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Sharing current research information and trends in the fiber and textile industries.

International Textile Center
Texas Tech University
Lubbock, Texas
79409 - 5019
phone 806.747. 3790
fax 806.747. 3796
itc@ttu.edu
http://www.itc.ttu.edu

STUDENTS COMPLETE FALL 2004 COTTON SCHOOL

Ten students from around the world recently completed the Fall 2004 course of the Texas International Cotton School. Attending students gained a better understanding of U.S. cotton production, processing, testing techniques, and marketing systems. Students were also able to experience the warm hospitality and culture of West Texas.

Since October 1989, the Texas International Cotton School has graduated 24 classes bringing the total attendance to 385 graduates since its inception. These graduates have come from more than 52 countries from around the world as well as 16 states across the United States.

Pictured are: (L-R Top Row) Subhasis Sukhenchandra Basu, Mafatlal Burlington Industries, Ltd., India; Francisco Agudelo, Diagonal, Colombia; Scott Irlbeck, Cotton School Coordinator; James Langley, Texas Department of Criminal Justice, Texas; Amit Patel, Sintex Industries, Ltd., India; Manuel Tenorio, Creditex, Peru.
(L-R Bottom Row) Iftekhar Ahmed Farrukh, Al-Karam Textile Mills, Ltd., Pakistan; Dominique Kpolo, Areca, Ivory Coast; Christy Lewis, Southwestern Irrigated Cotton Growers, Texas; Judy Teeas, Cotton School Coordinator; Paulino Escobar, Creditex, Peru; Rajasekaran Ramdas, Super Spinning Mills, Ltd., India.

The school accepts students for spring and fall sessions. To learn more about the two-week school, including dates of upcoming sessions, tuition expenses and curriculum, visit the official school website: www.texasintlcottonschool.com.

The Texas International Cotton School is a cooperative effort between the Lubbock Cotton Exchange and the International Textile Center.

EXCHANGE AGREEMENT ANNOUNCED

The International Textile Center has signed a formal Memorandum of Agreement with the Universite de Haute-Alsace in Mulhouse, France. It enables the exchange of students and research faculty between the two institutions. The first student is planned to arrive at the ITC in January and will conduct research leading to the Ph.D. degree.

A Qualitative Approach to Estimating Cotton Spinnability Limits

Mourad Krifa and M. Dean Ethridge

Adapted with permission from article originally published in the Textile Research Journal ***74****(7), 611-616 (2004).*
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INTRODUCTION

The spinnability limit, or spinning potential yarn number, of cotton fibers with given properties refers to the finest count (i.e., smallest diameter) yarn that can be produced below a tolerance threshold of yarn breakage. As a practical matter, this threshold depends on manufacturer expectations and production conditions.

Traditionally, this limit is determined by spinning a series of yarns with increasingly finer counts under constant spinning conditions (spindle speed, twist factor, etc.), while monitoring the end-breakage (or "ends-down") rate [1, 2, 9, 10, 14].

Given the low frequency of the occurrence of yarn ends-down when spinning under normal conditions, it is necessary to run long tests in order to obtain an accurate assessment of the cotton spinning performance. Early efforts to investigate the accuracy of spinning performance assessment were reported by Ruby and Parsons [10]. The authors suggested a minimum number of 5,000 spindle hours to achieve acceptable accuracy under controlled testing conditions. The ASTM standard method D2811-77 [1] describes four different options for running the test, with the number of spindle hours ranging from 84 (small laboratory scale) to 25,000 (mill scale). The laboratory scale procedure (84 spindle hours) is presented as a rough screening method.

Through several decades, different approaches to determining cotton spinnability were proposed as alternatives to the long tests described above. One approach was to use accelerated tests by increasing the yarn tension or reducing its twist during the spinning trials. Data from such tests were criticized as being hard to relate to the actual spinning conditions due to the multiple interactions between machine and fiber parameters [4].

Another approach was the measurement of the "spinning end strength", which was defined as the maximum stress sustained by the yarn during the end-breakage sequence [4, 12]. The researchers developed an automatic apparatus mounted on a ring-spinning tester to measure the spinning end strength by stressing the yarn to the breaking point, while recording its tension. According to the authors, a high spinning end strength with a low variability is an indicator of the suitability of a given cotton to be processed into fine yarns.

Using the neural network technique, Pynckels et al. [9] proposed a model for predicting the spinnabilty of fibers based on their properties and on the spinning machine parameters. The experimental procedure used to train the neural network was based on the traditional principle of assessing yarn ends-down when spinning increasingly finer yarns.

More recently, Zhu and Ethridge [14] developed a method for estimating the cotton spinning potential on the open-end rotor spinning system. The procedure was based on empirically determining the minimum twist needed to successfully spin yarn. A formula was provided to estimate the Spinning Potential Yarn (SPY) number. The yarn size was held fixed in order to limit the fiber/machine interactions.

All the spinnability assessment methods described above rely on the number of ends-down as the only criterion defining the spinning potential. No reference to the produced yarn quality and to its relationship with the spinning performance was encountered in the literature. Yet, it appears obvious that the spinning potential concept should capture both (i) the suitability of a given fiber to be spun with few ends-down and (ii) its potential to yield a yarn with acceptable quality levels.

This paper advances an approach to determining spinning limits that relies on yarn quality criteria, rather than relying solely on the end-breakage rate. A primary motivation for this approach is that quality criteria are obtainable with sufficient accuracy after relatively short spinning tests, relative to the end-breakage criterion.

Logically, the quality criterion may be done in conjunction with an ends-down criterion. As a practical matter, however, it is likely that the quality criterion would be more constraining than the existing ends-down criterion. To the extent that the quality criterion is more limiting, it could become a de facto replacement for the ends-down criterion.

Among the important yarn quality criteria, the number of thin places stands out for two reasons:

1. As successively finer-count yarns are ring-spun, the number of thin places is typically the most sensitive of the yarn defects.
2. Thin places are among the most quality- and process-disrupting yarn faults [8, 13].

Therefore, the number of thin places is used as the surrogate quality variable for determining the spinning potential of alternative cotton fibers. The decision criterion applied to this quality indicator is the main subject of this paper.

PROCEDURES

A sample of nine upland cotton bales with different levels of length and Micronaire was selected for this study. Each bale was sampled at 10 layers throughout, with fiber measurements being done on each layer. The main HVI (High Volume Instrument, 4 replications for Micronaire, 4 for color, and 10 for length and strength) and AFIS® (Advanced Fiber Information System, 3 replications of 3000 fibers each) fiber properties of the selected bales are reported in Table I. The fiber length (Upper Half Mean Length: UHML) ranged from 25.1 mm to 28.4 mm and the Micronaire from 3.8 to 4.6.

A wide series of yarn counts was spun on a Suessen Fiomax 1000 ring spinning frame from the same lot of roving for each sample. The tests were started at initial coarse yarn counts of 37 tex (16 Ne), 33 tex (18 Ne) and 27 tex (22 Ne), depending on the fiber length. Each sample was spun into gradually finer yarn (by increasing the English cotton count in increments of 2 units) until the yarn was too fine to be processed (excessive ends-down). For each count, the test was run until a sufficient yarn length was produced for evenness and single-end strength tests on Zellweger UT3 (4000 m per sample) and Tensorapid (100 breaks per sample), respectively. All samples could be run simultaneously, each on ten spindles. The tested yarn quality parameters were averaged over the ten bobbins.

Since the lengths of the selected cottons were relatively short (Table I), no combing was done. The preparatory process (opening-cleaning, carding, drawing, roving) was conducted under similar conditions for all the tested samples. Finisher drawing sliver samples were collected and tested on the Uster AFIS® for individual fiber properties measurements (see Table II).
All spinning parameters other than yarn count were kept constant (spindle speed, twist, travelers relative weight, etc.).

RESULTS

As expected, most of yarn quality parameters were highly correlated with yarn count. These relationships are well known and we shall not provide detailed description at this point.

While several of these relationships were non-linear, the curvilinear fit between thin places and yarn count was especially noteworthy. This is made clear by the scatter plot in Figure 1, which treats all 9 bales (represented by different point markers).

Table I: Main Fiber Properties of the Tested Bales (HVI and AFIS on Raw Fiber)

	Property \ Bale ID	1	2	3	4	5	6	7	8	9	Min.	Max.
HVI	*Micronaire*	3.8	4.2	4.6	3.8	4.1	4.6	4.1	3.8	4.6	3.8	4.6
	UHML (mm)	25.4	25.7	25.1	26.7	26.9	26.9	28.2	27.7	28.4	25.1	28.4
	Uniformity (%)	81.5	81.6	81.8	82	82.2	81.1	82.2	82.1	82.9	81.1	82.9
	Strength (g/tex)	28.5	26.8	24.4	28.1	28.7	28.0	29.0	32.2	30.0	24.4	32.2
	Elongation (%)	6.0	5.9	6.2	6.3	6.4	6.0	6.5	6.3	6.0	5.9	6.5
AFIS	*Ln (mm)*[1]	18.5	18.6	17.6	19.5	19.5	18.6	19.7	19.1	20.5	17.6	20.5
	SFCn (%)[2]	24.5	23.8	28.3	23.5	24.0	26.6	24.9	26.7	23.4	23.4	28.3
	Lw (mm)[3]	22.0	22.1	21.4	23.4	23.5	22.7	24.1	23.5	25.0	21.4	25.0
	SFCw (%)[4]	10.3	9.9	11.3	8.9	9.0	10.6	9.2	10.2	7.8	7.8	11.3
	UQL (mm)[5]	26.4	26.4	25.6	28.1	28.2	27.6	29.3	28.6	30.0	25.6	30.0
	Maturity Ratio	0.87	0.88	0.88	0.89	0.91	0.92	0.91	0.88	0.93	0.87	0.93
	Fineness (H [mtex])	165	167	172	169	174	173	168	158	172	158	174
	Standard Fineness (Hs [mtex])	189	190	195	189	191	189	185	180	186	180	195

[1]Mean length by number, [2] Short Fiber Content by number, [3] Mean length by weight, [4] Short Fiber Content by weight, [5] Upper Quartile Length by weight.

Table II: AFIS Measurement of Fiber Properties on Finisher Drawing Sliver

Property \ Bale ID	1	2	3	4	5	6	7	8	9	Min.	Max.
Ln (mm)	17.0	17.3	18.3	17.5	17.3	18.5	18.0	18.8	19.8	17.0	19.8
SFCn (%)	30.8	29.8	25.3	31.0	31.7	26.2	30.7	26.9	24.3	24.3	31.7
Lw (mm)	21.1	21.1	21.8	22.1	22.1	22.6	23.1	23.4	24.6	21.1	24.6
SFCw (%)	13.1	12.6	9.9	12.3	12.5	10.0	11.7	10.1	8.1	8.1	13.1
UQL (mm)	25.7	25.9	26.2	27.2	27.2	27.4	28.7	28.4	29.7	25.7	29.7
MR	0.87	0.89	0.96	0.89	0.89	0.95	0.90	0.92	0.95	0.87	0.96
H (mtex)	172	178	192	173	176	184	175	172	185	172	192
Hs (mtex)	198	200	200	194	198	194	194	187	195	187	200

Note that, in order to adequately represent the execution of the spinning trials (from coarse to fine yarn) and to emphasize the increasing nature of thin places with yarn fineness, the primary abscissas axis of Figure 1 (yarn count in tex) is reported in reversed scale. For indicative purposes, a secondary axis with the cotton count units (Ne) is also reported.

The same representation will be used for all subsequent figures having the yarn count in the abscissas axis.

Two conclusions are apparent from Figure 1:

- The finer the yarn, the larger the number of thin places; this is a well-known result.
- As the yarn counts get finer, the number of thin places increases at an increasing rate.

While the shapes of the curves differed for each cotton bale, in all cases the sensitivity of thin places was relatively low (i.e., low slope, low variation rate) for the coarser yarn counts. For finer yarns, the number of thin places increases more rapidly with yarn fineness. The overall observed trend resembles an exponential growth pattern.

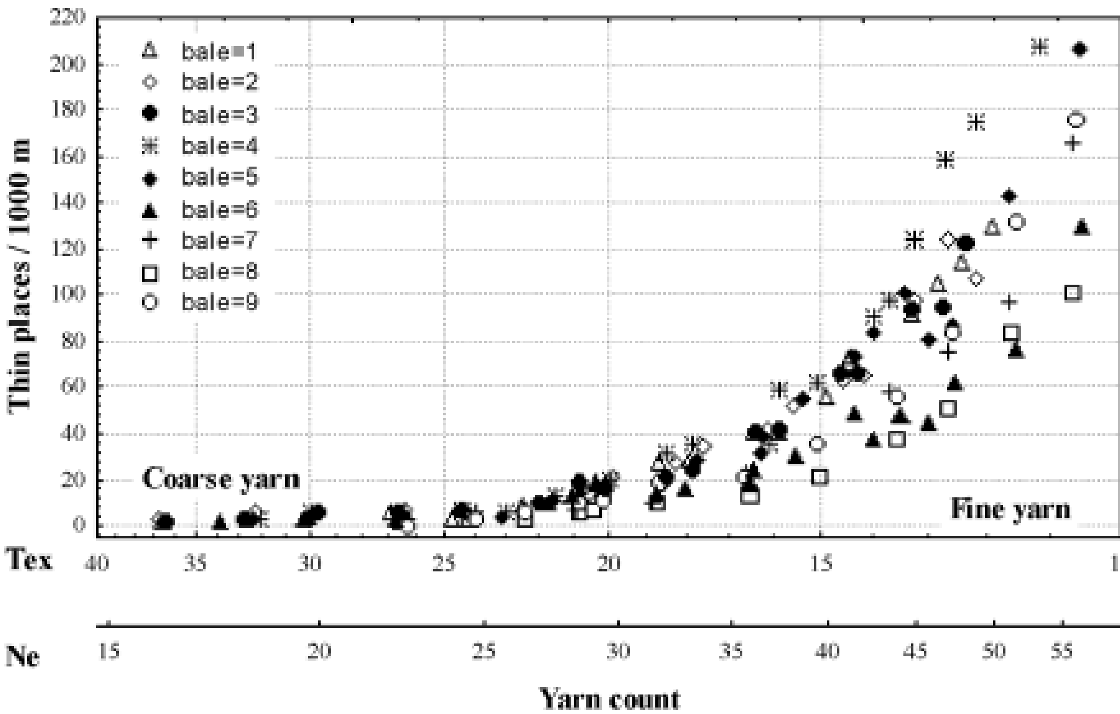

Figure 1: Thin Places vs. Yarn Count

Given the dependence between the response-variable mean and variance (characteristic of counting data following a Poisson distribution) and the nonlinear pattern shown in Figure 1, it is appropriate to model the relationship between yarn fineness and the number of thin places using a log-linear Poisson regression (i.e., a Generalized Linear Model with a Poisson-distributed response variable and the logarithm as link function, [3, 7]). This would model the logarithm of the expected response (Y = thin places) as a linear function of the independent variable (X = yarn count):

$$\log E(Y) = \alpha + \beta X \qquad (1)$$

The response expectation could then be expressed as:

$$E(Y) = e^{(\alpha + \beta X)} \qquad (2)$$

Which is a non-linear function both in the variable and the parameters, reflecting the exponential pattern shown above.

A log-linear Poisson model was built based on two predictors: the cotton bale as a categorical factor and the yarn fineness as a continuous covariate (expressed in tex). The analysis was treated as a separate slope model and estimates of the α and β parameters were obtained within each cotton. It is to be noted that a slight over-dispersion (1.4) with reference to the Poisson distribution was observed and taken into account in the analysis.
Figure 2 shows the model-predicted values plotted against the observed thin places counts.

The plot of the predicted values against the observed ones (Figure 2) shows a slight curvature. The log-linear model tends to fit the data well towards the upper end of the curve. On the lower end, however, the predicted values appear to stray from the observed ones, suggesting the existence of a different pattern describing the relationship between yarn count and the number of thin places.

This may be explained by the fact that in the coarser yarns range, the curve relating the number of thin places to the yarn fineness (Figure 1) appears to form a linear segment with an almost-constant low thin places count, rather than the tail of the exponential function expressed by the model (Equation 2). The linear segment of the curve represents a spinning range where the number of thin places can be limited to a low level.

Based on this pattern, it is intuitive that an adequate yarn quality cannot be obtained with any cotton fiber if it is spun beyond this linear segment. Past this zone, not only does the number of thin places increase abruptly, but its variance also increases and strays considerably from the Poisson distribution, showing high levels of over-dispersion for the finer yarn counts (see Figure 3 for an illustration).

Thin places are among the most quality- and process-disrupting yarn faults [8, 13]. They provide a sensitive indicator of yarn quality. In addition to being detrimental to the yarn and fabric aspects, thin places are related to the mechanical performance of the yarn, including the number of end breaks occurring in spinning and in further processing.

Therefore, the number of thin places appears to be an adequate quality constraint to be used in order to determine the spinnability or the spinning potential of the bales tested. The key indicator, however, is not the absolute number of thin places. Rather, it is the point at which the slope changes enough to signal that spinning limits are reached. This point occurs when the "low slope" (i.e., linear zone with low level of thin places) line ceases to describe the spinning performance.

ESTIMATING THE SPINNABILITY LIMIT

In order to estimate the spinnability limit as defined above, a breakpoint is to be located between the linear and curvilinear zones of the relationship between thin places and yarn counts. This may be done using "segmented" or "piecewise" regression methodology, which fits sub-models (phase models or regimes) describing the behavior of the expected response variable over different intervals of the independent variable [6, 11]. In addition to the sub-models' parameters, the abscissa of the join-point or breakpoint between the two regimes is unknown and must be estimated. This join-point, where the slope changes between the two regimes, is used to establish the spinning limits of the fibers being evaluated.

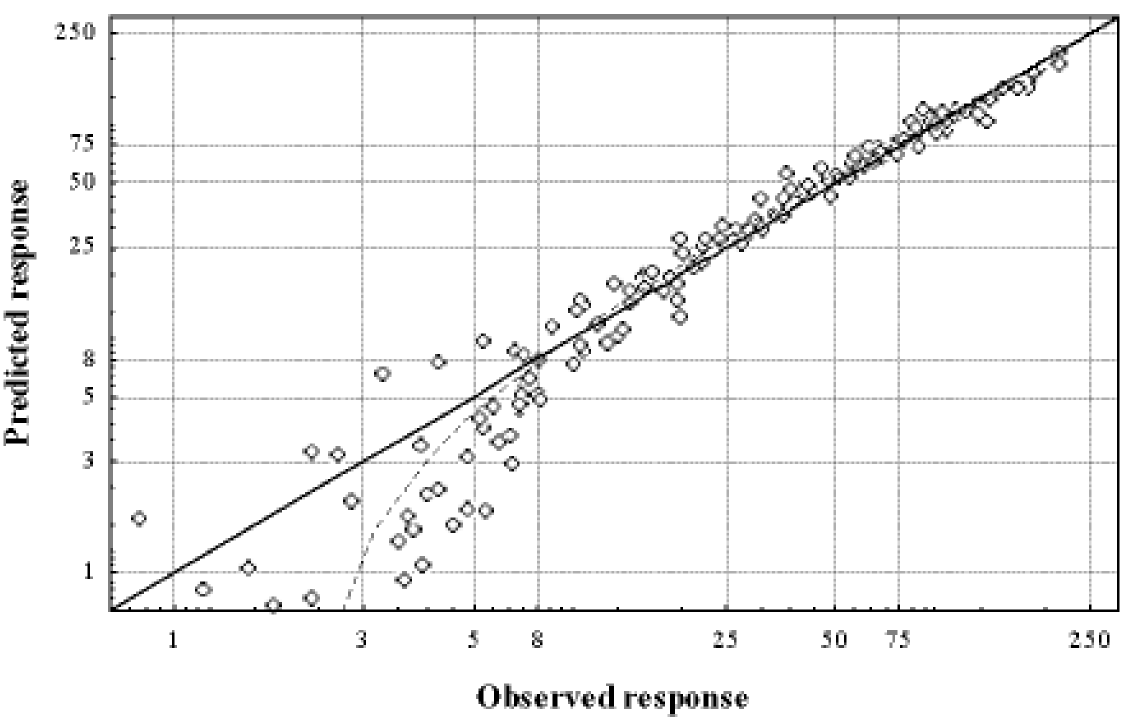

Figure 2: Log-linear Poisson Regression, Predicted vs. Observed thin place Numbers

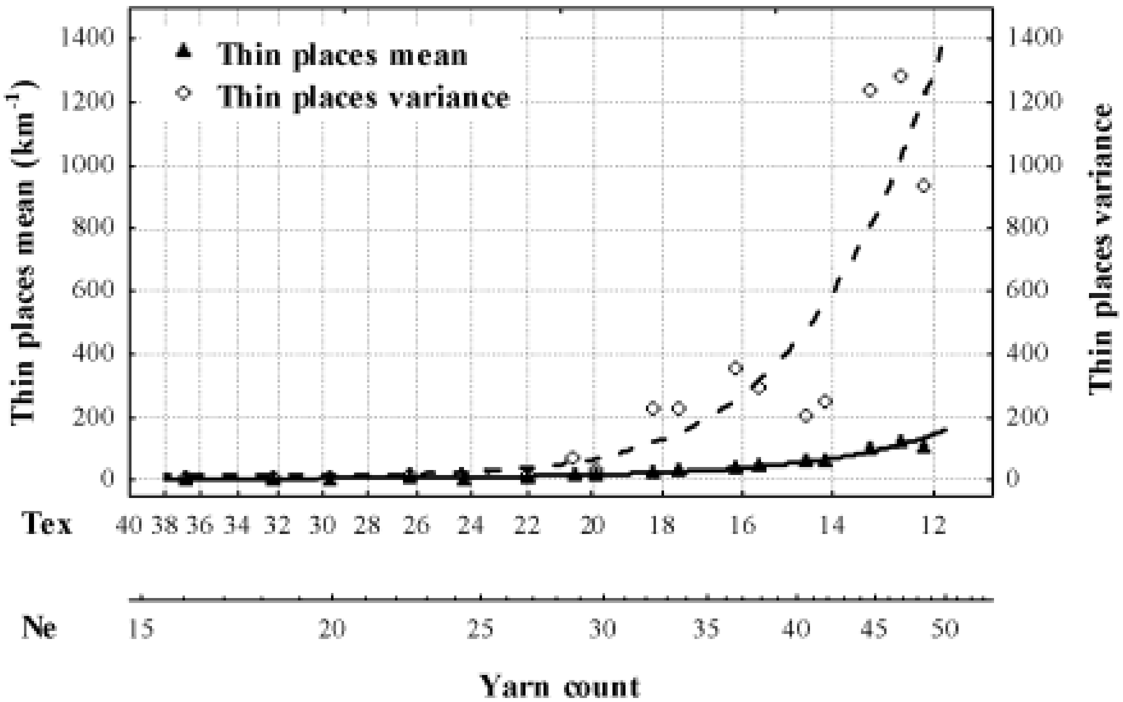

Figure 3: Thin Places Mean and Variance Increase with Yarn Fineness

All statistical analyses were done using the "nonlinear estimation" facility in Statistica (Statsoft, Inc.). This allows the sub-models to be fitted to the data using iterative algorithms to minimize the loss function and thus find the best statistical fit.

After evaluation of several linear-curvilinear segmented models, the choice was made to retain a continuous linear-quadratic model of the form:

$$E(Y) = a + b\,X + \left[c\left(x_b - X\right)^2\right]\phi \qquad (3)$$

where: E(Y) = expected value of thin places,
X = yarn count (tex),
a, b and c = regression parameters,
x_b= join-point between the two lines,

$$\phi = \begin{cases} 0 & \text{if } X \geq x_b \\ 1 & \text{if } X < x_b \end{cases}$$

Equation 3 constrains the curves of the two sub-models to be equal at x_b, which is expected to be the case if one could dispose of sufficient data points to obtain a full resolution of the zone of change of regime. Moreover, the continuity-constrained model converged to a consistent solution regardless of start-values used in the iterative regressions.

Figure 4 depicts the model fit obtained for bale n^o 1. The spinnability limit (spinning potential yarn numbers), as estimated by the join-point between the linear and quadratic segments of the model, is 23.16 tex. Curves plotted for the other bales have a similar shape, but with differing spinning potential yarn numbers. Detailed parameter estimates for each bale, along with the proportion of variance explained by the regression model, are summarized in Table III.

The results show that the linear-quadratic model fitted the experimental data quite well for all the tested bales, with a proportion of variance explained ranging from 94.5 to 99.57 % (Table III). The estimated spinnability limits varied from one cotton bale to another and ranged from 16.47 tex to 23.16 tex.

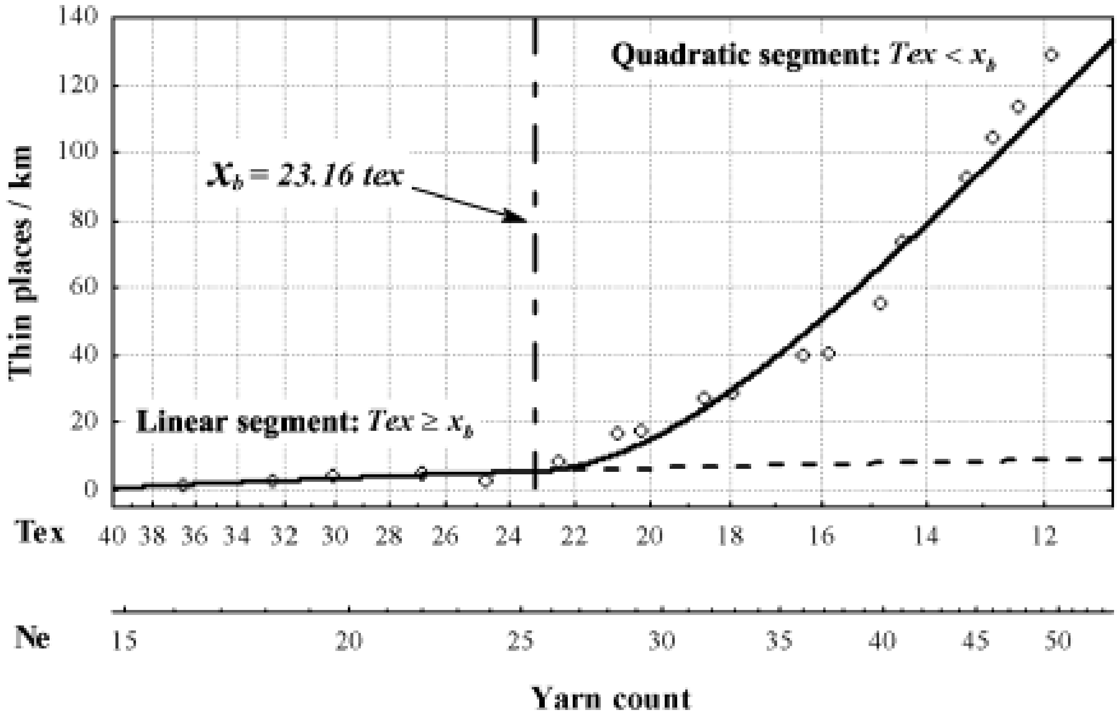

Figure 4: Continuous Linear-Quadratic Model (bale nº 1)

Table III: Parameters Estimates and Proportion of Variance Explained by the Continuous Linear Quadratic Model

Bale	*a*	*b*	*c*	x_b *(tex)*	R^2
1	12.507	-0.300	0.838	**23.16**	97.81
2	20.240	-0.501	0.905	**22.42**	96.78
3	26.918	-0.707	1.425	**20.43**	98.78
4	29.099	-0.829	2.502	**19.70**	98.04
5	19.652	-0.520	1.579	**20.42**	94.50
6	30.710	-0.897	1.597	**17.84**	94.72
7	29.984	-1.006	2.223	**18.04**	96.42
8	22.892	-0.844	1.891	**17.42**	99.23
9	50.467	-1.920	4.101	**16.47**	99.57

The variation among the bales is most likely related to the intrinsic fiber properties distinctive of each cotton. Table IV gives the correlation coefficients between estimated spinning potential yarn numbers and (i) selected HVI measurements on raw cotton, (ii) AFIS measurements on raw cotton, and (iii) AFIS measurements on cotton from the finisher drawing sliver. Significant relationships are apparent throughout the table, with the highest correlations occurring for the sliver. The higher correlations with sliver fibers are expected, due to changes in fiber length

Table IV: Correlation Between Fiber Properties (HVI & AFIS) and the Estimated Spinnability Limits

	Fiber Properties	*Correlation Coefficient*
HVI (Raw fiber)	Mic.	-0.35 ns
	UHML (mm)	-0.87 **
	Uniformity (%)	-0.49 ns
AFIS (Raw fiber)	Ln (mm)	-0.55 ns
	SFCn (%)	-0.14 ns
	Lw (mm)	-0.75 *
	SFCw (%)	0.38 ns
	UQL (mm)	-0.79 *
	MR	-0.63 ns
	H (mtex)	-0.03 ns
	Hs (mtex)	0.61 ns
AFIS (Sliver)	Ln (mm)	-0.87 **
	SFCn (%)	0.57 ns
	Lw (mm)	-0.94 ***
	SFCw (%)	0.78 *
	UQL (mm)	-0.93 ***
	MR	-0.63 ns
	H (mtex)	-0.21 ns
	Hs (mtex)	0.70 *

ns: non-significant, *: significant at α=0.05,
: significant at α=0.01, *: significant at α=0.001.

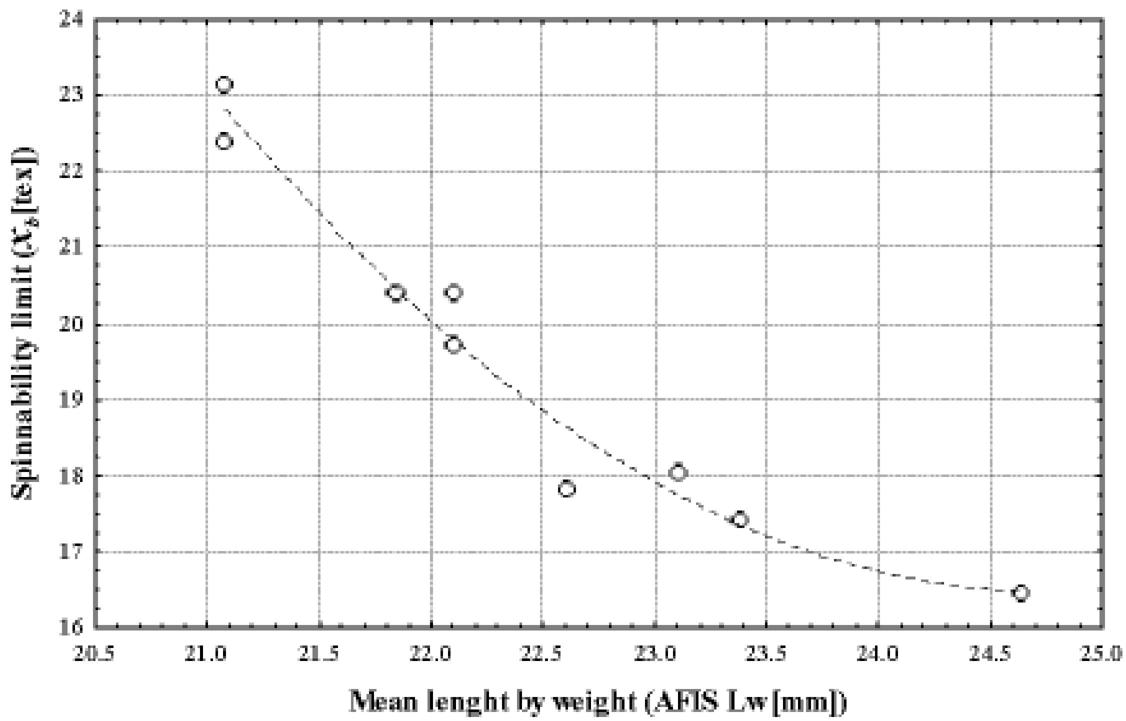

Figure 5: Relationship Between the Fiber mean Length (AFIS Lw[mm])

distribution during processing (e.g., fiber breakage). However, impacts on AFIS measurement results of different sample preparations (unorganized fibers versus organized slivers) may also be a factor.

The mean length and the upper quartile mean length by weight (Lw and UQLw) appear to have the best correlations with the spinnability limit parameter for the present range of cottons. The Short Fiber Content by weight (SFCw) and the standard fineness (Hs) show significant correlations when considering the sliver results.

As expected, these relationships show that longer and finer fibers are more suitable for spinning finer yarns than are short and coarse ones. It should be noted that the standard fineness (Hs [mtex]) – which is closely related to the fiber perimeter [5] – is significantly correlated with fiber spinning potential. However, the fineness parameter (H [mtex]) did not show any significant relationship with the spinnability limit.

The relationship between the spinnability limit and the fiber mean length by weight (lw) is plotted in Figure 5. The relationship appears to be curvilinear, which is consistent with the necessity for the spinnability limit to be asymptotic to the abscissas axis. However, both the limited number of observations and limited range of fiber lengths used in the study constrain conclusions about the exact shape of the curve. The use of longer fibers would allow description of the lower end of the curve in Figure 5, while a resort to combing of the fibers would be expected to shift the curve downward from that shown in Figure 5. These issues should be the subject of further investigation.

CONCLUSION

This study indicates that a useful determination of the spinnability limit, or spinning potential yarn number of a cotton fiber with given properties, can be made with substantially shorter spinning tests by using the number of thin places as the primary criterion.

The examination of the relationship between thin places and ring spun-yarn fineness led to the hypothesis that it can be satisfactorily described by two different regimes on distinct ranges of yarn count: (i) a linear segment where the number of thin places increases slowly as the yarn gets finer, and (ii) a curvilinear segment where the thin places increase at an increasing rate with yarn fineness. The spinning potential yarn number was estimated by the join-point or the breakpoint between the two regimes.

Application of the model to cottons with different fiber properties demonstrated that the resulting values of spinning potential yarn number were dependent on fiber properties and showed significant correlations with fiber length, short fiber content, and standard fineness.

Since the quality criterion is likely to be more constraining than the ends-down criterion, critical aspects of both spinning performance and yarn quality are captured in the spinnabilty determination. Therefore, this approach has a claim to superiority over the traditional methods that rely solely on ends-down, and appears more relevant for a decision-making in the spinning mill.

Further experimentation is needed to extend the results obtained here to a wider range of fiber properties, as well as to other spinning processes such as the combing.

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