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BREEDING AND GENETICS

Development and Utility of Q-score for Characterizing Cotton Fiber Quality

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ABSTRACT

Cotton (*Gossypium hirsutum* L.) fiber quality characteristics may be improved with an index that incorporates weighted values of multiple fiber measurements. Our objectives were to describe the logic and calculation of a numerical index (Q-score), to evaluate the relationship of Q-score to loan value, and to illustrate the use of Q-score in cotton breeding and cultivar testing. The Q-score is calculated by first normalizing fiber properties from 0 to 1 and then algebraically combining the normalized values by quality-weighting factors based upon input from textile processing experts. Fiber properties (weights) for Q-score calculations included fiber length (50%), micronaire (25%), length uniformity index (15%), and strength (10%). Q-scores and loan values were calculated for the 2001-2007 Arkansas Cotton Variety Tests (1478 observations). Economic analysis included summary statistics and correlations for the parameters. Q-score values were normally (or near normally) distributed, while loan values followed a Poisson or chi-square distribution. Q-score and loan value were positively correlated, and similarly correlated to the fiber parameters. Obtaining optimum loan values was more likely as Q-score increased. Q-score was more conservative and discriminating than loan values. Data for 16 cultivars at four sites over three years indicated that Q-score values were relatively consistent over years and sites. Q-score was normally distributed in data extracted from the 2005-2008 Arkansas cotton breeding trials. This distribution facilitates subsequent development of superior cotton lines. These results indicate that Q-score may assist with characterizing fiber quality. However, application of Q-score is limited because relative weights of four fiber traits are subjectively assigned, and measurement of trash and color are not included.

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Improved fiber quality is needed for the continued competitiveness of U.S. cotton (*Gossypium hirsutum* L). Unfortunately, cotton genotypes that display superior fiber quality, often are late-maturing and do not yield well over different environments (Meredith, 2002, 2003; Miller and Rawlings, 1967). Since fiber quality may be characterized by different methods and measurements, superior fiber quality is sometimes difficult to define and identify. Most cotton breeding and cultivar testing programs utilize High Volume Instrument (HVI) determination of fiber parameters, and most frequently report fiber length, length uniformity index, strength and micronaire. Other instruments, e.g. Advanced Fiber Information System (AFIS), provide many more fiber measurements. Users of these data are challenged to determine which parameter or group of parameters should be given priority.

Improvement of fiber quality may be complicated by several factors. First, values defining high fiber quality vary with different spinning technologies and end-uses (Chapp, 1995). For example, relatively longer and finer fibers are preferred for ring spinning, while HVI fiber bundle strength is more important for rotor spinning. Secondly, changing world markets have led to changing emphasis on various fiber properties, which to some extent, is related to differing spinning technologies. Thirdly, some fiber traits are not genetically linked (Ulloa and Meredith, 2000; Weaver et al., 2009). Genotypes may have excellent values for one or more fiber traits, but have moderate or poor values for other ones. When selecting a genotype, arbitrary weights must be assigned to the different traits. Determining the best combination of these traits leads to confusion for breeders, as well as, cotton producers. Fourthly, inheritance patterns of these traits differ (Meredith, 1984). Fiber length and strength tend to be highly heritable and respond well to selection. Fiber length uniformity is less heritable and thus more strongly influenced by environment. Micronaire is a special case trait since it is neither minimized, nor maximized by breeders but maintained within a set range that is rewarded by the U.S. loan system. Trash and color can be improved by good agronomic practices, particularly effective defoliation and timely harvest, and can be preserved by good seed cotton storage and ginning practices (Hake et al., 1990). Also, trash can be reduced by use of cultivars that have less plant pubescence (Anthony and Rayburn, 1989). Finally, prices associated with certain fiber parameter values, which are established by the U.S. government loan program, are sometimes used to define fiber quality. Loan values vary with respect to base loan rate, warehouse location differential, color, trash, fiber length, fiber strength, micronaire, and uniformity. Cotton is often bred and produced to meet loan parameters rather than for actual improved fiber quality.

Cotton breeding and cultivar testing programs usually collect hand-picked boll samples and gin the samples on small laboratory gins with no seed cotton or lint cleaners (Bourland et al., 2000; Bowman, 1997). Since fiber breakage during ginning is minimized on these small gins, resulting values of fiber length and length uniformity index usually are slightly exaggerated relative to commercially produced and ginned cotton in the U.S. However, variation in the HVI measured fiber properties derived from boll samples does provide valid comparisons of entries within a test. Color and trash are important components of fiber quality. However, valid measurements of color and trash either are not or cannot be attained from these hand-picked boll samples.

A numerical index, which characterizes variation in cotton quality, would be an asset to cotton breeding and cultivar testing programs. Indexing fiber quality is confounded by many of the factors noted above. The research report herein proposes a simple numerical index, “Q-score”, based on four frequently reported fiber parameters. Since Q-score does not include consideration of trash or color, it does not completely define fiber quality. However, Q-score does combine four fiber parameters into a single score and should facilitate the improvement of fiber quality. Fiber properties and their relative contributions to Q-score calculations in this report were fiber length (50%), micronaire (25%), fiber length uniformity (15%) and fiber strength (10%). The objectives of this report were to explain the development and calculation of Q-score, to evaluate the relationship of Q-score to loan values, and demonstrate the use of Q-score in a cotton breeding and cultivar testing program.

MATERIALS AND METHODS

Logic and calculation of Q-score. To generate a single value quality score that can be based on weighting values derived from textile experts, it was necessary to transform all of the individual HVI quality measurements to non-dimensional units with similar scales. Such normalization procedures are often used in decision support tools to integrate expert information with quantitative data (Hagemeister et al., 1996; Jones and Barnes, 2000). Every fiber quality measure was scaled from 0 to 1 before being used to compute the quality index, with 1 indicating the desired condition. In most cases, the limits beyond which a particular measure would be set equal to 0 or 1 was based on the actual mean of the cultivar test in question, plus or minus two standard deviations of the HVI measurement typical of the U.S. crop. The standard deviations for each HVI measure used in this study were based on the average of the standard deviations occurring in the 2001 to 2005 crop years as listed in Table 1. These standard deviations for the U.S. crop were calculated from USDA classing office data using EFS(R) USCROP (TM) software v. 3.7 (Cotton Incorporated, Cary, NC). Table 1 also includes

Table 1. Standard deviations [z] of selected HVI measurements for the U.S. crop from 2001 to 2005.

HVI measurement	Standard deviation for the U.S. crop by year					
	2001	2002	2003	2004	2005	Mean
Strength (kN m kg^{-1})	21.6	23.5	21.6	21.6	19.6	21.6 (2.2 g tex^{-1})
Uniformity (%)	1.1	1.2	1.2	1.3	1.3	1.2
Length (mm)	10	13	13	10	10	10 (0.04 in.)
Micronaire	0.49	0.48	0.47	0.54	0.56	0.51

[z] Standard deviations for the U.S. crop were calculated from USDA classing office data using EFS(R) USCROP (TM) software v. 3.7 (Cotton Incorporated, Cary, NC).

the individual years to illustrate that standard deviation is fairly constant across years for a given HVI measurement. In the case of micronaire or strength, there are theoretical circumstances where the absolute limits used in the normalization process would result in limits that were not determined by this procedure as will be explained in the discussion of those measurements. The scaling limits were based on the U.S. crop to prevent a possible over-weighting of a particular HVI measure in a test that did not have entries with a particular large variance in one or more HVI measures.

Normalization of Length and Uniformity Index. In general, increases in fiber length and length uniformity are desirable from a yarn spinning perspective. To scale these values within a single test, the mean value of the data for entries tested is used as the starting point. With length, the lower value is the mean minus two times the standard deviation of HVI length for the U.S. crop (Table 1), and the upper value plus two standard deviations. Figure 1 is an example of a test where the average length was 302 mm (1.19 in.) with a standard deviation for the U.S. crop of 10 mm (0.04 in.). The length parameter was set to 0 for any entries that had a shorter length than the trial mean minus two standard deviations and to 1 for lengths greater than two standard deviations. The values within that range were scaled from 0 to 1 using the formula:

$$D_L = \frac{L - (L_m - 2s_L)}{(L_m + 2s_L) - (L_m - 2s_L)}$$

Where D_L is the dimensionless length factor, L_m is mean length of the test in question, and s_L is one standard deviation in length for the U.S. crop. The same procedures used for fiber length were also used to normalize the length uniformity index.

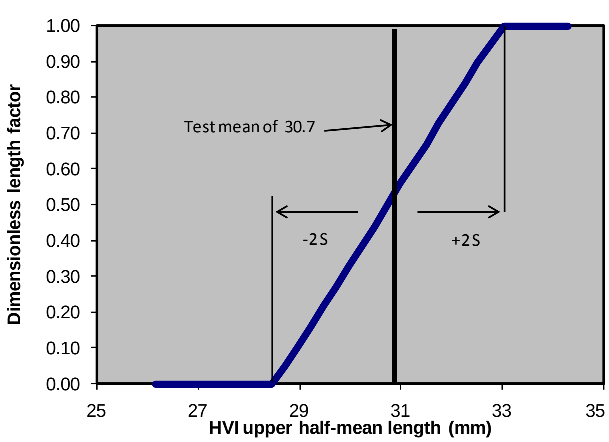

Figure 1 – Example of the normalization of HVI length for a trial with a mean of 30.7 mm, and s equal to the standard deviation of length for the U.S. crop (10 mm from Table 1).

Micronaire. Micronaire between 3.8 and 4.6 is a desirable range based on international buyer demand trends (which differ from the U.S. loan chart); therefore, all micronaire values in this range are set to 1. For values that fall outside this range, they are scaled from 1 to 0 using a procedure similar to that for length and uniformity. Upper and lower limits are set by adding and subtracting, respectively, twice the mean U.S. standard deviation of the micronaire in Table 1. Any micronaire value that is outside of that range is set to 0 and values between the standard deviation limits and the desired range are scaled from 0 to 1 as illustrated in Figure 2. In the event a trial has a high or low mean micronaire value such that the trial mean plus or minus the standard deviation falls within the bounds of 3.8 and 4.6, the procedure preserves a scaling factor of 1 for any value in the 3.8 to 4.6 range.

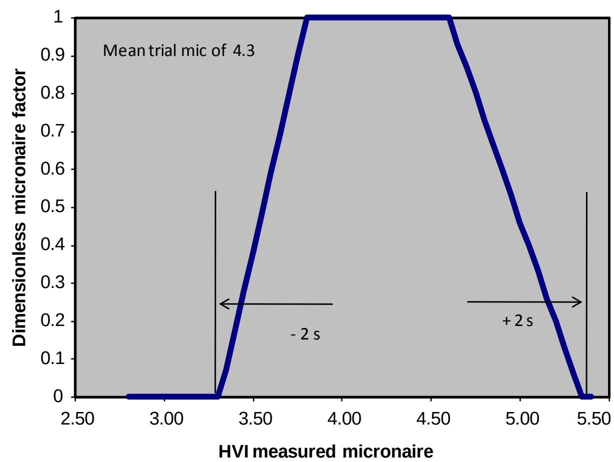

Figure 2 – Illustration of the normalization of micronaire for a test with a mean value of 4.3 and s equal to 0.5 from Table 1.

Strength. For strength, an absolute strength range is assigned from 274 to 333 kN m kg^{-1} (28 to 34 g/tex) where the factor is assigned a constant of 0.8, a level arrived at through interviews with Cotton Incorporated textile experts. The value of 0.8 versus 1 was used to note that there was some desirability of strength above 333 kN m kg^{-1} (34 g tex $^{-1}$). For most textile applications, strength in the range of 274 to 333 kN m kg^{-1} (28 to 34 g tex $^{-1}$) is sufficient. Values outside of this range were then scaled from 0 to 1 as illustrated in Figure 3.

Final Computation of the Q-Score. Once all of the HVI fiber quality measures were scaled from 0 to 1, the final Q-score was calculated as:

$$Q_{score} = 100\sum_{i=1}^{i=4} D_i W_i$$

where D_i is the scaled value of the HVI measurement (length, strength, uniformity or micronaire) and W_i is the weighting factor for each. Note that the weighting factors should always sum to 1, resulting in a Q-score that is bound between 0 and 100, with 100 representing the desired condition from a textile processing perspective.

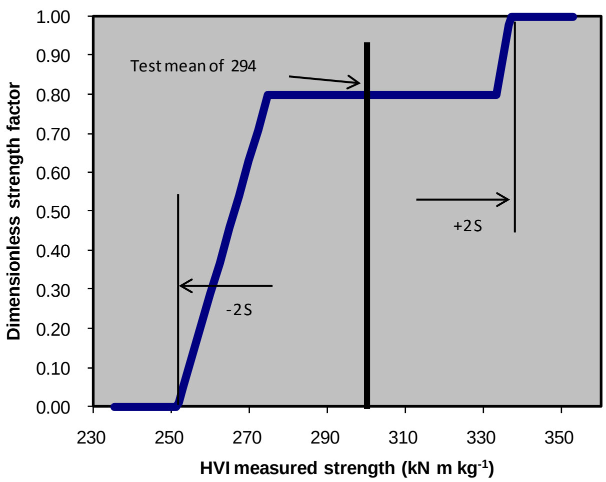

Figure 3. Example of the normalization function for strength, for a test with a mean of 294 kN m kg-1 and using s equal to 21.6 kN m kg-1from Table 1.

Running the EXCEL Macro. The EXCEL Macro contains numerous worksheets, which provide detail and explain the derivation of the Q-score functions. To utilize the Macro, the user's EXCEL security level must be set so macros can run. Key worksheets in the Macro are titled Readme, Configure, and DataforCalc. Review the Configure worksheet to determine if cells B3, B4, B5, and B6 have the proper weights. Note, cells B3 through B6 must sum to 1. Next, click on the DataForCalc worksheet. HVI measures of length (in); Mic (1 to 6); UI (%); and strength (g/tex) must be pasted in the columns H, I, J, and K. Columns A, B, and C must identify the year, site code, and test. The cell just below the last line of data in column A must have 9999 in order for the Macro to work properly. Select the Configure work sheet and click on the "**Green"** box in the lower left-hand area of the worksheet. Q-score values will be output to column N in the DataForCalc worksheet.

Since there may be variation for fiber quality measures in different years, between testing sites, and even within a field, calculation of Q-score is restricted to data generated from entries grown in the same year at the same site in the same test. The EXCEL Macro lists this as year, site code, and test respectively.

Relation of Q-score to loan value. Fiber data were extracted from annual reports of the Main trial of the Arkansas Cotton Variety Test conducted at multiple sites in 2001 through 2007 (Table 1). At each site, cultivars were evaluated in a RCB design with four replications. All bolls from consecutive plants were hand-picked to obtain 50-boll samples from two of the four replications. The boll samples were ginned on a laboratory gin, and fiber samples were evaluated at the Louisiana State University Cotton Fiber Laboratory, Baton Rouge, LA, using HVI equipment. Seed cotton yields, determined by machine-picking each plot, were converted to lint yields using lint percentages determined by site and entry.

Fiber parameters in the extracted data set included fiber length, micronaire, fiber length uniformity index, and fiber strength. Q-score was calculated in the manner described above. Color and trash determinations were not obtained since accurate measures of these parameters cannot be obtained from hand-picked boll samples that are ginned on small laboratory gins. A color of 41 and a leaf of 4 for each observation were assumed for each cultivar at each test site. Using USDA Commodity Credit Corporation (CCC) Loan Value premiums and discounts for quality data, the loan value was then computed for fiber parameter means for each cultivar at each location. The data set was created with Q-score, loan value, micronaire, fiber length, uniformity, and strength. Summary statistics and simple correlation coefficients were computed for each random variable (Q-score, loan value, micronaire, etc.). Histograms were developed for both Q-score and loan values to observe the distributions. A normal probability plot was constructed for the Q-score values and probabilities were computed to express the likelihood of having high loan value if a cultivar has a high Q-score.

Use of Q-score in breeding and cultivar testing programs. Q-score was calculated for sets of individual plant selections (IPS's) made in 2004 through 2008 in the University of Arkansas Cotton Breeding Program (Bourland, 2004). After screening for specific host plant resistance and morphological traits, boll samples were taken from F_2 and F_3 populations each year. IPS's were then selected from the subsequent F_4 populations. The boll samples were ginned to produce seed and fiber samples. Resulting fiber samples were evaluated by HVI to determine fiber properties. Q-score was determined for each individual plant using the method described above. Q-score was used as an aid for selecting IPS's for fiber quality in both 2007 and 2008, but was not available before 2007.

Routinely, seed collected from the IPS's are acid-delinted and evaluated as "preliminary progeny" at two sites in the fourth year after an initial cross is made (Bourland, 2004). Superior preliminary progeny are promoted to "advanced progeny", which are subsequently evaluated at three sites in the fifth year. The best advanced progeny are subsequently promoted to strain status and evaluated in replicated tests at four Arkansas locations for up to three years. Q-score and fiber data for an advanced experimental line and two check cultivars, that were included in the Preliminary Progeny Test in 2005, the Advanced Progeny Test in 2006, a Preliminary Strain Test in 2007, and the New Strain Test in 2008, were extracted and used to examine the consistency of Q-scores over years.

An additional evaluation included lint yield and fiber data for 16 cultivars, which were extracted from four irrigated locations of the 2006, 2007 and 2008 Arkansas Cotton Variety Tests (Bourland et al., 2007, 2008, 2009). The 16 cultivars included all cultivars evaluated in each of the three years. For each location within each year, cultivars were arranged in a RCBD using four replications for lint yield. Boll samples from two of the replications were ginned and subsequent lint samples were used to determine HVI fiber parameters and to calculate Q-score. Analysis of variance was accomplished using SAS v. 9.1 PROC GLM (SAS Institute, Cary, NC) with years and replications considered as random variables and cultivars and locations as fixed variables.

RESULTS AND DISCUSSION

Logic and calculation of Q-score. Q-score is a numerical index calculated using an EXCEL Macro spreadsheet, which is available from the third author (djones@cottoninc.com). Q-score may include up to six HVI parameters with specific weightings of parameters assigned by user. To some degree, the relative weightings should reflect end-use, but should also consider availability and heritability of traits. Q-score weightings of four HVI parameters in this paper included fiber length = 50%, micronaire = 25%, length uniformity = 15%, and strength = 10%. These weights were based upon perceived demands of the current cotton market, and are particularly weighted in favor of fibers desirable for ring-spinning technology. Also, improved cotton fiber quality has for decades been generally defined by longer, finer fibers. Users of Q-score may change the relative weights of these four HVI parameters and add weights for elongation and short fiber content. These latter two parameters were not included in this paper because some cultivar testing programs do not report them, and genetic influence of these traits is not well defined.

HVI parameters of trash and color are not included in Q-score. When fiber data are determined from hand-harvested boll samples, reliable measurements of trash and color cannot be attained. Amount of trash in a sample may vary among persons picking the samples. Also, the lack of seed cotton or lint cleaners on most laboratory gins negates accurate measurement of trash. Measurement of color is primarily associated with weathering in field prior to harvest and may also be affected by moisture during ginning. Except for added exposure to weathering associated with early maturing lines, little or no genetic control of color exist.

Relation of Q-score to loan value. A total of 1,478 observations of Q-scores and CCC loan values were collected from the Arkansas Cotton Variety Tests conducted from 2001 through 2007 (Table 2). As indicated in summary statistics (Table 3) and associated histograms (Fig. 4), loan values appeared to be distributed as a Poisson or chi-square distribution and obviously were not normal. Loan values expressed a low standard deviation and coefficient of variation, and range of only \$0.356 kg^{-1} (16.15 cents lb^{-1}). Consequently, over 80% of loan values were within \$0.051 kg^{-1} (2.31 cents lb^{-1}) of maximum loan value.

In contrast, distribution of Q-score values was close to a normal distribution and expressed the classical bell-shaped curve (Table 3, Fig. 5). Figure 6 shows a normal probability plot of the Q-score dataset. Statistical theory would dictate the data points would cover the sloped line. In this case, data points were on the line over the middle of the plot, but deviated slightly at each end of the line. This suggests some deviations in the tails of the distribution curve, but the distribution is near normal. A normal distribution of values is common for quantitative traits, and often provides opportunity for selection. The relative wide range in Q-scores (28.0 to 92.0) among these commercial cultivars also suggests Q-score might be improved by selection (Table 3).

Table 2. Test sites and number of entries in annual Arkansas Cotton Variety Tests used as sources of data for comparing Q-score and loan value.

Year	Irrigated sites[z].	Non-irrigated sites[z].	No. of entries	Reference
2001	Kei, Clk, Mar, Roh	Kei, Mar	31	Benson et al., 2002
2002	Kei, Clk, Mar, Roh	Kei, Mar	37	Bourland et al., 2003
2003	Kei, Clk, Mar, Roh	Kei, Mar	33	Bourland et al., 2004
2004	Kei, Clk, Mar, Roh	Kei, Mar	27	Bourland et al., 2005
2005	Kei, JH, Mar, Roh	Kei	26	Bourland et al., 2006
2006	Kei, JH, Mar, Roh	Kei	52[y]	Bourland et al., 2007
2007	Kei, JH, Mar, Roh	none	38	Bourland et al., 2008

[z] From north to south (spanning approximately 320 km), tests sites were on Arkansas Agricultural Experiment Stations at Keiser (Kei), Judd Hill (JH), Clarkedale (Clk), Marianna (Mar) and Rohwer (Roh). Within a year, the same entries were evaluated at each test site.

[y] Round-up Ready Flex entries (26) and non-Flex (26) entries were evaluated in two adjacent trials.

Table 3. Summary statistics for CCC loan value and Q-score associated with data from the 2001 through 2007 Arkansas Cotton Variety Tests.

Statistic	Loan value ($ kg^{-1})	Q-score (index)
Mean	1.19	62.4
Standard Deviation	0.04	11.3
Coefficient of Variation	3.46	18.1
Minimum	0.87	28.0
Median	1.20	62.0
Maximum	1.23	92.0
Skewness	-3.11	0.0
Kurtosis	13.64	-0.1
Count	1478	1478

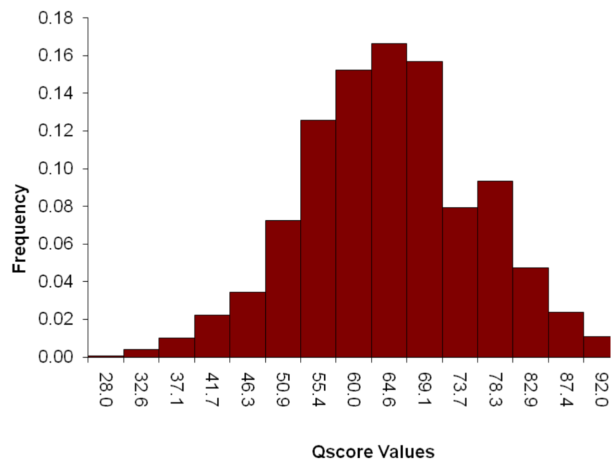

Figure 5. Distribution of Q-score values associated with data from the 2001 through 2007 Arkansas Cotton Variety Tests.

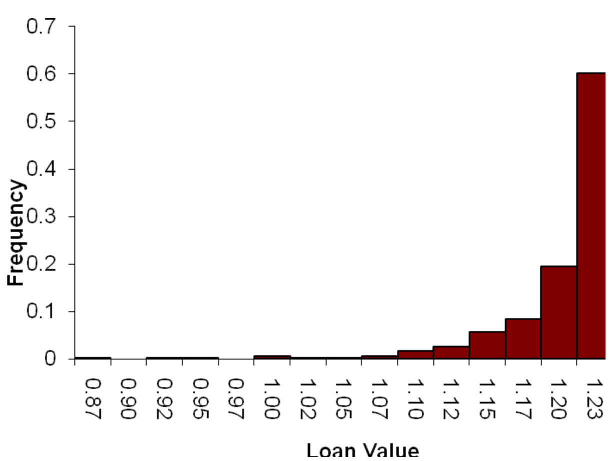

Figure 4. Distribution of CCC loan values ($ kg-1) associated with data from the 2001 through 2007 Arkansas Cotton Variety Tests.

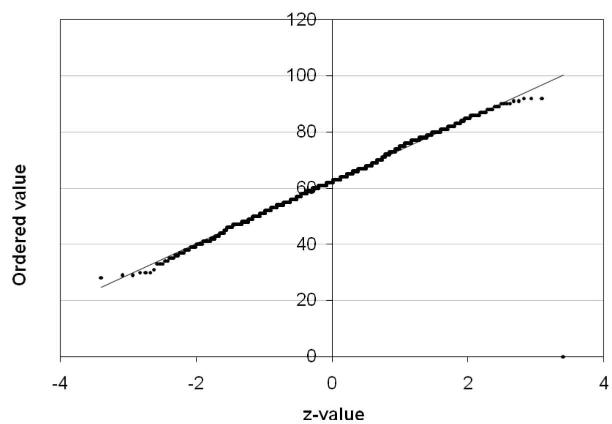

Figure 6. Normal probability plot of Q-score values associated with data from the 2001 through 2007 Arkansas Cotton Variety Tests.

Q-score and loan value were positively correlated (Table 4). The correlation implies that as the Q-score value increases (decreases) by one point, loan value would increase (decrease) by 0.47 point. However, the distribution of loan values relative to Q-scores indicates that variation in the two traits is not linear (Fig. 7). The correlations of Q-score and loan value with the fiber traits indicate that fiber length had a greater influence on Q-score than on loan value (Table 4). The opposite trend was found for micronaire. These relationships may change if relative weights of fiber traits used in Q-score calculation were modified or if data from other cotton growing regions were included. Correlations among the fiber traits were similar to those reported by Meredith (2005) with longer fibers associated with lower micronaire and higher strength.

One of the objectives of the statistical analysis of Q-score data was to determine if inferences could be drawn concerning loan value if the associated Q-score were known. Two observations may be readily made from Table 5, which provides the probability of obtaining specified loan values for given Q-scores. First, the preponderance of high probabilities reflects the relative narrow range for loan values and the clumping of observations near maximum loan value (Fig. 7). This demonstrates that Q-score is more conservative and more discriminating than loan value. Second, as Q-score increases the likelihood of attaining maximum loan value also increases (Table 5). With a Q-score of 60 or greater, there was a 90% probability that the resulting loan value was within 10% of maximum loan value.

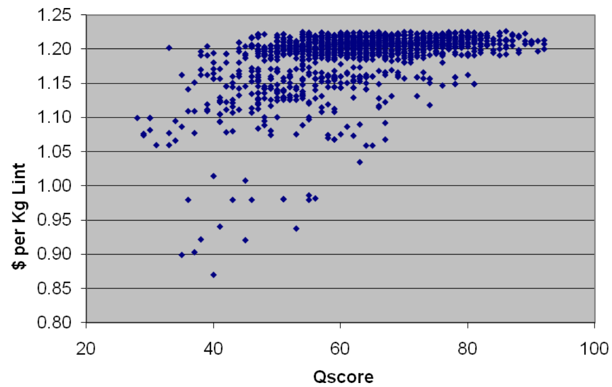

Figure 7. CCC loan values ($ kg-1) by Q-score values associated with data from the 2001 through 2007 Arkansas Cotton Variety Tests.

Table 4. Correlation matrix[z] of random CCC loan value and fiber quality variables associated with data from the 2001 through 2007 Arkansas Cotton Variety Tests.

	Loan Value	Micronaire	Fiber Length	Length Uniformity	Strength
Q-score	0.47	-0.35	0.73	0.47	0.11
Loan Value		-0.52	0.55	0.42	0.17
Micronaire			-0.33	-0.15	0.14
Fiber Length				0.64	0.20
Uniformity					0.29

[z] All correlation coefficients differed significantly from zero at 0.05 probability level.

Table 5. Conditional probability[z] of Q-score vs. CCC loan values associated with data from the 2001 through 2007 Arkansas Cotton Variety Tests.

Q-score	Proportion of loan values, and corresponding maximum loan value								
	9/10, 53.99	8/10, 52.40	7/10, 50.76	6/10, 49.14	5/10, 47.53	4/10, 45.91	3/10, 44.30	2/10, 42.68	1/10, 41.07
90	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
80	0.967	0.983	1.000	1.000	1.000	1.000	1.000	1.000	1.000
70	0.939	0.976	0.997	1.000	1.000	1.000	1.000	1.000	1.000
60	0.897	0.972	0.991	0.998	1.000	1.000	1.000	1.000	1.000
50	0.873	0.959	0.987	0.993	0.999	1.000	1.000	1.000	1.000
40	0.830	0.937	0.977	0.989	0.997	0.997	1.000	1.000	1.000
30	0.788	0.900	0.969	0.986	0.995	0.996	0.999	0.999	1.000
20	0.764	0.880	0.958	0.982	0.992	0.992	0.998	0.998	1.000
10	0.751	0.871	0.948	0.977	0.988	0.989	0.995	0.995	0.998

[z] For example, the probability of a cultivar that has a Q-score ≥ 80% and a loan value ≥ 90% of all observations = 0.967.

Use of Q-score in cotton breeding programs. If a cotton breeder makes selections without regard to fiber quality, resulting lines will frequently have poor fiber quality. Therefore, fiber quality must be considered throughout the development of a germplasm line - from making a cross to individual plant selections (IPS's) to progeny evaluation, and subsequent strain testing. Sets of fiber data associated with IPS's and progeny tend to be very large and difficult to handle. Since these data are typically not replicated, statistical analyses and summaries are limited. Genotypes are often selected by carefully examining each line of data for predetermined critical values of each trait. A genotype may possess superior values for one or more fiber traits, but poor values for other traits. Considerable time is required to examine each line of data and additional time is required to subjectively evaluate lines having marginal fiber quality for some or all traits.

Q-score greatly facilitates the process of discarding IPS's and/or progeny based on fiber quality. After combining the four fiber parameters into a single index, lines of IPS data may be sorted by Q-score. In 2004 through 2008, near normal distributions of Q-scores were found for IPS's in the University of Arkansas Cotton Breeding Program (Table 6). Within each year, the highest frequencies of IPS were found to have Q-scores in the range of 51-60 or 61-70. Since 2006, this program has used fiber data to discard IPS's before planting progeny. Although ginning and processing must be completed sooner, discarding the IPS's prior to planting decreases the time and space required for field evaluation of progeny. Discarding of IPS's can be accomplished with little prejudice since other data are limited and relatively little time and effort have been invested in the genotype.

Based on the distribution of Q-scores and the desired selection intensity, all IPS's having a Q-score of 50 or less were discarded in 2007 (Table 6). A slightly different approach was used in 2008. All IPS's having Q-score of 50 or less were tentatively discarded, and then sorted for fiber length. From these discards, IPS's having fiber length of 29 mm or greater were rescued. IPS's having Q-score in the range of 51-60 were then examined, and some having highest micronaire or shortest fiber length were discarded. None of the IPS's having Q-score greater than 70 were discarded. Without the aid of Q-score in 2006, two IPS (9%) having Q-score of less than 30 were kept and one (1%) having Q-score greater than 60 was discarded. Selection intensity for fiber quality was similar each year with 68% IPS's retained in 2007 and 2008 compared to 73% in 2006.

The primary benefit of Q-score with regard to IPS's and progeny is the reduced time and effort required to make selections. A second benefit is that Q-score facilitates quick recognition of high quality lines, and thus provides an increased priority on fiber quality. Recently developed strains in the University of Arkansas Cotton Breeding Program illustrate this increased priority. The

Table 6. Distribution of progeny by range of Q-scores and discards within specified ranges in University of Arkansas Cotton Breeding Program from 2004-2008[z].

Q-score range	Distribution of progeny (%)					Discards, % within range		
	2004	2005	2006	2007	2008	2006	2007	2008
< 20	3	3	1	2	1	100	100	100
21-30	8	7	2	5	3	91	100	100
31-40	11	9	8	10	10	92	100	91
41-50	14	16	15	14	13	83	100	97
51-60	21	17	24	16	19	19	0	38
61-70	20	21	25	21	23	1	0	0
71-80	11	14	17	18	15	0	0	0
81-90	8	9	5	9	10	0	0	0
91-100	3	4	2	3	6	0	0	0
Total no.	738	948	871	679	890	235	208	289

Individual plants having low Q-scores were discarded prior to planting progeny in 2007 and 2008. Discards for poor fiber quality were made in 2006 without aid of Q-score calculations. No discards were made for poor fiber quality before planting progeny in 2004 or 2005.

experimental line in Table 7 displayed excellent fiber quality during progeny testing. However, its fiber quality did not gain attention until one plot within a strain test generated a Q-score of 100. Since this was the first time that a Q-score of 100 had been observed, the breeder initially thought that a mistake had been made. After examining its Q-score in replicated plots of the strain and in previous progeny tests, the high fiber quality of the line was confirmed. Relative Q-score values for the experimental line and two check cultivars have been consistent over two years of progeny tests and two years of strain tests. This suggests that progeny having high Q-scores will produce strains with high Q-scores. Lint yields of the experimental line over two years of strain tests suggest that it possesses both high yield and high fiber quality traits.

Use of Q-score in cotton cultivar testing. Typically, lint yield is the primary consideration when examining results from cultivar testing. Fiber quality is often ignored because of its value relative to yield and the difficulty of accessing the multiple traits, i.e. defining enhanced quality. Although not always realized by increased loan price, improved fiber quality is essential for long-term viability of cotton.

When 16 cultivars were analyzed over three years and four locations, all sources of variation had significant effects on lint yield and fiber strength (Table 8). Micronaire and length uniformity index were affected by all sources of variation except site by cultivar. Fiber length was affected by year, cultivar and year by cultivar interactions. Remarkably, year and cultivar were the only factors that affected Q-score at the 5% probability level. Based on these data, correlations of Q-score values for 2006 vs. 2007 (r = 0.83), 2006 vs. 2008 (r = 0.85) and 2007 vs. 2008 (r = 0.90) were all high and differed statistically from zero. Unlike data for lint yield, Q-score values for cultivars are relatively consistent over years and sites.

When choosing a cultivar, both high yield potential and good fiber quality should be considered. A good approach would be to first identify a group of cultivars that express high yields, then choose cultivars within that group that express the highest fiber quality. Since Q-score does not encompass any measure of trash, leaf or bract pubescence data may also be considered and preference should be given to cultivars having lower pubescence on leaves and bracts. Data from the 2008 Arkansas Cotton Variety Test report (Bourland et al., 2009) provide a good example. Averaged over four locations, lint yields of the top 10 yielding cultivars did not vary significantly in 2008. Of this group of 10 cultivars, two had Q-scores significantly higher than the other eight. Both of these cultivars were glabrous (smooth leaf) and had relatively low marginal bract trichome density. So, both should have good potential to provide excellent yield and fiber quality.

Table 7. Lint yield (LY), Q-score (QS), micronaire (Mic), fiber length (UHM), uniformity index (UI) and strength (Str) for an experimental breeding line and two cultivars in progeny and strain tests from 2005 through 2008[z].

Year	Line	LY kg ha^{-1}	QS	Mic	UHM mm	UI %	Str kN n kg^{-1}
2005 Prel. Progeny	Exp. Line[y]	n/a	97	4.5	32.5	86.0	358
	DP 393	n/a	69	4.5	29.5	84.8	319
	SG 105	n/a	59	4.8	29.2	84.7	304
2006 Adv. Progeny	Exp. Line	n/a	94	4.8	32.9	86.5	364
	DP 393	n/a	69	4.3	29.3	85.1	300
	SG 105	n/a	65	4.7	29.1	85.4	291
2007 Prel. Strain Test	Exp. Line	1586	91	4.8	32.0	87.2	360
	DP 393	1496	57	4.7	29.2	85.2	316
	SG 105	1542	48	5.0	28.7	85.3	301
	LSD 0.10	75	6	0.2	0.5	0.7	9
2008 New Strain Test	Exp. Line	1272	86	4.8	33.3	87.0	338
	DP 393	1185	59	4.7	30.5	84.4	305
	SG 105	1282	57	4.9	30.5	85.4	288
	LSD 0.10	75	8	0.2	0.5	0.8	8

[z] Q-score and associated HVI fiber data from non-replicated progeny tests at Keiser, AR, in 2005 and 2006, and from two replications of replicated strain tests across four Arkansas locations in 2007 and 2008.

[y] "Exp. Line" stands for "Experimental line – seed not offered for sale".

Table 8. Probabilities (P>F) associated with lint yield (LY), Q-score (QS), micronaire (Mic), fiber length (UHM), uniformity index (UI) and strength (Str) for 16 cultivars over four sites in 2006 through 2008 Arkansas Cotton Variety Tests[z].

Source of variation	LY	QS	Mic	UHM	UI	Str
Year	<.0001	0.0019	<.0001	<.0001	<.0001	<.0001
Site	<.0001	0.5159	<.0001	0.3869	0.0005	<.0001
Year*Site	<.0001	0.2498	<.0001	0.4375	0.0010	<.0001
Cultivar	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Year*Cultivar	<.0001	0.1426	<.0001	<.0001	<.0001	<.0001
Site*Cultivar	<.0001	0.1320	0.5679	0.0882	0.1511	0.0313
Year*Site*Cultivar	0.0018	0.0570	0.0836	0.0455	0.3574	0.0008

[z] Q-score and associated HVI fiber data from two replications and lint yield from four replications of tests at each location and within each year. (Bourland et al., 2007, 2008, 2009).

SUMMARY

Q-score incorporates weighted values of four HVI cotton quality parameters into a single numerical index. Users of Q-score may adjust the relative weights of the HVI parameters in their calculations. Based on perceived international market demands, weights assigned to fiber length, micronaire, length uniformity, and strength for calculations of Q-score in this paper were 50, 25, 15, and 10%, respectively.

Q-score and loan values were calculated for data from seven years of the Arkansas Cotton Variety Test (1478 observations). A near-normal distribution of values was found for Q-score, while loan values displayed a Poisson or chi-square distribution with values congregated at near optimum values. The normal distribution found for Q-score is typical for many quantitative biological measurements, and provides better discrimination and selection opportunities among cotton genotypes. High Q-score increased the probability of obtaining optimum loan values, although optimum loan value was sometimes obtained with lower Q-score.

Within cotton breeding and cultivar testing programs, superior fiber quality is often associated with lower yielding, late-maturing genotypes. Using Q-score in early generations facilitates the elimination of low and medium fiber quality genotypes and subsequent focus on selecting for improved yields among the high quality genotypes. Q-score values for cultivars were found to be more consistent over years and locations than the HVI fiber parameters. Therefore, Q-score may be useful in cultivar testing programs to facilitate the identification of cultivars having the high yields and superior fiber quality.

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