RELATIONSHIP BETWEEN AFIS FIBER CHARACTERISTICS AND YARN EVENNESS AND IMPERFECTIONS

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Abstract

Evenness and number of imperfections are important quality properties of cotton yarn. If fiber characteristics correlated with these properties could be identified early, this would allow breeders to take these into consideration during the very first stages of breeding. In this context, the Advanced Fiber Information System (AFIS) presents two distinct advantages : i) it provides an estimate of fiber maturity and fineness which are often cited as basic factors in yarn properties, and ii) gives distribution characteristics, in particular as concerns length. The study presented here shows that data provided by the AFIS gives a relatively good prediction (r^2 between 0.71 and 0.84) of the evenness (CV%), the number of thin places and thick places and the hairiness of ring-spun yarns. Yarn produced by open-end spinning is more even and its properties do not seem to be related to the same fiber characteristics. Therefore, they cannot be evaluated with the same precision.

Introduction

The properties of cotton yarn depend on the spinning technique used, the composition of the process and the quality of the raw-material. Important properties for yarn are its strength, evenness and number of imperfections. As these have an impact on weaving efficiency and product appearance, these characteristics govern yarn value (Faeber and Deussen, 1994). Yarn strength is measured on a dynamometer and its relationship with fiber characteristics is well established (Frydrych and Gourlot, 1993 ; Hunter, 1988).

Characteristics evaluated on the regularimeter are listed below :

- yarn evenness; this corresponds to the variation in fiber mass around the mean, and is expressed by a coefficient of variation (CV%).
- number of imperfections or defects per unit length ; these imperfections can be divided into 3 categories. The thin places are areas in the yarn where less fibers are present. The thick places are caused by an increased number of fibers in the cross-section, and result in decreased torsion and strength. Neps are lumps composed of entangled fibers or seed coat fragments.
- hairiness is caused by fibers that over part of their length are not held within the structure of the yarn.

Evenness and imperfections depend on the yarn manufacturing process and on the characteristics of the cotton fiber used as raw material.

In general, breeders do not have available any results of systematic spinning tests conducted on the vegetal material for which they attempting varietal improvement. In their breeding work, they require data for criteria that can be measured rapidly in a small sample of fiber, and that are well correlated with yarn-quality characteristics. It was with this intention that the CIRAD laboratory of cotton technology developed methods used to predict strength from fiber characteristics (Gutknecht, 1984 ; Frydrych and Gourlot, 1993) and predict neppiness - caused by seed coat fragments - from countings made by image analysis of card webs (Gourlot, 1995 and 1996).

Taking account of evenness and yarn imperfections during genetic improvement of the cotton plant requires investigation of fiber characteristics that are sufficiently correlated with these parameters to provide a good prediction. Several fiber characteristics have been correlated with yarn evenness and imperfections (Hunter, 1988 ; Jones, 1995 ; Smith, 1995). Some of these are mean parameters obtained from fiber bundles, e.g. on HVI (length, strength, maturity, fineness). But other important characteristics are related to distribution, particularly short fiber content (SFC). The role played by dispersion characteristics and others such as maturity suggests that the AFIS can contribute greatly in predicting yarn evenness and defects. The study presented here was conducted to evaluate this interest.

Materials and Methods

Cotton samples

23 Upland cottons (*G. hirsutum*) were used in the study. These were commercial cottons produced by saw ginning. Their geographic origin is presented in table 1. A sample (1,200 g) of each cotton was opened manually to form a web 1 m x 1 m. The web was folded to form 4 layers and slices removed as samples. Two 500 g samples were used for micro-spinning (ring-spinning and rotor-spinning) and 50 g were used for fiber analyses on the AFIS.

Micro-spinning and yarn analyses

The micro-spinning tests were conducted with preparation on a Shirley-Platt process including an opener, a minicard and a drawing frame. Both ring-spinning (Shirley-Platt) and rotor-spinning (Suessen) were performed on 500 g of fiber spun to 20 tex yarn after 3 processings on the drawing frame. Spinning conditions were set at 22°C and 50% relative humidity.

Yarn properties were analyzed at 22°C and 65% relative humidity. Yarn strength was measured on a Uster Dynamat

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 1:512-516 (1997)
National Cotton Council, Memphis TN

after 160 breakages. Yarn evenness was measured on an Uster UT3 with 4 repetitions of 250 m. The following settings were used : yarn speed set at 50 m/min, thin places at -50%, thick places at +50% and neps at +200% for ring-spinning and +280% for rotor-spinning.

Fiber analyses

Fibers from each cotton sample were analyzed on the Zellweger Uster Advanced Fiber Information System (AFIS), modules L&D, N and F&M.

The sample placed in the machine is prepared by the fiber individualizer. Each fiber is then separated from the sample and pneumatically transported to the electro-optic sensor. Two signals are measured simultaneously as the fiber passes through the light beam. The extinction signal (attenuation of the light transmitted as the fiber passes in front of the light source) is used to evaluate length and diameter (mean projected width of the fiber). The combination of the scattering signal and the extinction signal is used to measure the degree of thickening (theta or θq) of the secondary wall and the area of the section. A full distribution of these 4 characteristics is therefore available. The mean is then calculated along with the coefficient of variation and other parameters :

- short fiber (< 12.7mm) content by number (SFCn) and by weight (SFCw)
- quantiles corresponding to the longest fibers
  (*UQLw*, i.e. length exceeded by 25 % of the fibers by weight)
  (*5%n*, i.e. length exceeded by 5% of the fibers by number)
  (*2.5%n*, i.e. length exceeded by 2.5% of the fibers by number)
  (*1%n*, i.e. length exceeded by 1% of the fibers by number)
- fine fiber fraction or FFF (area < 60 μ^2), immature fiber fraction or IFF ($\theta < 0.25$) and mature fiber fraction or MFF ($\theta > 0.5$).

Routine parameters for maturity and fineness, such as Maturity Ratio, PM% or H, are evaluated along with micronaire equivalent “Micronafis”.The N module provides a nep count (fiber neps + seed coat neps) per gram of fiber and a nep size distribution.

The precision of the AFIS measurements depends on the number of specimens analyzed for each cotton and the number of fibers measured for each specimen. The variance of estimation, used to calculate the confidence interval for the mean of any particular parameter measured on a fiber by fiber basis, depends on intra- and inter-specimen variances and is calculated as follows :

$$\sigma_s^2 = [\frac{\sigma_B^2}{J} + \frac{\sigma_E^2}{JK}]$$

σS^2 = variance of estimation
σE^2 = intra-specimen variance
σB^2 = inter-specimens variance estimated by calculation = variance between specimens - σE^2/ number of fibers per specimen
J = number of specimens analyzed per coton
K = number of fibers analyzed per specimen

$$\textit{Confidence interval of the mean} = \textit{mean} \pm 1.96\sqrt{\sigma_s^2}$$

The confidence interval of the mean was calculated by:

Work conducted by the CIRAD-CA laboratory on the methodology of measurements with AFIS, as a function of precision sought for the different fiber parameters, was used to draw up data tables. Figures 1 and 2 give examples for length by weight and degree of thickening (from measurements obtained in 73 cottons).

In order to remain consistent with precision results retained by the laboratory for other machines (HVI, fibrograph), a mean length confidence interval of 0.5 mm was chosen as an objective. As shown by figure 1, this degree of precision is obtained by the AFIS L&D processing 5 specimens of 3,000 fibers. This sample size was therefore employed in the study presented here. The precision of the various characteristics evaluated by the AFIS under these sampling conditions is presented in table 2.

As far as fiber neppiness (AFIS-N) is concerned, the neps were counted in five 0.4 g specimens of each cotton.

Results

The main statistical results for the 23 cottons tested in the study are presented in table 3. The evenness of the ring-spun yarns varied from 18.6 to 23.3 %. Expressed over a length of 1 km, the number of thin places varied from 64 to 818, thick places from 576 to 1,426 and neps from 395 to 1,298. Rotor-spun yarns also showed considerable variations between the cottons studied, but with greatly reduced level for evenness and defects. As far as the raw fiber is concerned, mean length by weight varied from 24 to 27.4 mm and UQLw from 28 to 33.8 mm. Theta varied from 0.43 to 0.51 and area from 95 to 118 μ^2. This range of characteristics is a good representation of the *hirsutum* cottons analyzed in the laboratory for breeding programs.

Significant correlation coefficients at a 5% threshold (r > 0.406) between the yarn and the AFIS variables are presented in tables 4 and 5. Correlations for the countings were calculated from data transformed to square-root values. Numerous significant coefficients of correlation are noted. Yarn characteristics taken into account are correlated with numerous AFIS variables, particularly for ring-spun yarns. Fiber length parameters have far less impact for rotor-spun yarns than for ring-spun yarns. Yarn neppiness, unlike hairiness, showed little relationship with fiber parameters measured. No significant correlation could be established between yarn neppiness and that of the raw fiber. This is logical as yarn neppiness is largely governed by the processing of the material during preparation (particularly carding).

None of the fiber parameters measured, and considered individually, was able to provide a satisfactory prediction of any particular yarn characteristic. Several were required in combination to explain these characteristics. Calculations of progressive multiple regressions (risk = 5% at introduction and elimination) gave the following predictive equations :

CV% ring = - 0.1168*Area - 0.837*Lw + 1.848*Dn + 30.73
(r2 = 0.72)
CV % rotor = 0.062*Area + 10.709
(r2 = 0.41)
√Thin places ring = - 3.342*Ln + 5.773*Dn + 15.267
(r2 = 0.74)
√Thin places rotor = 0.463*IFF + 0.314*Area - 27.348
(r2 = 0.61)
√Thick places ring = - 1.985*UQLw - 0.407*FFF - 0.409*MFF + 109.125
(r2 = 0.71)
√Thick places rotor = 1.552*CVTheta - 0.401*FFF - 39.791
(r2 = 0.43)
√Neppiness ring = 0.802*√Neps AFIS - 1.14*CVLn + 64.98
(r2 = 0.44)
√Neppiness rotor /

Hairiness ring = - 0.14*Ln - 0.323*IFF - 0.067*MFF + 13.76
(r2 = 0.84)
Hairiness rotor = - 0.064*IFF - 0.056*n5 + 7.169
(r2 = 0.41)

The coefficients of determination (r^2) are in all cases lower for rotor-spun yarns. Certain characteristics of rotor-spun yarns are therefore difficult to predict from the data provided by the AFIS.

The relationships, in ring-spinning, between the measured values and the values estimated by regression are illustrated in figures 3 to 6.

Conclusion

The study confirmed that fiber maturity and fineness characteristics are involved in explaining yarn evenness and defects, as already suggested by Hunter, 1988.

In many cases, mean parameters such as mean length, mean degree of thickening and mean fineness are insufficient to explain correctly the yarn characteristics. Here, most of the predictive equations involve dispersion parameters (coefficients of variation, immature, mature or fine fiber fraction).

Use of the AFIS fitted with the F&M module, and providing dispersion parameters, can therefore be considered as an interesting tool for prediction of the evenness of ring-spun yarns.

For the rotor-spun yarns and in this study, it is difficult to predict evenness and defect levels from AFIS fiber parameters.

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Table 1 : origin of the 23 cottons used for the study

Geographic zone	Number
Africa	12
U.S.A.	4
South America	1
Central Asia	5
Europe	1

Table 2 : AFIS precisions with 5 spécimens of 3000 fibers

Characteristic	Precision
Mean length by weight	± 0.42 mm
Short fibers content of 10 %	± 0.5 %
Theta	± 0.006
Area	± 1.61

Table 3 : Main statistical parameters for the technological characteristics of the 23 cottons

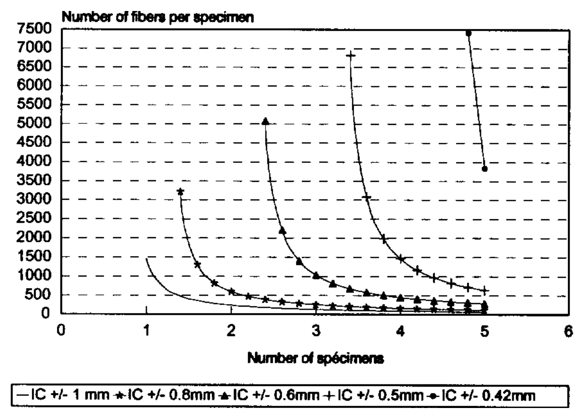
Characteristic	Minimum	Maximum	Mean	Std. Dev.
Ring-spun yarn 20 tex				
Yarn strength (cN)	225.7	316.5	268.8	24.9
Elongation (%)	5.1	7.4	6.0	0.66
Evenness (CV%)	18.6	23.3	20.9	1.29
Thin pl. (1/1000m)	64	818	361	198.7
Thick pl. (1/1000m)	576	1426	961	224.9
Neps (1/1000m)	395	1298	832	285.4
Hairiness	4.49	5.36	4.89	0.29
Rotor-spun yarn 20 tex				
Yarn strength (cN)	160.0	230.4	196.2	17.4
Elongation (%)	5.0	7.6	6.3	0.72
Evenness (CV%)	16.1	18.2	17.2	0.49
Thin pl. (1/1000m)	59	215	106	33.5
Thick pl. (1/1000m)	107	233	165	34.2
Neps (1/1000m)	52	248	146	51.6
Hairiness	4.18	5.07	4.56	0.20
Fiber				
Mean length w (mm)	24.0	27.4	25.8	0.91
CV length w (%)	29.42	35.0	32.0	1.11
Short fibers cont. w (%)	5.60	8.88	7.15	0.91
UQLw (mm)	28.82	33.84	30.98	1.24
Diameter n (μ)	12.0	14.0	13.0	0.52
Theta	0.43	0.51	0.47	0.02
Area (μ^2)	95.2	117.6	105.1	5.14
FFF	4.22	16.18	9.00	2.95
IFF	6.56	11.68	9.80	1.29
MFF	32.34	50.56	40.42	4.58
Neps per g of fiber	119	536	307	94.2
Mean nep size (μ)	795	861	829	16

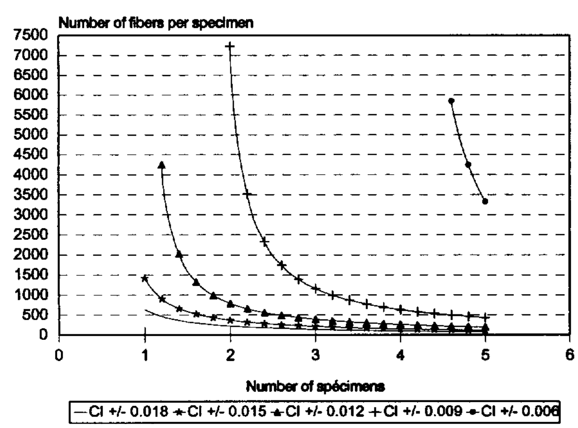
Table 4 : Correlation coefficients between ring-spun yarn 20 tex and AFIS

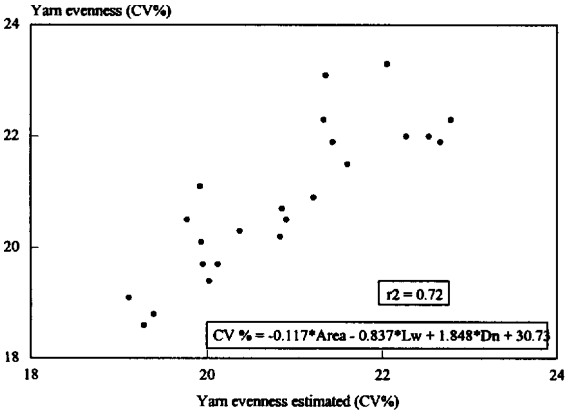
AFIS characteristic	CV%	√thin places	√thick places	√neps	hairiness
Mean length by w	-0.75	-0.72	-0.74		-0.71
CV length w					
Short fibers content w		0.47			0.52
UQLw	-0.71	-0.65	-0.73		-0.61
Mean length by nb (mm)	-0.66	-0.67	-0.61		-0.72
CV length n				-0.46	
Short fibers content n				-0.42	0.47
5%n	-0.72	-0.69	-0.72		-0.66
2.5%n	-0.74	-0.73	-0.70		-0.72
1%n	-0.74	-0.81	-0.64		-0.83
Diameter	0.58	0.70	0.45		0.62
Theta					
CV theta	-0.55	-0.66		0.49	-0.70
IFF					-0.57
Area		0.47			0.55
CV Area	-0.50	-0.54			-0.50
FFF	-0.52	-0.55	-0.42		-0.52
Micronafis					0.43
MFF					
MR					
PM %					
Fineness H		0.47			0.55
√ neppiness					
Mean nep size					

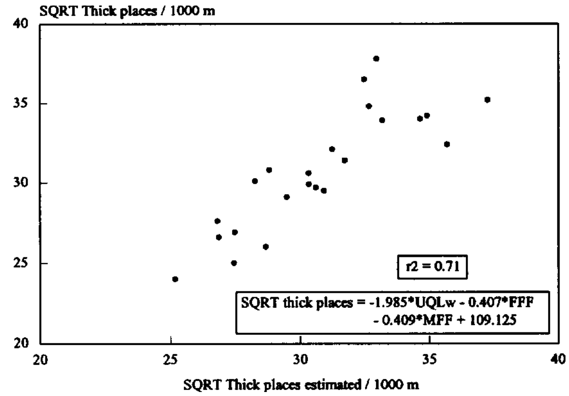
Table 5 : Correlation coefficients between rotor-spun yarn 20 tex and AFIS

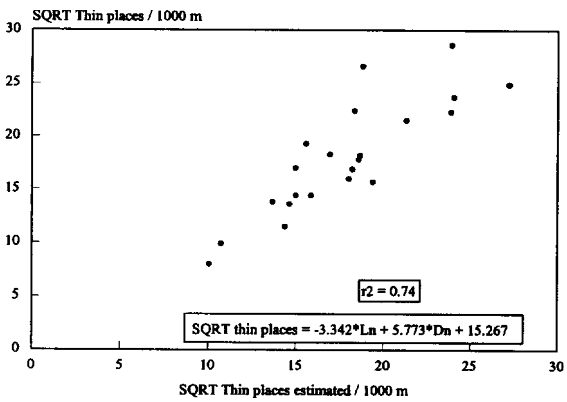
AFIS characteristic	CV%	√thin places	√thick places	√neps	hairiness
Mean length by w					-0.45
CV length w	-0.52	-0.50	-0.56		
Short fibers content w			-0.54		
UQLw					-0.48
Mean length by nb (mm)					
CV length n			-0.53		
Short fibers content n			-0.55		
5%n					-0.51
2.5%n					-0.50
1%n	-0.45			0.45	
Diameter	0.65	0.66			
Theta					0.46
CV theta		-0.45			
IFF		-0.42			-0.53
Area	0.64	0.74			
CV Area	-0.60	-0.63			
FFF	-0.65	-0.66			
Micronafis	0.47	0.54			0.44
MFF					0.45
MR					0.49
PM %					0.48
Fineness H	0.64	0.74			
√ neppiness					
Mean nep size					

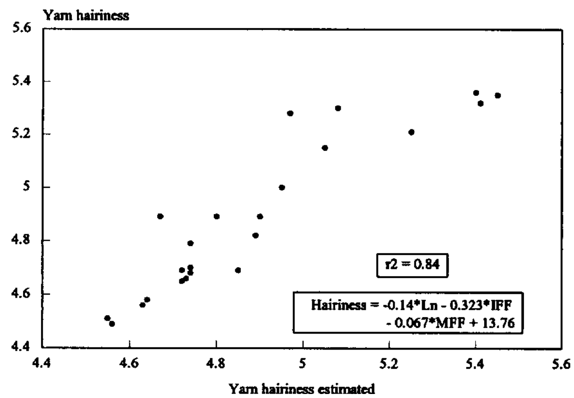





Yarn evenness (CV%)
r2 = 0.72
CV % = -0.117*Area - 0.837*Lw + 1.848*Dn + 30.73
Yarn evenness estimated (CV%)


SQRT Thick places / 1000 m
r2 = 0.71
SQRT thick places = -1.985*UQLw - 0.407*FFF - 0.409*MFF + 109.125
SQRT Thick places estimated / 1000 m


SQRT Thin places / 1000 m
r2 = 0.74
SQRT thin places = -3.342*Ln + 5.773*Dn + 15.267
SQRT Thin places estimated / 1000 m


Yarn hairiness
r2 = 0.84
Hairiness = -0.14*Ln - 0.323*IFF - 0.067*MFF + 13.76
Yarn hairiness estimated