1097 COMPARISON OF COMPLEX INDICES FOR COTTON FIBER QUALITY CHARACTERIZATION

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KEYWORDS: cotton fiber quality, complex indices, utility value concept,HVI data, Bootstrap simulation

INTRODUCTION

Quality is very frequent word used in industry as synonym for good product, technologies etc. Strictly speaking this word is frequently misused or misinterpreted. In some cases word "quality" is used for expression maintainability, reliability or economy of production Especially in the textile branch is necessary to define quality very tightly because textile products (e.g. weaves) can be used for a lot of various applications (ranged from clothing to wipes). One of general definition of quality is:" Quality express ability to fulfill needs of applicability". Therefore before speaking about quality it is necessary to specify the potential target application of textiles.
The quality of the textile fibers is dependent on the aims of evaluation:

- Fiber producers: quality means the achievement of required technological parameters (geometrical evenness, fineness, shrinkage, mechanical and physical parameters etc.).
- Textiles producers: quality means the ability to fulfill requirements of technologic operations and process ability (friction, surface properties, cohesion, selected mechanical and physical properties, and evenness).
- Consumers: fiber quality is hidden in the properties and comfort of fabrics (hand, wearing pleasance, thermal comfort, transport properties etc.).

Natural fibers: controlled changes of properties are very difficult (selection, breeding, gene manipulation) and therefore the quality is oriented to the process ability, yarns characteristics (especially strength) and mixing potency.
Chemical and synthetic fibers: by variation of fiber geometry (fineness, cross section profile, texturing) and spinning conditions (rate of production, drawing degree, temperature, forming conditions) is possible to markedly change majority of properties. The chemical modification is another way to change of properties. The general definition of quality according to the aim of utilization can be here used for ranking and classification.
According to the general definition, the quality is characterized by several properties expressing the ability of a product to fulfill functions it was designed for. The degree of quality (complex criterion) is often expressed as utility value U (Militký (1980)). Evidently, general quality of textiles is characterized by many of various utility properties R_i (i=1,…m). These are such properties that make it possible for the product to fulfill its function. Utility value $U \in <0, 1>$ aggregates then in some certain way partial quality properties (Arrow (1971), Cerny (1980)).
The purpose of the paper is to describe the complex evaluation of cotton fiber quality (cotton quality index *U*) based on this idea. The results of HVI measurements are used as input information. The applicability of cotton quality index is demonstrated on the simulation-based and practical examples.

COTTON FIBER QUALITY

In 1907 an international group of cotton industry representatives recommended to establish uniform cotton standards to "eliminate price differences between markets and make the farmers more cognizant of the value of the value of their products". In response to requirements of standardization the cotton grade standards and cotton classification systems were elaborated and authorized by US Dept. of Agriculture.
The cotton classification is now system of standardized procedures for measuring of raw cotton properties (physical attributes) that affect quality of processing (spinning mainly) and quality of products (yarns). The classification system of US cottons is described on the net (http://www.cottonic.com/CottonClassification).
There exists a plenty of standard and HVI techniques for characterization of cotton fibers. It is known that there are some differences in the principles of measurements and the results of AFIS

and HVI spectrum apparatus. The differences exist between measurements of fiber strengths based on the bundles concept or single fiber concept as well (Militký (2004)). Despite of these differences it is possible to specify basic cotton fiber properties having potential influence to the cotton yarn strength (Rasked (2002)):

Fiber length (expressed as upper half mean *UHM* [mm],
fiber length uniformity (expressed as uniformity index *UI* [%]),
fiber strength (as bundle strength *STR* [cN/tex]),
fiber elongation ant break (*EL* [%])
fiber fineness and maturity (expressed by micronaire reading (*MIC* [-]),
short fiber content (*SF* [%]),
thrash content *TR* [%].

The importances of these properties are generally dependent on the spinning technology. The relative weight *b* of above listed properties (as importance percentages divided by 100 and then standardized - sum of weights should be one) are given in the Table I.

TABLE I. Contribution of cotton properties to the yarn strength

Property/ weight	Rotor yarn	Ring yarn
UI [%]	0.20	0.22
MIC [-]	0.16	0.17
UHM [mm]	0.14	0.24
STR [g/tex]	0.28	0.22
EL [%]	0.09	0.06
SF [%]	0.06	0.06
TR [%]	0.07	0.03

The values in the Table I were derived from pie graphs presented in the work (Rasked (2002)). The main problem with utilization of above-mentioned properties for quality characterization is multivariate character of information, various units and lack of transformation to the utility scale. One of first attempts to create aggregated criterion of cotton fiber quality was **fiber quality index** (FQI) expressed by relation (Anonym (1983))

*FQI = (fiber strength*length)/fineness* (1)

South India Textile Research Association proposed modified version in the form (see. Majundar et. all (2005)))

*FQI = (fiber strength*length*uniformity*maturity coefficient)/fineness*

For HVI results is *FQI* expressed in the form

$$FQI = \frac{UHM * UI * STR}{MIC} \qquad (2)$$

Some other criteria are based on the regression models connecting fiber properties with parameters characterized spinning ability or quality of yarn (characterized by yarn strength). The **spinning consistency index** (SCI) is connected with cotton HVI properties through regression model (Anonym (1999))

$$SCI = -414.67 + 2.9 * STR + 49.1 * UHM + 4.74 * UI - 9.32 * MIC + .95 * Rd + 0.36 * b \qquad (3)$$

where *Rd* is reflectance degree and *b* is yellowness of fiber. Based on the regression equation relating fiber properties with yarn strength the **premium discount index** (PDI) was derived. The PDI expressed in the standardized fiber parameters (see. Majundar et. all (2005)) has the form

$$PDI = 22.15 * STR^{*} - 4.75 * EL^{*} - 4.37UHM^{*} + 11.9UI^{*} - 20.78 * SFC^{*} - 7.8 * MIC^{*} \quad (4)$$

where superscript (*) denotes the standardized variable (mean value subtraction and division by standard deviation). The **multiplicative analytic hierarchy process** (MIA) criterion (see. Majundar et. all (2005)) can be expressed by relation

$$MIA = \frac{STR^{0.27} * EL^{0.039} * UHM^{0.291} * UI^{0.145}}{MIC^{0.11} * SFC^{0.145}} \quad (5)$$

In the book (Korickij (1983)) so called **geometric properties index** (IG) was introduced. This index is based on LVI measured properties

$$IG = 0.1*L_m*UI*(1-SF/100)*MAT*(FI)^{-0.5} \quad (6)$$

where L_m is cotton fibers weighted mean length, *FI* is fiber fineness and *MAT* is maturity. For HVI measured properties can be *IG* expressed as

$$IGa = \frac{UHM * UI * (100 - SF)}{10000 * \sqrt{MIC}} \quad (7)$$

or

$$IG = \frac{UHM * UI * (100 - SF) * MAT}{1000000 * \sqrt{FI}} \quad (8)$$

The relation (7) is very rough because the micronaire is combination of fiber fineness and maturity. Index *IG* correlates with yarn mass unevenness by empiric relation (Korickij (1983))

$$CV = \frac{100 * A_2}{I_g \sqrt{T_P}} \quad (9)$$

where $A2 = 11.7$ for long staple cottons and $A2 = 14.7$ for medium staple cottons. *TP* is yarn fineness. Index *IG* correlates with yarn strength variation coefficient *CVP* by empiric relation (Korickij (1983))

$$CV_P = \frac{100 * A_3}{I_g * \sqrt[4]{T_P}} \quad (10)$$

where $A3 = 3.85$ for long staple cottons and $A3 = 4$ for medium staple cottons. Cotton yield during spinning is expressed by relation

$$B = 95.4 - 2.9 * TR \quad (11)$$

Complex quality index (IK) expressing the spinning ability of cottons is then defined as combination of *IG* and *B* with including of cotton fibers price *C.*

$$IK = A_4 * B * I_g^{4} / C \quad (12)$$

where $A_4 = 0.0108$ for long staple cottons and $A_4 = 0.0141$ for medium staple cottons. These relations were derived from Russian cottons and LVI measurements.
The main problem with all above mentioned characteristics of cotton fiber quality are:

1. strong dependence on the units for individual cotton properties and methods for their evaluation,
2. utilization of dimensional parameters based on the limited amount of experimental data (from the past crops),
3. no inclusion of individual fiber properties importance for individual spinning technologies.

4. no possibility to change parameters for new crops without tedious experimentation
5. no defined ranges (limits) for quality indices.
6. no possibility to include the direction of some properties influence to quality indices dependent on their real values (case of micronaire).

Our approach based on the utility function concept is more general and be easily modified for the future (the properties of cottons are in dependence on time progressively changed in positive sense due to breeding and genetic manipulation)

UTILITY VALUE CONCEPT

Evaluation of quality based on complex criterion (cotton quality index *U*) is closely related to the well-known problem of complex evaluation of variants (Cerny (1980)). For complex evaluation of variants, the ***X*** matrix of the (n x m) order is available containing for individual $V_1, \ldots, V_n$ variants (***X*** matrix rows) the values of selected $R_1, \ldots, R_m$ characteristics (***X*** matrix columns).
The x_{ij} element of the matrix thus expresses the value of the *j - th* characteristic of R_j for the *i-th* variant of V_i. The aim is to sort individual variants in the order of their importance. In economics several different methods are used in this field and most of them are based on preferential relations (Cerny (1980)). A special technique is the so called "useful effect method" or "base variant method". Base variant practically represents an ideal state where individual characteristics get optimum values.
By means of o_j ($j = 1,...m$) values for individual characteristics of a base variant, dimensionless standard quantities u_{ij} are calculated. If the increase of the R_j characteristic is accompanied by the increase of quality, the standard quantities are calculated according to the relation

$$u_{ij} = \min(\frac{x_{ij}}{o_j}, 1) \qquad (13)$$

In opposite case, the dividend and the divisor are interchanged. As $U(R) = U(u)$ is aggregating function a suitable weighted average is used. Generally a question may arise whether a suitable aggregating function really exists (Arrow (1971)).
Modification of this approach for expressing of textiles quality is shown in the work (Militký (1980)). The procedure for prediction of cotton fibers quality from point of view of the yarn strength is described in sequel.
Let we have K utility properties $R_1, \ldots, R_K$ (cotton fiber properties selected in the Table I). Based on the direct or indirect measurements it is possible to obtain some quality characteristics $x_1, \ldots, x_K$ (mean value, variance, quantiles etc.). These characteristics represent utility properties. Functional transformation of quality characteristics (based often on the psycho physical laws) lead to partial utility functions

$$u_i = f(x_i, L, H) \qquad (14)$$

where *L* is value of characteristic for just non acceptable cotton ($u_i = 0.01$) and *H* is value of characteristic for just fully acceptable product ($u_i = 1$). **Cotton quality index (**U) i.e. utility value is weighted average of u_i with weights b_i

$$U = ave(u_i, b_i) \qquad (15)$$

Weight b_i corresponds to the importance of given utility property (Dobrov (1977)) and is closely connected with area of cotton application. The weighted geometric mean used as average has following advantages:

- For zero value of u_i is also $U = 0$. This means that combinations of other utility properties cannot replace non-acceptable utility property.
- Geometric mean is for not constant u_i always lower that arithmetic mean. This reflects evaluation based on the concept that the values of utility properties close to unsatisfactory cottons are more important for expressing the quality than those close to optimum cotton.

Basic steps of utility function computation are:

- Selection of characteristics x_i corresponding to utility properties R_i,

- Determination of preferential functions $u(x_i)$ expressing "partial quality" for chosen utility property,
- Assessment of the importance of individual utility properties via weights b_i,
- Proper aggregation, i.e., determination of the U function.

For the cases of cotton fibers quality are utility properties and weights already selected (see. Table I).

For aggregation the weighted geometric mean can be used and therefore the preferential functions $u(x_i)$ have to be proposed only. Partial utility function is in fact psychophysical variable expressing the sensation of quality induced by (measured) characteristic of cotton property. The computation of preferential functions is dependent on the measurement scale and property type.

Ordinal characteristics - in this type of scale, classification has been introduced, but differences are not quantified. Grades are awarded by the comparison with etalons. Usually the higher is the grade; the higher is the partial quality.

Cardinal characteristics - are usually expressed in physical units. There are two types of cardinal characteristics.

One-side bounded characteristics are those where after the H_j value has been exceeded utility does not change any more (fiber strength, length, etc.). After standardization the partial utility function is computed e.g. by using Harrington preference function

Two-sides bounded characteristics are those where on both sides from "the optimum" partial utility decreases. (e.g. fiber micronaire)

The nonlinear transformation to preference functions for cardinal utility values is given in the work (Militký (1980)). For expressing quality of cotton fibers it is sufficient to replace standardization and nonlinear transformation to the partial utility function by the piecewise linear transformation.

For one side bounded properties quality is monotone increasing or decreasing function of quality characteristic x and therefore the piecewise linear transformation has form shown on the Fig. 1.

For the case of LB (lower is better) properties were limits selected according to the known ranges published e.g. in (Rasked (2002))

Thrash content *TR [%]* $L = 6$ $H = 2$

Short fibre content *SF [%]* $L = 18$ $H = 6$

For the case UB (upper is better) properties were limits selected according to the known ranges published e.g. in (Rasked (2002))

Strength HVI *STR [g/tex]* $L = 23$ $H = 31$

Length *UHM [mm]* $L = 25$ $H = 32$

Uniformity index *UI [%]* $L = 77$ $H = 85$

Elongation *EL [%]* $L = 5$ $H = 7.7$

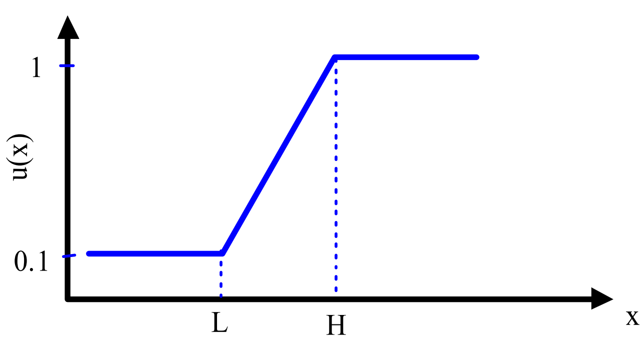


Fig. 1 Transformation for one side bounded cotton properties (L is lower limit and H is upper limit)

For two side bounded properties quality is monotone decreasing function of property value x on both sides from optimal (constant) region and therefore has the piecewise linear transformation form shown on the Fig. 2

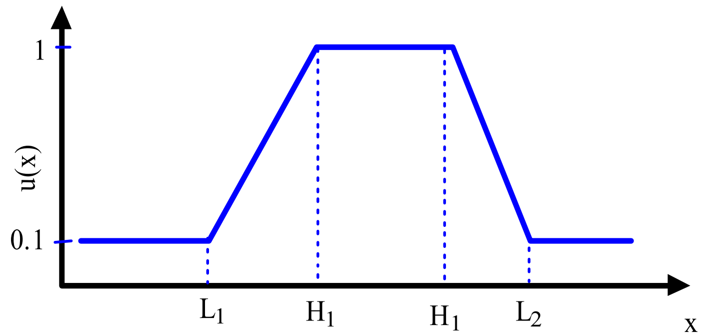


Fig. 2 Transformation for two side bounded cotton properties (L_1, L_2 are lower limits and H_1, H_2 are upper limits)

For this case were limits selected according to the known ranges published e.g. in (Rasked (2002))

Micronaire *MIC [-]* *L1 = 3.4, H1 = 3.7* *L2 = 5, H2 = 4.2*

The weighted geometrical average *U* characterizing cotton fibers quality i.e **cotton quality index** is then simply calculated by the relation

$$U = \exp\left(\sum_{j=1}^{m} b_j * \ln(u_j)\right) \tag{16}$$

When forming the aggregating function *U* from experimentally determined values of individual utility properties, the statistical character of the x_j quantities should be considered and the corresponding variance *D(U)* should be also determined.

PROGRAM QCOTTON

Program *QCOTTON* written in MATLAB is based on the above-proposed procedure. The Bootstrap type technique described in (Meloun (1993)) has been applied for computation of the statistical characteristics of cotton quality index. This technique is based on the assumption that for each utility property R_j the mean value x_j and variance s^2_j are determined by standard treatment of the measured data. The procedure of the statistical characteristics of cotton quality index *U* estimation is divided to the following parts:

I. Generation of $x^{(k)}_j$ ($j=1,.....m$) values having normal distribution with mean values x_j and variances s^2_j. The pseudorandom number generator built in MATLAB is used.

II. Calculation of the cotton quality index $U^{(k)}$ using the relation (12).

III. The steps I and II are repeated for $k=1,.....n$ (usually $n=600$ is chosen).

IV. Construction of a histogram from the values $U^{(k)}$ (k=1,.....n) and computation of the estimators of *E(U)*, *D(U)*.

SIMULATION RESULTS

The influence of micronaire changes and upper half mean changes to the cotton quality index of some ideal cotton fiber is shown on the fig. 3

Fig. 3 Influence of *MIC* and *UHM* on utility value

In accordance with expectation leads increase of *UHM* to better quality expressed by *U* value. Micronaire influence is more complex because the small values indicate immature cottons and high values are for too coarse cottons. The distribution of *U* for the idealized case when relative errors of measurement CV are 3 % for all properties are given on the Fig. 4.

Fig. 4 Distribution of U values for measurements with 3 %precision

There are visible differences between the U values for rotor and ring yarn weighting coefficients.

Complex criterion (weights for rotor) :

Mean	lower limit	upper limit
0.49 ¨	0.4.86	0.494

Complex criterion (weights for ring) :

Mean	lower limit	upper limit
0.479 ¨	0.4.75	0.484

The differences between both types of weights are not so high but the confidence intervals are not overlapped and conclusion is "this cotton is significantly better for rotor yarn production".

EXPERIMENTAL PART

For evaluation of proposed cotton quality index and comparison with other quality criteria the two data sets are selected.

Data set I

The results of the crop study of 1997 and 1998, which includes 33 sets of cottons (Majundar et. all (2005)) were used for comparison of *U* with some other cotton quality indices. For different cotton varieties the International Textile Center (USA) evaluated the all characteristics required to computation of cotton quality index U excluding thrash content (in evaluation of U the value $TR = 2$ was selected). The quality of data were investigated by multivariate exploration techniques (Meloun, Militký and Forina (1993)).

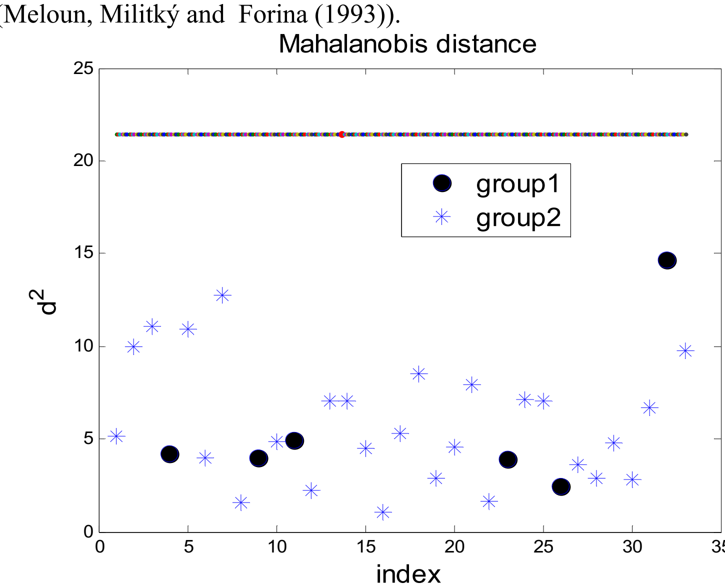
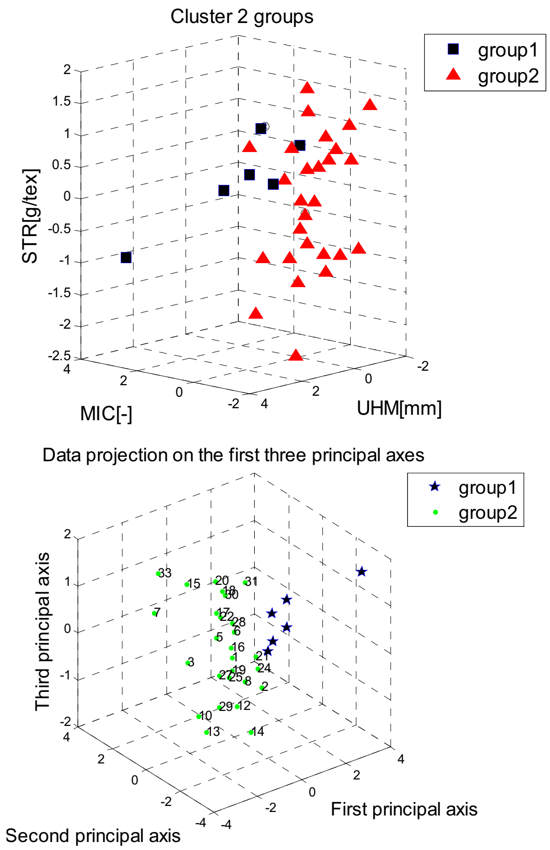


Fig. 5 Mahalanobis distance for cotton varieties properties

The Mahalanobis distance (Meloun, Militký and Forina (1993)) for all cotton varieties are shown on the fig. 5. It is clear that all points are below the limit for highly influential points. Based on the cluster analysis the data were divided into two groups as is shown on the fig 6a. These groups are visible in the projection into first three principal components.



a) Clustering b) principal component plot

Fig. 6 Multivariate exploration of cotton varieties properties from HVI

In the smaller group (7 cotton varieties) are cottons having extra high STR, higher UHM and lower SCF i.e. this group contains cotton varieties of higher quality.

Data set II

The 15 typical cotton varieties used in Czech Republic was selected (Militký (2004a)). Their basic properties obtained from HVI apparatus are graphically summarized on the figure 7.

Fig. 7 Cotton varieties properties from HVI

From point of view of mechanical properties and geometry is the extreme the cotton GIZA 70. This fiber has highest strength STR.

7. RESULTS AND DISCUSSION

It is useful to discuss the results for each data set individually, because the purpose of evaluation is slightly different.

Data set I

The cotton quality index *U* for all cotton varieties are given on the fig. 8.

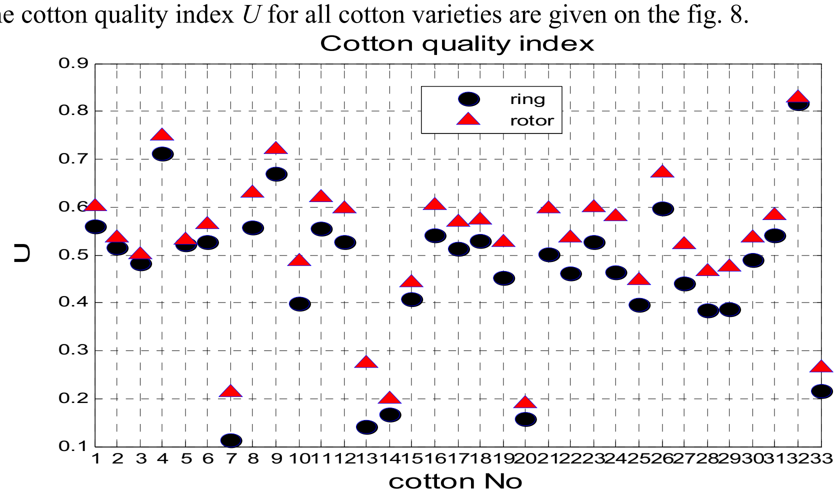
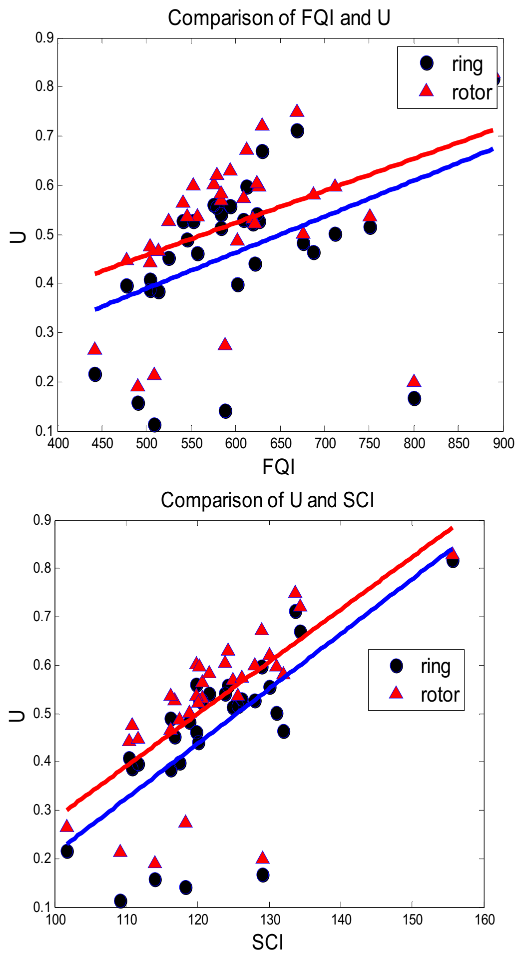


Fig. 8 Computed cotton quality indexes (utility values)

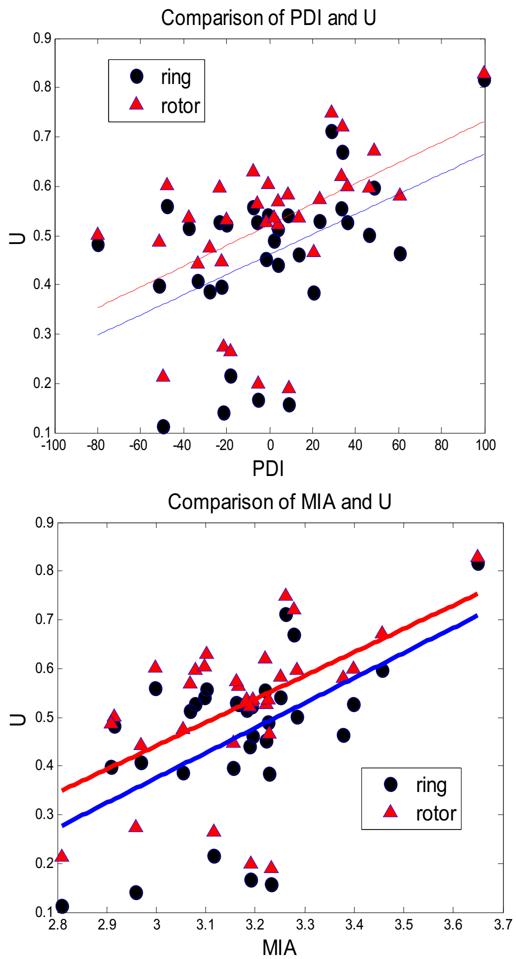
It is visible that according to the cotton quality index are cotton varieties separated into two groups. In the low value of *U* are cottons with very low UHM (No. 7, 13, 33) or very high micronaire (No. 7, 14, 20, 33). The comparison of U with FQI is shown on the fig. 9a. Corresponding correlation coefficient for ring yarn is $r = 0.434$ and for rotor yarn is $r = 0.408$. The comparison of U with SCI is shown on the fig. 9b. Corresponding correlation coefficient for ring yarn is $r = 0.692$ and for rotor yarn is $r = 0.693$.



a) b)

Fig. 9 Computed cotton quality indexes (utility values)

The comparison of U with PDI is shown on the fig. 10a. Corresponding correlation coefficient for ring yarn is $r = 0.473$ and for rotor yarn is $r = 0.510$. The comparison of U with MIA is shown on the fig. 10b. Corresponding correlation coefficient for ring yarn is $r = 0.538$ and for rotor yarn is $r = 0.530$.



a) b)

Fig. 10 Computed cotton quality indexes (utility values)

The best correlation exists between U and SCI. Other correlations are highly significant as well. In each cases are visible the outlying points with very low values of *U.* Main reason of this deviations are higher low limits for UHM (25 mm) and low higher limit for MIC (5) used for computation of U.

Data set II

The correlation matrix between basic HVI parameters is given in the table II.

Table II. Correlation matrix between HVI parameters

Variable	STR	EL	UHM	MIC
STR	1	-0.25851	0.925335	-0.16529
EL	-0.25851	1	-0.39094	-0.18283
UHM	0.925335	-0.39094	1	-0.30175
MIC	-0.16529	-0.18283	-0.30175	1

The strength STR correlates strongly with length of fiber expressed by UHM. The other parameters are not significant. The relation between UHM and HVI cotton strength (STR) are shown on the fig. 11.

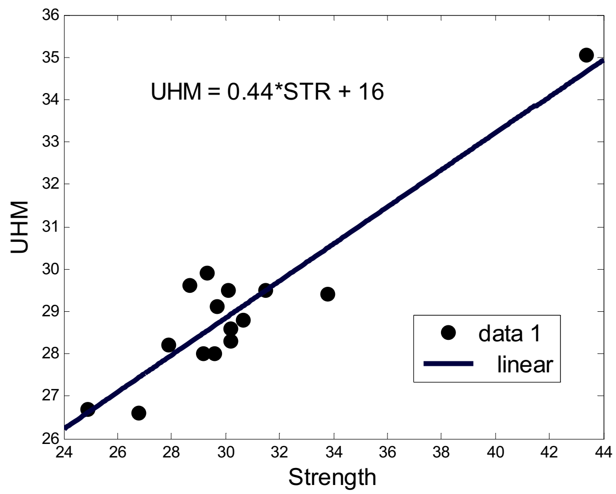


Fig. 11 Relation between UHM and HVI cotton strength

The utility value for all cotton varieties are given on the fig. 7. Because the short fiber content and trash content were not measured their corresponding optimal value are used (*TR = 2*, *SF = 6)*

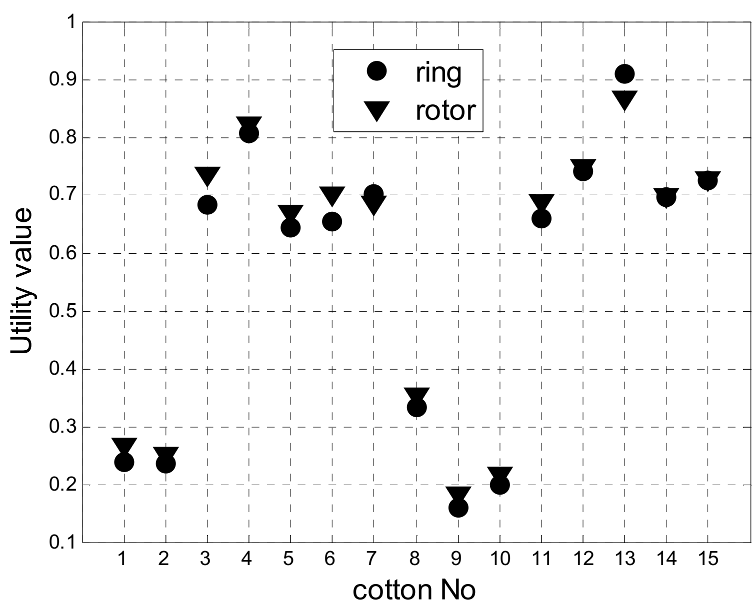


Fig. 12 Computed cotton quality indexes (utility values)

It is visible that according to the quality indexes are cotton varieties separated into two groups. In the low value of *U* are cottons with very low strength (No. 8, 9) or very low maturity (No. 1, 2, 10). The greatest *U* value is for USA 2121 (No. 13) variety. The differences between ring and rotor yarn quality are not very high.

8. CONCLUSION

Described procedure for evaluation of cotton quality index (U) can be very simply modified for other selected properties or other set of weights. This is important for future cotton varieties. Based on preliminary results it will be probably necessary to solve problems with some cotton varieties having small micronaire due to fineness and relatively high strength. For these cases will be necessary to add restriction to the L_l and H_l.

ACKNOWLEDGEMENTS: This work was supported by the research project "Textile Center" of Czech Ministry of Education 1M4674788501

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