ASSESSING RAW COTTON ON PREDICTED YARN QUALITY: A NEW APPROACH TO MARKETING COTTON

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Cottonspec, a yarn quality prediction program, is used to introduce a new index for assessing cotton fibre quality. The yarn quality index (YQI) is defined as the ratio between the predicted yarn property of a given cotton and that of a suitable reference cotton. The new index was compared with two often used fibre quality indices, the fibre quality index (FQI) and the spinning consistency index (SCI), on yarn spun from ten international cotton samples. The results demonstrate that the new YQI was superior to the two widely used indices in terms of correlations with the observed yarn quality. The YQI can also be converted into a combined and weighted score. The yarn quality score (YQS) enables cotton to be valued by merchants and mills on the most important properties for particular yarn types.

INTRODUCTION

The accurate prediction of yarn quality from fibre quality will continue to challenge the world cotton industry in terms of appropriate market signals to growers for quality and spinning mill process efficiencies. The supply chain from growers through to the mill needs better tools to ensure that (1) growers are properly paid for the quality of fibre they grow, and (2) spinning mills can buy cotton specific to their needs in a market; where consumer expectations but not margins will continue to increase.

The quality of cotton yarn is largely determined by the quality of fibre from which it is spun provided that spinning equipment and process factors are optimized to realize the potential of the fibre. However, the relatively complex relationships between fibre properties and yarn quality, e.g., yarn tenacity and evenness, mean that combinations of fibre properties into simple indices or equations are unable to accurately predict the quality of a cotton yarn outside limited ranges.

Two indices, the fibre quality index (FQI) [1] and the spinning consistency index (SCI) [2], which use fibre quality values measured by high volume instrumentation (HVI), are often advocated as indices to assess the quality of a cotton in terms of yarn quality.

The FQI is calculated using the formula shown in Equation 1.

$$FQI = \frac{UHML\ x\ UNI\ x\ TEN}{MIC} \qquad (1),$$

where UHML is the upper half mean length (inches), UNI is the length uniformity index (%), TEN is the fibre bundle tenacity value (cN/tex) and MIC is the HVI airflow measurement of fibre fineness, or more truthfully the specific surface area of the compressed fibre sample, all measured by HVI.

The SCI is a regression-based equation derived from multiple year HVI crop averages of US Upland and Pima cotton, see Equation 2.

$$SCI = -414.67 + 2.9TEN + 49.17UHML + 4.74UNI - 9.32MIC + 0.65Rd + 0.36b \quad (2),$$

where in addition to the variables used to calculate the FQI, Rd, percent reflectance (lightness/darkness) and +*b*, the yellowness, of the cotton fibre are also used.

In this paper, values of a new yarn quality index (YQI) and a yarn quality score (YQS) derived using values from Cottonspec [3, 4], are compared with the FQI and SCI indices for a range of cotton samples obtained from a high quality ring spinning mill that were then spun into yarns at CSIRO.

MATERIALS AND METHODOLOGY

Fifty kilogram samples of 10 cottons sourced from a reputable Chinese spinning mill were used in this study. The cottons included three Upland samples from the San Joaquin Valley (SJV) in the USA, five Upland samples from Australia and two long staple varieties from China's Xinjiang region. The samples were picked directly from single bales in the mill's laydown, used to spin combed Ne 50 and 60 count ring yarns with a weaving twist.

Specimens from each sample were tested on an Uster Technologies HVI1000 line at Auscott Classing Offices, Sydney, Australia under standard testing conditions. The test results in Table I are averages of five measurements.

Table I – HVI values of the sourced cotton samples.

Sample No	UHML (inches)	UNI (%)	SFC (%)	TEN (g/tex)	ELO (%)	MIC	Rd	+b
1	1.108	82.9	8.9	32.1	7.0	4.18	78.1	9.0
2	1.179	81.3	9.2	34.8	8.9	3.99	80.1	9.2
3	1.184	82.6	8.8	34.6	8.4	4.14	79.6	9.1
4	1.213	83.2	8.4	31.6	6.3	4.17	81.1	7.7
5	1.208	82.7	8.5	30.5	6.3	4.31	80.0	7.8
6	1.203	82.2	9.9	34.3	6.3	4.32	80.2	7.4
7	1.211	82.9	8.5	32.3	6.0	4.29	78.3	7.5
8	1.224	82.9	8.2	31.3	5.9	4.47	77.1	7.0
9	1.554	88.9	5.0	47.2	5.5	4.59	77.6	8.1
10	1.434	86.8	5.0	41.6	5.9	4.30	77.7	7.6

Each cotton sample was then combed and spun into fine count, ring spun yarn (Ne 50 and 60) with a metric twist factor of 120 using CSIRO's pilot plant, which comprises modern, industrial scale preparation and spinning equipment.

Ten yarn bobbins per sample were collected, oven dried overnight at 90^{o}C and conditioned under standard conditions for 48 hours prior to testing for linear density, evenness (Uster Evenness Tester) and tensile properties (Uster Tensorapid).

DISCUSSION OF ANALYSIS

Using Cottonspec (Version no. 1.2.1.0), four key yarn properties; tenacity (YTEN), elongation (YELO), work-to-break (W-to-B) and yarn evenness, were predicted using each sample's HVI values and spinning data, i.e., count and twist factor.

Work-to-break values (cN.cm) were calculated from measured and predicted yarn values using the following formula [5]:

$$Work\ to\ break = YTEN \times YLD \times L \times YELO \times work\ factor \qquad (3),$$

where YTEN = yarn tenacity (cN/tex), YLD = yarn linear density (tex), L = the gauge length used in the yarn elongation measurement (50 cm), YELO = yarn elongation (%) and a constant work factor of 0.5 was assumed. It is understood the load-elongation curves for cotton yarns do not exactly obey the linear nature of Hooke's Law. However, it is assumed because the yarns were prepared on the same spinning frame that work factor differences between cotton samples and between the two counts of yarn spun would not be significantly different.

Comparison of Cottonspec predicted yarn values, using no mill factor correction [4], versus measured values for the Ne 50 and 60 count yarns are shown in Tables II and III. Despite the Cottonspec database including 1820 yarn lots from 1604 different bale laydowns gathered over three years [4], predictions of yarn imperfections, e.g., thick places, thin places and neps, have still not been adequately modelled.

Table II – Measured and predicted yarn properties for Ne 50 yarn.

Sample No.	Observed				Predicted			
	YTEN (cN/tex)	YELO (%)	W-to-B (cN.cm)	Evenness (%)	YTEN (cN/tex)	YELO (%)	W-to-B (cN.cm)	Evenness (%)
1	17.56	6.00	316.1	18.24	19.49	5.27	308.1	12.40
2	17.27	6.39	331.1	17.74	20.89	5.66	354.7	12.26
3	16.69	6.22	311.4	18.24	20.64	5.53	342.4	12.27
4	16.85	5.69	287.6	18.14	19.62	5.28	310.8	12.16
5	16.37	5.43	266.7	17.82	18.80	5.21	293.8	12.32
6	16.02	5.24	251.8	17.73	19.41	5.20	302.8	12.77
7	16.11	5.24	253.2	17.78	19.57	5.18	304.1	12.29
8	15.93	5.47	261.4	17.92	18.89	5.11	289.6	12.37
9	22.39	5.66	380.2	15.64	25.70	5.32	410.2	11.19
10	21.97	5.81	382.9	15.80	25.06	5.38	404.5	11.02

Table III – Measured and predicted yarn properties for Ne 60 yarn.

Sample No.	Observed YTEN (cN/tex)	YELO (%)	W-to-B (cN.cm)	Evenness (%)	Predicted YTEN (cN/tex)	YELO (%)	W-to-B (cN.cm)	Evenness (%)
1	17.34	5.32	230.6	18.54	18.87	5.06	238.7	13.53
2	16.91	5.80	245.2	18.42	20.21	5.45	275.4	13.39
3	16.09	5.76	231.7	18.87	19.97	5.32	265.6	13.40
4	16.63	5.19	215.8	18.89	19.01	5.07	241.0	13.30
5	16.50	5.07	209.1	18.58	18.21	5.01	228.1	13.45
6	14.98	5.03	188.4	18.54	18.74	5.00	234.3	13.90
7	15.47	4.91	189.9	18.41	18.94	4.98	235.8	13.42
8	15.42	5.02	193.5	18.42	18.28	4.91	224.4	13.51
9	22.23	5.44	302.3	16.04	24.78	5.12	317.2	12.32
10	21.93	5.39	295.5	16.36	24.26	5.18	314.2	12.15

Coefficient of determination (R^2) values between measured and predicted yarn properties are shown in Tables IV and V for the Ne 50 and 60 count yarns respectively. The R^2 values between measured yarn properties and calculated SCI and FQI values (see Table XIII) determined from the HVI values are also shown. The correlations indicating the best relationship are highlighted in bold.

Table IV - Square of correlation coefficient (R^2) between predicted yarn properties, SCI, FQI and observed yarn properties for Ne 50 yarn.

Predicted	**Observed** YTEN	**YELO**	**W-to-B**	**Evenness**
YTEN	**0.943**			
YELO		**0.794**		
W-to-B			**0.887**	
Evenness				0.824
SCI	0.908	0.003	0.671	0.904
FQI	0.906	0.010	0.702	**0.908**

Table V - Square of correlation coefficient (R^2) between predicted yarn properties, SCI, FQI and observed yarn properties for Ne 60 yarn.

Predicted	Observed			
	YTEN	**YELO**	**W-to-B**	**Evenness**
YTEN	**0.900**			
YELO		**0.899**		
W-to-B			**0.918**	
Evenness				0.843
SCI	0.861	0.077	0.774	0.906
FQI	0.854	0.110	0.799	**0.912**

The results show the Cottonspec predicted yarn properties were highly correlated with measured values. For Ne 50 yarn, the R^2 was 0.943 for tenacity, 0.794 for elongation, 0.887 for work-to-break and 0.824 for evenness. With the exception of yarn evenness, R^2 values between FQI and SCI values and the predicted yarn properties were lower than those between observed and Cottonspec predicted values.

In particular, there was no correlation between SCI and FQI values and the observed yarn elongation values. Correlations between SCI and FQI values and observed work-to-break values were 0.671 for SCI and 0.702 for FQI, lower than the relationship between predicted and observed work-to-break (0.887) values. Similar values were observed for the Ne 60 yarns, although the effect of fibre and yarn elongation was more pronounced.

The poorer correlations between SCI and FQI values and observed work-to-break values, and in particular yarn elongation, illustrate a flaw in assessing cotton fibre quality in relation to overall yarn quality using the FQI and SCI indices. Particularly, if measures of spinning and weaving performance are to be recognized. The flaw is perhaps a reflection of the calibration sets used to develop these indices; wherein fibre and yarn elongation were not considered.

The lower correlation between Cottonspec predicted and observed yarn evenness values is primarily a result of the relatively small quantity of cotton (50 kg per cotton sample) used in the spinning trial. It is recognized that if the trial had been carried out on a larger scale, whereby the blending and drawing operations could be optimized, the predicted yarn evenness, and indeed the yarn tensile properties would be closer to the observed values.

Yarn quality index

In order to further appraise fibre quality, a yarn quality index (YQI) is defined by the ratio shown below:

$$YQI = \frac{P_1}{P_2} \quad (4),$$

where P_1 can be the measured or predicted yarn property from the cotton at hand, and P_2 is the predicted yarn property of a reference cotton, ideally the best cotton available to the mill for the particular yarn quality. The best cotton can be a particular mill's yardstick or an industry's yardstick.

In the example here, the reference cotton is a high quality, long staple *Gossypium barbadense* cotton from the Xinjiang region in China. This cotton, from the Cottonspec database, was used in laydowns in the production of combed, fine count ring spun yarn. Its HVI properties are shown in Table VI and its predicted yarn properties using Cottonspec are shown in Table VII.

Table VI – HVI properties of the Cottonspec reference cotton.

UHML (inches)	UNI (%)	SFC (%)	TEN (cN/tex)	ELO (%)	MIC
1.388	85.99	8.6	44.64	5.11	3.77

Table VII – Predicted Ne 50 and 60 yarn yarn properties of the Cottonspec reference cotton.

Yarn Count (Ne)	50	60
YTEN	27.4	26.5
YELO	5.5	5.3
W-to-B	450.5	350.2
Evenness	10.72	11.58

Yarn quality indices for the two yarn counts for measured and predicted yarn tenacity, elongation, work-to-break and evenness values were calculated. Values greater than 1 for tensile properties and values less than 1 for evenness mean the sample cotton exceeds the reference cotton's (fibre and) yarn property values. The values for each sample in the two yarn counts (Ne 50 and 60) are tabulated in Tables VIII and IX.

The ratio allows merchants and spinners to assess the properties of a particular cotton for sale and spinning, against a recognized standard. A ratio of one essentially means that the fibre quality of the sample from a merchant, or at hand in the mill, is equal to the spun yarn quality required by the mill.

Table VIII – Average YQI of the Ne 50 yarn count for measured and predicted yarn tenacity, elongation, work-to-break and evenness values.

Sample No.	Observed				Predicted			
	YTEN	*YELO*	*W-to-B*	Evenness	*YTEN*	*YELO*	*W-to-B*	Evenness
1	0.641	1.091	0.702	1.701	0.711	0.958	0.684	1.157
2	0.630	1.162	0.735	1.655	0.762	1.029	0.787	1.144
3	0.609	1.131	0.691	1.701	0.753	1.005	0.760	1.145
4	0.615	1.035	0.638	1.692	0.716	0.960	0.690	1.134
5	0.597	0.987	0.592	1.662	0.686	0.947	0.652	1.149
6	0.585	0.953	0.559	1.654	0.708	0.945	0.672	1.191
7	0.588	0.953	0.562	1.659	0.714	0.942	0.675	1.146
8	0.581	0.995	0.580	1.672	0.689	0.929	0.643	1.154
9	0.817	1.029	0.844	1.459	0.938	0.967	0.910	1.044
10	0.802	1.056	0.850	1.474	0.915	0.978	0.898	1.028

Table IX – Average YQI of the Ne 60 yarn count for measured and predicted yarn tenacity, elongation, work-to-break and evenness values.

Sample No.	Observed				Predicted			
	YTEN	*YELO*	*W-to-B*	Evenness	*YTEN*	*YELO*	*W-to-B*	Evenness
1	0.654	1.004	0.659	1.601	0.712	0.955	0.682	1.168
2	0.638	1.094	0.700	1.591	0.763	1.028	0.786	1.156
3	0.607	1.087	0.662	1.630	0.754	1.004	0.758	1.157
4	0.628	0.979	0.616	1.631	0.717	0.957	0.688	1.149
5	0.623	0.957	0.597	1.604	0.687	0.945	0.651	1.161
6	0.565	0.949	0.538	1.601	0.707	0.943	0.669	1.200
7	0.584	0.926	0.542	1.590	0.715	0.940	0.673	1.159
8	0.582	0.947	0.553	1.591	0.690	0.926	0.641	1.167
9	0.839	1.026	0.863	1.385	0.935	0.966	0.906	1.064
10	0.828	1.017	0.844	1.413	0.915	0.977	0.897	1.049

Yarn quality score

The YQI value can also be used to compare the relative performance of a cotton in terms of a given yarn property. A yarn quality score (YQS) is proposed as per Equation 5 to provide a score for each cotton, e.g., in a laydown. For a given number of samples, the i^{th} sample yarn quality score for a given yarn property is given by:

$$YQS_i = abs\left(\frac{YQI_i - YQI_1}{YQI_2 - YQI_1}\right) \times 5 + 5 \quad (5),$$

where YQI_i is the yarn quality index of the i[th] sample, YQI_2 is the best yarn quality index and YQI_1 is the worst yarn quality index among the sample set.

According to the equation the best yarn quality score is 10, when $YQI_i = YQI_2$. Correspondingly, the lowest score is 5, when $YQI_i = YQI_1$. Note that for yarn tenacity, elongation and work-to-break, YQI_2 is the highest value and YQI_1 is the lowest value, while for yarn evenness, and yarn imperfections, the situation is opposite, i.e., the lowest YQI is the best value.

Using Equation 5, YQS values were calculated for yarn tenacity, elongation, work-to-break and evenness for the ten cottons. The results for measured and predicted yarn properties of the Ne 50 and 60 yarns are tabulated in Tables X and XI.

Table X – Average YQS of Ne 50 yarn count for measured and predicted yarn tenacity, elongation, work-to-break and evenness values.

Sample No.	Observed				Predicted			
	YTEN	*YELO*	*W-to-B*	Evenness	*YTEN*	*YELO*	*W-to-B*	Evenness
1	6.27	8.30	7.45	5.00	5.50	6.46	5.77	6.05
2	6.04	10.00	8.02	5.95	6.52	10.00	7.70	6.45
3	5.60	9.26	7.27	5.00	6.34	8.82	7.19	6.42
4	5.72	6.95	6.37	5.18	5.60	6.55	5.88	6.74
5	5.35	5.82	5.57	5.80	5.00	5.91	5.17	6.28
6	5.08	5.00	5.00	5.97	5.44	5.82	5.55	5.00
7	5.15	5.00	5.05	5.88	5.56	5.64	5.60	6.37
8	5.00	5.99	5.37	5.61	5.07	5.00	5.00	6.14
9	10.00	6.82	9.90	10.00	10.00	6.91	10.00	9.51
10	9.68	7.47	10.00	9.69	9.54	7.46	9.77	10.00

Table XI – Average YQS of Ne 60 yarn count for measured and predicted yarn tenacity, elongation, work-to-break and evenness values.

Sample No.	Observed				Predicted			
	YTEN	*YELO*	*W-to-B*	Evenness	*YTEN*	*YELO*	*W-to-B*	Evenness
1	6.63	7.31	6.85	5.61	5.50	6.39	5.77	5.00
2	6.33	10.00	7.49	5.82	6.52	10.00	7.75	5.51
3	5.77	9.78	6.90	5.04	6.34	8.80	7.22	5.47
4	6.14	6.58	6.20	5.00	5.61	6.48	5.89	5.83
5	6.05	5.90	5.91	5.54	5.00	5.93	5.20	5.29
6	5.00	5.68	5.00	5.61	5.40	5.83	5.53	3.66
7	5.34	5.00	5.07	5.84	5.56	5.65	5.62	5.40
8	5.31	5.62	5.23	5.82	5.05	5.00	5.00	5.07
9	10.00	7.98	10.00	10.00	10.00	6.94	10.00	9.38
10	9.79	7.70	9.70	9.44	9.60	7.50	9.84	10.00

Total yarn quality score

The results shown in Tables X and XI reflect the difficulty in ranking a particular cotton successfully on the basis of a single quality index. In the above tables it can be seen that YQS rankings vary considerably for different yarn properties. For example, Sample No. 2 has the best score for yarn elongation but quite poor rankings for other fibre (yarn) properties, despite the intrinsic importance of this property. In order to make an assessment of overall spinning quality, a total yarn quality score (YQS_T) is introduced as per Equation 6. For a given cotton sample the YQS_T is defined as:

$$YQS_T = \sum_{i=1}^{n} YQS(x_i) * w(x_i) \qquad (6),$$

where YQS_T = total yarn quality score, $YQS(x_i)$ = score for i^{th} yarn property, $w(x_i)$ = weight for i^{th} yarn property and n = number of yarn properties being incorporated into the total score. The weightings can have different values to reflect the requirement of particular yarn properties for the end use of the yarn. For demonstration purposes, the four yarn properties, tenacity, elongation, work-to-break and evenness are arbitrarily given weights of 0.25 as shown in Table XII.

It is understood these weights would change dependent on the end use of the yarn, e.g., spinners requiring cotton for fine count weaving yarns might require heavier weightings for yarn elongation and evenness. Using Equation 6 and the weights below, measured and predicted YQS_T values for the ten cotton samples were calculated along with their corresponding FQI and CSI values (Table XIII).

Table XII – YQS_T weight indices for yarn properties.

	YTEN	YELO	W-to-B	Evenness

Weight	0.25	0.25	0.25	0.25

Table XIII – Observed and predicted YQS_T with corresponding SCI and FQI indices.

Sample No	Observed YQS_T	Predicted YQS_T	SCI	FQI
1	6.63	5.94	137	705
2	7.44	7.68	144	836
3	6.79	7.20	148	817
4	6.01	6.19	144	765
5	5.74	5.59	136	707
6	5.27	5.45	144	785
7	5.27	5.81	141	756
8	5.50	5.30	136	711
9	9.29	9.12	227	1421
10	9.22	9.22	197	1204

The relationship between the observed yarn properties described by the YQS_T for each sample, the predicted yarn quality scores from Cottonspec and the two fibre quality indices are illustrated in Figure 1.

The Figure shows the R^2 value between observed YQS_T and predicted YQS_T (0.945) is significantly higher than the corresponding values for SCI (0.771) and FQI (0.803). It is clear the Cottonspec defined total YQS value is superior over SCI and FQI in terms of its sensitivity to assessing overall cotton fibre quality. This result is expected because of Cottonspec's ability to accurately predict yarn tenacity, work-to-break and in particular elongation. This ability is not seen using SCI and FQI values.

As mentioned previously, the lower correlations for yarn evenness between YQS predicted and observed values are associated with the small quantity of cotton used in these trials. If the trials were carried out on a larger scale, it is expected these results would improve.

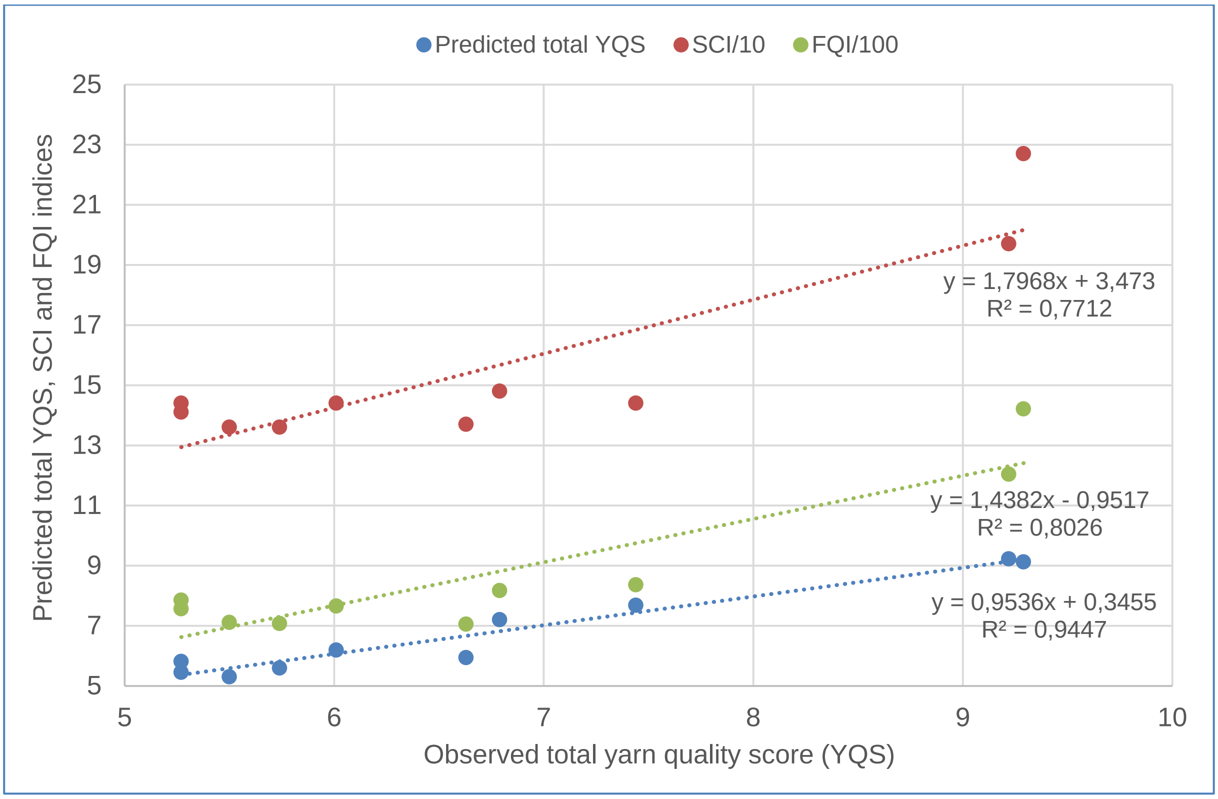

Figure 1 – XY plots of observed total yarn quality scores (from yarn values) versus predicted yarn quality scores generated using predicted yarn quality values from Cottonspec and SCI and FQI indices. Scores are calculated with equal weightings for each yarn property.

CONCLUSION

A new method of assessing cotton fibre quality has been introduced. Two new indices, the Yarn Quality Index (YQI) and Yarn Quality Score (YQS), derived from predicted Cottonspec yarn quality values were assessed against the SCI and FQI indices using ten different international cottons spun into two counts of fine count, combed ring spun yarn.

The results demonstrate the new Cottonspec indices were superior over the two traditional indices in terms of correlations with the observed yarn quality. The chief reason for their improved performance was the ability of Cottonspec to accurately predict yarn tensile, work-to-break and elongation values.

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