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Frictional Characteristics of Cotton-Modal Yarns

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Abstract
In this study, structural or physical properties such as the unevenness, hairiness and frictional properties of cotton-modal blended yarns were studied. For this purpose, 100% cotton, 50/% cotton/modal and 100% modal ring spun yarns were produced in five different twist coefficients (α_e: 3.5, 3.7, 4.0, 4.2, 4.5) and four different yarn linear densities (21, 25, 30 and 37 tex). General factorial design was used and the response surface was plotted for analysing the data. In conclusion, the most influential factors for the yarn characteristics were the yarn linear density and blend ratio. Contrary to expectations, the twist coefficient factor had a minor effect on yarn characteristics, especially on the friction coefficient.

Key words: *blending, cotton, modal, unevenness, hairiness, friction coefficient.*

Introduction

Modal fibres give a soft sensation on the skin and are preferred either in a pure form or in blends with wool, cotton, silk and polyester [1, 2]. Blends of cotton with modal fibres are preferred for towels, underwear, socks, and sportswear for their moisture regain, strength and natural-feeling. The dyeing characteristic of this fibre is close to cotton dyeing, and the wet-strength characteristic is higher than for viscose. There are some studies regarding fibre, yarn and fabric properties of modal and modal-cotton blends. Three kinds of modal (Lenzing, Birla and Formotex modal fibres) siro-spun yarns were compared by Wang and Mao [3]. They found that the strength of Lenzing Modal was higher than for other modal fibres. The yarn evenness, imperfections and hairiness of compact and conventional ring spun yarns were studied by Altas and Kadoglu [4]. They used carded and combed cotton, modal, polyester, tencel and viscose in a pure form in three different twist coefficients and in three yarn counts. Their results showed that compact yarns have less optical evenness, fewer imperfections and less hairiness than conventional ring spun yarns. Vortex, ring and open-end rotor spun cotton, viscose and 50%/50% modal/cotton blended yarns were compared in another study [5], in which vortex yarn showed lower hairiness and better pilling resistance. The influence of process variables on the characteristics of modal siro spun yarns was studied by Gowda et al. [6] using response surface methodology. They suggested some process parameters for optimum sirospun 100% modal yarn quality. The tensile properties of modal/polyurethane core-spun stretch yarn were modelled by Shi and Jin [7]. They used a nonlinear viscoelastic model in which theoretical calculations were carried out by curve fitting that conform to the values measured. Blends of viloft (modified viscose) with cotton and polyester were studied [8]. The mechanical and thermo-physiological comfort properties of modal blended fabrics were also studied [9-11]. Yang and Dou [9] investigated the tensile and tearing properties of modal/soybean protein fibre blended fabrics. Increasing soybean protein fibre in the blend increased the tensile properties but decreased the tearing and bursting strength properties. Dimensional and thermal properties of 50%/50% modal microfibre/cotton blended fabrics were compared with 50%/50% conventional modal/cotton and 100% cotton fabrics by Gun [10]. The modal microfibre blended fabrics showed the lowest thermal resistance and highest thermal absorptivity values. Kayseri et al. [11] investigated the pilling, bursting strength, and thermo physiological properties of viscose, modal and lyocell fabrics. Lyocell fabrics showed higher bursting strength and thermal conductivity values compared to other fabrics. There are additional studies investigating blended yarn and fabric properties in the literature [12-18].

Friction on yarns is an important property in addition to the traditional yarn properties. This property is generally affected by the fibre type, fibre surface characteristics, yarn count, twist, unevenness, hairiness and spinning type [19]. The frictional behaviour and other yarn properties of carded and combed cotton yarn were examined [20], and it was found that an increase in hairiness decreased the friction coefficient. The frictional properties of cotton-lyocell blended yarns produced from different spinning systems were also investigated [21]. Cui et. al [22] examined the twist distribution and twist irregularity of self-twist yarns. Svetnickiene [23] investigated the friction properties of natural fibres such as flax, bamboo, bamboo with flax, soy, and cotton with sea cell yarns. The highest friction coefficient was found for flax. Kayseri [24] studied the frictional properties of 100% lyocell, modal and viscose yarns. The fibre type and yarn linear density had a significant effect on the frictional and lint shedding properties, while yarn twist was only effective for yarn-to-yarn friction.

The structural and physical properties of yarns are important for fabric properties. Traditional (unevenness, imperfections and hairiness) yarn properties as well as friction on yarns are important parameters during processing and use. Yarns are exposed to yarn-to-yarn or yarn-to-metal friction during production. In order to avoid rupture during spinning, the friction coefficient of yarns is important in determining optimum wax application.

Traditional yarn characteristics of the modal blended yarns studied are summarised above; however, there are few studies examining the frictional property of modal/cotton blended yarns. For this aim, in this study, 100% cotton, 50%/50% cotton/Birla modal and 100% Birla modal ring spun yarns were produced having five different twist coefficients (α_e: 3.5, 3.7, 4.0, 4.2, 4.5) in four different linear densities (21, 25, 30 and 37 tex). Statistical analysis was carried out and ANOVA tables and regression curves were obtained as response surface plots.

Materials and methods

In this study, cotton/modal blends were prepared in 0/100, 50/50 and 100/0 percentages in sliver form, and yarns were spun in five different yarn twists (α_e: 3.5, 3.7, 4.0, 4.2, 4.5) and four yarn linear densities (21, 25, 30 and 37 tex) using a sample ring spinning machine from Shanghai Erfangji Co. (China), with 96 spindles, at a 14000 rpm spindle speed. Modal and cotton fibres were supplied by Basyazicioglu Tekstil from Turkey and yarn spinning was also carried out in this factory.

Birla modal fibre (India) of 38 mm length and 1.33 dtex fineness was used. The cross section of this fibre is given in ***Figure 1***. Urfa St1 type cotton fibre (Turkey) was used as the second blending material, the properties of which were measured by means of a Premier ART testing device, and are given in ***Table 1***.

A Zweigle L232 and Zweigle D314 (Switzerland) were used for validation of the linear density and twist factor of yarns, respectively. Unevenness (CV_m%), imperfections and hairiness (H) were measured by a Premier PT 7000 (India). Here, "H" is the length of protruding hairs in 1 cm of yarn [25]. The frictional property of the spun yarns was measured by a Zweigle-G 534 (Switzerland), which runs according to the Capstan method.The coefficient of friction is calculated by,

$$\mu = \frac{\ln \frac{T_2}{T_1}}{\theta} \quad (1)$$

Here, "μ" is the friction coefficient, T_1 the input tension, T_2 the output tension, and θ is the contact angle. The total number of experiments for each test can be calculated by taking the number of blends (3), yarn twist factors (5), yarn linear densities (4) and replication (5) as $3 \times 5 \times 4 \times 5 = 300$.

Results and discussions

Data obtained from the study were analysed by general factorial design as a statistical analyzing technique using Design Expert software, and response surfaces were plotted for each yarn property. For this purpose, the optimum model was selected by considering the F-test and lack of fit tests, which give the highest R^2 and least p-value in a 95% confidence interval. Analysis of variance (ANOVA) tables were obtained using the model selected. In these tables, 'A' represents the cotton ratio in the blend, 'B' the yarn linear density in "tex", and 'C' the twist coefficient in α_e-values of model terms lower than 0.05 are considered to be significant. The contributions of each model term were also calculated and given in ANOVA tables. The optimum blend ratio, twist factor and yarn linear density for the response variables (unevenness-CV_m%, hairiness (H) and friction coefficient-μ) of yarns are discussed below using the response surface, respectively.

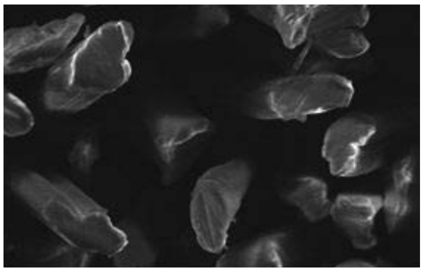

Figure 1. *Microscopic view of Birla modal fibre.*

Table 1. *Cotton fibre properties.*

Property	Value
Fineness, mic.	4.57
Length, mm	29.13
Uniformity index	85.04
Tenacity, cN/tex	30.04
Extension, %	6.72

Unevenness (CV_m%)

The mass or weight variation per unit length of yarn is defined as unevenness or irregularity. The coefficient of the variation in mass (CV_m%) is one of the calculation methods of the variation in mass of the yarns [26, 27].

An ANOVA table for the CV_m% of cotton/modal blended yarns is demonstrated in ***Table 2***. The quadratic model was selected for CV_m%. The R^2 value is obtained as 91.33%, in which the model explains 91.33% of the response CV_m%. The significant model terms are indicated in the table. The maximum contribution is obtained from the linear effect of yarn linear density (B) at 60.19%. The sum of the linear and quadratic effect of the blend ratio ($A + A^2 = 25.06\%$) is of secondary importance for CV_m%. Other factors have minor effects. The linear and quadratic effect of the twist factor is insignificant.

The unevenness variation with the yarn linear density and blend ratio can be seen in ***Figure 2*** in different twist coefficients (α_e = 3.5, 4.0, 4.5) as a three-dimensional response surface. The blend ratio is demonstrated on the x-axis for the cotton blend value in the yarn, whereas the modal blend value is just the subtraction of the actual cotton blend value from 100. For example, on the "cotton percentage axis", "25" represent the actual 25% cotton and 75% modal in the yarn. While the z-axis represents the yarn linear density, CV_m% values predicted by the model selected are shown on the y-axis. The meshed surface is called the response surface and represents the regres-

Table 2. *ANOVA of CV_m%.*

Source	Sum of squares	Contribution, %	Degrees of freedom	Mean squares	F value	p-value	Significance
Model	354.30	91.33	9	39.37	299.53	< 0.0001	Significant
A	33.76	8.70	1	33.76	256.83	< 0.0001	Significant
B	233.49	60.19	1	233.49	1776.56	< 0.0001	Significant
C	0.06	0.02	1	0.06	0.48	0.4871	Insignificant
A²	63.45	16.36	1	63.45	482.76	< 0.0001	Significant
B²	0.01	0.00	1	0.01	0.10	0.7479	Insignificant
C²	0.20	0.05	1	0.20	1.51	0.2208	Insignificant
AB	1.90	0.49	1	1.90	14.43	0.0002	Significant
AC	0.34	0.09	1	0.34	2.55	0.1115	Insignificant
BC	0.72	0.19	1	0.72	5.44	0.0204	Significant
Residuals	33.65	8.67	256	0.13			
Lack of fit	8.59	2.21	47	0.18	1.52	0.0243	
Error	25.06	6.46	209	0.12			
Corrrected total	387.94	100.00	265				

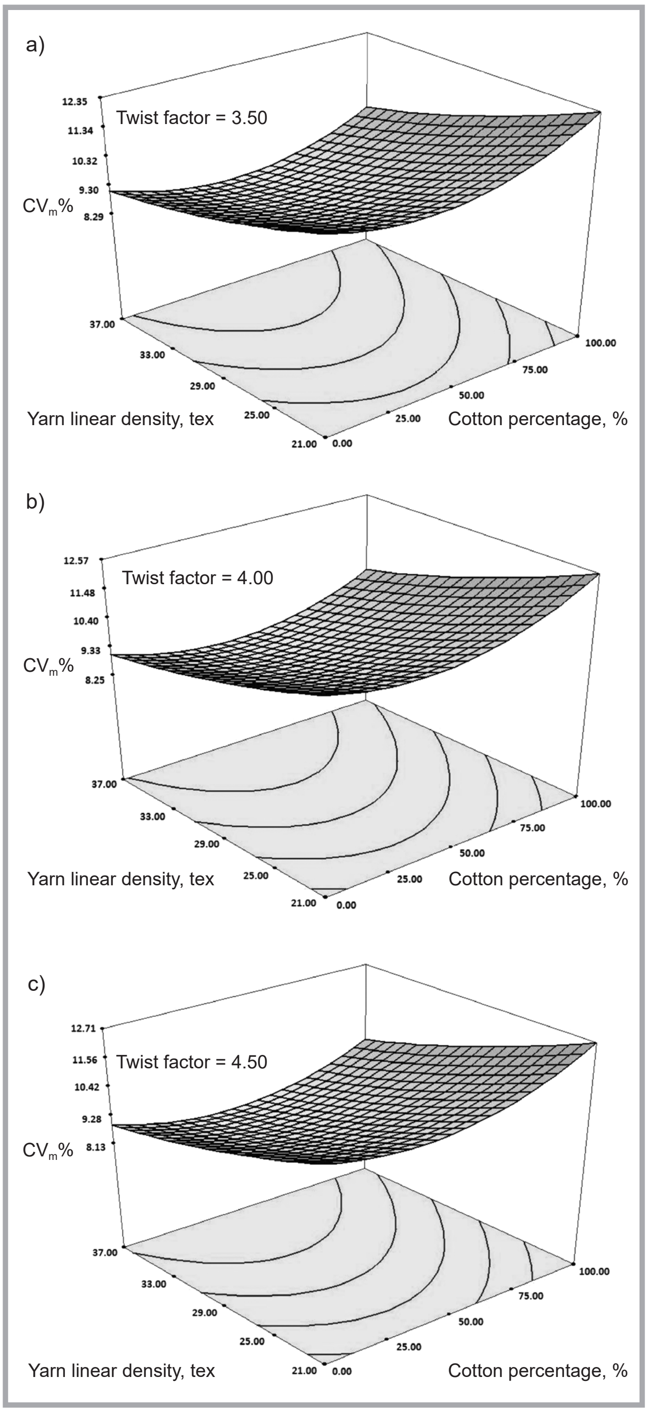

Figure 2. *CVm% variation with cotton percentage and yarn linear density for different twist factor values: a) twist factor = 3.5, b) twist factor = 4.0, c) twist factor = 4.5.*

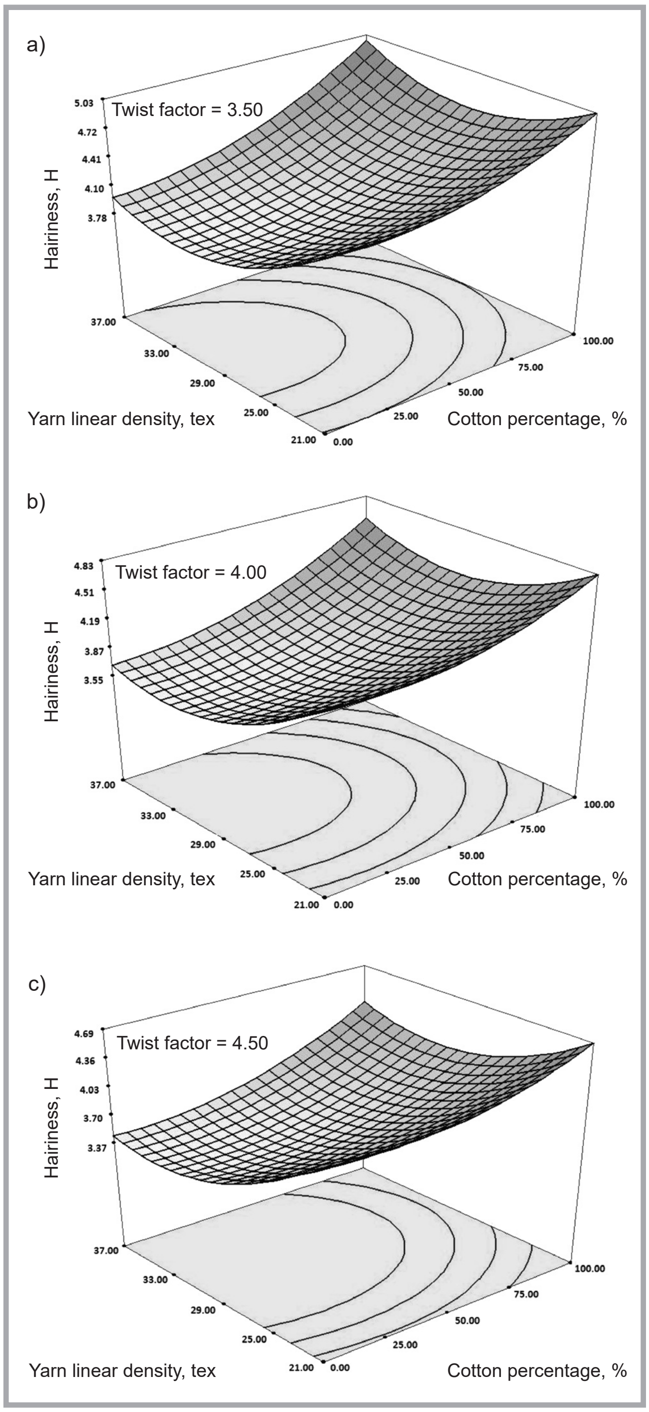

Figure 3. *Hairiness variation with cotton percentage and yarn linear density for different twist factor values: a) twist factor = 3.5, b) twist factor = 4.0, c) twist factor = 4.5.*

sion of the model on a three-dimensional axis. Curves on the plane between the x-axis and z-axis are called contour plots. The variation in selected yarn twist coefficients is represented in ***Figures 2.a, 2.b*** and ***2.c*** for α_e = 3.5, 4.0 & 4.5, respectively. As the number of fibres in the yarn cross section decreases in finer yarns, which results in a variation in the yarn diameter, the maximum unevenness is obtained for finer yarns. Increasing the cotton blend in the ratio also raises the CV$_m$% value, which may be due to the higher length and diameter variation of cotton fibres compared to modal fibres. Increasing the twist coefficient raises the cohesion forces between fibres in the yarn, which results in a decrease in yarn diameter, and the yarn becomes more rigid. This situation is clear in coarse yarns since the increased number of fibres in the yarn cross section increases the friction forces between fibres and, in turn, the holding of fibres in the yarn bodies, which decreases the CV$_m$% values. However, in finer yarns, increasing the twist coefficient again increases the friction forces between fibres; but these forces also result in shear forces between fibres, which causes deformation. Thus the unevenness values in finer yarns increases in coarser yarns. The CV$_m$% decreases down to the minimum point – to that of the %40modal/%60 cotton blend, and increases from this point to that of 100% cotton yarns. The CVm% values

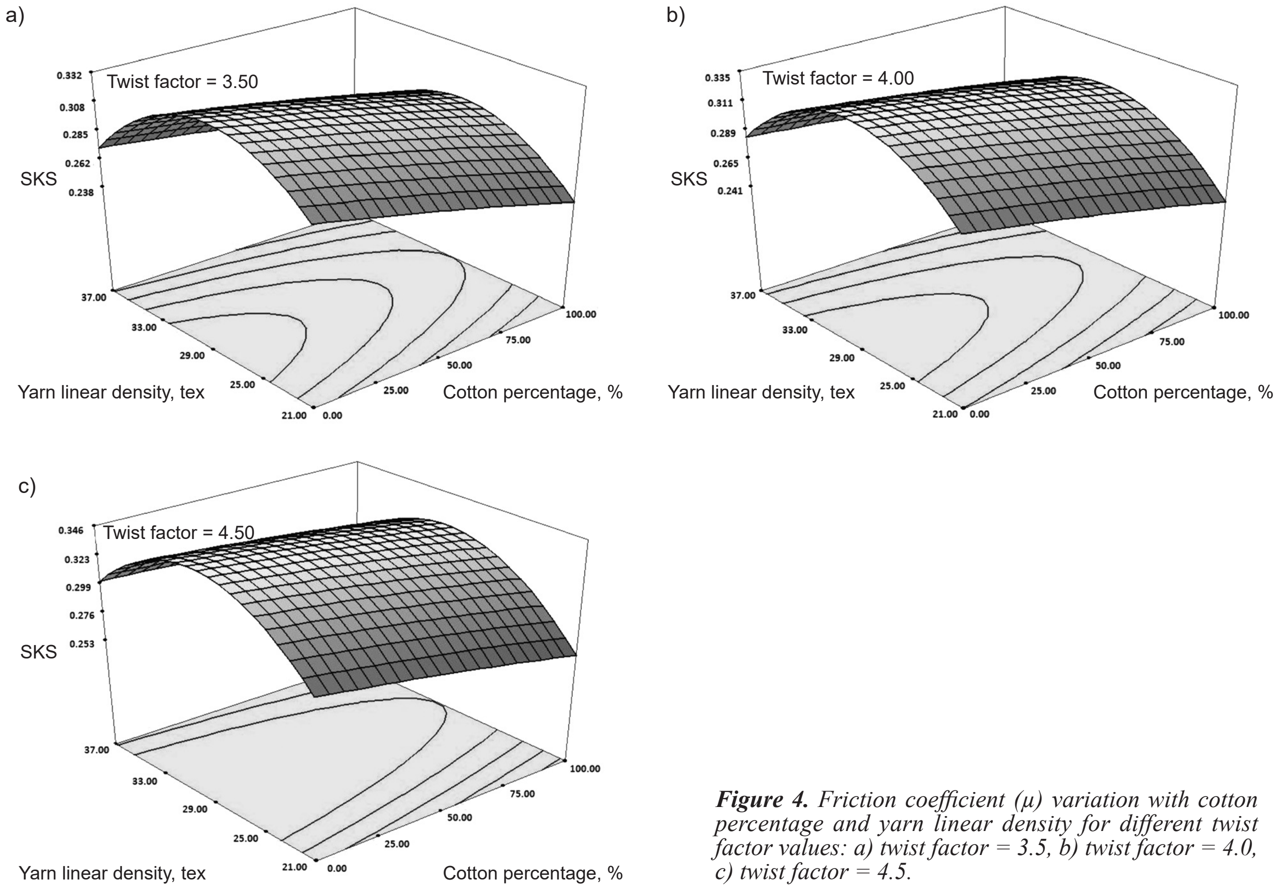

Figure 4. *Friction coefficient (μ) variation with cotton percentage and yarn linear density for different twist factor values: a) twist factor = 3.5, b) twist factor = 4.0, c) twist factor = 4.5.*

of 100% modal yarns are lower than that of 100% cotton fibres. The optimum blend achieved is 40%modal/60% cotton blends for CV_m%, which may be due to the optimum friction forces obtained between modal fibres of ellipse cross section and bean-like cotton fibre. Due to the high length and fineness variation of cotton fibres as compared to the constant staple length of modal fibres, cotton-rich blends have high CV_m% values.

An ANOVA table for the hairiness of cotton/modal blended yarns is demonstrated in ***Table 3***, where the quadratic model was used. The R^2 value is obtained as 45.3%, in which the model explains 45.3% of the response hairiness. Significant model terms are indicated in the Table. The maximum contribution is obtained by the sum of linear and quadratic effects of the blend ratio ($A + A^2$) with 22.75%. The effect of the yarn linear density ($B + B^2$) is second with 10.79%. Other factors have minor effects. The quadratic effect of the twist factor is insignificant.

Figure 3 shows the hairiness variation with cotton percentage and yarn linear density for different twist coefficients (α_e = 3.5, 4.0, 4.5). In these figures, increasing the cotton percentage in the blend increases the hairiness values in general, which is related to the higher length and fineness variation of cotton fibres compared to modal fibres. The hairiness values are high in finer yarns, whereas low hairiness is obtained in coarser yarns, in general. Increasing the twist coefficient again decreases the hairiness, especially in coarse yarns, which may be due to better fibre inclusion in the yarn body with more friction forces. Increasing the twist coefficient decreases the hairiness values for coarse yarns, which can be related to the inter-yarn friction forces between fibres, which help to hold fibres in the yarn body. Minimum hairiness was obtained for pure modal yarns with 37 tex yarn linear density, whereas maximum hairiness was obtained for 100%cotton yarns of 21 tex.

Table 3. *ANOVA for Hairiness (H).*

Source	Sum of squares	Contribution, %	Degrees of freedom	Mean squares	F value	p-value	Significance
Model	45.43	45.30	9	5.05	22.82	< 0.0001	Significant
A	19.47	19.41	1	19.47	88.02	< 0.0001	Significant
B	7.14	7.12	1	7.14	32.28	< 0.0001	Significant
C	3.52	3.51	1	3.52	15.93	< 0.0001	Significant
A^2	3.35	3.34	1	3.35	15.16	0.0001	Significant
B^2	3.68	3.67	1	3.68	16.63	< 0.0001	Significant
C^2	0.31	0.31	1	0.31	1.41	0.2369	Insignificant
AB	0.97	0.97	1	0.97	4.38	0.0373	Significant
AC	0.54	0.54	1	0.54	2.46	0.1184	Insignificant
BC	1.23	1.23	1	1.23	5.56	0.0192	Significant
Residuals	54.86	54.70	248	0.22			
Lack of fit	33.37	33.27	46	0.73	6.82	< 0.0001	
Error	21.49	21.43	202	0.11			
Corrrected total	100.29	100.00	257				

Table 4. ANOVA for friction coefficient (μ).

Source	Sum of squares	Contribution, %	Degrees of freedom	Mean squares	F value	p-value	Significance
Model	Hairiness	53.85	9	0.02	35.15	< 0.0001	Significant
A	0.04	10.26	1	0.04	62.06	< 0.0001	Significant
B	0.00	0.00	1	0.00	3.24	0.0731	Insignificant
C	0.02	5.13	1	0.02	28.57	< 0.0001	Significant
A²	0.00	0.00	1	0.00	0.03	0.8548	Insignificant
B²	0.14	35.90	1	0.14	208.54	< 0.0001	Significant
C²	0.00	0.00	1	0.00	3.08	0.0805	Insignificant
AB	0.00	0.00	1	0.00	1.24	0.2674	Insignificant
AC	0.00	0.00	1	0.00	3.90	0.0493	Significant
BC	0.00	0.00	1	0.00	2.06	0.1526	Insignificant
Residuals	0.17	43.59	255	0.00			
Lack of fit	0.16	41.03	47	0.00	78.61	< 0.0001	
Error	0.01	2.56	208	0.00			
Corrrected total	0.39	100.00	264				

An ANOVA table for the friction coefficient of cotton/modal blended yarns is demonstrated in ***Table 4***, where the quadratic model was used. The R^2 value is obtained as 53.85%, in which the model explains 53.85% of the response friction coefficient. Significant model terms are indicated in the Table. The maximum contribution is obtained from the quadratic effect of yarn linear density with 35.9%. The contribution of the blend ratio is 10.26%, while the twist coefficient has a 5.13% contribution.

Figure 4 shows the friction coefficient variation with cotton percentage and yarn linear density for different twist coefficients (α_e = 3.5, 4.0, 4.5). In these figures, increasing the yarn linear density raises the friction coefficient up to 25 tex, which then decreases. Minimum friction forces are obtained for 37 tex yarns. In addition, the friction coefficient increases along with the twist factor, especially for coarse yarns, as expected. Increasing the cotton blend in the yarn structure generally decreases the friction coefficient, which may be due to the high hairiness of cotton-rich blended yarns. Increased hairiness in the yarn decreased the friction coefficient, as Altas and Kadoglu described [20].

Conslusions

In this study, some important yarn characteristics, such as unevenness, hairiness and friction properties of cotton-modal blended yarns were characterised. Cotton/modal yarns were produced in 0/100, 50/50 and 100/0 blend proportions in four different yarn linear densities and five different twist coefficients. The following conclusion can be drawn from this study:

- The yarn linear density and blend ratio were the most important factors for unevenness, respectively. Increasing the yarn linear density raised the unevenness. Increasing the cotton blend ratio also raised the unevenness due to the high length and evenness variation of cotton fibres with respect to the modal fibres. The optimum blend ratio for CV_m% was obtained as 40% modal/60% cotton.
- The blend ratio and yarn linear density were the most important factors for hairiness, respectively. Increasing the cotton percentage in the blend increased the hairiness due to the high length and evenness variation of cotton fibres. Increasing the twist coefficient decreased the hairiness. Minimum hairiness was obtained for pure modal coarse yarns (37 tex).
- The yarn linear density, blend ratio and twist factor were the most important factors for the friction coefficient, respectively. Increasing the yarn linear density raised the friction coefficient up to 25 tex, which then decreased. Increasing the cotton blend in the yarn structure decreased the friction coefficient due to the high hairiness values of cotton-rich blends.
- The twist coefficient was expected to be the most influential factor for the blended yarn characteristics, especially for the friction coefficient. However, the results indicated are in contrast to expectations, and a minimum contribution to yarn properties was obtained from the twist factor. In this study, the most influential factors for blended yarn characteristics were the yarn linear density and blend ratio.

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