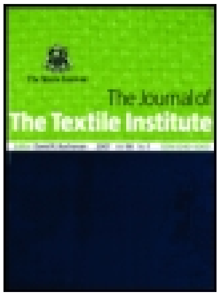

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Yarn hairiness versus quality of yarn

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Yarn hairiness is usually characterized by the amount of free fibers protruding from the compact yarn body towards the outer yarn surface. Its determining is essential because it influences the post spinning operation and parameters of the textile product. Factors influencing yarn quality, mainly yarn hairiness, are correlated and therefore the conclusions depend on all production conditions. Main aim of this article is to show, how quickly and effectively the statistical methods principal component analysis can be applied to obtain information about similarity of yarn samples behavior and build complex quality criterion for yarn. A set of ring yarns is produced for complex quality analysis. The Zweigle G 567 and Uster Tester 4 are used for yarn hairiness investigation.

Keywords: multivariate data analysis; principal component analysis; yarn count; yarn diameter; yarn hairiness; yarn twist

Introduction

Yarn hairiness is an important parameter because it gives the information about the arrangement and behavior of fiber in hairiness sphere (Barella, 1983). The study of yarn structure and fiber arrangement allows to understanding the spinning process deeply and describes the yarn parameters change during yarn processing. Yarn hairiness has great influence on the weaving process and parameters of textile product (porosity, permeability, transport of moisture, comfort, aesthetic properties and hand mainly). This knowledge can be used for precise predicting of yarn behavior and design the textile structures according to customers demand and quality control of the yarn.

The article concentrates on verification of yarn hairiness importance as a yarn qualitative parameter and possibility of principal component analysis (PCA) for building yarn quality criterion. The complex quality of yarn is usually determined by analysis of yarn unevenness and yarn mechanical parameters. Many regression models have been published and a few of yarn complex quality criteria exists. The problem is reliability of this model. PCA can help with building quality criteria effectively for various sets of yarns. Yarn hairiness itself is influenced by many factors. The fiber material, yarn count and yarn twist coefficient are considered mainly. This topic has been studied by many researchers but in some cases the contradictory conclusions are presented. It can be given by the fact that the purpose of use determines the quality of yarn and also its hairiness. Conclusions of various authors cannot be compared completely due to reality that they did not describe all details of experiment. The experiment presented here is prepared with respect to these results.

Yarn hairiness definition and instruments used for yarn hairiness analysis

Yarn hairiness as quantitative parameter is related with yarn diameter (Neckář, 2000). Hairiness of yarn is usually characterized by the amount of free fibers (fiber loops and fiber ends) protruding from the compact yarn body towards the outer yarn surface (Barella, 1983; Deussen & Faerber, 1995). It can be measured by a number of methodologies.

System Zweigle G 567 counts the number of hair ends exceeding 1 mm up to 25 mm length from the compact body of yarn. The internal convention, which takes the variation of light intensity in all optical sensors into consideration, is used for the setting of yarn surface. Output of measurement is absolute occurrence of hairs in given length category n_i. In case that the fiber covers more than one category is counted only in further category (Barella & Manich, 1997). Sum criteria S_{12}, S_3, and S are used for hairiness description, see Equation (1). S_{12} is defined as a sum of absolute

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occurrence of hair ends in the first two categories. S_3 gives the information about the occurrence of hair ends longer than 3 mm. These instruments are used for measuring yarn hairiness in experimental parts.

$$S_{12} = \sum_{i=1}^{i=2} n_i,\ S_3 = \sum_{i=3}^{k} n_i,\ S = \sum_{i=1}^{k} n_i. \qquad (1)$$

Uster Tester allows testing of yarn quality from the point of view of yarn unevenness, number of faults and by the additional optical sensor yarn diameter. The cumulative hairiness index H used by Uster Tester 4 for yarn hairiness quantification is specified as an average value of hairiness over the total test length. It means, in other words, that the cumulative length of all protruding fibers over 1 cm length of yarn is scanned for all testing yarn segments and row data are statistically processed (Barella, 1983; Barella & Manich, 1997).

Influencing factors – bibliography search

Factors influencing yarn hairiness can be generally divided into several groups according to hierarchy of technological process (fiber parameters, yarn geometrical characteristics, settings of production technology, and methodology of yarn hairiness observation) (Barella, 1983; Barella & Manich, 1997). The quality of fiber in terms of fiber fineness, diameter, shape factor, length, flexural rigidity, torsion rigidity, tenacity, extension to break, and friction influence yarn hairiness significantly (Barella, 1983), and (Atlas & Kadoglu, 1972; Barella & Manich, 2002; Barella, Torn, & Vigo, 1972; Basal & Oxenham, 2006; Steadman, 1997). Short fiber content, trash content, and thresh area measured by HVI are also important in the case of cotton fibers (Barella, 1966; Barella & Manich, 2002). Earlier experience shows that the synthetic yarns have higher hairiness than the cotton yarns (Barella, 1975). There are two yarn geometrical parameters influencing yarn hairiness significantly (Barella, 1983; Barella & Manich, 1997). It is yarn count T and yarn twist Z. Helical model is usually used for describing idealized fiber assembly in yarn structure (Neckář, 2000). During twisting of the yarn some fibers are displaced from their central position to the yarn surface (migration effect). The hairiness depends on fibers in periphery layer of yarn. The level of twisting is usually given by the twist coefficient. Twist coefficient is generally defined as multiplication of yarn twist Z and yarn count T in appropriate power. The Phrix a and Köchlin α twist coefficient type is defined by the Equation (2) (Neckář, 2000). Differences in level of twisting are caused by various units, which are in Europe based on SI and in England or Asia is based on inch, pound and yard. This diversity limits the comparison of experimental results presented by various authors because of other range of experimental variables.

$$a = ZT^{2/3}, \quad \alpha = ZT^{1/2}. \qquad (2)$$

The probability of fiber occurrence in hairiness sphere is higher when the number of fibers in yarn cross-section is higher. It means, in other words, higher yarn count. The number of fiber loops represents the major part of hairs in case of cotton yarns produced by classical technology. The increase in yarn twist can reduce the number of fiber loops and their dimension. The fiber loops formation is affected thanks to forces action during sliver formation and yarn twisting. Therefore, it is generally accepted that hairiness increases when the yarn count increases and it decreases when yarn twist increases (Barella, 1983; Das, 2004).

Experimental yarns and testing conditions

The set of ring yarn has been produced and analyzed. The comparative study of various yarn samples produced from similar fibers in terms of fiber length

Table 1. Basic fiber characteristics.

Fiber/technology	Fineness $t_{nom.}/t_{exp.}$ (dtex)	Mass density r (kg m^{-3})	Length ML, l (mm)	Flexural rigidity R_f (mN mm^2 tex^{-1})	Relative strength f (cN tex^{-1})	Elongation ε_v (%)
PAN	0.9/1.17 (1.13; 1.21)	1170	38	0.33–0.48	33.97 (32.85; 35.08)	31.86 (30.63; 33.08)
PES	1.3/1.4 (1.36; 1.45)	1360	38	0.3	53.32 (51.67; 54.98)	17.51 (16.27; 18.74)
VS	1.3/1.34 (1.30; 1.37)	1520	38	0.19	17.56 (16.77; 18.34)	30.05 (29.11; 30.99)
Carded CO m	1.75 (1.63; 1.86)	1520	30	0.19	28.93 (26.17; 31.69)	5.52 (4.93; 6.11)
Combed CO c	1.91 (1.78; 2.04)	1520	30	0.19	24.8 (22.22; 27.37)	5.12 (4.6; 5.6)

and diameter is realized. The range of yarn geometrical parameters (yarn count T and yarn twist Z) is selected in respect to the typical production of yarn for clothing textile. Upper and lower limits of geometrical parameters are given by the technological limits of spinning frames. All kinds of yarns are spun in five levels of yarn count and three levels of twist coefficient. Cotton yarns have been produced by T.M. type twist coefficient in level, which is optimal only for given yarn count. Other yarns have been produced by Phrix twist coefficient and the levels are selected as optimal for the whole range of materials and yarn counts. The natural cotton fibers – CO together with synthetic fibers (polyester fibers – PES, polyacrylonitrile – PAN) and chemical viscose fibers – VS have been used for yarn production. In case of 100% cotton yarn ring spun yarn, the combed (CO c) and carded (CO m) technology have been used.

Vibroskop and Vibrodyn are used to evaluate fiber fineness t and mechanical parameters of single fibers (absolute strength p, relative strength f, and elongation ε_v) (number of measurement 50). Basic fiber characteristics are shown in Table 1. Level of yarn count T (testing length 1000 m, repeating 10) and yarn twist Z (testing length 500 mm, pretension selected in respect to yarn count, repeating 50) is verified according to international standards. Absolute occurrence of hairs in given distances from yarn surface is analyzed on 100 m yarn length by the speed 100 mmin^{-1}, 5 times. The sum criteria S_{12} and S_3 are calculated according to Equation (1). Cumulative hairiness index H and its variability is evaluated on 1 km yarn length by the speed 400 mmin^{-1}, 5 times. The analysis of yarn unevenness CV, number of faults (*Thin-40%*, *Thin-50%*, *Thick + 35%*, *Thick + 50%*, *Neps + 200%*, and *Neps + 280%*), *Shape*, yarn density r_p and yarn diameter D_{UT4} is realized by Uster Tester 4 under the same conditions. The mechanical parameters like the relative yarn strength F and yarn elongation ε are measured by Instron under standard conditions (testing length 500 mm, pretension 0.0825 mNtex^{-1}, testing time 20 ± 3s, repeating 50). Basic yarn characteristics are shown in Table 2. The data for 100% cotton yarn samples have been recalculated from Ne to T [tex] and T. M. [$\text{Ne}^{1/2}\text{in}^{-1}$] to a [$\text{ktex}^{2/3}\text{m}^{-1}$] because of results comparison.

Discussion

Experimental data of all analyzed yarn characteristics was firstly statistically processed and graphically compared with technological parameters to obtain the idea about the basic tendencies from the point of view of fiber material, yarn count, and yarn twist coefficient. Only a part of comparative figures for yarn hairiness

Table 2. Basic yarn sample characteristics.

Sample mat.	Yarn count (twist coefficient) T [tex] (a [$\text{ktex}^{2/3}\text{m}^{-1}$])
PAN	16.5(50), 16.5(56), 16.5(62), 20(50), 20(56), 20(62), 29.5(50), 29.5(56), 29.5(62), 35.5(50), 35.5(56), 35.5(62), 42(50), 42(56), 42(62)
PES	16.5(50), 16.5(56), 16.5(62), 20(50), 20(56), 20(62), 29.5(50), 29.5(56), 29.5(62), 35.5(50), 35.5(56), 35.5(62), 42(50), 42(56), 42(62)
VS	16.5(50), 16.5(56), 16.5(62), 20(50), 20(56), 20(62), 29.5(50), 29.5(56), 29.5(62), 35.5(50), 35.5(56), 35.5(62), 42(50), 42(56), 42(62)
CO m	14.7(55), 14.7(59.47), 14.7(63.93), 19.68(57.7), 19.68(62.39), 19.68(67), 24.6(59.9), 24.6(64.75), 24.6(69.61), 29.5(61.75), 29.5(66.75), 29.5(71.76), 36.9(64), 36.9(69.28), 36.9(74.48)
CO c	14.7(55), 14.7(59.47), 14.7(63.93), 19.68(57.7), 19.68(62.39), 19.68(67), 24.6(59.9), 24.6(64.75), 24.6(69.61), 29.5(61.75), 29.5(66.75), 29.5(71.76), 36.9(64), 36.9(69.28), 36.9(74.48)

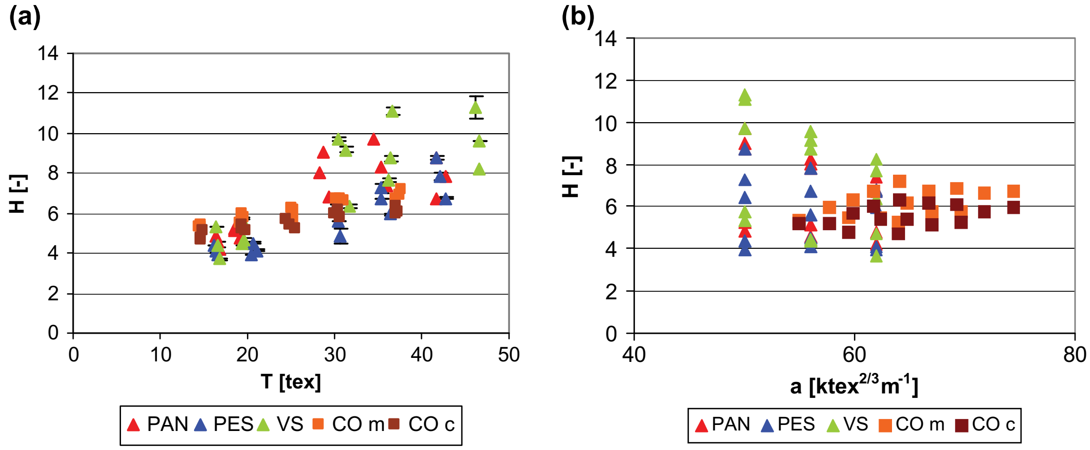


Figure 1. (a, b) Comparison of cumulative yarn hairiness index *H*.

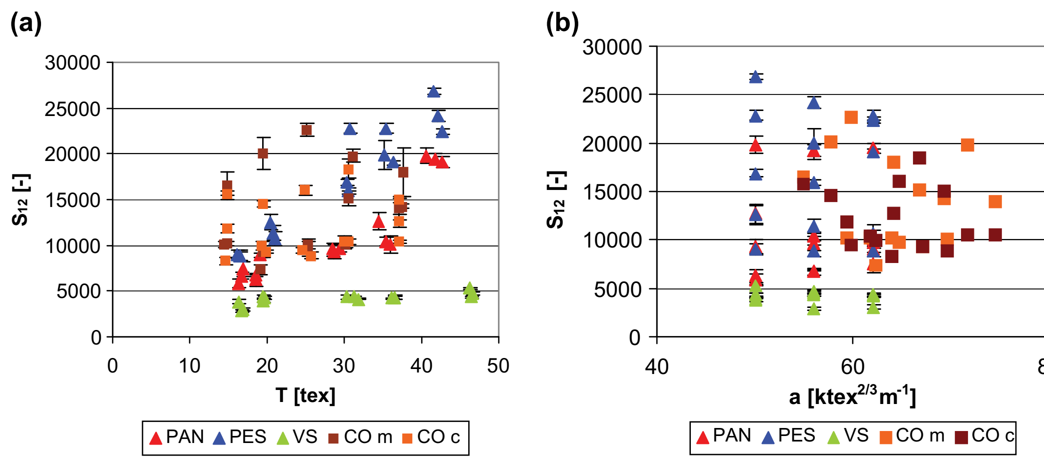


Figure 2. (a, b) Comparison of cumulative yarn hairiness index S_{12}.

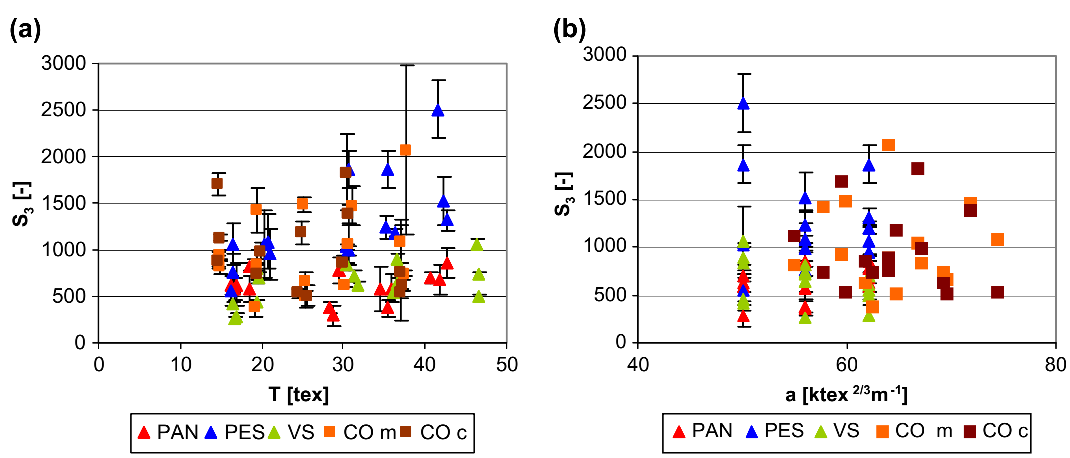


Figure 3. (a, b) Comparison of cumulative yarn hairiness index S_3.

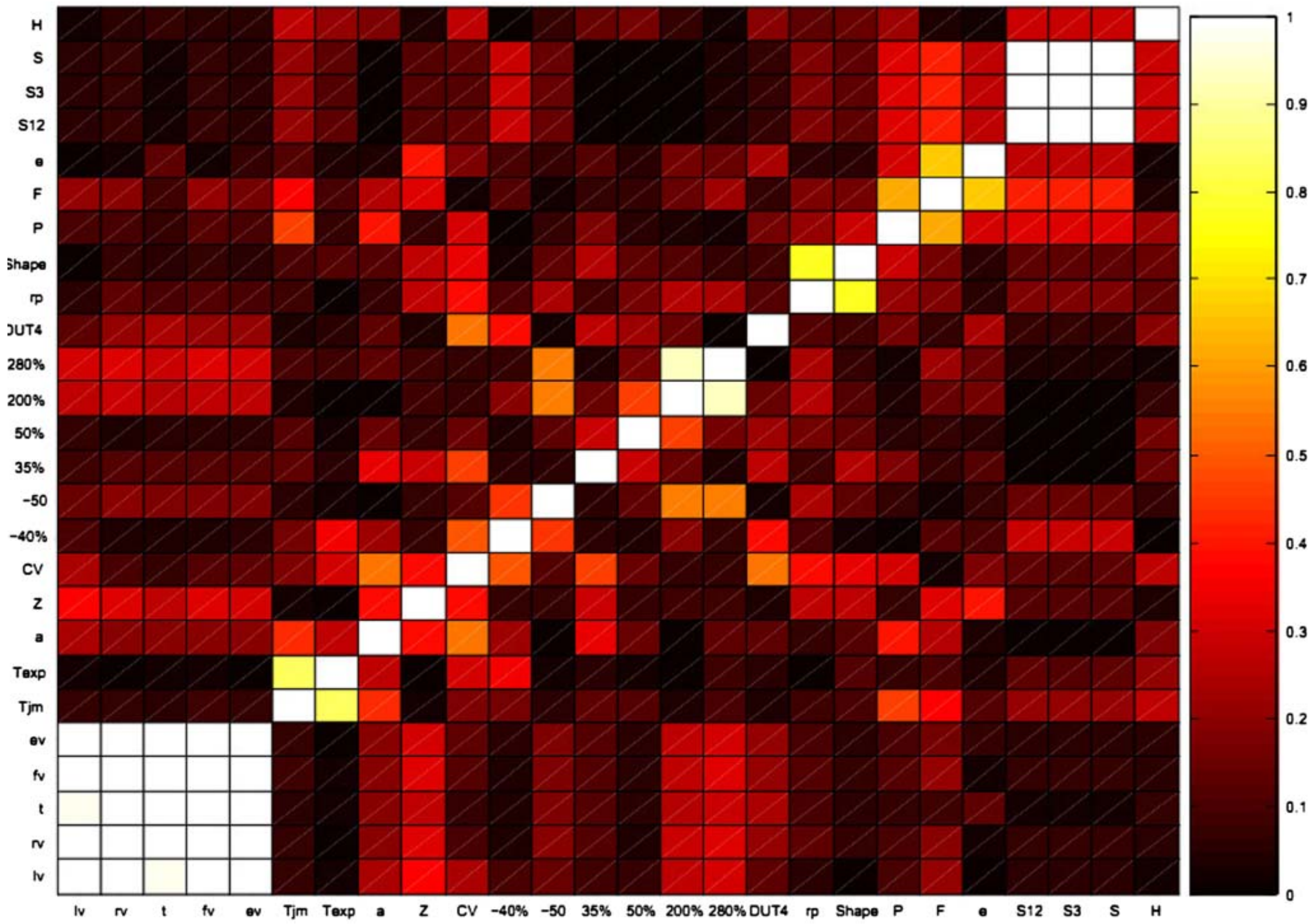


Figure 4. Correlation matrix for partial correlation coefficients $R_{1i\ (1,2,3,\ldots k)}$.

characteristics is presented. Comparisons of yarn hairiness (cumulative hairiness index H and sum criteria S_{12} and S_3) and yarn count or twist coefficient for all fibre materials are shown in Figures 1–3.

Thanks to figures, it can be concluded, that fiber material determines the level of yarn hairiness. The higher diversity is seen in the case of sum criterion S_{12}. Cumulative hairiness index increases when yarn count increases and tends to decreases when the twist coefficient increases. Similar tendency is seen in the case of sum criterion S_{12}. Sum criterion S_3 shows relatively high variability.

Multivariate data analysis is applied in the second step to verify basic tendencies from comparative figures and earlier experience. Matrices of paired correlation coefficients R_{12} and partial correlation coefficients $R_{1i\ (1,2,3,\ \ldots\ k)}$ are computed for estimation of mutual dependencies. The importance of these coefficients was evaluated by so called p values ($1-p$ is computed confidence level). The correlation analysis confirms that there exist strong fiber-fiber and fiber-yarn parameters multicolinearities. This phenomenon can complicate the building of yarn qualitative criteria model based on regression. Graphical results are presented on Figure 4.

The PCA is used for that reason to reduce the number of variables. It is proved that the quality of fibre materials and yarn technological parameters affects the quality of yarn. The question is, what parameters of fibers and yarns should be used for quality assessment and why. In which case, there is a big group of characteristics, which should be measured and evaluated. The PCA is used to reduce the number of variables. Orthogonal transformation converts a set of observations of possibly correlated variables into a set of linearly uncorrelated new quantities – components (Meloun, Militky, & Forina, 1992). These components summarize the information on original variables at the cost of minimal information loss. These components are mutually independent and are arranged according to their contribution to explaining the total dispersion of observed variables. The number of principal components is less than or equal to the number of original variables. Basic

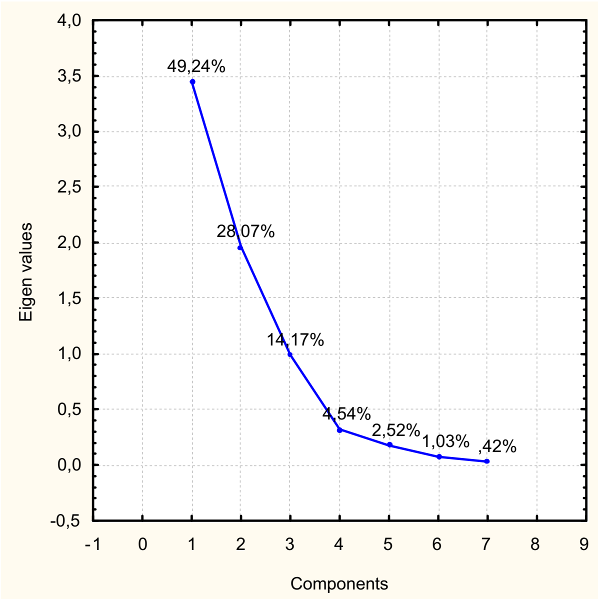
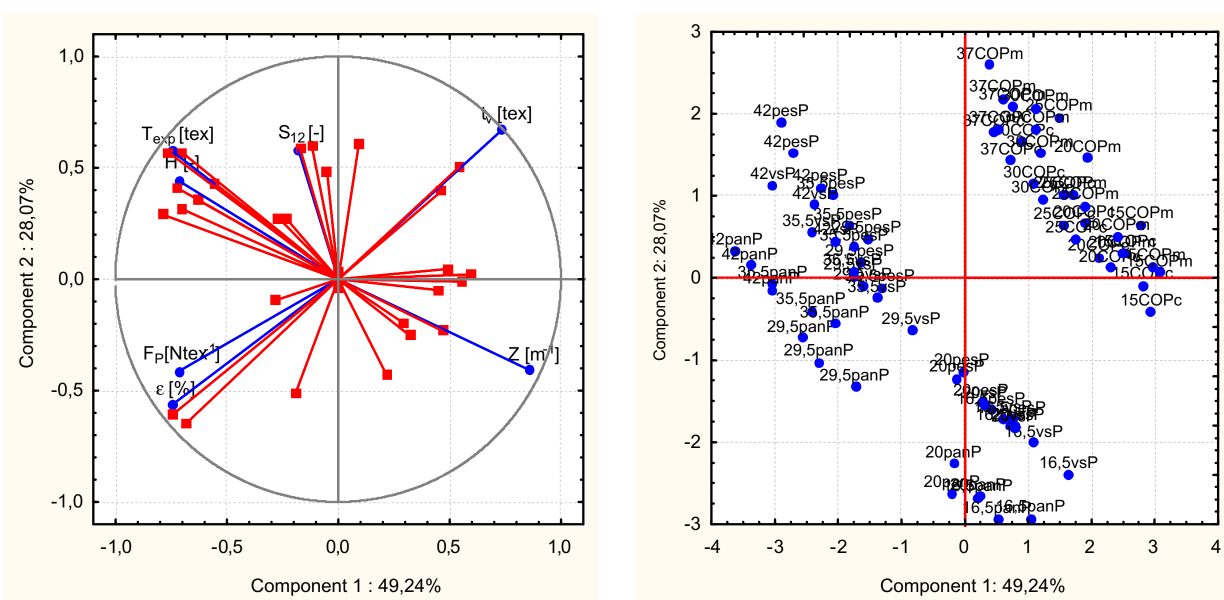


Figure 5. Eigen value scree plot.

characteristics of each principal component are their level of variability – in other words dispersion. PCA is arranged according to their importance, so according to decreasing dispersion, most of the information on the variability of original data concentrates in the first component, the least is in the last component. PCA is the simplest of the true eigenvector-based multivariate analyses and can be used as a tool in explanatory data analysis and for making predictive models (Meloun et al., 1992).

Properties of fibers and yarns are chosen according to previous experiences and the variability of the original data, which we describe. Selection of the most significant components number is realized by Scree plot of Eigen value shown on Figure 5. The structured nature of data from the point of view of variables and observation is visible from corresponding PCA plots on Figure 6(a) and (b). The importance of individual variables to principal components can be read from Figure 6(a). New latent variables – components have the center in center of gravity data. The vector length of original characteristic in projection is proportional to the importance of characteristics from the point of view of its dispersion. The unit circle helps with assessment of results (less significant characteristics are close to center). The angle between vectors is proportional to the correlation coefficient (strong positive correlation – angle 0°, strong negative correlation – angle 180°, and no linear correlation – angle 90°). The reduction of variables is done in respect to PCA leading plot on Figure 6(a) the selected variable is marked by blue color. Material is defined by fiber fineness and the yarn is defined by technological parameters – yarn count and yarn twist. Yarn hairiness is described by two parameters H and S_{12}. Similarly, mechanical parameters of yarn are defined by relative strength F and elongation ε. Characteristics describing yarn hairiness gives the information about the quality of fiber orientation in hairiness sphere and also the mechanical characteristics can give the information



(a) Projection of variables to the plane 12 (b) Projection of observations to the plane 12

Figure 6. Principal component analysis plots for ring spun yarns.

Table 3. Contribution of individual variables to the principal components.

Component/yarn		1/*P*	2/*P*	3/*P*
t_v	(tex)	0.155102	0.226275	0.000004
T_{exp}	(tex)	0.160868	0.168579	0.019229
Z	(m^{-1})	0.216422	0.085837	0.000011
H	(–)	0.148853	0.099551	0.195796
S_{12}	(–)	0.009142	0.171217	0.565905
F	($cN\,tex^{-1}$)	0.148947	0.086968	0.215482
ε	(%)	0.160667	0.161573	0.003573

about fiber orientation in the core of the yarn. Contributions of individual variables to the first three component of PCA are shown in Table 3.

There are three groups of points representing the yarns in scatter component weights plot in projection plane 12, which are clearly separated in respect to fiber material and yarn mechanical parameters. When the subgroups are analyzed, it is clearly visible that the points representing the yarns are arranged according to their count, twist and level of hairiness defined by H and S_{12}. This simple multivariate analysis leads to conclusion that the influence of fiber quality and yarn characteristics is significant. Reduction of variables and orthogonal transformation enable building the PCA model, which is based on the first three components.

Conclusion

It is generally accepted that yarn hairiness influences the quality of yarn, post spinning operation, comfort and aesthetic properties of final product. Yarn hairiness is not the parameter, which is included to complex quality criteria used for yarns assessment automatically. Yarn unevenness and number of faults are prioritized by many authors. This experiment shows that criterion based on technological and mechanical parameters of yarn together with yarn hairiness and fiber fineness can be alternatively used with better results in terms of minimal information loss. The correlation analysis confirms existence of strong fiber-fiber and fiber-yarn parameters multicolinearities. Therefore, the criterion based on the regression model can be questionable from the point of view of its reliability.

The experiment and data analysis also confirms previous experience: When yarns produced from the same fiber material with similar level of yarn twist are compared, it can be expected that increase of yarn count leads to increase of yarn hairiness because of higher number of fibers in yarn cross-section. When yarns produced from the same fiber material with same level of yarn count are compared, it can be expected that increase of yarn twist leads to decrease of yarn hairiness. Ring spun yarns have characteristic well organized structure, which leads to good level of yarn unevenness, given level of yarn hairiness and relatively high level of mechanical parameters mainly yarn strength. Due to the experiment arrangement, expected increase of hairiness and generally slightly worse quality of fine ring yarns is confirmed. The reason is that the sliver has been prepared optimally for coarser yarns and it was necessary to apply the higher draft for them.

Acknowledgement

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