BARRIERS TO BREEDING HIGH FIBER QUALITY COTTON VARIETIES

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The overall objective of most cotton breeding programs is to develop varieties that produce consistently high yields with acceptable values for all other traits. Acceptable values for fiber quality traits are generally considered to be values that do not invoke price discounts. Most fiber traits display good inheritance patterns, and respond well to selection. However, years of selecting high lint yields have produced very few varieties which provide both excellent yields and excellent fiber quality. Three barriers to breeding high fiber quality cotton varieties are noted in this paper. The first barrier is the problem of defining high fiber quality. Most breeders determine fiber quality by High Volume Instrument (HVI) testing, and pay close attention to fiber length, length uniformity, strength, and micronaire. Attempting to establish optimum values of traits becomes increasingly difficult as the number of traits increase. An easy to use, single index (such as Q-score which is described) helps breeders to define and improve fiber quality. A second barrier is the negative relationships between yield and fiber quality traits. Yield and fiber traits do not appear to be controlled by the same genes. Therefore, improvement of both should be possible, but additional effort is required to break the negative relationships. A method of establishing high fiber quality genotypes in early generations, then selecting for high yielding types in later generations is suggested. A third barrier is lack of market incentive to breed and produce high fiber quality varieties. The likely culprit causing a lack of market incentive is the poorly understood relationship between fiber and yarn quality traits. If fiber quality traits were better related to certain yarn quality traits such as neps, the market would be more able and more likely to provide incentives (higher prices) to produce high quality cotton varieties. Further work is needed to better define high fiber quality, to break negative relationships of yield and high fiber quality traits, and to improve the associations between fiber and yarn quality traits.

INTRODUCTION

The art of cotton breeding was once described by Dr. Bob Bridge, renowned cotton breeder now deceased, as trying to get a bunch of monkeys up a tree. Just when you think you have them all there, one will fall out. High fiber quality is one of the "monkeys" that often falls out as breeders attempt to develop improved cotton varieties. With current pricing, discounts for poor cotton fiber quality can be offset by increases in yield, while premiums for superior fiber quality will only slightly offset losses in yield performance. Therefore, cotton producers demand varieties that produce consistently high yields. Since growing conditions vary greatly over years

and locations, consistently high yielding varieties must be able to perform well over a wide range of environments. Unfortunately, yielding ability in cotton expresses a low heritability, and does not respond well to selection. Consequently, breeders usually give highest selection priority to yield – hoping that one of their selections will produce consistent high yields in subsequent generations and across contrasting environments. Other traits are generally relegated to secondary emphasis in breeding programs. A genotype that produces consistent high yields will be advanced as long as its fiber quality and other traits are within "acceptable" tolerance limits.

Although the first priority for evaluating a variety must be its ability to produce competitive high yields, high yields have less value if the cotton is difficult to market. Marketing of low quality cotton may be subject to high price discounts and delayed cash flow. Adverse environmental conditions will always provide an ample supply of low quality cotton. Historically, marketing of low quality cotton has often been supported by governmental marketing loans. Re-structuring or elimination of these loan programs will further weaken marketing opportunities for low quality fibers. Consequently, the development of cotton varieties possessing enhanced cotton fiber quality is essential for sustaining long-term cotton production in any region. Varieties possessing a genetic capacity for higher fiber quality can build and sustain greater marketability and price. Even with harsh growing conditions, such varieties will maintain a better quality than varieties without a high capacity for quality.

In this paper, I will discuss three intrinsic barriers associated with the development of high fiber quality varieties and how these barriers may be broken. The three barriers are: 1) defining high quality cotton, 2) negative relationships among traits, and 3) lack of market incentive.

DEFINING HIGH QUALITY COTTON

The basic steps for a breeder to positively affect any trait are to properly define the trait, establish a means to measure or characterize the trait, and then determine the extent of genetic variation available for defined trait. Since fiber quality can be characterized by different methods and measurements, superior fiber quality is often difficult to define. Most cotton breeding and variety 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 parameters should be given priority. For breeders, these multiple parameters used to define fiber quality often add confusion (more "monkeys), which can hinder progress.

Defining high fiber quality using these HVI parameters is further complicated by several factors. First, values defining high fiber quality vary with different spinning technologies and end-uses (Chapp, 1995). For example, ring spinning gives priority to length and fineness, while strength is a higher priority for rotor spinning. Secondly, changing world markets have led to changing priorities for fiber properties. To some extent, this change is related to differing spinning technologies. Finally, prices

associated with certain fiber parameter values (often established by government loan programs), are sometimes used to define fiber quality. When defined by price, fiber quality definitions become fluid because price is affected by supply and demand. Additionally, loan values vary with respect to base loan rate, warehouse location differential, color, trash, fiber length, fiber strength, micronaire and uniformity. Prices and loan values reflect quality in very broad terms, but may change over time and are not sufficiently precise for most breeding operations. Consequently, cotton may be bred to meet broad pricing parameters rather than for actual improved quality.

Ideally, breeders would like to have one parameter to characterize fiber quality. To address this desire, Bourland et al. (2010) developed "Q-score", a simple numerical index based on up to six HVI fiber parameters. Fiber properties and their relative contributions to Q-score calculations initially used in Q-score included fiber length (50%), micronaire (25%), fiber length uniformity (15%) and fiber strength (10%). These weights were based upon perceived demands of the current cotton market, and were particularly weighted in favor of fibers desirable for ring-spinning technology. Users of Q-score may change the relative weights of these four HVI parameters and add weights for elongation and short fiber content.

Q-score can be effectively used throughout the breeding process beginning with evaluation of non-replicated data from individual plant selections (IPS) and progenies and ending with replicated data used in the release of a variety. A primary benefit of Q-score with regard to IPS and progeny is the reduced time and effort required to make selections. Breeders typically make thousands of IPS each year. Discarding IPS based on relative values for multiple fiber property traits is a daunting task. Without the use of Q-score, a breeder will usually examine each fiber parameter value for an IPS and somehow mark whether each value is within some arbitrary tolerance limit. Frequently, the breeder must then mentally assign weights to the different parameters to determine which IPS to discard. Sorting the data by Q-score facilitates rapid discard of lower quality lines and recognition of high quality lines. Once Q-score is calculated in a spreadsheet, the IPS can be sorted by their relative Q-score and segregates with low Q-score values can be quickly and painlessly discarded.

Using Q-score facilitates an increased priority on fiber quality in breeding programs. A recently developed variety, 'UA48' from the University of Arkansas Cotton Breeding Program illustrates this increased priority (Bourland and Jones, 2012). As indicated by its Q-scores, the experimental line, which was later released as UA48, displayed excellent fiber quality during IPS and progeny testing (Table I). Fiber data for an IPS may be skewed, but generally reflect the fiber quality found in subsequent generations. These data suggest that individual plants and progeny having high Q-scores will produce strains with high Q-scores and illustrate the relative consistency of the genetic basis for fiber quality traits over years. The use of Q-score assisted with recognizing the high fiber quality of the experimental line, and was useful in the eventual release of the variety.

Table I. Q-scores for Ark 0102-48 (experimental line released as 'UA48') during its development.

Year	Test	Q-score	Length (mm)	Length uniformity (%)	Micronaire	Strength (g/tex)
2004	Individual plant	83	33.3	89.2	5.4	40.1
2005	1st year progeny	97	32.5	86.0	4.5	36.5
2006	Advanced progeny	94	32.9	86.5	4.8	37.1
2007	Prel. Strain (4 loc.)	91	32.0	87.2	4.8	36.7
2008	New Strain (4 loc.)	86	33.3	87.0	4.8	34.5
2009	Adv. Strain (4 loc.)	88	33.0	87.0	4.8	34.6
2010	Adv. Strain (4 loc.)	87	32.8	87.0	5.0	36.2

Q-score can also be employed in variety testing programs. Like breeders, cotton growers are often confused by the multiple measurements of fiber quality. Many define fiber quality as the absence of price discounts or by loan value. When choosing a variety, both high yield potential and good fiber quality should be considered. Bourland et al. (2010) suggested that a good approach would be to first identify a group of varieties that express high Q-score, then choose varieties within that group that express highest yields.

The HVI parameters of elongation and short fiber content may be employed in Q-score calculations, but have received little attention. In most tests, varieties and/or breeding lines display significant variation for elongation. However, values for elongation often vary greatly among years and among testing laboratories, but more importantly standard values have not been established. Without established premium and discount values for elongation, its use in Q-score is limited. In contrast to the measure of elongation, varieties and/or breeding lines seldom display meaningful variation for short fiber content. This may be related to the small laboratory gins employed by breeders. Without meaningful differences in a trait, breeders can make little progress.

Since Q-score does not include consideration of trash or color, it does not completely define fiber quality. Meaningful measures of trash and color are typically not available from small samples that are taken and processed by breeders. Color is primarily affected by field conditions after boll opening and prior to harvest, and by conditions during storage and ginning. Since color has little genetic basis, breeders have little opportunity to improve color grades of cotton.

By reducing plant hairiness, breeders can effectively reduce trash content in ginned fiber. Therefore, breeders should consider both leaf and bract pubescence ("hairiness") and give preference to breeding lines and varieties having lower pubescence on leaves and bracts. Reduced pubescence on cotton leaves has been associated with improved seedcotton cleaning efficiency and low foreign matter levels in harvested lint, and thus higher leaf grades in ginned cotton (Novick et al., 1991). To assist with characterizing leaf pubescence, Bourland et al. (2003) developed a rating system that could be easily used to identify less pubescent genotypes.

Pubescence on cotton bracts has received little attention until recently. Bracts are modified leaves surrounding the flower buds and bolls of the cotton plant. Morey et al. (1976) found that bracts are a major contributor to "leaf trash" in harvested cotton. This seems reasonable since bracts are in closer proximity to the cotton fibers than are plant leaves, and most leaves are removed from the plant prior to harvest if defoliation is successful. By examining variation in marginal bract trichomes ("hairs") on different canopy positions and varieties as well as over time and environments, sampling methods were established by Bourland and Hornbeck (2007). They found that glabrous leaf varieties tended to have lower marginal bract trichome density than did hairy leaf varieties, but there was some overlap of bract trichome density among glabrous and hairy leaf varieties. Of all the Upland cotton genotypes that we have examined, none were found to have glabrous marginal bract surfaces. Hornbeck and Bourland (2007) found significant but low magnitude correlations (r = 0.33 to 0.35) between trichome density on abaxial leaf and marginal bract surfaces. This suggests some degree of independence of the two traits. Preliminary results from a ginning study of contrasting varieties appear to verify that lower marginal bract trichomes are related to lower trash in ginned cotton (Boykin and Bourland, 2012).

The obvious question regarding Q-score is whether it actually defines high fiber quality. Undoubtedly, the parameter weightings used in the above Q-score calculations gives particular attention to lines that produce long fibers and have moderate micronaire and gives less attention to lines having high length uniformity and strength. Work is underway to determine the optimum relative contributions of each of these parameters to Q-score. A single Q-score (or any other index) will certainly not identify the optimum fiber quality for all spinning methods and end-uses. However, Q-score (in combination with leaf pubescence and marginal bract trichome data) can certainly be useful in breeding and variety testing programs to identify relative fiber quality of different lines. In this sense, Q-score provides a "workable" definition of fiber quality for cotton breeders.

NEGATIVE RELATIONSHIPS AMONG TRAITS

Once a workable definition of fiber quality is attained, the primary barrier for a cotton breeder to develop high fiber quality cotton varieties is the poor genetic relationships associated with fiber quality with yield and maturity. Unfortunately, cotton genotypes, that display superior fiber quality, often are late-maturing and do not yield well over different environments (Meredith, 1984 and 2002; Miller and Rawlings, 1967). If improved yield and fiber quality were positively related, fiber quality would be improved as breeders have selected higher yielding varieties. This obviously has not been the case. Strong negative associations have long been found between lint yield and many fiber traits (Al-Jibouri et al., 1958; Meredith and Bridge, 1971).

Using data sets from both Australia and U.S., Clement et al. (2012) recently showed that negative associations still exist between yield and fiber quality parameters. In each set of data, they found that fiber length and strength had significant negative associations with yield; fiber maturity had a positive association with yield, while associations of micronaire and fineness with yield were inconsistent.

Table II. Simple correlations † between lint yield and fiber quality parameters in the 2007 through 2011 Arkansas Cotton Variety Tests at Marianna, AR.

Year	N	Q-score	Length	Length unif.	Micronaire	Strength
2007	76	**-0.34**	**-0.32**	-0.01	**0.31**	0.16
2008	60	**-0.36**	**-0.31**	-0.09	-0.03	-0.11
2009	60	**0.35**	**0.33**	0.29	0.22	0.21
2010	64	-0.07	-0.06	-0.04	0.04	-0.17
2011	48	**-0.38**	**-0.48**	**-0.24**	**0.40**	**-0.26**

† Correlation coefficients in bold differ significantly from zero at the 0.05 probability level.

The findings of Clement et al. (2012) are generally confirmed by simple correlations of lint yield with fiber quality parameters in the Arkansas Cotton Variety Tests at Marianna, AR (Table II).
The Marianna location is centrally located in the Mississippi River Delta of Arkansas. Relationships between yield and fiber traits at other test sites in Arkansas were similar to those found at Marianna. Lint yield was negatively correlated with Q-score and fiber length in four of the last five years. Associations of traits in 2009 differed markedly from the other years. Rainfall accumulation at Marianna during the 2009 growing season was 201% of the historical average, and harvest was delayed about a month from normal. Relative yields of different varieties appeared to be more affected by the conditions than were fiber quality traits. These data illustrate the difficulty in establishing firm relationships between lint yield and fiber quality traits.

In addition to the negative relationship with yield, improvement of fiber quality is complicated by the relationships among fiber traits. Fiber traits that are not strongly genetically linked may vary independently (Ulloa and Meredith, 2000; Weaver et al., 2009). Consequently, genotypes may have excellent values for one or more fiber traits, but have moderate or poor values for other ones. When selecting a genotype, a breeder must assign arbitrary weights to the different traits. Also, inheritance patterns of the traits differ (Meredith, 1984). Fiber length and strength tend to be highly heritable and respond well to selection. Micronaire and fiber length uniformity are less heritable and are more strongly influence by environment. Trash and color can be improved by good agronomic practices, particularly effective defoliation and timely harvest, and can be preserved by good seedcotton storage and ginning practices (Hake et al., 1990). Also, trash can be reduced by use of varieties that have less plant pubescence (Anthony and Rayburn, 1989).

Poor relationships that are not genetically bound together can be broken, but considerable effort and focus is usually required. Historically, one of the strongest negative relationships was between yield and fiber strength. Culp et al. (1979) was successful in breaking the negative association between fiber strength and yield. Their findings and subsequent germplasm releases have led to improved fiber strength among high yielding varieties, and demonstrate that many negative relationships can be broken.

Placing a high priority on fiber quality traits in early generations is an approach that appears to work. As noted above, Q-score greatly facilitates the process of discarding IPS's and progeny based on fiber quality. Evaluation of IPS on the basis of Q-score can be accomplished with little prejudice since limited other data are available and relatively little time and effort have been invested in the genotype. In addition, discarding IPS prior to planting decreases the time and space required for field evaluation of progeny. Using high selection pressure for fiber quality at IPS stage ensures that only high fiber quality lines will be advanced in a breeding program. The goal then is to find the best yielding line among the selected high fiber quality lines.

The relative yield and fiber quality of UA48 documents the success of this approach. Over years, UA48 produced lint yields equal to two standard conventional cotton varieties (Table III). Its fiber quality greatly exceeded either check variety. Moreover, UA48 matures earlier than either DP 393 or SG 105, both of which are considered to be early maturing varieties (data not shown). This combination of early maturation, competitive yields, and exceptional fiber quality is unprecedented. Additional information on this variety is available in its registration publication (Bourland and Jones, 2012).

Table III. Lint yield and fiber traits for UA48 compared to two check cultivars over years from 2007 through 2010 at four Arkansas test sites†.

Variety	Lint yield (kg ha^{-1})	Quality score‡	Micro-naire	Fiber length (mm)	Unif. index (%)	Strength (g/tex)	Elon-gation (%)
UA48	1250	88	4.86	327	87.0	35.5	7.5
DP 393	1217	57	4.69	300	84.8	32.2	9.6
SG 105	1226	49	4.83	295	85.1	30.6	9.3
LSD0.05	ns	4	ns	3	0.5	0.8	0.4

† Fiber parameters were determined in tests at Keiser, Judd Hill, Marianna, and Rohwer in 2007-2010. Location by line interaction was not significant (P = 0.10) for any parameter. Fiber parameters were determined by HVI on lint from boll samples taken from two replications per test.

‡ Quality score is an index based on four fiber parameters (relative weight): fiber length (50%), micronaire (25%), uniformity index (15%) and strength (10%).

LACK OF MARKET INCENTIVE

Cotton breeders attempt to develop varieties that meet market demand. Two good examples come to mind. In the 1970's, earlier maturing varieties were needed in the U.S. mid-south region so that producers could escape late-season problems associated with insect pests and diseases. Producers encouraged public cotton breeders to develop and release an early maturing variety - even if the variety had lower yield potential than their currently available full season ones. Two early season

public varieties were subsequently released, and fortunately their early maturity was actually accompanied by increased yields. In a short time, private companies released early maturing varieties and the production in the region was soon transformed.

A second example is more directly associated with fiber quality. Prior to the accepted use of HVI for classing U.S. cotton in 1990's, growers had little knowledge or concern for fiber strength. After a premium/discount scale became established for strength, growers began to demand higher strength varieties. Varieties meeting this demand soon found their way into the market.

In both cases above, breeders did not instantly generate the desired varieties. About 10 years is required from the time a breeder makes a cross until a variety from that cross is released. Obviously, breeders had been concerned with each of the above issues and had materials that approximated these demands in their breeding pipeline. Once a demand was established, breeders were able to redirect priorities in their programs to meet these needs.

Rapid change in varieties can only occur if genetic variability is available and if no strong negative relationships exist. Considerable genetic variability for fiber traits is readily available to cotton breeders. As indicated above, some negative relationships exist - but most could likely be broken. Varieties that produce longer, finer, more uniform, and stronger fibers can be developed. However, a major impediment is establishment of optimum values for these traits. In turn, the market must reward (give premiums) cottons that meet these values.

Unfortunately, optimum values for fiber traits are not well understood and/or communicated within the cotton breeding community. A knowledge gap on how fiber traits (primarily determined by HVI) are related to yarn quality appears to exist. Jones et al. (2011) examined the relationship of Q-score to spinning performance (yarn quality) as measured by yarn strength, evenness, and entanglements in a data set obtained from 20 years of U.S. National Variety Trial results. They found that yarn strength was fairly well predicted using either of two Q-score indices that used different weighting of HVI traits. However, yarn evenness was less well predicted using HVI while the same fiber quality parameters had no predictive ability for yarn neps. Other studies from Hequet (personal communication) have found much better predictive ability of HVI parameters on yarn quality, and AFIS measures increase the predictive ability when combined with HVI parameters too. Why then are fiber quality traits commonly used to predict yarn quality traits? The likely answer is that fiber traits are the only predictors available. Further refinement of the weightings of fiber traits may improve the relation of Q-score to yarn quality traits.

Obviously, optimum values for fiber and yarn quality traits are not the same for every end-use. If sets of optimum values for fiber quality traits were established and associated with specific end-uses, breeders would likely be able to identify varieties that best meet those sets. Marketing pools, which would provide premiums for pre-described sets of traits, might then be developed. Such pools would encourage the production of pre-described cottons and would provide spinners with sufficient quantity of fiber having the pre-described quality.

The ultimate lack of market incentive to develop improved fiber quality traits may simply be due to the poorly understood relationship between fiber and yarn traits. Improved spinning performance and yarn traits should have value to the spinning industry. If this value could be better related to fiber traits, then a market incentive would likely be realized.

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