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# BREEDING AND GENETICS

## Sources of Fiber Strength in the U.S. Upland Cotton Crop from 1980 to 2000

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### ABSTRACT

**The U.S. cotton (*Gossypium hirsutum* L.) crop had shown remarkable improvements in fiber strength until the late 1990s. At the same time, concerns about the lack of genetic diversity had been raised. The objective of this study was to discern the sources of improved fiber strength and decline during the 1980s and 1990s. Using data from the USDA-Agricultural Marketing Service on area planted to commercial cultivars, pedigree information, and fiber data from the USDA-ARS Regional Cotton Variety Testing Program, the most popular cultivars, their pedigrees, and their fiber strength were discerned. The source of fiber strength genes was determined by examining pedigrees. The Acalas, particularly from New Mexico State University, accounted for half of the fiber strength improvements during this period. Transgressive segregation accounted for 25% of the improvements, while the USDA-ARS Pee Dee Program supplied 12.5% of the high fiber strength genes. The decline in fiber strength improvement from 1995 to 2000 was the result of backcrossing to existing cultivars to produce transgenic cultivars, which accounted for the bulk of the hectarage in the latter part of the 1990s.**

Recently, there has been renewed interest in genetic diversity in cotton (*Gossypium hirsutum* L.). Stagnation in improvements in cotton yield is thought to be the result of a narrow germplasm base, i.e. lack of genetic diversity in breeding programs, among other factors (Lewis, 2001). May et al. (1995) predicted a decline in long-term gains in lint yield and fiber quality based on a narrow gene base, but only a year before, based on a history of genetic gains by breeders, Culp (1994) concluded that the trend for improved cotton yields should continue,

Declines in grower yields in the 1990s have been attributed to a lack of progress by breeders, but there was a general decline in grower yields (-0.92 kg ha$^{-1}$ year $^{-1}$), while there was a positive genetic improvement in lint yield (around 10.4 kg ha$^{-1}$ year $^{-1}$) from 1960 to 1980 (Meredith and Bridge, 1984). This implies that there were other factors involved in the decline of grower yields.

Limited genetic diversity may restrict genetic progress. Bowman et al. (1996) used pedigree information to calculate an average coefficient of parentage between 260 upland cotton cultivars to be 0.07, which suggests that the germplasm base is not as narrow as many breeders originally thought. Field uniformity, on the other hand, has increased over the years (Van Esbroeck et al., 1998). Field uniformity is defined as the relatedness of any two plants selected at random in a growers' fields. This is the best indicator of genetic vulnerability of the crop. Genetic variability does exist although it may not be evident in the pedigrees of many commercial cultivars (Van Esbroeck and Bowman, 1998). This would explain the upward trend in field uniformity, i.e. breeders find that their most successful releases tend to come from less diverse parents. Private breeders primarily use in-house germplasm and commercial cultivars (84%) in their breeding programs (Bowman, 2000). Only 1% of their parental sources are genetic materials that one would label as exotic or truly diverse. Germplasm lines rarely show up in pedigrees of successful commercial cultivars unless they were developed in-house by the breeder. Van Esbroeck and Bowman (1998) clearly showed that genetic progress for yield could be made from closely-related parents. Either genetic variability existed or was created during the breeding process. Gains during the reselection process are most likely attributed to residual heterozygosity, or more rarely, favorable spontaneous mutations. From 1987 to 1996, 25% of the successful cultivars were derived from direct reselection of existing cultivars.

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Significant gains in fiber strength in the past, followed by a more recent decline in fiber strength of the U.S. cotton crop, have been documented (USDA-AMS, 1980 - 2000a). This brings up the question of the source for the improvement of fiber strength. Did breeders bring in alleles from exotic germplasm, i.e. did they make wide crosses to make improvements? Did these alleles from exotic sources come from crosses made several generations prior to the final cross? Was there sufficient genetic variability in the existing gene pool to allow for improvements in fiber quality? Did the alleles for improved strength arise from spontaneous mutations? Did transgressive segregation play a role?

Although it has not been well documented, it is generally thought that the sources of strength for upland cotton came from the USDA-ARS Pee Dee Program, and the Del Cerros and Acalas from New Mexico and California (Gannaway, 1981). Meredith (1992) developed 'MD51ne', which had high fiber strength. The high fiber strength was attributed to a germplasm line FTA 263, developed by the USDA-ARS Pee Dee Program from exotic sources. Since MD51ne was not planted extensively, it did not impact USDA figures for fiber quality. Transgressive segregation for improved fiber strength has rarely been reported in the literature. Abdel-Nabi et al. (1965) only found one transgressive segregate out of 1731 $F_3$ plants from a high fiber strength Acala by a low fiber strength upland cross. Although this may be a rare occurrence, it could be a major source of fiber strength improvement from U.S. cotton cultivars.

The objectives of this study were 1) to determine the source of fiber strength in the U.S. crop from 1980 to 2000, and 2) to examine the reason for the decline in fiber strength from 1995 to 2000.

## MATERIALS AND METHODS

High Volume Instrument (HVI) fiber data on the U.S. crop from 1980 to 2000 were obtained from the USDA classing offices (USDA-AMS, 1980-2000a) (Table 1). Fiber data included upper half mean (UHM) span length, strength, and micronaire

**Table 1. Fiber quality of upland cotton from 1980-2000 in the United States**

| | Fiber trait[z] | | | |
|---|---|---|---|---|
| Year | Length (mm) | Strength (g/tex) | Micronaire | Length uniformity index (%) |
| 1980 | 27.00 | 24.0 | 4.3 | - |
| 1981 | 26.68 | 24.1 | 4.1 | - |
| 1982 | 27.39 | 25.6 | 4.2 | - |
| 1983 | 27.23 | 25.7 | 4.2 | - |
| 1984 | 27.55 | 26.1 | 3.9 | - |
| 1985 | 27.39 | 25.4 | 4.2 | - |
| 1986 | 27.47 | 25.9 | 4.2 | - |
| 1987 | 27.55 | 27.1 | 4.1 | - |
| 1988 | 27.39 | 25.8 | 4.1 | - |
| 1989 | 27.55 | 26.8 | 4.0 | - |
| 1990 | 27.31 | 26.3 | 4.1 | - |
| 1991 | 27.95 | 27.5 | 4.1 | 81.4 |
| 1992 | 27.95 | 27.7 | 4.1 | 81.4 |
| 1993 | 27.79 | 28.5 | 4.4 | 81.5 |
| 1994 | 27.95 | 28.5 | 4.3 | 81.2 |
| 1995 | 27.79 | 29.1 | 4.4 | 81.2 |
| 1996 | 27.95 | 28.4 | 4.3 | 81.4 |
| 1997 | 27.87 | 28.9 | 4.3 | 81.5 |
| 1998 | 27.23 | 28.0 | 4.5 | 81.3 |
| 1999 | 27.08 | 28.3 | 4.4 | 81.4 |
| 2000 | 27.15 | 27.7 | 4.3 | 81.1 |

[z] Determined by HVI ; source: USDA-Agricultural Marketing Service; length uniformity was not available until 1991.

that were averaged across all cultivars across the entire U.S. Cotton Belt. Length uniformity index (HVI data) became available in 1991. Data were regressed over years to determine significant trends.

We chose to examine cultivar information only for the years 1980, 1985, 1990, 1995, and 2000. Typically, major changes in the cultivars that are grown do not occur from year to year, but should be evident every 5 yr.

Data on cultivars planted to 1% or more of total cotton hectarage were gathered from the USDA Agriculture Marketing Service (USDA-AMS, 1980b, 1985b, 1990b, 1995b, 2000b). Pedigree information was obtained from Calhoun et al. (1997). Fiber data for individual cultivars were obtained from respective publications of the USDA-ARS Regional Cotton Variety Testing Program (USDA-ARS, 1980, 1985, 1990, 1995, 2000).

Cultivars that occupied 1% or more of the total cotton hectarage and had fiber strength numerically above the national average were deemed to have contributed to the increase or positive improvement in this fiber trait. Conversely, for the year 2000, those popular cultivars that had fiber strength below the national average were deemed to have contributed to a decrease in strength. Pedigrees were then examined to determine a possible source of genes for fiber strength. If one or more parents in the pedigree of a successful cultivar were characterized as having high fiber strength, that parent(s) was assumed to be the source of genes for fiber strength. If neither parent had high fiber strength, i.e. the resulting progeny had higher fiber strength than either parent, than high fiber strength was deemed to have resulted from transgressive segregation, i.e. a unique combination of alleles. The same approach was used for progeny with fiber strength lower than either parent.

## RESULTS AND DISCUSSION

Average fiber strength improved from 24.0 g $tex^{-1}$ in 1980 to 29.1 in 1995, a 21% increase (Table 1). Fiber strength declined from 1995 to 2000 ($P$ = 0.04). Micronaire, which is highly influenced by the environment, showed a significant upward trend ($P$ = 0.007), but this fiber trait is not examined in this manuscript. Length uniformity index (LUI) showed a very slight decline from 1990 to 2000, but the relationship was not significant. Since fiber strength was the fiber characteristic showing the most change in this time frame, it is the focus of this study.

Since 1980 was the beginning date for comparisons, 1985 became the first year for examination. Successful cultivars in 1985 that had higher fiber strength compared with the 1980 averages included one Acala (‘GC 510’), two Texas cultivars (‘SR 383’ and ‘Paymaster 145’), and two Delta cultivars (‘Deltapine 41’ and ‘Stoneville 506’) (Table 2). From examination of pedigrees, it appeared that the improved strength of GC 510 came from two New Mexico Acalas (NMB 3080 and Acala 4-42-71) (Table 3). The high fiber strength of Paymaster 145 was derived from a direct selection out of ‘Tamcot SP-21’, a low strength cultivar. Apparently, Tamcot SP-21 possessed a degree of variability for fiber strength. It is not known whether SR 383 received high strength alleles from CA 1073 that was developed by the program at Texas A & M University in Lubbock. The parents of the two Delta cultivars, Deltapine 41 and Stoneville 506, had lower fiber strength than their progeny, so we suspect they were transgressive segregates.

In 1990, two Delta, one Western, and one Texas cultivar contributed to improved fiber strength in the U.S. crop (Table 2). The source of high lint strength for ‘DES 119’ came from the USDA-ARS Pee Dee Program (PD 2164) via DES 2134-047. The triple hybrids from John Beasley’s program provided the high strength alleles in the Pee Dee materials. ‘Stoneville 453’ is another example of a transgressive segregate that had higher strength than either parent. ‘Paymaster HS26’ attained its high fiber strength genes from ‘Acala SJ-4’; this is an example of using one parent outside the region of adaptation to produce a successful cultivar (Meredith and Brown, 1998). Line 6022-4-4 from the University of Arizona, which had an Acala background, is thought to be responsible for the strength genes in ‘Deltapine 90’. Deltapine 90 was developed for the Acala market but failed to meet the standards required for release as an Acala. John Cotton Polycross also may have contributed to fiber strength in Deltapine 90 because it was composed of New Mexico Acalas, as well other germplasm.

By 1995, fiber strength had reached its peak in this study (Table 1). Seven cultivars contributed to improved lint strength over the 1990 average (Table 2). Two were developed for the Texas Plains, ‘All Tex Atlas’ and ‘HS 200’. Three were developed in the West, 'Deltapine 5415', 'Deltapine 5690', and 'Paymaster HS46', although they were planted heavily in the Delta. Two were developed for the Delta, 'Stoneville LA887' and 'Sure-Grow 501'. The Acalas were the source of high strength genes for the Plains cultivars (Table 3). Deltapine 90 was the source for the three western cultivars. The high strength genes in Stoneville LA887 came from LA 434 RKR, which acquired its fiber strength genes from Bayou 7769. Bayou 7769 apparently was a transgressive segregate from a cross of 'Deltapine 15' and 'Clevewilt 6' (Jack Jones, personal communication). Sure-Grow 501 attained its lint strength genes from both parents, which originated in PD 2164.

The decline in fiber strength from 1995 through the 2000 in the U.S. crop can be traced to large hectarages of transgenic cultivars developed through a backcross program (Table 2). The exception was 'Paymaster 1218BR', which appears to be a transgressive segregate (Table 3). Even though Deltapine 5415 and Stoneville 453 were recognized in earlier years for contributing to improved lint strength, these cultivars contributed to the decline in fiber strength in the U.S. crop in 2000 by producing a lower fiber strength than the average for 1995. 'Stoneville 474' was a high-yielding stable cultivar and proved to be a successful cultivar, which is why the company used it in their transgenic program.

In summary, half of the influential donors that resulted in fiber strength improvement were Acalas. Four of the 16 influential donors were simply the result of transgressive segregation. In other words, 25% of the cultivars with improved fiber strength had unique gene combinations that were not expected. This shows that the current upland genome has great capacity and improvements should be attainable without bringing in new alleles. There are over 2,000 loci for fiber quality (Ben Burr, personal

**Table 2. Pedigrees or recurrent parent of influential cultivars in 1985, 1990, 1995, and 2000**

| Cultivar | Pedigree/recurrent parent |
|---|---|
| ---------- 1985 ---------- | |
| GC 510 | CGTE/NMB 3080//NM 7403/Acala 4-42-71 |
| Deltapine 41 | Deltapine 55/Stoneville 603 |
| Paymaster 145 | Tamcot SP-21 (selection) |
| SR 383 | Deltapine SR5/CA 1073 |
| Stoneville 506 | Stoneville 7/Stoneville X1834 |
| ---------- 1990 ---------- | |
| DES 119 | DES 24/DES 2134-047 |
| Deltapine 90 | 6022-4-4/Deltapine 16//John CottonPolycross/Deltapine 16 |
| Paymaster HS26 | Acala SJ-4/5B9-184 |
| Stoneville 453 | Stoneville 603/Stoneville 213 |
| ---------- 1995 ---------- | |
| All Tex Atlas | CA 3006/Paymaster HS 26 |
| Deltapine 5415 | Deltapine 50/Deltapine 90 |
| Deltapine 5690 | Deltapine 90/Deltapine 80 |
| Paymaster HS 46 | AZ 7209/Deltapine 90 |
| Paymaster HS 200 | 107X329 123171-74/160X145145521 |
| Stoneville LA 887 | DES 119/LA 434 RKR |
| Sure-Grow 501 | DES 119/DES 237-7 |
| ---------- 2000 ---------- | |
| Deltapine 458BR | Deltapine 5415 |
| Paymaster 1218BR | H1220*2/H1215/BG//H1220*4//LA 887/RR donor |
| Sure-Grow 125BR | Sure-Grow 125 |
| Stoneville 474 | Stoneville 453/DES 119 |
| Stoneville BXN 47 | Stoneville 474 |
| Stoneville 4691 B | Stoneville 474 |

**Table 3. Assumed donor of lint strength for influential cultivars for 1985, 1990, and 1995, and lack of improved lint strength for 2000**

| Cultivar | Donor |
|---|---|
| ---------- 1985 ---------- | |
| GC 510 | NMB3080 and Acala 4-42-71 |
| Deltapine 41 | Transgressive Segregate |
| Paymaster 145 | Suspect mutations or residual heterozygosity |
| SR 383 | Ca 1073?? |
| Stoneville 506 | Transgressive segregate |
| ---------- 1990 ---------- | |
| DES 119 | DES 2134-047 (PD 2164) |
| Deltapine 90 | 6022-4-4 |
| Paymaster HS26 | Acala SJ-4 |
| Stoneville 453 | Transgressive segregate |
| ---------- 1995 ---------- | |
| All Tex Atlas | Acala SJ-4 |
| Deltapine 5415 | Deltapine 90 |
| Deltapine 5690 | Deltapine 90 |
| Paymaster HS 46 | Deltapine 90 + AZ 7209 |
| Paymaster HS 200 | Acalas B4364 and B3080 |
| Stoneville LA887 | LA 434RKR (transgressive segregate) |
| Sure-Grow 501 | DES 119 and DES 237-7 (PD 2164) |
| ---------- 2000 ---------- | |
| Deltapine 458BR | Deltapine 5415 |
| Paymaster 1218BR | Transgressive segregate |
| Sure-Grow 125BR | Sure-Grow 125 |
| Stoneville 474 | Stoneville 453 |
| Stoneville BXN47 | Stoneville 453 |
| Stoneville 4691NB | Stoneville 453 |

communication), so possibilities for recombination are tremendous. The USDA-ARS Pee Dee Program was responsible for contributing 12.5% to improve the fiber strength in the cultivars, and could be considered an exotic source of alleles.

In terms of breeding programs, the Acala germplasm from New Mexico State University has had the most influence on improving fiber quality. This influence extended to cultivars grown in the Plains of Texas, the Delta, and the Southeast.

The decline in fiber strength from 1995 to 2000 was the direct result of seed companies using parents that had lower fiber strength than the national average in 1995 in their transgenic breeding programs. Until the transgenic cultivar development programs start using higher strength cottons as their recurrent parents, fiber strength will either decline or remain stagnant in the U.S. crop.

The anecdotal evidence from Abdel-Nabi et al. (1965) suggests that large segregating populations are needed to identify the transgressive segregates. Currently, most cotton breeders only look at 1,000 $F_2$ and $F_3$ plants from each genetic combination (Bowman, 2000). Larger segregating populations with fewer genetic combinations to maintain the same effort level would be in order.

## REFERENCES

Abdel-Nabi, H., J.E. Jones, and K.W. Tipton. 1965. Studies on the inheritance of fiber strength and fiber elongation in the F3 generation of a cross between two varieties of Upland cotton. p. 80-89. In Proc. Cotton Improvement Conf., Atlanta, GA, 12-13 Jan. 1965. Natl. Cotton Counc. Am., Memphis, TN.

Bowman, D.T. 2000. Attributes of public and private cotton breeding programs. J. Cotton Sci. 4:130-136 [Online]. Available at http://journal.cotton.org/2000/issue02/article09.pdf

Bowman, D.T., O.L. May, and D.S. Calhoun. 1996. Genetic base of upland cotton cultivars released between 1970 and 1990. Crop Sci. 36:577-581.

Calhoun, D.S., D.T. Bowman, and O.L. May. 1997. Pedigrees of upland and pima cotton cultivars released between 1970 and 1995. Miss. Agric. For. Exp. Stn., Bull. #1069. Mississippi State, MS.

Culp, T.W. 1994. Genetic contributions to yield in cotton. In G.A. Slafer (ed.) Genetic improvement of field crops. Marcel Dekker Inc., New York.

Gannaway, J.R. 1981. Breeding for high strength cotton. Textile Res. J. 52:31-35.

Lewis, H. 2001. A review of yield and quality trends and components in American upland cotton. p. 1447-1453. In Proc. Beltwide Cotton Conf., Anaheim, CA, 10-13 Jan. 2001. Natl. Cotton Counc. Am., Memphis, TN.

May, O.L., D.T. Bowman, and D.S. Calhoun. 1995. Genetic diversity of U.S. upland cotton cultivars released between 1980 and 1990. Crop Sci: 35:1570-1574.

Meredith, W.R., Jr. 1992. Improving fiber strength through genetics and breeding. p. 289-303. In C.R. Benedict and G.M. Jividen (ed.). Proc. Cotton Fiber Cellulose: Structure, Function, and Utilization Conference. Natl. Cotton Counc. Am., Memphis, TN.

Meredith, W.R., Jr., and J.S. Brown. 1998. Heterosis and combining ability of cottons originating from different regions of the United States. J. Cotton Sci. 2:77-84 [Online]. Available at http://journal.cotton.org/1998/issue03/cot_imp/art01/article.pdf

Meredith, W.R., Jr., and R.R. Bridge. 1984. Genetic contributions to yield changes in upland cotton. p. 75-87. In W.R. Fehr (ed.) Genetic contributions to yield gains of major crop plants. ASA Spec. Publ. AC32243. ASA, Madison, WI.

USDA - Agricultural Marketing Service. 1980 - 2000a. Fiber and processing tests. Survey of leading cotton varieties. 1980 - 2000 crop. USDA-AMS, Memphis, TN.

USDA - Agricultural Marketing Service. 1980 - 2000b. Cotton varieties planted-1980 - 2000 crop. USDA-AMS, Memphis, TN.

USDA - Agricultural Research Service. 1980. Regional cotton variety tests. USDA-ARS, Stoneville, MS.

USDA - Agricultural Research Service. 1985. Regional cotton variety tests. USDA-ARS, Stoneville, MS.

USDA - Agricultural Research Service. 1990. Regional cotton variety tests. USDA-ARS, Stoneville, MS.

USDA - Agricultural Research Service. 1995. Regional cotton variety tests. USDA-ARS, Stoneville, MS.

USDA - Agricultural Research Service. 2000. Regional cotton variety tests. USDA-ARS, Stoneville, MS.

Van Esbroeck, G.A., and D.T. Bowman, 1998. Cotton germplasm diversity and its importance to cultivar development. J. Cotton Sci. 2:121-129 [Online]. Available at http://journal.cotton.org/1998/issue02/cot_imp/art01/article.pdf

Van Esbroeck, G., D.T. Bowman, D.S. Calhoun, and O.L. May. 1998. Changes in the genetic diversity of cotton in the USA from 1970 to 1995. Crop Sci. 38:33-37.