km		
Blend	1	2
4	12.0	
2	13.0	
3	15.0	
1		32.04
Sig.	0.32	1.00

Neps, +280%/km				
Blend	1	2	3	4
4	3.02			
2		7.0		
3			12.0	
1				20.96
Sig.	1.00	1.00	1.00	1.00

H				
Blend	1	2	3	4
4	4.26			
2		4.63		
3			4.86	
1				5.32
Sig.	1.00	1.00	1.00	1.00

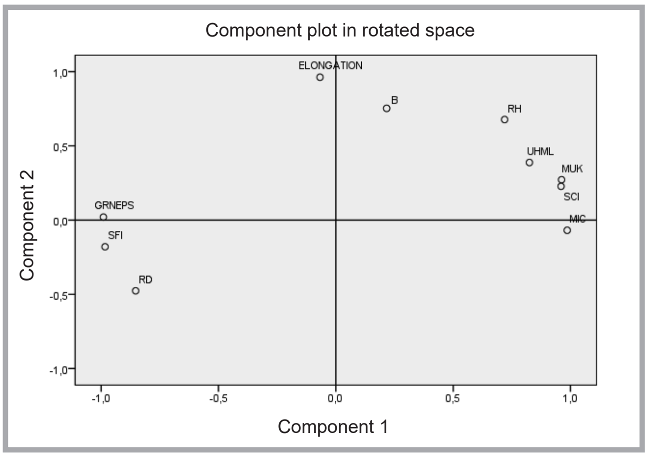


Figure 13. *Loading plot for fibre quality principal component analyses.*

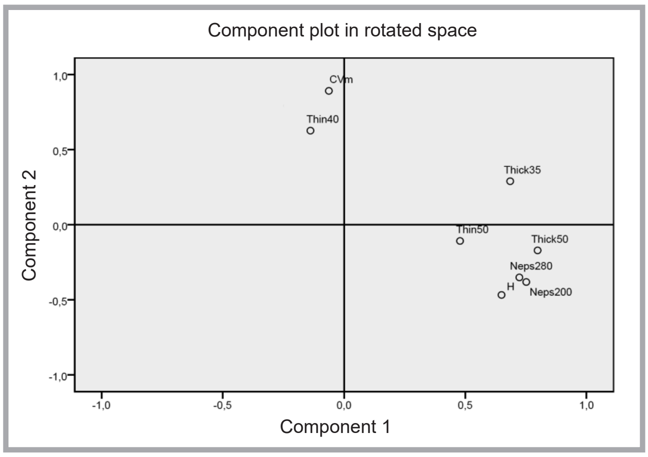


Figure 14. *Loading plot for yarn quality principal component analyses.*

and hairiness, respectively. The tensile properties of spun yarn are important for determining the quality of yarn. These parameters directly influence weaving and knitting efficiency as well as warp and weft breakages during weaving [6]. Tenacity (cN/tex), breaking force (cN), elongation at break values (%), yarn unevenness, imperfections and hairiness are evaluated in terms of randomized one-factor analysis of variance (one way-ANOVA).

The results of the ANOVA tests revealed that there were statistically significant (5% significance level) differences between yarn unevenness, imperfection, hairiness and tensile values of the compact yarns produced from the four different cotton blends. ***Table 5*** shows Tukey test results of the compact yarn properties evaluated.

According to the Tukey test results, the highest yarn breaking force (B-force) value was found for compact yarns produced from blend No. 2 i.e. 350.95 (cN), whereas the minimum B-force value of yarns obtained from blend No. 3 was 309.312 (cN). Additionally the B-force of compact yarns from cotton blends No. 1 and No. 3. was estimated in the same subset at a significance level of 0.116.

Table 6. *Component factors for fibre parameters.*

Total variance explained				Rotated component matrix[a]		
		Component			Component	
		1	2		1	2
Rotation sums of squared loadings	Total	6.746	2.492	Spinning consistency index, SCI	0.960	0.228
	% of Variance	67.457	24.917	Micronaire	0.986	-0.069
	Cumulative %	67.457	92.374	Upper half mean length, UHML	0.825	0.388
Extraction method: principal component analysis. Rotation method: Varimax with Kaiser normalisation [a]. Rotation converged in 3 iterations				Short fibre index, SFI	-0.984	-0.180
				Tenacity, cN/tex	0.962	0.272
				Neps/gr	-0.991	0.020
				Reflectance degree, Rd	-0.853	-0.476
				B	0.217	0.753
				RH	0.719	0.677
				Elongation	-0.067	0.962

Table 7. *Component factors for yarn parameters.*

Total variance explained				Rotated component matrix[a]		
		Component			Component	
		1	2		1	2
Rotation sums of squared loadings	Total	3.209	2.141	CVm		0.892
	% of variance	35.650	23.791	Thin50	0.478	
	Cumulative %	35.650	59.441	Thick50	0.798	
Extraction method: principal component analysis. Rotation method: Varimax with Kaiser normalization [a]. Rotation converged in 3 iterations				Neps200	0.752	
				Neps280	0.723	

The highest breaking work (B-work) was found for compact yarns produced from blend No. 2 i.e. 553.738 (cN.cm), whereas the lowest B-work value of yarns obtained from blend No. 1 was 390.338 (cN.cm). B-work values of compact yarns produced from cotton blends No. 1 and No. 3 were estimated in the same subset at a significance level of 0.569.

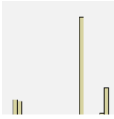
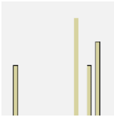
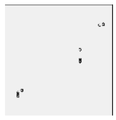
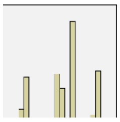
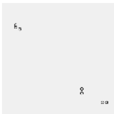
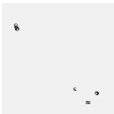
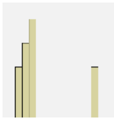
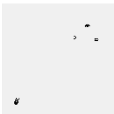
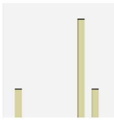
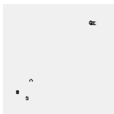
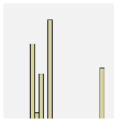
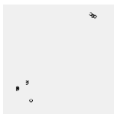
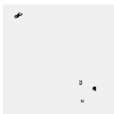
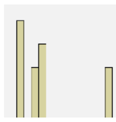
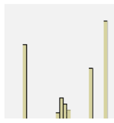
The maximum tenacity (cN/tex) was found in compact yarns produced from blend No. 2. i.e. 17.822, whereas the minimum tenacity was obtained for yarns from blend No. 3. Tenacity results of compact yarns produced from the four different cotton blends were estimated in different subsets at a significance level of 1.00.

The highest elongation at break (%) belonged to compact yarns produced from blend No. 2 i.e. 6.142%, whereas the minimum elongation at break (%) of yarns produced from the blend was 4.274%. The elongation at break of compact yarns produced from blend No. 3 and No. 4 were estimated in the same subset at a significance level of 0.823.

Regarding yarn evenness, imperfections, and hairiness results, the mass variation (CVm%) of compact yarns produced from blends No. 2 and No. 4 was estimated in the same subset at a significance level of 0.054, which was lower than the cVm% of yarns produced from blends No. 2 and No. 4, which were in the same subset at a significance level of 0.389.

The maximum number of thin places (-40%/km) belonged to compact yarns from blend No. 4 i.e. 19, whereas the minimum number of thin places (-40%/km) of yarns was obtained from blend No. 1

***Table 8.** Correlation matrix for fibre parameters. **Note:** * Scatter plot diagrams whose correlation coefficients are lower than 0.9 are not shown in the Table. ** Correlation is significant at a 0.01 level (2-tailed).*

	SCI	Micronaire	UHML	SFI	Tenacity	Neps/gr	Rd	Elongation
Spinning consistency index, SCI		0.910**	0.949**	-0.985**	0.989**	-0.928**	-0.898**	0.201
Micronaire			0.736**	-0.960**	0.931**	-0.999**	-0.848**	-0.159
Upper half mean length, UHML				-0.885**	0.910**	-0.764**	-0.810**	0.425**
Short fibre index, SFI					-0.995**	0.972**	0.929**	-0.113
Tenacity, cN/tex						-0.948**	-0.949**	0.206*
Neps/gr							0.870**	0.110
Reflectance degree, Rd								-0.346**
Elongation								

i.e. 7.96. The number of thin places (-40%/km) of compact yarns produced from cotton blends No. 3 and No. 2 were in the same subset at a significance level of 1.00.

The maximum number of thick places (+35%) was found in compact yarns produced from blend No. 2 i.e. 186.00, whereas the minimum number of (+35%) of yarns produced from blend No. 1 was 130.00. The number of thick places (+35%) of compact yarns produced from blends No. 3 and No. 4 was estimated in the same subset at a significance of 0.153, whereas compact yarns produced from blends No. 2 and No. 1 were in the same subset at a significance of 0.846.

The maximum number of thick places (+50%) were observed in compact yarns produced from blend No. 1 i.e. 32.04, whereas the minimum number of (+50%) of yarns was obtained from blend No. 4 i.e. 12.00. The number of thick places (+50%) of compact yarns produced from cotton blends No. 2, No. 3 and No. 4 were in the same subset at a significance level of 0.32.

The maximum nep count (+200%) of compact yarns was found in blend No. 1 i.e. 72.04, whereas the minimum nep count (+200%) of compact yarns was in blend No. 4 i.e. 27. The nep count of (+200%) of compact yarns of blends No. 2 and No. 4 was estimated in the same subset at a significance of 0.98. The maximum nep count (+280%) was found in compact yarns from blend No. 1 i.e. 20.96, whereas the minimum nep count (+280%) of compact yarns was obtained from blend No. 4 – 3.02.

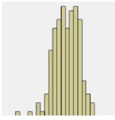
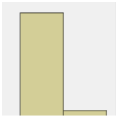
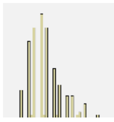
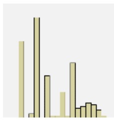
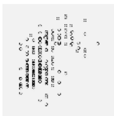
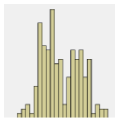
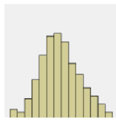
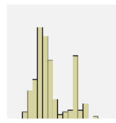
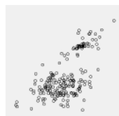
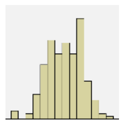
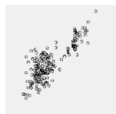
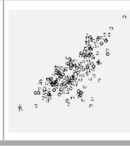
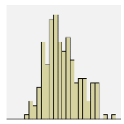
Regarding hairiness, the maximum hairiness was obtained from compact yarns produced from blend No. 1 – 5.32, whereas the minimum hairiness of compact yarns was obtained from blend No. 4 – 4.26.

Principal component analysis (PCA) of fibre and yarn parameters

A standardised principal component analysis (PCA) was performed for all fibre and yarn quality data to gain insight into the causes of deviation between samples and to identify outlying ones. PCA results obtained using all data from HVI test results for fibres are shown in ***Figure 13*** and ***Table 6***.

The first two PC's explained 92.374 % of the variance in the fibre quality dataset. PC1 explained 67.457% of the variance in the fibre property data and primarily differentiated between samples based on SCI, Micronaire, UHML, SFI and neps. PC2 explained 24.917 of the

__Table 9.__ Correlation matrix for yarn parameters. ***Note:*** **. Correlation is significant at a 0.05 level. **. Correlation is significant at a 0.01 level (2-tailed). *** Scatter plot diagrams whose correlation coefficients are lower than 0.49 are not shown in the Table.*

	CVm	Thin Pl. -50%	Thick Pl. +50%	Neps +280%	Hairiness	Breaking force	Elongation at break	Tenacity	Breaking work
CVm		-0.143*	-0.233**	-0.356**	-0.395**	0.325**	0.373**	0.324**	0.414**
Thin Pl. -50%			0.346**	0.186**	0.261**	-0.0272	-0.182*	-0.0483	-0.0744
Thick Pl. +50%				0.580**	0.492**	-0.243**	-0.325**	-0.276**	-0.310**
Neps +280%					0.592**	-0.280**	-0.310**	-0.341**	-0.299**
Hairiness						-0.283**	-0.261**	-0.274**	-0.297**
Breaking force							0.542**	0.808**	0.603**
Elongation at breaking								0.629**	0.832**
Tenacity									0.726**
Breaking work									

variance in the fibre quality dataset and primarily differentiated samples based on B, RH (%) and elongation at break (%) (***Table 6***).

PCA results obtained using all data from USTER test results of yarns are shown in ***Table 7*** and ***Figure 14***.

The first two PC's explained 59.441 % of the variance in the yarn quality dataset. PC1 explained 35.650% of the variance in the yarn property data and primarily differentiated between samples based on thickness (+50%) and neps (+280%). PC2 explained 23.791 of the variance in the yarn quality dataset and primarily differentiated between samples based of CVm.

Correlation matrix for fibre properties

The correlations between fibre parameters are shown in ***Table 8***, acccording to which the SCI and Micronaire value are correlated with a correlation coefficient of 0.910, SCI and UHML with a correlation coefficient of 0.949. and SCI and Rd with a correlation coefficient of -0.898. Our correlation results support the idea of SCI being highly correlated with the following HVI parameters: micronaire, UHML and Rd, which are also used in the SCI regression equation mentioned above (***Equation (1)***). As is expected, SCI and nep values are highly correlated, with a correlation coefficient of -0.928. Another remarkable result is the negative correlation between the micronaire value and neps. This result can be attributed to finer (lower) micronaire-value cotton fibres, which are easily bent, buckled and entangled during mechanical actions, tending to form neps more easily than coarser fibres. It may also be useful to state that there is a strong positive correlation coefficient between UHML and fibre tenacity. SFI and fibre bundle strength are highly correlated, with a coefficient of -0.995.

Correlation matrix for yarn properties

Correlations between yarn evenness, imperfection, hairiness and tenacity parameters are shown in ***Table 9***. Thick places (+50%) and neps (+280%) are correlated, with a correlation coefficient of 0.580. Neps (+280%) and H are correlated, with a correlation coefficient of 0.592, The correlation between the elongation at break and tenacity was slightly higher than that between the elongation at break (%) and B-force (cm.cN). Additionally the B-work and elongation at break (%) are correlated. with a correlation coefficient of 0.832. The tenacity and B-force are correlated, with a correlation coefficient of 0.808. The other significant correlations between each yarn parameter were also marked by exponential notification (*, **).

Conslusions

This study focused on the production of compact yarns of 20 tex from four different 100 % cotton blends (American cotton, Aegean cotton, Urfa cotton, Greek cotton) as raw material individually. Four kinds of bales were exposed to processes in a blow room and to subsequent yarn preparation processes under identical conditions in order to analyse the influence of cotton type on yarn quality parameters.

HVI parameter results were found to be different for each cotton blend, attributed to their inherent fibre properties, during all stages of the spinning process, from bale to the second (2nd) draw frame. The SCI value, as one of the main indicators of cotton fibre spinnability was calculated for each cotton blend and each spinning process stage. Regarding the changes in SCI during the processes, it was found that, the carding process causes a clear improvement in cotton fibre spinnability. Especially for cotton blend No. 1. the SCI value dramatically increased after carding, due to to high amount of short fibre elimination. In the case of the micronaire value, it was shown that the combing process leads to a clear improvement in cotton blend No. 1, which had the lowest micronaire value among all four cotton blends before the combing process. According to our work, UHML values of the cotton blends in dependence on the yarn processing stages do not show any consistent value in general. In the case of UI (mm), the combing process leads to a clear improvement in cotton blend No. 1 which has the lowest UI (mm) and highest SFI (%) value among all four cotton blends. Another remarkable result from the HVI measurements is the nep value, which increased from the bale to dust separator, owing to external mechanical factors connected with actions of the machine's working elements on the fibres.

It was found that the fibre elongation at break (%) values of the HVI test instrument, which is a bundle elongation at break value, do not fully support the yarn breaking elongation (%) values. Such a statement was also emphasised in Faulkner et al.'s study [9] i.e. that there is a need for a new calibration method, formula or coefficient for efficient measurement of fibre elongation at break (%) in order to predict yarn elongation at break (%). It is important to emphasise that our results affirm that there is a strong reverse relationship between SCI and SFI values, where samples with a higher SFI (%) value have lower SCI values.

Results of this research point to the influence of the cotton blend on yarn properties. Fibre quality is extremely important to the producer as it will largely determine the spinning efficiency of converting the fibre into yarn and the yarn to fabric for the next step. In our further study, it is planned to analyse the effect of cotton blends on fabric properties.

Disclaimer

Mention of trade names or commercial products in this manuscript is solely for the purpose of providing specific information and does not imply recommendation or endorsement.

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