2005 Beltwide Cotton Conferences, New Orleans, Louisiana - January 4 - 7, 2005

GENETIC IMPROVEMENT OF NEW MEXICO ACALA COTTON GERMPLASM AND THEIR GENETIC DIVERGENCE

Jinfa Zhang, Y. Lu and H. Adragna
Department of Agronomy and Horticulture, New Mexico State University
Las Cruces, NM
E Hughs
Southwest Cotton Ginning Lab
Mesilla Park, NM
R. G. Cantrell
Cotton Incorporated
Cary, NC

Abstract

The New Mexico cotton breeding program was established in 1926 and has been led by five generations of breeders and geneticists (G. N. Stroman, G. Staten, D. Davis/N. Maim, R. G. Cantrell, and Jinfa Zhang). The program has released more than 30 Acala 1517 cotton cultivars (Table 1) and numerous germplasm lines known for high fiber quality and Verticillium wilt tolerance. The present project was initiated in 2003 to evaluate the genetic improvement of Acala 1517 cultivars and lines released over the past 75 years in yield, boll size, seed index, lint percentage, fiber length, fiber strength, and micronaire. Their genetic divergence was also estimated using simple sequence repeat (SSR) markers. Based on the data available from annual yield trials, lint yield and lint percentage in Acala 1517 cotton have been steadily increased since 1930-1940, while boll size and seed index have been gradually reduced since the 1960s. Fiber strength has been enhanced since the 1960s, which has been accompanied by steady increase in micronaire. However, fiber length in Acala 1517 cultivars was seen a tendency of reduction from 1.22 to 1.18 inch from 1960 to 1990, whereas newly released Acala 1517 cultivars (Acala 1517-95, 1517-99, 1517-02, 1517-03, and 1517-04) have fiber greater than 1.20 inch. Genetic distance among Acala 1517 genotypes ranged from 0.06 to 0.38 with an average of 0.18 based on 189 SSR marker alleles, indicating a substantial genetic diversity among Acala 1517 cotton germplasm. Divergent germplasm introgression in the program has contributed to genetic diversity of Acala cotton germplasm and continuous genetic gain in Acala cotton cultivar improvement.

Discussion

Comparing performance of obsolete and current cultivars and analyzing annual variety trials not only provide detail information on genetic gain in yield and fiber quality improvement, but also shed light into trends of trait changes over time. This should enable breeders and geneticists to evaluate breeding progress that has been achieved, and review and design their breeding strategies in terms of parental line selection, population development, and selection methods. Annual variety trials usually have more than two years data across multiple locations, which provide reliable estimates on performance of newly released cultivars and breeding lines, and also can accommodate many more lines to be compared. However, the drawbacks are that, except that at least two common standard cultivars should be used during consecutive testing years, genotype x environment interaction could have different effects on performance of different cultivars. Furthermore, this analysis assumes that tested cultivars and standards have similar linear responses to environments, so that yield and other traits for tested cultivars can be linearly adjusted based on the common standards. After comparing obsolete and modern cotton cultivars grown in the Mississippi Delta, Bridge et al. (1971) and Bridge and Meredith (1983) indicated that higher-yielding modern cultivars had higher lint percentage, smaller bolls and seed, and higher micronaire values. Yield improvement over time was mainly due to the increase in lint percentage, number of bolls per plant, and early maturity (Bridge et al., 1971; Hoskinson and Stewart, 1977; Wells and Meredith, 1984c; Culp and Green, 1992). Fiber length and strength showed little change over time, except that fiber strength in the Pee Dee germplasm was enhanced (Culp and Green, 1992). In the present study, based on the data available from annual yield trials in New Mexico, our analysis shows that lint yield and lint percentage in Acala 1517 cotton have been steadily increased at a rate of 1.4% and 0.04% since 1930-1940, respectively, while boll size and seed index have been gradually reduced since the 1960s. Yield improvement can be divided into two periods, 1930-1982 and 1982-2004. In the first period, the genetic gain in yield improvement was 0.77% per year, which agreed with the estimated national average (0.74%) by Meredith and Bridge (1982). However, due to the long-lasting concerted effort of four scientists including three breeders/geneticists and one agronomist in the 1980s, the breeding progress in yield improvement was accelerated and the trend has been maintained since the 1990s. The genetic gain in lint yield improvement was estimated to be

3.1% in the second period. Fiber strength has also been improved since the 1960s, which has been accompanied by steady increase in micronaire values. However, fiber length in Acala 1517 cultivars was seen a tendency of reduction from 1.22 to 1.18 inch from 1960 to 1990, whereas newly released Acala 1517 cultivars (Acala 1517-95, 1517-99, 1517-02, 1517-03, and 1517-04) have fiber greater than 1.20 inch. Therefore, our analysis on the statewide annual variety trials generally agrees with the previous findings for other regions. However, no yield plateau in the breeding program has been noticed. In fact, an accelerated genetic gain in yield improvement in New Mexico Acala cotton germplasm has been achieved since the early 1980s. Further field tests will be conducted to more accurately estimate the genetic gains sustained in the Acala cotton germplasm.

According to the data provided by Culp and Green (1992), number of seed per boll remained unchanged, while seed size was gradually decreased. This should have relatively increased seed surface area per boll for lint fiber production. Since fiber length is largely unchanged, increased lint percentage in modern cultivars was either due to more fiber number per boll (or per seed) or heavier fiber (coarser) or both. Based on our analysis, lint percentage and micronaire value have been concurrently increased over years, whereas fiber length did not follow the same pattern. Therefore, coarser not longer fiber was the main contributing factor to higher lint percentage in the New Mexico Acala cotton germplasm improvement. Historically, obsolete Acala cotton had significantly larger bolls and seed, finer fiber, and lower lint percentage than other short staple commercial cultivars. However, the newly released high-yielding Acala cotton cultivars have comparable small boll and seed size, and high lint percentage and micronaire readings. Even though their yield potential has been substantially increased, the tendency in unintentionally reducing seed size and fiber fineness should be reversed. Otherwise, low seed germination and seedling vigor due to small seed could become an adverse factor in cotton production. The lint price premium in the market that Acala cotton growers have been enjoying could disappear if Acala cotton fiber does not meet the quality standards. How to increase lint yield in Acala cotton while maintaining its current high lint percentage and fiber quality presents a tremendous challenge. Measures in cotton breeding should be also taken to prevent new cultivars from further reduction in boll and seed size and increase in micronaire.

Several strategies in further improving lint yield through breeding could be envisioned. First, increasing boll number per plant or per unit planting area should be paid more attention since the other two yield components, boll size and lint percentage cannot be unrestrictedly increased. Studies by Wells and Meredith (1984a, b, c) and Meredith and Wells (1989) have provided some clues for further improving cotton yield. They found that high yield in modern cultivars was due to two mechanisms in selection processes: (i) greater dry matter was partitioned into reproductive organs and therefore higher harvest index; and (ii) greater reproductive organs (squares, flowers and bolls) were produced during early reproductive development stage. Meredith and Wells (1989) suggested that "yield increases through the use of conventional breeding methods are likely to be achieved through continued partitioning of dry matter from vegetative to reproductive structure". Wells and Meredith (1984a) and Heitholt et al. (1998) indicated that leaf area indexes and net assimilation rates were not responsible for yield improvement in modern cultivars under different conditions (e.g., years, locations, and nitrogen levels). However, Pettigrew and Meredith (1994) showed a significant positive but small association between lint yield and leaf CO2-exchange rate on 18 cotton genotypes during the boll filling period, indicating that some cotton breeders may have inadvertently selected for increased photosynthesis while breeding for higher yielding genotypes. Lu et al. (1994) and Faver et al. (1997) reported that modern high-yielding Pima cultivars had reduced leaf area, higher photosynthetic capacity, and stomatal conductance than obsolete cultivars under semi-arid field and water stress conditions. Therefore, photosynthetic rate can be increased to develop new high-yielding Acala cultivars.

The second strategy is to increase number of fibers per boll or per seed. Boll size is composed of seed number, seed size, number of fibers per seed, fiber length, and micronaire, i.e., unit weight per unit length fiber. Seed number per boll is limited by total ovules and reducing ovule abortion can increase number of mature seed, but the room is very limited. Due to the reasons as indicated before, seed size might not be further reduced. Micronaire should be maintained if not reduced; otherwise, its further increase could result in penalty in fiber pricing. Even though logically, longer fiber could increase fiber yield, fiber length beyond certain point is negatively associated with lint yield. Therefore, improving fiber length is not a viable option for yield improvement. This only leaves one option open, i.e., increasing number of fibers per seed or per boll. This could lead to increase in boll size or/and lint percentage if seed size and other boll components are not genetically altered. Cotton genotypes differ in number of fiber initials and mature fibers, and short fiber content (Bowman et al., 2001). To achieve the goal of increasing number of lint fibers, cotton breeders can either increase the number of lint fiber initials or reduce the short fiber content, or both. Van't Hof (1998) developed a technique that makes it possible to count the number of fiber cell initials on the ovules. However, a reliable and simple method in measuring fiber number is needed for a practical use. Currently, number of fibers per seed can be indirectly estimated based on lint index, fiber length, and micronaire. But the indirect measurements could result in higher experimental error and unreliable selection in breeding.

In New Mexico, verticillium wilt (*Verticillium dahliae* Kleb) and root-knot nematodes [*Meloidogyne incognita* (Kofoid & White) Chitwood] each causes 5% yield loss. A third strategy in yield improvement is to breed and grow Acala cotton cultivars that are resistant to these two major pathogens. Developing and employing resistance cultivars is the most efficient tactic for management of the two diseases. The use of host resistance has the following advantages: (1) yield potential of high-yielding cultivars can be realized by increasing number of bolls per plant due to establishment of uniform field seedling stand, and normal plant growth and development; (2) it offers season long control in suppressing the pathogen population; (3) it eliminates the toxic chemical use, so it is environmentally friendly; (4) it reduces production cost without using specialized machinery and additional fuels in spray; and (5) it can also limit other diseases, such as fusarium wilt [*Fusarium oxysporum* f.sp. *vasinfectum* (Atk.) Snyd. & Hans.]. The current Acala 1517 cultivars have relatively good tolerance to verticillium wilt, but are susceptible to root-knot nematodes (Zhang, unpublished data).

In the arid and semi-arid Southwest U.S. including New Mexico, abiotic stresses, such as drought and heat especially during the summer are constantly encountered during cotton growing season. Cotton productivity is limited because of insufficient plant growth and abscission of reproductive organs (mainly young bolls). Therefore, the fourth strategy in improving cotton yield is to develop Acala cotton cultivars that have promising heat and drought tolerance. So cotton plants can have rapid vegetative growth and establish their canopy for an early transition to reproductive growth. Improving heat tolerance in Acala cotton to reduce boll abscission during summer would substantially increase number of bolls per plants, thus improve lint yield.

Zhang et al (2005a) reported that four most recently released New Mexico Acala cultivars (1517-95, 1517-99, 1517-02, and 1517-03) were as dissimilar to one another as to commercial cultivars from other sources. Compared with other commercial cultivars, Acala 1517-99 was more similar to Acala 1517-95 since both had a common ancestor germplasm (Acala 9130) in the pedigrees. Both were also relatively similar to 1517-03, but these three were highly dissimilar to 1517-02, even though 1517-02 had 1517-95 in its pedigree. In the present study where more than 30 Acala germplasm lines were genotyped, 1517-95 was not grouped together with 1517-99, although they were grouped together with most of the other Acala germplasm to form a giant Acala family.

The earlier Acala germplasm were mainly re-selections from introductions of Mexico, which did not have known germplasm introgression from *G. barbadense*. Interspecific hybridization with Triple Hybrid and *G. barbadense* including Sealand, Pima, and Tanguis was evident in perhaps the late 1930s and 1940s, and out-crossing with *G. barbadense* was also frequent, which resulted in Acala cotton germplasm with verticillium wilt tolerance and better fiber quality. The SSR marker data showed that the more recently released Acala germplasm seemed to contain more common SSR markers with Pima 3-79, while they are more distant from TM-1 (JC = 0.67- 0.76). Early Acala cotton germplasm were closer to TM-1 (JC = 0.72-0.80), and Acala Original and 1064 were even grouped together with TM-1. On average, the Acala cotton shared 2/3 more SSR markers with Pima 3-79 than TM-1 did. Thus, the limited molecular marker data support the notion based on the breeding history that Acala germplasm developed since the 1940s indeed contained genetic introgression from *G. barbadense*.

Another surprising note is that Acala Hopi and NM 24016 were consistently distant to other Acala germplasm (JC = 0.62-0.76 and 0.47-0.63, respectively), indicating their significant divergence from other Acala cottons. NM 24016 was an upland cotton type developed from interspecific hybridization between upland and *G. barbadense* (Cantrell and Davis, 2000). Based on the rDNA and AFLP marker data, Pillay and Myers (1999) grouped NM 24016 together with *G. barbadense*, but not with Acala SJ-2.

The Acala 1517 cotton germplasm developed from the New Mexico cotton breeding program contain desirable genes for larger boll and seed size, high vigor, verticillium wilt tolerance, and fine fiber quality. They are also most genetically diverse from other current commercial cultivars and should be promising sources in breeding to be used as parental lines to broaden genetic variations within upland cotton.

References

Barnes, C.E., D.D. Davis, N.R. Malm, C.L. Roberts & R.L. Wood, 1980. Registration of Acala 1517-77 upland cotton. Crop Sci. 20: 113.

Bowman, D.T., G.A. Van Esbroeck, J. Van't Hof & G.M. Jividen, 2001. Ovule fiber cell numbers in modern upland cottons. J. Cott. Sci. 5: 81-83.

Bridge, R.R., W.R. Jr. Meredith, & J.F. Chism, 1971. Comparative performance of obsolete varieties and current varieties of upland cotton. Crop Sci. 11:29-32.

Bridge, R.R. & W.R. Jr. Meredith, 1983. Comparative performance of obsolete and current cotton cultivars. Crop Sci. 23: 949-952.

Cantrell, R.G., C.L. Roberts, D.D. Davis, C.E. Barnes & N.R. Malm, 1992a. Registration of 'Acala 1517-91'cotton. Crop Sci. 32: 831-834.

Cantrell, R.G., C.L. Roberts, D.D. Davis, C.E. Barnes & N.R. Malm, 1992b. Registration of 'Acala 1517-SR3'cotton. Crop Sci. 32: 1295.

Cantrell, R.G., C.L. Roberts & C.E. Barnes, 1995. Registration of 'Acala 1517-95'cotton. Crop Sci. 35: 1227-1228.

Cantrell, R.G., C.L. Roberts & C. Waddell, 2000. Registration of 'Acala 1517-99'cotton. Crop Sci. 40: 1200-1201.

Cantrell, R.G. & D.D. Davis, 2000. Registration of NM24016, an interspecific-derived cotton genetic stock. Crop Sci. 40: 1208.

Cantrell, R.G. et al., 2001. *In* Smith, C.W. & J.T. Cither, 1999. Cotton. John Wiley and Sons, New York

Culp, T.W. & C.C. Green, 1992. Performance of obsolete and current cultivars and Pee Dee germplasm lines of cotton. Crop Sci. 32: 35-41.

Davis, D.D., N.R. Malm, G. Staten, R.L. Wood, & G.N. Stroman, 1978a. Registration of Acala 1517C cotton. Crop Sci. 18: 163.

Davis, D.D., N.R. Malm, C.L. Roberts, C.F. Chew, C.E. Barnes, G. Staten & R.L. Wood, 1978b. Registration of Acala 1517-70 cotton. Crop Sci. 18: 164.

Davis, D.D., N.R. Malm, C.L. Roberts, C.F. Chew, C.E. Barnes & R.L. Wood, 1978c. Registration of Acala 1517E-1 cotton. Crop Sci. 18: 165.

Davis, D.D., N.R. Malm, C.L. Roberts & C.E. Barnes, 1980. Registration of Acala 1517E-2 cotton. Crop Sci. 20: 113.

Faver, K.L., T.J. Gerik & R.G. Percy, 1997. Modern Pima cultivars have higher photosynthetic capacity than obsolete varieties. Proc. Beltwide Cott. Conf. pp. 1499-1502.

Heitholt, J.J., W.R. Jr. Meredith & S.T. Rayburn, 1998. Leaf area index response of four obsolete and four modern cotton cultivars to two nitrogen levels. J. Plant Nutrition. 21: 2319-2328.

Hoskinson, P.E. & J.M. Stewart, 1977. Field performance of two obsolete cotton cultivars. Proc. Beltwide Cott. Res. Conf. pp.78-79.

Lu, Z. M, J.W. Radin, E.L. Turcotte, R. Percy & E. Zeiger, 1994. High yields in advanced lines of Pima cotton are associated with higher stomatal conductance, reduced leaf area and lower leaf temperature. Physiologia Plantarum 92: 266-272.

Malm, N.R., R.L. Wood, C.E. Barnes & C.L. Roberts, 1975. Variety tests of American Upland cotton, 1965 to 1974. pp1-9.

Malm, N.R., D.D. Davis, C.L. Roberts, C.E. Barnes, R.L. Wood & G. Staten, 1978a. Registration of Acala 1517V upland cotton. Crop Sci. 18: 163-164.

Malm, N.R., D.D. Davis, C.L. Roberts, C.E. Barnes, R.L. Wood & G. Staten, 1978b. Registration of Acala 1517-75 upland cotton. Crop Sci. 18: 164-165.

Malm, N.R., C.E. Barnes, D.D. Davis & C.L. Roberts, 1984. Registration of Acala 1517-SR1 upland cotton. Crop Sci. 24: 382-383.

Malm, N.R., C.E. Barnes, C.L. Roberts & D.D. Davis, 1987. Registration of Acala 1517-SR2 upland cotton. Crop Sci. 27: 382-383.

Meredith, W.R. Jr. & R.R. Bridge, 1982. Genetic contributions to yield changes in cotton. p. 75-87. *In* W.R. Fehr (ed.) Genetic contributions to yield gains of five major crop plants. CSSA Spec. Publ. 7. ASA, Madison, WI. USA.

Meredith, W.R. Jr. & R. Wells, 1989. Potential for increasing cotton yields through enhanced partitioning to reproductive structures. Crop Sci. 29: 636-639.

Pettigrew, W.T., & W.R. Jr. Meredith, W.R., 1994. Leaf gas exchange parameters vary among cotton genotypes. Crop Sci. 34: 700-705.

Pilley, M. & G.O. Myers, 1999. Genetic diversity in cotton assessed by variation in ribosomal RNA genes and AFLP markers**.** Crop Sci. 39: 1881-1886.

Roberts, C.L., N.R. Malm, D.D. Davis & C.E. Barnes,1982. Registration of Acala 1517-77BR upland cotton. Crop Sci. 22: 382.

Roberts, C.L., N.R. Malm, D.D. Davis & C.E. Barnes, 1988. Registration of Acala 1517-88 cotton. Crop Sci. 28: 190-191.

Staten G., 1970. Breeding Acala 1517 cottons, 1926-1970. Memoir Series #4, New Mexico State University.

Van't Hof, J. 1998. Production of micronucleoli and onset of cotton fiber growth. Planta 205:561–566.

Wells, R. & W.R. Jr. Meredith, 1984a. Comparative growth of obsolete and modern cotton cultivars. I. Vegetative dry matter partitioning. Crop Sci. 24: 858-862.

Wells, R. & W.R. Jr. Meredith, 1984b. Comparative growth of obsolete and modern cotton cultivars. II. Reproductive dry matter partitioning. Crop Sci. 24: 863-868.

Wells, R. & W.R. Jr. Meredith, 1984c. Comparative growth of obsolete and modern cotton cultivars. III. Relationship of yield to observed growth characteristics. Crop Sci. 24: 868-872.

Zhang, J.F., Y. Lu & R.G. Cantrell, 2005a. Molecular marker diversity and field performance in commercial cotton cultivars evaluated in the Southwest U.S. Crop Sci. (in press)

Zhang Jinfa, R.G. Cantrell, C. Waddell, and E. Hughs. 2004b. Registration of 'Acala 1517-02' cotton. Crop Sci. (Submitted)

Zhang Jinfa, R.G. Cantrell, C. Waddell, and E. Hughs. 2004c. Registration of 'Acala 1517-03' cotton. Crop Sci. (Submitted)

Zhang Jinfa, R.G. Cantrell, C. Waddell, and E. Hughs, 2004d. Registration of 'Acala 1517-04' cotton. Crop Sci. (Submitted)

Table 1. Acala 1517 cotton cultivars released.

Cultivar	Year Released	Pedigree	Reference
Acala Young*	1929	Watson's	Staten, 1970
College Acala	1930	Acala P12	Staten, 1970
Acala 1064*	1937	Acala Young	Staten, 1970
Acala 1517*	1939	Acala 1064	Staten, 1970
Acala 1517A	1941	Acala 1064	Staten, 1970
Acala 1517WR	1946	Acala 1517	Staten, 1970
Acala 1517B	1949	Watson's Acala	Staten, 1970
Acala 1517C(7133)	1951	NM 1544 x NM 1577	Staten, 1970; Davis et al., 1978
Acala 1517C(8893)	1954	Reselection from 7133	Staten, 1970
Acala 1517BR	1954	ST 20/Acala/1517WR/Acala 1517B	Staten, 1970
Acala 1517-BR1	1957	Acala 1517BR/Acala 1517C	Staten, 1970
Acala 1517C (1028)*	1958	Reselection from 7133	Staten, 1970; Davis et al., 1978
Acala 1517D*	1960	Cross of two strains of unknown parentage	Staten, 1970
Acala 1517-BR2 (B479)	1961	(8373/ST20)/Acala216/(Acala49/Hartsville)	Staten, 1970
Acala 1517V (6612)	1964	Acala 2503/Coquette	Staten, 1970; Davis et al., 1978
Acala 1517-BR2 (60-209B)*	1965	Reselction from Acala1517-BR2	Staten, 1970
Hopicala	1965	Acala 1517 selection 5-12/HA76	Staten, 1970
Acala 3080	1968	9136/49W	Staten, 1970
Acala 1517V (9450)*	1969	Acala 2503/Coquette	Staten, 1970; Davis et al., 1978
Acala 1517-70*	1970	B1413/Hopicala	Staten, 1970; Davis et al., 1978
Acala 1517-75*	1975	Acala 688/Acala 9608	Malm et al., 1975
Acala 1517-77	1977	Reselection from Acala 1517-70	Barnes et al., 1980
Acala 1517-77BR*	1982	Selection from Acala 1517-77	Roberts et al., 1984
Acala 1517-E1	1976	Acala 3080/PD 2165	Davis et al., 1978
Acala 1517-E2*	1978	Selection from Acala 1517 E-1	Davis et al., 1980
Acala 1517-SR1	1982	Acala 1517-E1/Unknown storm-proof	Malm et al., 1984
Acala 1517-SR2	1986	Acala 1517-E1/Unknown storm-proof	Malm et al., 1987
Acala 1517-SR3*	1990	Acala 1517-E1/Unknown storm-proof	Cantrell et al., 1992
Acala 1517-88*	1988	Acala 1517-77BR/DP 70	Roberts et al., 1988
Acala 1517-91*	1991	Acala 8130/Acala 8874	Cantrell et al., 1992
Acala 1517-95*	1995	From 1517-E2 (3080/PD2165)	Cantrell et al., 1995
Acala 1517-99*	1999	B742/E1141	Cantrell et al., 2000
Acala 1517-02	2004	Prema/(Acala 1517-95/GC-362)	Zhang et al., 2005b
Acala 1517-03	2004	B4222/H1014	Zhang et al., 2005c
Acala 1517-04	2004	Acala 1517-95/87D3-24	Zhang et al., 2005d

* Used for SSR fingerprinting