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BREEDING AND GENETICS

Gains in Breeding Upland Cotton for Fiber Quality

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ABSTRACT

Trends in fiber quality of United States (U.S.) Upland cotton (*Gossypium hirsutum* L.) recently have been positive for the three major traits of length, strength, and micronaire. From 1980 to 2010, micronaire trended upward, but it was not highly significant; emphasis on lint yield tends to result in higher micronaire fibers. Fiber strength continues to improve despite a respite in the late 1990s when transgenic cultivars first came on the market. Much of this improvement in fiber strength can be traced back to the New Mexico State University breeding program and its impact on the cultivar Deltapine 90 which is found in many of the improved cultivars. There was one case of possible transgressive segregation for fiber strength in 2006. Fiber length trended upwards until 1997, and then declined until 2006 when it began another period of improvement that currently continues in the U.S. cotton crop. Much of the improvement in fiber length in recent years can be attributed to the introduction of Australian breeding materials into FiberMax and Deltapine cultivars. Pedigree analyses only reveals that Deltapine 90 is in the background of this genetic material, thus much of the improvement in fiber quality over these years can be traced to material developed at New Mexico State University.

Upland cotton (*Gossypium hirsutum* L.) supposedly has a narrow genetic base due to genetic bottlenecks associated with polyploidy, domestication and modern plant breeding practices (Brubaker et al., 1999; Bowman et al., 1996; Iqbal et al., 2001; Wendel 1989; Wendel et al., 1992). The existence of this narrow genetic base has been validated by a multitude of molecular marker types and studies. Lu and Myers (2002) showed genetic similarities from 92.7 to 97.6% among 10 influential cultivars based on random amplification of polymorphic DNA (RAPDs). Tyagi et al. (2013) have shown similar numbers based on a wide selection of several hundred cultivars and germplasm lines using simple sequence repeat (SSR) marker-based genotyping. Tetraploid cotton cultivars from outside the United States also showed little diversity among cotton genotypes based on markers (Multani and Lyon, 1995; Iqbal et al., 1997; Tatineni et al., 1996). While several investigators (Lewis, 2001, May et al., 1995) suggested that narrow genetic diversity in cotton could impact the improvements in lint yield and fiber quality, others (Culp, 1994) indicated improved yields in cotton should continue based on reported gains.

Genetic similarity estimates based on phenotypic data show a closer relationship than coefficients of parentage (COP) numbers (Van Esbroeck et al., 1999) although the numbers are not as high as later marker studies have shown. This is in sharp contrast to published data on genetic relatedness as estimated through pedigrees. Bowman et al. (1997) estimated an average COP of 0.07 between 260 cultivars released between 1970 and 1990 indicating a wide genetic base. The COP among successful cultivars for this same time frame was 0.18 or 0.29 depending on the method of calculation (Van Esbroeck and Bowman, 1998). Assumptions for calculating these numbers probably are unrealistic such as assuming a relationship of 0.75 between a parent and its reselection; this says that 25 percent of the alleles in the reselection are different from the parent from which it was selected. Also assuming ancestral cultivars had no genetic relationship is probably unrealistic although many of those ancestors are several generations removed.

Breeding methods have contributed to either a lack of genetic gain or narrowing of the genetic base. For example, between 1986 and 1996 nearly 25% of the successful cultivars (those that occupy 1% or more of the planted area) were simply reselections from existing cultivars and 60% were from two-way crosses (Van Esbroeck and Bowman, 1998). Their study revealed that many successful cultivars resulted from crossing closely related, high–yielding, regionally-adapted parents as well as reselections. They concluded that unlike some other crop species there wasn’t a positive correlation between genetic

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distance and successful progeny in cotton. This may be due to lack of appreciable genetic distance in the primary gene pool. Unique gene combinations require diverse parents. However, the degree of diversity needed to make genetic gains in cotton can be debated. Even hybrid combinations may not require wide crosses. For example, Campbell et al. (2008) found high levels of heterosis between closely related parents equaling that from distantly related parents.

The impact of diversity, or the lack of diversity on fiber quality may appear to be quite different from that of fiber yield. Gains in fiber strength from 1980 to 2000 were elucidated by Bowman and Gutierrez (2003). They found half of the gains could be attributed to the cotton breeding program at New Mexico State University, 25 percent to transgressive segregation, and 12.5 percent to the USDA Pee Dee program in South Carolina. During this 20-year period no significant gains were evident in any other fiber trait. The present study examined gains, or changes in fiber quality parameters, especially fiber length, strength and micronaire, for the U.S. cotton crop from 1980 to 2010.

MATERIALS AND METHODS

Fiber data for the U.S. cotton crop for the years 1980 to 2010 (USDA-AMS, 1980-2010a) were examined for trends as described in Bowman and Gutierrez (2003). Fiber data were averaged over all cultivars across the entire U.S. Cotton Belt and included upper half mean-span length (UHML), strength, and micronaire (Figure 1, 2 and 3). Regression over years provided the trends. Statistical analysis was performed using PROC REG of SAS version 9.3 (SAS Institute Inc., Cary, NC).

Since the trends noted in this study (and not previously noted by Bowman and Gutierrez 2003) were most evident in the years 2000-2010, attempts were made to glean cultivar information for each of those years (USDA-AMS, 1980-2010b) (Table 1). Fiber quality data on specific cultivars were examined from USDA-ARS publications of regional cotton trials (1993-2010). Popular cultivars with fiber traits above the national average were defined as 'impact' cultivars in the present study.

RESULTS AND DISCUSSION

Fiber strength. The trend of the U.S. cotton crop for fiber strength is indicated in Figure 1. Regression of fiber strength on year for this time period was highly significant: there was 25% increase in fiber strength from 2001 to 2010. Breeders continue to make progress on improving fiber strength and have reversed the trend noted in the paper by Bowman and Gutierrez (2003) that occurred in the latter part of the 1990s. The downward trend in that time period may be due to the rush to incorporate transgenes into established cultivars.

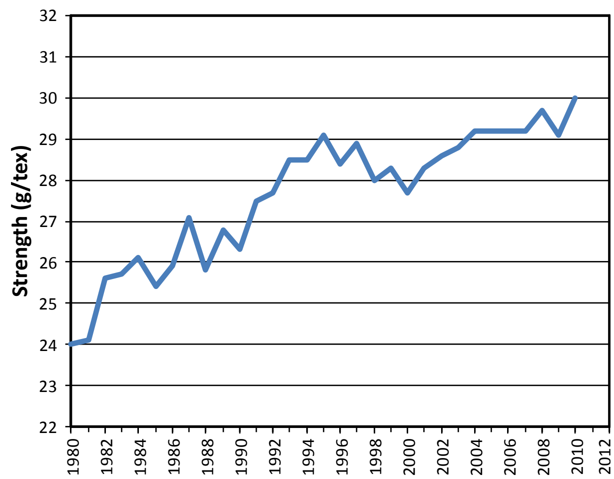

Figure 1. Changes in fiber strength from 1980 to 2010 in the US cotton.

Some of the popular cultivars that have impacted fiber strength in the U.S. from 2001 to 2010 are shown in Table 2. In 2002, cultivar DP5690RR (PVP, 9100116) boosted the average fiber strength of the U.S. crop by its popularity and fiber strength. It has Deltapine 90 (PVP, 9800202) in its pedigree, which was shown to be one of the influential high fiber-strength cultivars in 1990 by Bowman and Gutierrez (2003).

Up until 2003, the FiberMax (FM) (Bayer CropScience) brand did not have a significant portion of the U.S. cotton crop. That year 15.61% of the crop was planted to FiberMax cultivars. Their portion of the U.S. cotton crop increased each year of this study and was 39.0% in 2010. FM 958 (PVP, 200100208) (Bayer CropScience) was planted on 4.5% of total hectares in 2003 and remained a widely grown cultivar for the next 4 years (Table 1 and 2). The source of fiber strength genes for FM 958 is unknown from examination of the pedigree (88001/83055-33) (Bowman et al., 2007). In 2004 FM 960BR (PVP, 200400224) also became a popular cultivar and had high fiber strength; its recurrent parent was Sicot 41 from the Australian cotton breeding program. Bowman et al. (2007) indicated that Deltapine 90 and Tamcot SP37H (PVP, 7800096) are found in the Sicot 41 cultivar. This suggests that DP 90 is the source of the high fiber strength genes in FM 960BR since Tamcot SP37H is not known for its fiber strength (Bird, 1979).

Table 1. Most popular cotton cultivars grown in the U.S. from 2001-2010.

Cultivar	2001*	2002	2003	2004	2005	2006	2007	2008	2009	2010
AFD3511RR			0.1	2.2	2.3	1.5	0.4			
DP0912B2RF									2.4	3.7
DP0949B2RF									1.2	3.2
DP164B2RF						0.5	1.4	4.7	3.2	
DP444BG/RR			0.2	6.5	13.0	13.2	6.6	5.9	1.3	1.4
DP445BG/RR					0.5	4.7	5.1	3.9	1.2	
DP449BG/RR			0.8	2.0	2.2	1.6	0.9	0.6	0.2	
DP451BG/RR	6.4	6.8	6.5	2.8	1.2	0.1				
DP458BG/RR	5.4	6.0	4.6	1.5	0.2	0.1				
DP5415RR	2.5	4.1	3.0	1.8	0.6	0.4				
DP555BG/RR		0.4	8.7	14.9	17.9	17.3	18.1	17.2	16.0	4.3
DP5690RR	2.5	3.4	1.7	1.4	0.4	0.2	0.8			
FM1740B2F								2.9	0.9	4.2
FM9058F						0.1	3.7	7.1	9.4	10.4
FM9063B2RF						0.1	5.8	7.0	8.8	4.7
FM9160B2F									0.8	5.5
FM9170B2F										2.8
FM9180B2F									4.5	3.7
FM958	0.4	2.0	4.5	5.3	7.4	5.4	3.6	2.6	3.4	1.3
FM960B2R				0.4	1.2	6.0	5.1	1.9	0.9	
FM960BR			0.3	3.6	3.5	1.7	0.9	0.6	0.1	
FM960RR						2.2	1.3			
PHY375WRF						0.1		0.6	4.6	9.1
PM1218BG/RR	10.7	6.4	5.9	3.7	1.6	0.1				
PM2200RR	5.6	2.6	0.8	1.0						
PM2326RR	11.4	6.1	4.3	1.4	0.8	0.3	0.1	0.1		
ST BXN47	3.3	1.4	0.2	0.1						
ST4554B2RF						1.9	8.1	7.9	3.9	2.0
ST4892BR	5.8	5.7	7.9	4.2	2.1	0.6				
ST5599BR			1.4	5.1	7.6	3.7	1.4	1.0		

*** Percentage of U.S. crop**

Table 2. Some of the impact cultivars for fiber strength during 2001-2010.

Year	Cultivar	Pedigree
2002	DP5690RR	DP90/DP80
2003	FM958	88001/83055-33
2004	FM960BR	Recurrent Parent Sicot 41
2006	DP445BG/RR	Recurrent Parent DP50BG/RR
2006	FM960B2R	Recurrent Parent Sicot 41
2010	FM9170B2F	Not available
2010	FM9180B2F	Recurrent Parent FM 958

In 2006, DP 445BG/RR (PVP, 200400265) and FM 960B2R (PVP, 200500109) were the primary sources of high fiber strength in the U.S. cotton crop (Table 2). DP 445BG/RR has DP 50BG/RR (PVP, 9800205) as the recurrent parent. DP50 was not known for its high fiber strength. National test data did not include DP 449BGRR which may have above average fiber strength. FM 960B2R (PVP, 200500109) has the same pedigree as FM 960BR so we can assume the same source of high fiber strength genes, i.e., DP 90. We are assuming that some transgressive segregation occurred in the breeding of DP 445BG/RR though epistasis could also have played a role.

FM 9170B2F (PVP, 201000275) and FM 9180B2F (PVP, 200800194) were some of the main cultivars with high fiber strength grown in the year 2010. FM 9180B2F has as its donor parent FM 958. There is no information on the parents of FM 9170B2F; however, it is assumed that its pedigree traces back to the Australian breeding program (Table 2)..

Fiber length. The trend of the U.S. cotton crop for UHML is evident in Figure 2.

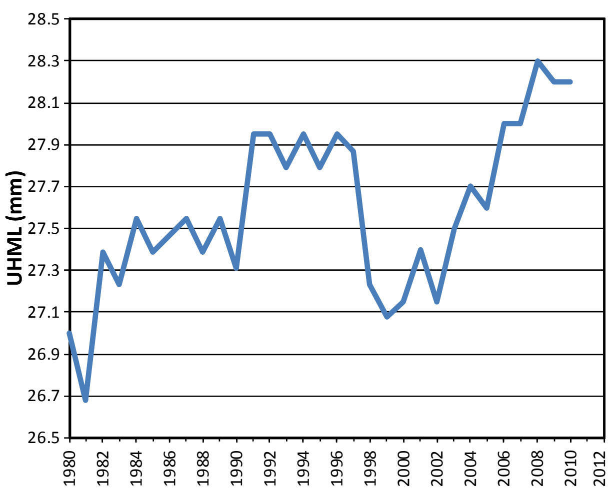

Figure 2. Changes in UHML from 1980 to 2010 in US cotton.

Fiber length has increased 4% with some of that increase occurring in the last five years. In the study by Bowman and Gutierrez (2003), the authors regressed fiber length on years from 1980 to 2000 and found no significance. Regressing length on years from 1980 to 2010 produced a small but significant 'b' value of 0.025 ($p=0.05$). However, when UHML was regressed on years from 1980 to 1997, a highly significant improvement in length with a $b=0.056$ ($p<0.0001$) was found. Further, regressing UHML on years from 2000 to 2010 gave a highly significant $b=0.12$ ($p<0.0001$).

Starting in 2006 UHML values were greater than any recorded in previous years. Five of the top six most popular cultivars had fibers longer than the U.S. average and may have contributed to the improvement in fiber length. However, the longest fibers were from commercial elite cultivars, FM 960B2R, FM 958, and FM 960BR. By this time, the Bayer CropScience Fiber Max (FM) cultivars had occupied over 26% of the U.S. market, while there were many cultivars that occupied less than 2% each

In 2007, the top cultivars (Table 1) had fibers longer than the U.S. average of 28 mm. Cultivars FM 9063B2F (PVP, 200700178), FM 960B2R, and FM 9058F (PVP, 200700206) exhibited the longest UHML, and FiberMax cultivars were planted on more than 29% of the cotton area.

In 2008 cultivar DP 164 B2RF (PVP, 200700010) joined the ranks of the most popular cultivars planted and it had longer than average fibers; its pedigree traces to Acala material, which usually is longer than the rest of the U.S. Upland cotton crop. In 2009, all of the most popular cultivars had longer than average UHML. In 2010 the longest fibers, within the popular cultivars, were produced by the FiberMax cultivars and DP 555BG/RR (PVP, 200200047) and contributed to the improvement of the U.S. cotton crop average UHML.

Thus part of the improvement in fiber length from 2000 to 2010 can be attributed to material from the Australian breeding programs. All of the FiberMax cultivars in Table 2 exhibited UHML longer than the national average and consistently had some of the longest fibers in cultivar trials (USDA-ARS1993-2010).

An additional cultivar that contributed to improved fiber length during this time frame was DP 555BG/RR, which produced above-average UHML and was grown on more area than any other cultivar from 2003 through 2009. However, its fiber length was not as long as the FiberMax cultivars. One of the parents of DP 555BG/RR came from the Australian breeding program where the FiberMax material originated (Bowman et al., 2007). Even though the genetic correlation between UHML and micronaire has generally made it difficult to combine long fibers with yield, the Australian breeding programs apparently have been successful in this effort.

Attempts to learn the basis for the success of the Australian breeding program were fruitless. Of the cultivars listed above for FiberMax, very few pedigrees were available in Bowman et al. (2007) and those that are listed trace back to material with little or no information. It is reported that Deltapine 90 and Tamcot SP37H are in the pedigree of some of that material (Bowman et al., 2007). Deltapine 90 was bred for the Acala market so it had longer than typical Upland fibers. Tamcot SP37H was not known for long or strong fibers.

Micronaire. Regression of micronaire values on year was slightly significant and the trend appears to be upward (7% over years) (Figure 3). As micronaire is known to be positively correlated with lint yield (Culp and Harrell, 1975; Meredith and Bridge, 1971; Meredith, 1984; Smith and Coyle, 1997; Zheng and Meredith, 2009) the increasing trend in micronaire from 2000 to 2010 could be the direct result of selecting for lint yield.

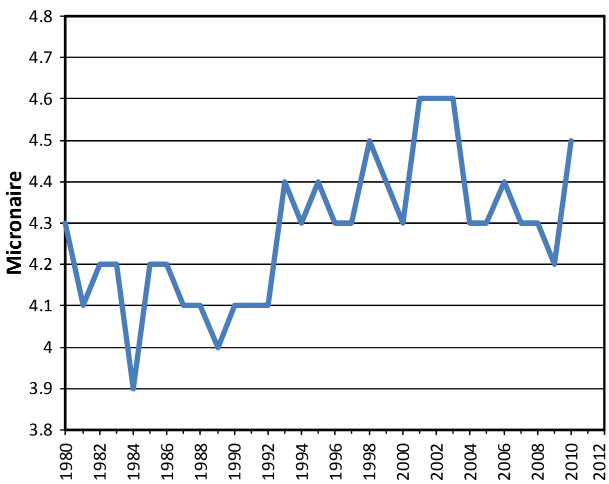

Figure 3. Changes in micronaire from 1980 to 2010 in the US cotton.

It is interesting to note that the Australian breeding program used material from the U.S. to generate excellent cultivars with high yield and high quality fiber. Further, it is encouraging that in spite of the suggested narrow genetic base, fiber quality has been improving for the last two decades. We suspect the trends in genetic gains for longer, stronger fibers will continue.

DISCLAIMER

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