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BREEDING AND GENETICS

Fiber Properties and Mini-spun Yarn Performance of Extra Long Staple Upland Cotton

Kolbyn Joy*, C. Wayne Smith, Eric Hequet, Steve Hague, Peggy S. Thaxton, and Chris Souder

ABSTRACT

Cotton, *Gossypium* spp., fibers are produced primarily by two species, *G. hirsutum* L., upland, and *G. barbadense* L., pima or American Egyptian, which also is referred to as Extra Long Staple (ELS) because the fibers produced are longer, stronger, and finer than those produced by upland. Breeders have sought to introgress the ELS trait from *G. barbadense* into upland with limited success. The Cotton Improvement Laboratory, Texas A&M University AgriLife Research, has developed ELS upland lines through intraspecific upland crosses and subsequent pedigree selection. The purpose of this study was to determine (1) High Volume Instrument (HVI) and the Advanced Fiber Information System (AFIS) fiber properties of eight of these TAM ELS upland strains and (2) spinning performance compared with 'FiberMax 832 LL' (FM 832), a modern, high-quality, upland cultivar. Eight ELS upland lines, along with FM 832, were grown at College Station and Weslaco, TX during 2006 and 2007. Picker-harvested seed cotton was ginned on a laboratory saw gin and the lint was evaluated by HVI and AFIS for fiber quality parameters at the Texas Tech University Fiber and BioPolymer Research Institute. Yarn was produced from each genotype through a mini-spinning protocol. All ELS upland lines exhibited longer ($p < 0.01$) HVI and AFIS length parameters with all other fiber properties not different than FM 832. All ELS lines produced stronger carded 11.8 tex ring-spun yarns than FM 832 with better yarn elongation and yarn hairiness. These ELS lines should be valuable parental material in breeding for improved fiber quality.

K. Joy*, C.W. Smith, and S. Hague, Department of Soil and Crop Sciences, Texas A&M University, 2474 TAMU, College Station, TX 77843-2474; E. Hequet, Fiber and Biopolymer Research Institute, Texas Tech University, PO Box 45019, Lubbock, TX 79409-5019; P.S. Thaxton, 9314 Caddo Springs Ct, Cypress, TX 77433; C. Souder, Monsanto Company, PO Box 244, Spencer, IA 51301
*Corresponding author: kolbynjoy@tamu.edu

The textile industry increasingly has become globalized during the past decade. From 1998 to 2008, U.S. domestic textile consumption of raw cotton dropped from 10.4 million to 3.7 million bales, while exports increased from 7.5 million to 12.5 million bales (Cotton Inc., 2009; USDA, 2008). The U.S. textile market has focused on coarser yarns produced by open-end spinning, whereas the global textile market has demanded finer yarns produced from ring spinning. These different spinning technologies require different types of fiber to produce an optimal yarn (both in terms of productivity and quality). Open-end technology requires cotton fibers with greater fiber bundle strength (Str) to overcome the inherent reduction in yarn strength of open-end yarns and to withstand higher processing speeds. On the other hand, fiber length and uniformity of length distribution are the most important fiber quality parameters affecting yarn quality when ring spun (Smith and Zhu, 1999). Upland cotton with an upper-half mean length (UHML) of 26.7 mm, Str of 250 kN m kg^{-1}, and micronaire (Mic) between 3.5 and 4.9 is considered nondiscount quality in the U.S., whereas 28.2 mm UHML, 265 kN m kg^{-1} Str, and 3.8 to 4.6 Mic are the minimum requirements on world markets (Hequet et al., 2006).

U.S. cotton not only competes in the current global market but faces competition with manmade fibers, which have more predictable and uniform fiber length and strength. Improved UHML, Str, fiber diameter, and fiber maturity of upland cotton fibers could be instrumental in maintaining the competitiveness of U.S.-grown upland cotton in global markets.

Yarn quality parameters such as strength, elongation at break, hairiness, and yarn evenness are correlated strongly with average fiber length (Perkins, et al., 1984; El Mogahzy, 1999; El Mogahzy and Chewning, 2001), and fiber length is critical to manufacturing yarn of specific size on draft spinning systems (Rusca and Reeves, 1968). Spinners require UHML information to set the drafting rollers at the proper distance to avoid yarn unevenness, floating fibers, and yarn breakage (Perkins, et al., 1984; Behery, 1993; El Mogahzy and Chewning, 2001). In ring spinning, long fibers provide more inter-fiber contact that produce friction forces, which enhances yarn strength (El Mogahzy and Chewning, 2001; Balasubramanian, 1995). Since the development of High Volume Instrument (HVI) fiber testing machinery in the 1970s, UHML has been measured as the mean length of the upper 50 percentile of fibers by weight. The HVI system also provides measurements of Mic, which is a combination of fiber diameter and fiber maturity, Str, elongation (Elong) at break, and Uniformity Index (UI), the ratio of the mean length of fibers and the UHML, which gives an indication of fiber length distribution. The Advanced Fiber Information System (AFIS) has allowed for more precise measurements of length and fineness based on either weight or actual number, thus providing breeders with valuable information. However, the AFIS is too slow and costly for most plant breeding programs. The AFIS length measurements reported herein include upper-quartile length by weight (UQLw), mean length by number (Ln), short fiber content by number (SFCn), maturity ratio (MR), standard fineness (Hs), and immature fiber content (IFC). SFCn is the percentage of fibers that are less than 12.7 mm, $MR = \frac{4\pi A_w}{0.577P^2}$ (where A_w is the cell-wall area (cross-sectional area minus lumen area) and P is the fiber perimeter), and Hs is the ratio of average fiber diameter to the MR and is directly related to fiber perimeter as Perimeter = (3.7853) $(Hs)^{1/2}$ (Hequet, 2006). In the AFIS process, fibers are individualized, then passed through a collimated beam of light that scatters the light as they pass through allowing for the detection of individual size and cross-sectional shape (Bragg and Shofner, 1993). For a given yarn count, finer fibers will allow the production of stronger yarns. Cotton fiber maturity has a large influence on individual fiber strength (Hsieh, 1999) and on cotton fabric dye uptake. Maturity measurements, IFC, MR and, indirectly, Mic, are indicators of spinning and dying performance. SFCn and UI are impacted by natural variation in fiber length as well as the amount of mechanical breakage during harvesting, ginning, and spinning processes, which is impacted by Str.

Ultimately the market value of any cotton crop is determined by the quantity produced and its quality. Fiber quality such as strength and diameter affect yarn quality, which affects the types and quality of fabrics that can be produced. Yarn parameters reported herein are based on the mini-spin test developed by Hequet (data not published) on 11.8 tex (50 Ne) carded yarn, i.e., fibers were processed through opening, carding, drawing, and roving (no combing), and ring spun to produce a relatively fine yarn that is at the upper limits of the normal usage of upland fibers. An 11.8 tex yarn is a small diameter yarn and requires 17,455 m yarn to produce 1 kg, compared to a coarser yarn, e.g., denim, in which 1 kg would have 6,284 m of yarn. Yarn parameters reported here are yarn strength, or tenacity (YnTen), yarn elongation at break (YnElong), the work or force required to rupture or break the yarn (YnWork), coefficient of variation for yarn mass (YnCVm), the number of thin places per km of yarn (Thin), the number of thick places per km of yarn (Thick), the hairiness of the yarn (Hair), and the number of neps per km of yarn (YnNeps200).

G. barbadense cultivars are referred to as Extra Long Staple (ELS) and generally produce UHML equal to or exceeding 35 mm, as well as Str and Hs superior to that of upland fibers. The USDA Germplasm Resources Information Network (www.ars-grin.gov/npgs) lists more than 15 *G. hirsutum* germplasm accessions with USDA-determined UHML ranging from 34 to 38 mm (USDA, 2009). These accessions were developed in the early to mid-twentieth century and exhibit lint percents less than 30. Many of these may be the result of introgression with *G. barbadense*. Texas A&M University AgriLife Research recently developed a number of non-introgressed *G. hirsutum* breeding strains, TAM ELS lines, that equal or exceed 35 mm and have slightly improved Str and fineness with all other fiber traits normal for upland cotton (Smith et al., 2009). F_2 populations, derived by crossing only upland genotypes, were identified in 2001 that exhibited HVI UHML ranging from 31 to 32 mm and Str readings of 315 to 370 kN m kg^{-1}. Individual F_3 plants were selected the following year that exhibited UHML of 33 to 36 mm and fiber bundle strength as high as 389 kN m kg^{-1}. Individual plants were again selected within the resulting $F_{3:4}$ progeny rows in 2003 that exhibited UHML as high as 36 mm. Each of those plants formed the basis of an ELS upland strain and progeny rows selected in 2004. Grab samples from machine harvested $F_{4:5}$ progeny rows exhibited UHML from 31 to 37 mm and fiber bundle strengths of 315 to 440 kN m kg^{-1}. Five upland ELS families were thus identified with each having one common parent, TAM 94L-25 (Smith, 2003; PI 631440; Smith et al., 2008)

The purpose of this study was to determine (1) HVI and AFIS fiber properties of eight of these ELS upland strains and (2) spinning performance compared with 'FiberMax 832 LL' (FM 832; Constable et al., 2001), a modern, high-quality, upland cultivar.

MATERIALS AND METHODS

Field Study. Eight TAM ELS upland strains (TAM B182-3 ELS, TAM B182-4 ELS, TAM B182-9 ELS, TAM B182-16 ELS, TAM B182-30 ELS, TAM B182-31 ELS, TAM B182-33 ELS, and TAM B182-34 ELS) and one commercial cultivar, FM 832, were grown in College Station, TX in 2006 and 2007 and in Weslaco, TX in 2007. To produce sufficient quantities of lint for mini-spinning, large, single blocks of each genotype were grown in 2006 and 2007 at the Texas AgriLife Research Farm near College Station, TX on a Weswood silt loam, a fine-silty, mixed, superactive, thermic Udifluventic Haplustepts integrated with Ships silty clay, a very-fine, mixed, active, thermic Chromic Hapluderts, and in 2007 at Weslaco on a Hidalgo fine sandy loam, a fine-loamy, mixed, active, hyperthermic Typic Calciustoll. Plots at College Station in 2006 and 2007 were four rows, 1 m x 120 m, and six rows, 1 m x 18 m at Weslaco in 2007. Genotypes were planted on 20 April 2006 and 8 May 2007 at College Station, and 14 March 2007 at Weslaco. Cultural practices, such as furrow irrigation, weed control, and insect control, including boll weevil, *Anthronomus grandis*, eradication, were normal for each location. Plots were harvested with a one-row spindle picker modified for plot harvest on 17 October 2006 and 3 October 2007 at College Station, and 22 August 2007 at Weslaco. Seed cotton samples were ginned on a 20-saw laboratory gin without lint cleaner and sent to the Fiber and Biopolymer Research Institute in Lubbock, TX for HVI, AFIS, and mini-spinning analyses.

The quantity of lint obtained for each genotype in each location was divided into two samples. An aliquot of approximately 100 g was taken from each sample of each genotype and homogenized by hand prior to HVI and AFIS evaluation. These samples were tested on HVI (HVI 900A, Uster, Knoxville, TN), with 10 repetitions for UHML, UI, Str, and Elong measurements and four repetitions for Mic. AFIS measurements (AFIS, Uster, Knoxville, TN) were averaged over five repetitions of 3,000 fibers.

Lint cleaning was necessary prior to mini-spin fiber processing because no lint cleaning was practiced at the time of ginning. A sample of cleaned lint was taken and tested on HVI and AFIS to ensure that the cleaning sequence used did not have any detrimental effects. Despite the lint cleaning effort, trash content was higher than desired and may have impacted some yarn properties such as Thick and Thin. Mini-spinning was accomplished on a Suessen Elite ring spinning frame following the protocol outlined in Figure 1. Opening, carding, drawing, roving, and ring-spinning machines used were all industrial-type equipment. The yarn count produced was 11.8 tex carded, which is also referred to as 50 count or 50 Ne yarn. The yarns were tested on UT3 (400 m bobbin^{-1} on 10 bobbins), and on Tensorapid (10 breaks bobbin^{-1} on 10 bobbins).

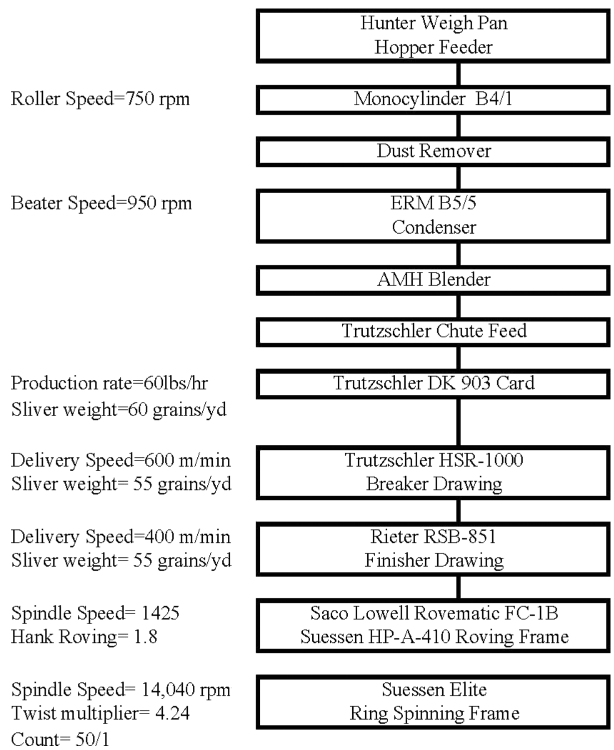

Figure 1. Mini-spinning flow chart with parameters set by the Texas Tech University Fiber and Biopolymer Research Institute.

Statistical Analysis. The General Linear Models procedure of SAS was used to conduct analysis of variance with environments and genotypes as fixed effects and means separated using protected Fisher LSD (SAS Institute Inc., SAS 9.2, Cary, NC). Although the test was grown in two different years in one location and one year in a second location, years and locations were combined and considered as three environments: College Station 2006 (CS06), College Station 2007 (CS07), and Weslaco 2007 (W07). Experimental error (genotype*environment) was utilized to test genotype and environment. Sampling error was used to test the significance of experimental error, i.e., genotype*environment, and thus provided the opportunity to statistically evaluate significant GxE interactions, which were observed for Mic, Hs, YnTen, YnCVm, and Thin (Tables 1, 2, 3). To determine if a specific genotype or environment was consistently causing these observed interactions, differences for each genotype performance between all combinations of two environments were calculated. This procedure, as outlined by Smith (1978), allows the separation of the differences in performance of two genotypes across two environments (e.g., difference in mean Mic values of FM832 in CS06 and CS07 compared with the difference in mean Mic values of B182-34 ELS for the same two environments). Then the differences can be separated using a Fisher LSD, α = 0.05, as shown in Tables 4 and 5. Because each comparison included four means, standard error was calculated as √ [(Error Mean Square*4)/r] as described by Smith (1978).

Table 1. Mean squares for HVI fiber properties for eight ELS upland strains compared with 'FiberMax 832LL' grown in Texas at College Station (2006 and 2007) and Weslaco (2007)

Source	df	Mic[z]	UHML[z]	Str[z]	UI[z]	Elong[z]
Environment (E)	2	28.73***	11.86***	9.95***	14.99***	15.64***
Genotype (G)	8	6.83	17.41***	1.94	1.14	0.30
G x E	16	3.73**	0.35	1.24	0.68	0.41
Sampling Error	27	1.06	0.45	0.93	0.42	0.39

, * Significant at $p < 0.01$, and 0.001, respectively.

[z] Mic = micronaire; UHML = upper half mean length; Str = fiber bundle strength; UI = uniformity index; Elong = elongation of fibers at break.

Table 2. Mean squares for AFIS measurements for eight ELS genotypes compared with 'FiberMax 832LL' grown in Texas at College Station (2006 and 2007) and Weslaco (2007)

Source	df	UQL[z]	Ln[z]	SFCn[z]	IFC[z]	MR[z]	Hs[z]	Neps[z]
Environment (E)	2	6.16***	8.04***	31.24***	20.05**	13.41***	48.88***	60.26**
Genotype (G)	8	24.41***	8.08***	11.15**	6.63	3.48	0.49**	21.2*
G x E	16	0.44	0.44	2.16	3.39	1.37	0.10*	6.91
Sampling Error	27	0.23	0.52	2.31	2.76	0.98	0.04	8.83

*, **, *** Significant at $p < 0.05$, 0.01, and 0.001, respectively.

[z] UQLw = upper quartile length by weight; Ln = fiber length by number; SFCn = short fiber content by number; IFC = percent immature fiber content; MR = maturity ratio; Hs = standard fineness; and Nep = number of neps.

Table 3. Mean squares for 11.8 tex carded mini-spun yarn quality measurements for eight ELS genotypes compared with 'FiberMax 832LL' grown in Texas at College Station (2006 and 2007) and Weslaco (2007)

Source	df	YnTen[y]	YnWork[y]	YnElong[y]	YnCVm[y]	Thin[y]	Thick[y]	Hair[y]	YnNeps200[y,z]
Environment (E)	2	46.23***	6.03**	0.28	0.77	1.82	12.44***	0.88	18.29***
Genotype (G)	8	40.46***	21.81***	12.57***	4.25*	24.98*	3.53***	8.50***	2.66***
GxE	16	2.47**	1.59	1.07	1.13*	6.6**	0.54	1.08	0.20
Sampling Error	27	0.74	0.81	0.82	0.46	2.27	0.30	1.12	0.11

*, **, *** Significant at $p < 0.05$, 0.01, and 0.001, respectively.

[y] YnTen = tensile Strength; YnWork = work force required to break the yarn; YnElong = elongation of yarn at break; YnCVm = coefficient of variation for yarn mass; Thin = number of thin places per m yarn; Thick = number of thick places per m yarn; Hair = the hairiness of the yarn; and YnNeps200 = number of yarn neps measuring greater than 200% diameter of yarn.

[z] Measured only in 2007 (df adjusted appropriately)

Table 4. Means of HVI fiber properties for eight ELS upland strains and 'FiberMax 832 LL' grown in Texas at College Station in 2006 (CS 06) and 2007 (CS 07) and at Weslaco in 2007 (W 07)

Genotype	Mic[y] CS 06	Mic[y] CS 07	Mic[y] W 07	UHML[y]	UI[y]	Str[y]	Elong[y]
	(units)			(mm)	(%)	(kN m kg^{-1})	(%)
FiberMax 832 LL	3.9 a[z]	4.2 a	4.4 a	31.2 b	84.1 a	322.8 a	3.7 a
TAM B182-3 ELS	3.7 bc	4.1 a	3.9 bc	34.9 a	84.9 a	327.7 a	3.8 a
TAM B182-4 ESL	4.0 a	4.1 a	4.0 b	35.4 a	85.2 a	332.6 a	3.8 a
TAM B182-9 ELS	3.8 abc	4.2 a	3.9 bc	35.7 a	85.1 a	328.2 a	3.7 a
TAM B182-16 ELS	3.9 ab	3.9 a	3.9 bc	35.1 a	85.2 a	339.0 a	3.8 a
TAM B182-30 ELS	3.9 ab	4.0 a	3.7 cd	35.1 a	85.5 a	327.7 a	3.9 a
TAM B182-31 ELS	3.9 a	4.2 a	3.7 cd	35.4 a	85.0 a	334.3 a	3.8 a
TAM B182-33 ELS	3.7 c	4.1 a	3.6 d	35.5 a	85.4 a	339.8 a	3.9 a
TAM B182-34 ELS	3.9 ab	4.1 a	3.9 bc	35.1 a	84.5 a	331.3 a	3.9 a
Test Mean	3.8	4.1	3.9	34.8	85.0	331.5	3.8
CV (%)	2.0	3.3	2.4	1.5	0.8	2.8	5.2

[y] Mic = micronaire; UHML = upper half mean length; Str = fiber bundle strength; UI = uniformity index; Elong = elongation of fibers at break.

[z] Values within a column followed by the same letter are not different at $p = 0.05$ according to protected Fisher LSD.

Table 5. Means of selected AFIS fiber properties for eight ELS upland strains and 'FiberMax 832 LL' grown in Texas at College Station in 2006 (CS 06) and 2007 (CS 07) and at Weslaco in 2007 (W 07)

Genotype	UQL[y]	Ln[y]	SFCn[y]	IFC[y]	MR[y]	Hs[y] CS 06	Hs[y] CS 07	Hs[y] W07	Nep
	(mm)	(mm)	(%)	(%)	(ratio)		(mtex)		(no. g^{-1})
FiberMax 832 LL	32.4 c[z]	20.8 c	25.5 a	7.4 a	0.92 a	147 a	174 a	178 a	175 b
TAM B182-3 ELS	37.0 b	22.5 b	26.7 a	8.3 a	0.91 a	141 a	172 ab	173 b	202 ab
TAM B182-4 ELS	36.9 b	22.7 b	25.9 a	8.3 a	0.90 a	141 a	173 ab	169 cd	202 ab
TAM B182-9 ELS	37.2 ab	22.5 b	26.5 a	8.4 a	0.90 a	137 a	171 bc	171 bc	196 ab
TAM B182-16 ELS	37.1 ab	23.1 ab	24.9 ab	8.1 a	0.91 a	142 a	169 cd	170 bcd	231 ab
TAM B182-30 ELS	36.9 b	23.3 ab	24.0 ab	7.9 a	0.91 a	140 a	168 cd	166 e	236 a
TAM B182-31 ELS	37.4 ab	23.5 ab	24.0 ab	7.7 a	0.92 a	145 a	169 cd	168 cde	202 ab
TAM B182-33 ELS	37.8 a	24.2 a	22.5 b	7.7 a	0.92 a	140 a	168 d	162 f	215 ab
TAM B182-34 ELS	36.8 b	22.8 b	25.0 ab	8.0 a	0.91 a	140 a	169 cd	167 de	217 ab
Test Mean	36.6	22.8	25.0	8.0	0.91	141	170	169	208
CV (%)	1.0	2.5	6.1	6.6	1.1	2.0	0.7	0.9	14.3

[y] UQLw = upper quartile length by weight; Ln = fiber length by number; SFCn = short fiber content by number; IFC = percent immature fiber content; MR = maturity ratio; Hs = standard fineness; and Nep = number of neps.

[z] Values within a column followed by the same letter are not different at $p = 0.05$ according to protected Fisher LSD.

RESULTS AND DISCUSSION

All TAM ELS upland strains exhibited UHML of 34.9 mm or greater, and all TAM ELS strains produced longer UHML ($p < 0.05$) than FM832, which had an UHML of 31.2 mm (Tables 1, 4). These lengths are meaningful advancements as they place these upland cottons in the *G. barbadense* ELS category based on the CCC Loan Schedule (National Cotton Council, 2009). All other HVI fiber data for the eight TAM ELS lines were normal and typical for upland cotton and comparable with FM 832. Smith et al. (2009) reported that TAM B182-33 ELS exhibited higher ($p < 0.05$) Str than FM 832 and slightly more uniform fiber lengths.

All ELS lines exhibited longer ($p < 0.05$) UQLw and Ln than FM832, which averaged 32.4 mm UQLw and 20.8 mm Ln (Tables 2, 5). TAM B182-30 ELS, TAM B182-31 ELS, and TAM B182-33 ELS exhibited lower SFCn than FM 832, whereas all other TAM ELS lines did not differ from FM 832. All TAM ELS lines did not differ from FM 832 for AFIS IFC and AFIS MR. All of the length measurements—HVI UHML, AFIS UQLw, AFIS Ln, and AFIS SFCn—supported that these ELS lines produce longer cotton fibers than FM 832 and represent a valuable upland cotton germplasm pool. Genotypes varied ($p < 0.05$) for all of the 11.8 tex carded yarn quality measurements except for YnCVm in W07 (Table 3). TAM B182-33 ELS produced the strongest ($p < 0.05$) carded yarn in all environments as indicated by YnTen and required a force to rupture, identified as YnWork, of 308 cN cm^{-1}, significantly greater than FM 832, which required significantly less force to rupture than all of the TAM ELS lines (Table 6). The carded yarn of the size produced in this study from TAM B182-33 ELS averaged 16% stronger and required 24% more energy to break than FM 832. The other ELS strains all performed the same or better ($p < 0.05$) than FM 832 for YnTen in all environments and all TAM ELS strains required more energy to break as defined by YnWork. Mini-spun 11.8 tex carded yarn from the TAM ELS lines exhibited greater ($p < 0.05$) YnElong than the upland check cultivar, ranging from 4 to 8% greater elongation before yarn rupture occurred.

Yarn produced from all of the TAM ELS lines with the exception of B182-4 and B182-9, had fewer Thin places per length of yarn and exhibited significantly fewer protrusions of fiber ends, i.e., less hairiness, than FM 832, further indicating superior yarn quality (Table 7). However, all TAM ELS lines produced an equal or greater number of Thick places per length of yarn and exceeded FM 832 for YnNeps200 by at least 42%.

The consistency or environmental stability of cultivars, or strains, of all agronomic commodities is an important breeding consideration. The multiple sampling of HVI, AFIS, and yarn quality parameters provided the opportunity to evaluate and determine the cause of any parameter exhibiting a significant genotype*environment interaction in this study. Of interest in the study reported herein, was whether or not one or more of the TAM ELS lines consistently performed differently across environments than the control cultivar, FM 832. There were no consistent patterns as to the cause of the interactions and, in general, the ELS lines responded similarly to environments as did FM 832 (Tables 8, 9).

As has been reported in the literature, these data suggest that improving fiber length while holding other fiber quality parameters constant leads to higher quality ring-spun yarns. In addition, these HVI, AFIS, and mini-spun 11.8 tex yarn data suggest that the TAM ELS upland genotypes are a valuable upland cotton germplasm pool. Based on data reported herein, TAM B182-33 ELS exhibited the highest quality cotton fiber that produced the highest quality yarn, i.e., longer fibers based on HVI and AFIS data, and better quality 11.8 tex carded yarn as indicated by greater YnTen and YnWork, and better yarn elongation and less hairy yarn than that produced from FM 832.

Table 6. Means of selected 11.8 tex carded yarn quality measurements for eight ELS upland strains and 'FiberMax 832 LL' grown in Texas at College Station in 2006 (CS 06) and 2007 (CS 07) and at Weslaco in 2007 (W 07)

Genotype	YnTen^y			YnWork^y	YnElong^y
	CS 06	CS 07	W 07		
		($cN\ tex^{-1}$)		(cN cm)	(%)
FiberMax 832 LL	17.2 d^z	16.7 e	15.8 e	248 d	4.9 d
TAM B182-3 ELS	18.7 bc	17.2 de	16.8 d	284 cb	5.2 abc
TAM B182-4 ELS	18.3 c	17.1 e	16.9 d	278 c	5.1 bc
TAM B182-9 ELS	17.2 d	17.3 de	17 d	271 c	5.0 c
TAM B182-16 ELS	18.8 bc	18.2 bc	17.5 c	301 ab	5.3 a
TAM B182-30 ELS	18.8 bc	18.4 bc	18.2 b	302 a	5.3 a
TAM B182-31 ELS	18.8 bc	18.5 ab	18.2 b	299 ab	5.2 ab
TAM B182-33 ELS	19.6 a	19.1 a	19 a	308 a	5.2 ab
TAM B182-34 ELS	19.1 ab	17.8 cd	18.3 b	296 ab	5.2 abc
Test Mean	18.5	17.8	17.5	288	5.2
CV (%)	1.6	1.6	1.2	3.1	1.8

^{y} YnTen = tensile Strength; YnWork = work force required to break the yarn; YnElong = elongation of yarn before break.

^{z} Values within a column followed by the same letter are not different at $p = 0.05$ according to protected Fisher LSD.

Table 7. Selected 11.8 tex carded yarn quality measurements for eight ELS upland strains and 'FiberMax 832 LL' grown in Texas at College Station in 2006 (CS 06) and 2007 (CS 07) and at Weslaco in 2007 (W 07)

Genotype	YnCVm[y]			Thin[y]			Thick[y]	Hair[y]	YnNeps200[y]
	CS 06	CS 07	W 07	CS 06	CS 07	W 07			
	(%)			(no. km^{-1})			(no. km^{-1})		(no. g^{-1})
FiberMax 832 LL	19.8 bc[z]	19.2 d	20.2 a	167 a	116 cd	187 a	934 d	3.94 a	1246 c
TAM B182-3 ELS	19.6 bcd	19.9 ab	19.6 a	113 d	144 abc	116 cd	1024 bcd	3.69 b	1768 b
TAM B182-4 ELS	19.8 b	20.1 ab	20 a	149 abc	153 ab	152 b	1114 ab	3.64 b	1884 ab
TAM B182-9 ELS	20.3 a	20.2 a	20.1 a	159 ab	166 a	147 bc	1179 a	3.76 ab	1997 a
TAM B182-16 ELS	19.6 bcd	19.4 cd	19.7 a	125 bcd	95 d	127 bc	1011 bcd	3.60 b	1835 ab
TAM B182-30 ELS	19.3 ef	19.3 d	19.6 a	104 d	106 d	117 cd	968 cd	3.59 b	1790 b
TAM B182-31 ELS	19.6 cde	19.7 bc	19.6 a	119 cd	126 bcd	115 cd	1044 bc	3.64 b	1860 ab
TAM B182-33 ELS	19.3 f	19.6 bcd	19.2 a	103 d	125 bcd	92 d	969 cd	3.55 b	1824 ab
TAM B182-34 ELS	19.4 def	19.4 cd	19.9 a	117 cd	106 d	140 bc	1009 bcd	3.59 b	1769 b
Test Mean	19.6	19.6	19.8	128	126	132	1028	3.67	1775
CV (%)	0.6	1.0	1.5	11.8	11.6	11.7	5.3	2.9	5.8

[y] YnCVm = coefficient of variation for yarn mass; Thin = number of thin places per m yarn; Thick = number of thick places per m yarn; Hair = the hairiness of the yarn; and YnNeps200 = number of yarn neps measuring greater than 200% diameter of yarn

[z] Values within a column followed by the same letter are not different at p = 0.05 according to protected Fisher LSD.

Table 8. Differences of genotypic means for micronaire and standard fineness among three environments in Texas at College Station in 2006 (CS 06) and 2007 (CS 07) and at Weslaco in 2007 (W 07)

Genotype	Difference in Mic[x] Means			Difference in Hs[x] Means		
	CS 06-CS 07	CS 07-W 07	W 07-CS 06	CS 06-CS 07	CS 07-W 07	W 07-CS 06
	(units)			(mtex)		
FiberMax 832 LL	-0.23[y] abc[z]	-0.25 a	0.48 c	-27.0 bc	-4.0 a	31.0 cde
TAM B182-3 ELS	-0.37 ab	0.25 bc	0.12 b	-31.5 ab	-0.5 ab	32.0 de
TAM B182-4 ELS	-0.09 bc	0.10 b	-0.01 ab	-32.5 ab	4.0 bc	28.5 bcde
TAM B182-9 ELS	-0.37 ab	0.30 bc	0.07 ab	-33.5 a	0.0 abc	33.5 e
TAM B182-16 ELS	0.00 c	0.05 ab	-0.05 ab	-27.5 bc	-0.5 ab	28.0 abcde
TAM B182-30 ELS	-0.1 bc	0.25 bc	-0.15 ab	-28.0 abc	2.5 bc	25.5 abc
TAM B182-31 ELS	-0.23 abc	0.45 c	-0.23 a	-24.5 c	1.0 abc	23.5 ab
TAM B182-33 ELS	-0.44 a	0.50 c	-0.06 ab	-28.0 abc	5.5 c	22.5 a
TAM B182-34 ELS	-0.25 abc	0.20 bc	0.05 ab	-29.0 abc	1.5 abc	27.5 abcd

[x] Mic = micronaire; Hs = standard fineness.

[y] Values within each column were calculated as the difference of the mean of the respective genotype in one environment from its mean the other environment.

[z] Values within a column followed by the same letter are not different at p = 0.05 according to Fisher LSD.

Table 9. Differences of genotypic means for selected 11.8 tex carded yarn quality measurements among three environments in Texas at College Station in 2006 (CS 06) and 2007 (CS 07) and at Weslaco in 2007 (W 07)

Genotype	Difference in YnTen[x] Means			Difference in YnCVm[x] Means			Difference in Thin[x] Means		
	CS06-CS07	CS07-W07	W07-CS06	CS06-CS07	CS07-W07	W07-CS06	CS06-CS07	CS07-W07	W07-CS06
		(cN tex^{-1})			(%)			(no. km^{-1})	
FiberMax 832LL	0.49[y] ab[z]	0.94 c	-1.44 ab	0.58 c	-0.98 a	0.40 ab	51 c	-72 a	21 a
TAM B182-3ELS	1.52 d	0.47 bc	-1.98 a	-0.28 ab	0.34 d	-0.06 ab	-31 a	28 d	2 a
TAM B182-4ELS	1.12 bcd	0.22 abc	-1.34 abc	-0.21 ab	0.10 bcd	0.10 ab	-4 ab	1 bcd	3 a
TAM B182-9ELS	-0.12 a	0.32 abc	-0.20 d	0.03 bc	0.13 cd	-0.16 a	-7 ab	19 d	-12 a
TAM B182-16ELS	0.63 abc	0.69 bc	-1.32 abc	0.26 bc	-0.30 bc	0.06 ab	30 bc	-32 abc	2 a
TAM B182-30ELS	0.35 ab	0.22 abc	-0.56 cd	0.07 bc	-0.32 bc	0.26ab	-2 ab	-10 bcd	12 a
TAM B182-31ELS	0.33 ab	0.27 abc	-0.60 cd	-0.18 ab	0.1 bcd	0.08 ab	-6 ab	11 cd	-4 a
TAM B182-33ELS	0.51 ab	0.10 ab	-0.62 cd	-0.36 a	0.44 d	-0.08 ab	-22 a	32 d	-10 a
TAM B182-34ELS	1.30 cd	-0.44 a	-0.86 bcd	0.02 abc	-0.50 ab	0.48 b	11 abc	-34 ab	22 a

[x] YnTen = tensile Strength; YnCVm = coefficient of variation for yarn mass; Thin = number of thin places per m yarn.

[y] Values within each column were calculated as the difference of the mean of the respective genotype in one environment from its mean the other environment.

[z] Values within a column followed by the same letter are not different at *p* = 0.05 according to Fisher LSD.

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