COTTONSPEC – A COTTON FIBER AND YARN QUALITY MANAGEMENT TOOL

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Abstract

A cotton fiber and yarn quality management software package that aims to predict yarn property from measured fiber quality parameters is introduced. The package, called Cottonspec, has been developed at CSIRO utilizing an industrial spinning database and theoretical modeling. The package can be used by spinners to select the most suitable cottons, which best meet the spinner's needs, or as a quality control tool to benchmark performance against "best commercial practice". Cottonspec can also be used as a trading tool for merchants to promote the value of a particular growth, or used by cotton researchers and grower collectives to assess and promote new cotton varieties. The role of cotton fiber properties on yarn properties, including length, short fiber content (SFC), tenacity and elongation, linear density, maturity and nep count are reviewed. The software package allows an optimum raw material price to be achieved while meeting a yarn customer's needs. The current status and operation of this computer program is described and its ability to predict yarn quality is demonstrated. Currently, Cottonspec is undergoing mill validation trials

Introduction

Choosing the right cotton in preparation of a laydown, which allows an optimum raw material price to be achieved while meeting the needs of a yarn customer, is of great economic importance to spinners. To help spinners achieve this goal CSIRO has introduced a cotton fiber and yarn quality management software package, Cottonspec, which aims to predict what a good modern mill can expect using a particular quality cotton for a given yarn under the specified spinning conditions. The package has been developed utilizing an industrial spinning database and employing theoretical modeling. Cottonspec is a user friendly software package that enables spinners to better predict the performance of cotton fiber. It is a powerful and necessary tool for mill quality control that enables ongoing yarn quality improvement and a reduction in error margins on raw material costs and predicted performance. Cottonspec can also be used as a marketing tool by merchants to promote the value of a particular growth, or used by cotton researchers and growers collectively to promote new cotton varieties.

Cottonspec is a computer software package that requires input parameters of cotton fiber properties, yarn parameters and limited processing information. Cottonspec predicts yarn evenness, thin and thick places, tenacity, elongation and spinning ends-down. The working principle of Cottonspec is illustrated schematically in Figure 1.

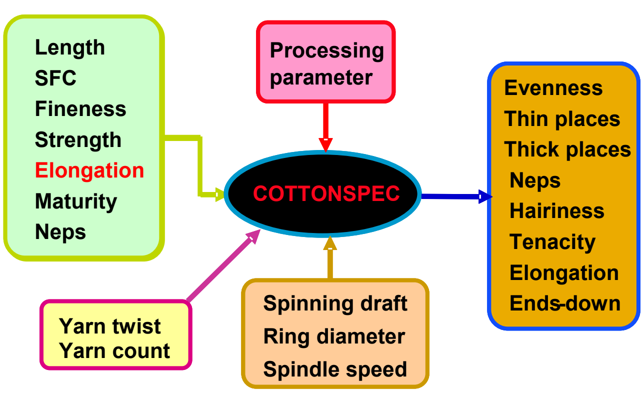

Figure 1. Cottonspec cotton spinning prediction software package

This paper briefly describes some of the concepts of Cottonspec including the basis of the spinning prediction models, results from spinning trials to date, the roles of fiber properties in spinning and the ranking of their relative importance to yarn quality, and the testing of the software package. Cottonspec is now undergoing mill validation trials.

Best Commercial Practice

Yarn evenness is limited primarily by the average number of fibers in the yarn cross-section, because the likelihood of having a given number of fibers present is governed by the statistics of random processes (Martindale 1945). This is acknowledged by the introduction of the term Index of Irregularity (I), which is the ratio of the measured evenness to the random limit. All spinners run up against the same statistical limit which, for a given yarn count, is determined by fiber fineness (linear density). How close the yarn evenness value gets to this limit is principally determined by the quality of drafting on the spinning frame. This can depend on the properties of input materials, for example cotton with high short fiber content (SFC) will have poor Index of Irregularity of both roving and yarn. The evenness of yarns approaches but never reaches the random limit, an Index of Irregularity of one. Yarn evenness, in turn, is a major factor in determining yarn strength as it influences the likelihood of thin or weak places. Yarn strength (tenacity) also depends on twist and fiber properties, notably strength, length and fineness.

There does not seem to be any great differences in the quality of yarn produced on different modern spinning frames. We have noted excellent quality, fine count yarn produced on spinning frames ranging in origin and age. We conclude therefore that the expected yarn quality is predominantly affected by the quality of the cotton used to spin the yarn. Herein is the concept of "best commercial practice". It assumes the drafting system settings on the spinning frame are optimized and that the machines used from opening through to spinning are well maintained. For a given yarn count and twist, the yarn properties and spinning performance of a "good" mill are essentially determined by the fiber properties.

Spinning Prediction Models

Cottonspec is a spinning prediction package that combines theoretical modeling with experimental/spinning trial information to predict yarn evenness, thin and thick places, yarn neps, yarn tenacity (strength) and elongation, and spinning ends-down.

The model is built on three main components: yarn evenness, yarn tenacity and spinning ends-down. Yarn evenness is fundamental as it affects both yarn tenacity and spinning performance. Yarn tenacity is mainly determined by yarn evenness with the yarn's intrinsic strength determined by twist, and the fiber properties of length, linear density, tenacity and elongation.

Yarn Evenness

From the drafting theory of Grishin (1945), measured yarn unevenness consists of three components; (1) roving unevenness, or input unevenness; (2) ideal unevenness and (3) non-ideal unevenness. A yarn evenness prediction model based on Grishin's theory is illustrated schematically in Figure 2. Roving unevenness is primarily determined by cotton fiber properties and the quality of the drawing steps prior to roving. The ideal unevenness is governed by the random distribution of fiber in the yarn cross-section, which is determined by the number of fibers, which in turn is determined by yarn count and fiber linear density as well as variations in fiber linear density (Martindale 1945). The non-ideal unevenness is additional unevenness in spinning caused by the non-ideal drafting of floating fibers in the draft zone. The size of this component is determined by fiber length, SFC, length variability and fiber crimp. Yarn twist, machine settings, e.g. ratch distances, draft and machine maintenance, also play a part. Experiments have shown that the yarn ideal unevenness is the major component of yarn unevenness, accounting for about three quarters of total yarn unevenness, confirming the important role of fiber linear density in determining yarn unevenness. Fiber length and its variability also contribute to yarn unevenness mainly through the non-ideal component and to some extent on roving unevenness.

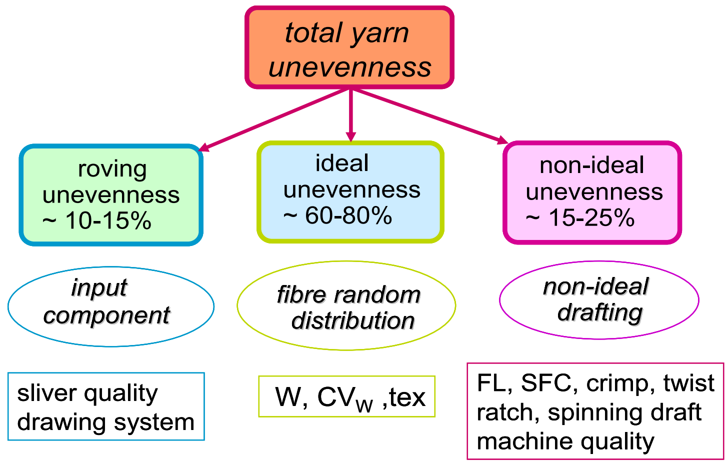

Figure 2. Yarn evenness prediction model

Yarn Tenacity

The yarn tenacity prediction model is illustrated schematically in Figure 3. Yarn mechanics theory shows that yarn strength or tenacity is determined by yarn evenness through the weak-link theory (Spencer-Smith 1947), which states that yarn tenacity is inversely proportional to the number of thin places, or the mass evenness, along a length of yarn. Yarn tenacity is also affected directly by fiber properties notably tenacity and elongation, but also length, SFC, linear density and inter-fiber friction, which determine the coherence force applied by the yarn twist. Theory and experiments show that yarn tenacity increases proportionally with fiber bundle tenacity (Hearle 1969). Doubling fiber tenacity doubles yarn tenacity. The coherence force between fibers in a helical yarn structure is determined by the combination of length, SFC, linear density, fiber surface properties and yarn twist (Hearle 1969). Theory and experiments also show that fiber elongation is the single most important fiber property affecting yarn elongation and the second most important property affecting yarn tenacity (William et al. 1966, Louis et al. 1961, Virgin et al. 1966). Using algorithms based on these models, very good predictions of yarn evenness and tenacity are realized, as well as the prediction of other yarn properties such as yarn imperfections and spinning ends-down.

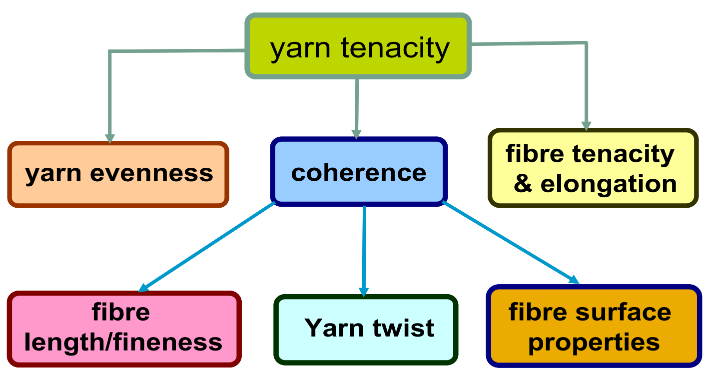

Figure 3. Yarn tenacity prediction model

The Role of Cotton Fiber Properties

The role of cotton fiber properties in spinning can be explained using the spinning prediction models. The relative importance of these properties can be established based on the theoretical modeling work described above and utilizing industrial spinning data collected from commercial partner mills. A summary is presented below.

Fiber Length

Amongst natural staple fibers, cotton is at the shorter end of the fiber length spectrum. Indeed, cotton approaches the minimum length of fiber able to be processed on modern draw and spinning frames and a premium is therefore placed on cotton fiber length. Length and the variability around the average length affect non-ideal unevenness via a floating fiber mechanism, i.e. fibers not held by either nip point are not properly drafted. For the same reason, fiber length also contributes to roving unevenness through the drafting systems of draw and roving frames, although to a much lesser extent compared to the effect on yarn non-ideal unevenness.

Fiber length also affects yarn tenacity through yarn evenness and the coherence force between fibers in the helical yarn structure. The coherence force between fibers is provided by inter-fiber friction where the frictional force provided by a fiber is proportional to its length.

Short Fiber Content (SFC)

The critical importance of SFC to yarn tenacity is well supported by yarn mechanics through the 'fiber ends' effect (Hearle 1969). A proportion of each of the two fiber ends does not make a positive contribution to the frictional forces applied by fibers when tension is applied to the end of a yarn. The fiber nearest to the pulling direction is more likely to be gripped by neighboring fibers and contribute to the yarn's cohesion, although a proportion of this leading fiber end because of migration within the yarn assembly may make little or no contribution to the yarn's cohesion. The trailing fiber end is more likely to make a negative contribution to yarn cohesion via frictional forces that pull the stretched fibers in the opposite direction to which the tension is applied to the yarn. The length of the fiber-ends, which make negative contributions to yarn tenacity, is nominally constant. With the magnitude of the 'fiber-ends' effect being dependent on fiber length, the shorter the fiber length, the greater the fiber-ends affect on yarn tenacity. Experimental results of the Cottonspec validation trial carried out recently at the Chongqing Sanxia mill on a range of growths gives strong support to this theory with yarn tenacity values affected significantly by higher levels of SFC.

It is worthwhile mentioning that the fiber length changes in processing due to fiber breakage, primarily during the carding operation. This results in reduced mean length and increased SFC. It is therefore important to understand that it is the fiber length in roving, rather than in raw cotton, that ultimately contributes to yarn evenness and strength.

Fiber Tenacity and Elongation

Theory and experimental results have confirmed that for yarns made from staple fiber, yarn tenacity varies proportionally with fiber bundle tenacity (Hearle 1969). Fiber tenacity and elongation also affects yarn evenness because of fiber breakage during processing, primarily during carding. The likelihood of a fiber surviving the carding operation depends on the fiber's tenacity (strength and linear density) and elongation. Since yarn tenacity depends on yarn evenness, fiber tenacity and elongation play a two-fold role in determining yarn tenacity and elongation.

Experimental results show that fiber elongation is the single most important property affecting yarn elongation and is therefore a secondary contributor to yarn strength (William et al, 1966). Fibers with low elongation are brittle and easier to break in processing, which leads to reduced fiber length and increased SFC. This in turn becomes a negative factor affecting yarn evenness and strength.

Fiber Linear Density

As discussed, fiber linear density determines the number of fibers in the yarn cross section for a given yarn count, and in turn determines about three quarters of yarn unevenness. Linear density also affects yarn strength through yarn evenness as well as its influence on the coherence between fibers. The finer the fibers, the larger the coherence force will be and hence the higher the yarn tenacity.

Fiber Maturity

Fiber maturity is the most important fiber property as far as dye uptake is concerned. Spinning trial results show that immature fiber content (IFC), as measured by the AFIS PRO, is negatively correlated to yarn evenness and tenacity. This is easy to understand because immature fibers normally have lower strength and break easily in processing, resulting in reduced mean fiber length and high SFC.

Fiber and Yarn Nep Count

Yarn nep count is an important yarn property, in particular for fine count weaving and dyed knitting yarns. The importance of fiber nep count to yarn quality is mainly reflected through yarn nep count. Neps in cotton and yarn are formed in processing as a result of fiber entanglement. Spinning trial results show that yarn nep count is correlated to fiber nep count. This means that although a large proportion of neps in lint cotton are removed during combing, some lint neps always survive to become neps in yarn.

Color and Yellowness

Color and yellowness are important cotton fiber properties since they may influence the color and luster of dyed cotton fabric, and importantly to the spinner the price of the raw fiber. The properties of color and yellowness by themselves in most situations should not have any direct effects on yarn evenness and tenacity, although strong correlations with yarn evenness and tenacity are observed. These cases tend to reflect strong correlations between color and yellowness with other cotton fiber properties, e.g. fiber tenacity and length.

Industrial Spinning Trials

Since July 2008, CSIRO has conducted a series of large scale industrial spinning trials in collaboration with Chongqing Sanxia Technical Textile Co. Ltd China, a large, modern spinning mill. Yarn counts spun cover a range from Ne 23 to Ne 80 with metric twist factors ranging between 114 and 136. Cottons of different origins were used including US CA, SJV and Pima, Chinese Xinjing, Brazilian, and Australian. Mean fiber lengths ranged from 28 to 37 mm, fiber tenacity ranged from 28 to 43 cN/tex and linear density ranged from 120 to 180 mtex.

Fiber samples were collected weekly from the lay-downs following CSIRO's sampling procedure, whereby 10 to 20 grams of cotton were sampled from each bale, with the samples accumulated separately by their origin. Fiber samples were tested using HVI by the Auscott Classing Office (Sydney NSW) and for linear density (Cottonscan), maturity (SiroMat), neps and length (AFIS PRO) at CSIRO's Cotton Test Laboratory. In addition, samples of semi-processed mill products, e.g. card, drawn sliver and roving, supplied by the mills were also tested for linear density (Cottonscan), maturity (SiroMat), neps and length (AFIS PRO). Table 1 list the fiber tests applied and results collected for the database.

Table 1. Fiber data used in Cottonspec models

Instrument	Fiber Properties
High volume instrument (HVI)	Micronaire, length – upper half mean length, uniformity, SFC, strength – tenacity and elongation to break, color – Rd and +b, trash - % trash, classing grade (machine) plus classing grade (classer)
Cottonscan (Cottonscope)	Linear density (fineness)
SiroMat (Cottonscope)	Maturity and distribution of maturity within sample
Advanced Fiber information System (AFIS)	Nep count, nep size, seed coat nep count and seed coat nep size, length – upper quartile length, mean length, SFC by weight and number, trash count, dust count, % trash

Yarn quality measurements included count (linear density), tenacity, elongation, evenness, imperfection counts and twist. These are standard yarn quality parameters that are tested as a matter of course in mills all over the world. Later, as the databases for each mill grew large, the data sets were segregated on the basis of their different count and quality ranges. Table 2 lists the number of fiber samples collected from bale lay-downs and the associated yarn data sets (weeks) attributable to the fiber samples.

Table 2. Spinning Database

Fiber data (bale laydowns)	Yarn data (weekly av.)*			
	Count Ne	**Lots**	**Yarn Type**	**Lots**
946 lots	40	32	compact	62
	50	46	ring spun	72
	60	56	weaving	9
	Total	134	knitting	125

*Weekly averages are averages of an entire week's yarn test results, e.g. yarn tenacity, elongation etc, for each count and yarn type processed from the corresponding bale laydown.

Ranking of cotton fiber properties

Partial correlations between specific fiber properties and yarn evenness and tenacity are given in Table 3 and Table 4 respectively. The data in Table 3 shows that yarn evenness is well correlated with these five fiber properties. On average, fiber length has the strongest correlation with yarn evenness, followed by SFC, tenacity, linear density and uniformity. The data in Table 4 shows correlations between yarn tenacity and these fiber properties that are much stronger than for yarn evenness. On average, fiber tenacity ranks number one, followed by length, SFC, linear density, and uniformity. Ranking of the influence of fiber properties on yarn evenness and tenacity are summarized in Table 5. The relative importance of cotton fiber properties for yarn evenness and tenacity shown in Table 5 is in good agreement with spinning prediction theories described earlier.

Table 3. Partial R^2 correlation coefficients (%) between specific fiber properties and yarn evenness

Yarn type	Lot	Tenacity	Length	Linear Density	SFC	Uniformity
compact	62	14	16	11	23	14
Ne60	56	10	12	0	9	7
Ne50	46	25	36	27	36	20
Ne40	32	10	32	22	3	4
AV		15	24	15	18	11
Order		3	1	3	2	4

Table 4. Partial R^2 correlation coefficients (%) between specific fiber properties and yarn tenacity

Yarn type	Lot	Tenacity	Length	Linear Density	SFC	Uniformity
compact	62	70	64	66	61	56
Ring	68	74	59	64	64	51
Ne60	56	41	34	10	27	23
Ne50	46	60	55	56	70	45
Ne40	32	12	48	31	13	18
AV		56	54	49	50	42
Order		1	2	3	3	4

Table 5. Ranking of the influence of fiber properties on yarn evenness and tenacity

Ranking	Yarn evenness	Yarn tenacity
1	Length	Tenacity
2	SFC	Length
3	Tenacity and Linear Density	Linear Density and SFC
4	Uniformity	Uniformity

Prediction algorithms and interface

The above results and theoretical understanding along with additional information such as the effect of twist has been incorporated into a series of prediction algorithms within a user-friendly computer program. The program provides an interface for the entry of data on cotton fiber properties for each constituent component of the laydown and desired yarn parameters and some processing parameters. Currently, the required processing variables include whether the cotton is carded or combed and the spinning method, ring spinning or compact spinning.

The Cottonspec interface has two formats. One is a windows format to be used mainly as an education and cotton trading tool. Another format is an Excel format to be used by cotton spinning mills for quality control. The windows format interface was developed first and an Excel version is currently being developed.

The programming of the prediction algorithms has been divided into two steps corresponding to the two formats of the interface. For the windows format, the Cottonspec prediction algorithms have been programmed using C+.net as part of the Microsoft visual studio package using OO (object oriented) design techniques. The language of C+.net has been chosen because of its flexibility on the windows platform, and because it provides a neat method of allowing multiple language usage.

The interface itself uses the windows MDI (Multiple Document Interface) forms, where one form houses or allows docking of the other (child) forms. All forms are kept in a hidden state when the program begins and are made available to the user on request from a dropdown menu at the top of the main (parent) form. The child forms each provide class member variables to store the data input by the user and to provide functionality to process this data according to the algorithms and output the result.

Testing of the Prediction Algorithms

A testing set of 20 lots of yarn data was obtained from a cotton blending trial, which was conducted at the Chongqing Sanxia mill in April 2010. In this trial, an average, good quality Australian cotton was blended with US San Joaquin Valley (SJV) cotton in percentages of 0%, 12.5%, 25%, 37.5% and 50%. For each blend ratio, four types of yarn were spun to give a total of 20 yarn types. The measured fiber properties of the blended cottons are listed in Table 6.

Table 6. Blended cotton fiber properties

No	%SJV	Length mm	Uniformity %	SFC %<16mm	Linear Density Nm	Tenacity cN/tex	Elongation %
AUS	0	29.8	81.70	19.23	5649	29.02	**6.54**
1	12.5	29.74	81.73	19.14	5665	29.42	**6.63**
2	25	29.68	81.76	19.04	5682	29.83	**6.72**
3	37.5	29.62	81.79	18.95	5698	30.23	**6.81**
4	50	29.56	81.81	18.86	5714	30.63	**6.91**
5	**100**	**29.32**	**81.93**	**18.49**	**5780**	**32.25**	**7.27**

Yarns were spun and their properties measured (yarn evenness and tenacity) and compared to predicted values that were derived using the developed algorithms (Table 7).

Table 7. Measured and predicted yarn evenness and tenacity values for the blending trial

No	% SJV	Yarn type	Ne	TF	MCV %	PCV %	MYT cN/tex	PYT cN/tex
1	12.5	JC	40	400	11.30	11.50	16.90	**17.07**
2	25.0	JC	40	400	11.36	11.47	17.50	**17.25**
3	37.5	JC	40	400	11.31	11.44	17.70	**17.42**
4	50.0	JC	40	400	11.44	11.40	17.00	**17.59**
5	100.0	JC	40	400	11.13	11.27	18.20	**18.29**
6	12.5	CF	40	400	11.07	11.15	18.50	**18.26**
7	25.0	CF	40	400	11.03	11.12	18.20	**18.45**
8	37.5	CF	40	400	10.96	11.09	18.40	**18.64**
9	50.0	CF	40	400	10.88	11.06	18.70	**18.82**
10	100.0	CF	40	400	10.73	10.94	19.40	**19.57**
11	12.5	JC	50	405	12.45	12.17	16.80	**16.40**
12	25.0	JC	50	405	12.33	12.12	16.40	**16.45**
13	37.5	JC	50	405	12.27	12.06	16.60	**16.49**
14	50.0	JC	50	405	12.20	12.00	16.70	**16.54**
15	100.0	JC	50	405	12.04	11.77	17.40	**16.72**
16	12.5	CF	50	405	12.20	12.40	18.30	**18.28**
17	25.0	CF	50	405	12.15	12.35	18.60	**18.32**
18	37.5	CF	50	405	12.21	12.29	18.60	**18.37**
19	50.0	CF	50	405	11.90	12.23	18.90	**18.41**
20	**100.0**	**CF**	**50**	**405**	**11.49**	**12.00**	**19.70**	**18.59**

MCV = measured yarn evenness, PCV = predicted yarn evenness (CV), MYT = measured yarn tenacity, PYT = predicted yarn tenacity, JC = ring spinning, CF = compact spinning.

The standard errors and relative standard errors for predicted yarn evenness and tenacity are shown in Table 8.

Table 8. Standard and relative standard errors for predicted yarn evenness and tenacity for the Chongqing Sanxia mill blending trial

	Standard error	**Relative standard error %**
Yarn evenness	0.21%	**1.84**
Yarn tenacity	**0.39 cN/tex**	**2.19**

The predicted yarn evenness and tenacity values vs. the measured values are plotted in Figures 4 and 5. The results confirm that the prediction algorithms work very well. Predicted yarn evenness and tenacity were highly correlated to the measured data with the regression co-efficient (r^2) being 0.87 for yarn evenness and 0.85 for yarn tenacity.

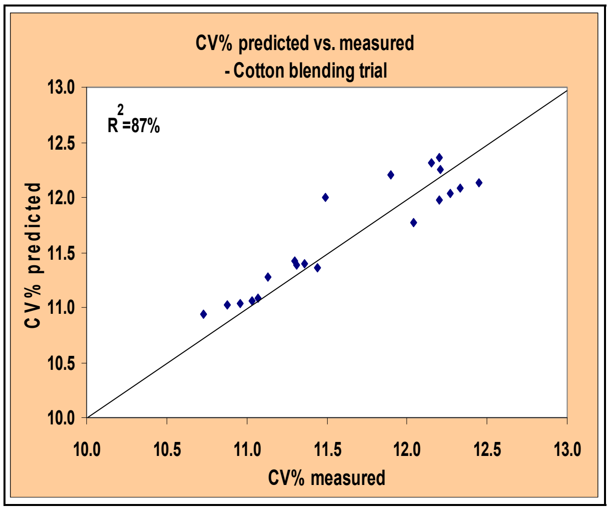

Figure 4. Yarn evenness predicted vs. measured for 20 lots of blended cotton yarn

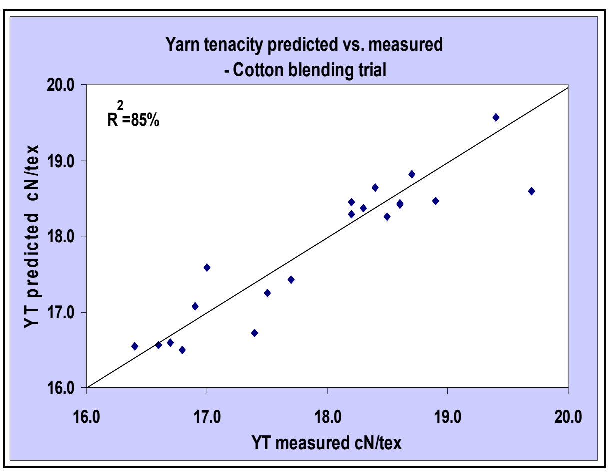

Figure 5. Yarn tenacity predicted vs. measured for 20 lots of blended cotton yarn

Summary

Cottonspec, a cotton fiber and yarn quality management software package, has been developed. The package can be used by spinners to select the most suitable cottons, which best meet the spinner's needs, or as a quality control tool to benchmark performance against "best commercial practice". Cottonspec can also be used as a trading tool for merchants to promote the value of a particular growth, or used by cotton researchers and grower collectives to assess and promote new cotton varieties. The basic model and operation of the computer program Cottonspec has been described, including the basis of the spinning prediction algorithms, industrial spinning trials, the roles of cotton fiber properties in spinning and the ranking of their relative importance to yarn quality. The ability of Cottonspec to predict yarn quality was demonstrated.

Acknowledgements

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