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BREEDING AND GENETICS

Performance of the Extra Long Staple Upland, Long Staple Upland, and Extra Strength Upland Fiber Traits in South Texas

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ABSTRACT

Enhanced phenotypic traits in crop plants must be evaluated to determine their expression or performance across environments. Texas A&M AgriLife Research has developed extra-long staple upland (ELSU) phenotypes, long staple upland (LSU) phenotypes, and extra strength upland phenotypes (ESU) of upland cotton (*Gossypium hirsutum* L.). Three of these improved strains, TAM 11K-13 ELSU, TAM 11T-08 ELSU/ESU, and TAM 11L-24 LSU, plus three additional experimental strains and ten commercial cultivars, were grown with irrigation at Weslaco, TX and with no irrigation at Corpus Christi, TX. These sites are 250 km apart but share similar temperature and rainfall patterns. The objective of this research was to evaluate and compare the performance of three advanced strains possessing elite fiber length and strength, and secondarily for yield and lint percent, in these two south Texas environments. These entries were grown in a randomized complete block design with four replications at Corpus Christi (non-irrigated) and Weslaco (irrigated) in 2013 and 2014. All genotypes evaluated produced lower upper half mean length (UHML) under drought conditions at Corpus. However, reduction in UHML of the ELSU, LSU, and ESU phenotypes were not different than most of the commercial cultivars and remained significantly longer than the medium staple upland cultivars. TAM 11T-08 ELSU/ESU was numerically stronger when grown under dryland culture and exhibited significantly less reduction in strength when grown without irrigation at Corpus Christi as when grown at Weslaco under irrigation. The enhanced fiber quality traits responded similarly to these environments as standard genotypes.

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The United States (U.S.) is the third largest global cotton (*Gossypium* spp.) producer but is the leading exporting country, exporting ten million bales in 2015 (Cotton Inc, 2016). The U.S. textile industry primarily uses open-end spinning technology while most other textile producing countries utilize ring spinning, including vortex, technology with which they can produce a more varied product portfolio that includes finer yarns to produce high-end finished products (Felker, 2001). The order of importance of fiber properties important in open-end spinning is strength, fineness, length, cleanliness, friction, and micronaire, while the order for ring and vortex is fiber length, strength, fineness, friction, and uniformity (May and Green, 1994). The predominate global production of ring spun yarns and the expected future dominance of vortex spinning (Eric Hequet, Fiber and Biopolymer Research Institute, Texas Tech University, personal communication) mandates that U.S. cotton breeders consider fiber length and strength, as well as other fiber properties, during the selection process if the U.S. is to maintain a competitive edge in the global fiber market.

The minimum requirements of upland cotton in the world market are upper half mean length (UHML) of 28.2 mm, 263 kN m kg^{-1} fiber bundle strength (Str), and micronaire (Mic) between 3.6 and 4.8; whereas UHML of 26.7 mm, Str of 250 kN m kg^{-1}, and Mic of 3.5 to 4.9 are of non-discount quality upland cotton in the U.S. (Joy, 2012). Upland cotton has to compete with international standards and with manmade fibers, which provide stable and predictable fiber characteristics.

Geng et al. (1987) suggested that genotype stability for fiber quality was an important selection criterion for cotton breeders, while Bowman (2000) suggested that such stability was important in the selection of parents to initiate breeding cycles. Geng et al. (1987) and Paterson et al. (2003) noted that genotype x environment interactions impact the selection of superior fiber genotypes. Henderson (1959) noted that repeatability, as an indicator of stability, was first developed in the early 1900s and was later applied to breeding by Kempthorne (1957) and Lush (1945). Traits with high repeatability tend to be more stable across testing locations while traits with low repeatability, such as yield, are less stable due to the complexity of the trait and the cumulative component trait interaction and sensitivity to environmental effects. Fiber traits such as UHML and Str typically are more stable across environments due to fewer genes governing them and hence possess a higher repeatability (Paterson et al., 2003). Ng et al. (2012) reported repeatability values for UHML and Str of 0.85 and 0.75, respectively, which suggested a large genotypic component relative to the environmental component governing trait expression. The repeatability value for yield was only 0.22 across multiple locations in Texas, suggesting a large environmental impact.

Over 50 % of the cotton grown in Texas and approximately 65 % of U.S. hectares are grown without irrigation (Cotton Inc., 2016). Many of these hectares suffer from moderate to severe drought during the growing season which reduces yield and fiber quality attributes (Pettigrew, 2004; Smith et al., 2011; Wiggins et al., 2014). Wiggins et al. (2014) noted that UHML and Str decreased with decreasing irrigation in Tennessee and a comparison of irrigated and non-irrigated cultivar trials in Texas clearly denotes the impact of drought on fiber quality values (http://varietytesting.tamu.edu/cotton/).

Pima cotton (*Gossypium barbadense* L.), also referred to as Extra Long Staple (ELS) cotton, exhibits UHML of 35 mm or higher while medium staple upland cultivars (*G. hirsutum* L.) exhibit UHML ranging from 27 to 29 mm (http://www.cottoninc.com/fiber/quality). Development of Long Staple Upland (LSU) or Extra Long Staple Upland (ELSU) cultivars or cultivars with greater repeatability of fiber properties when grown in drought-stressed environments could improve the market position of U.S. cotton and especially upland cotton produced in regions of Texas that receive little rainfall during the growing season. These production regions often produce upland cotton with UHML less than 27 mm and receive discounts for short fibers (http://varietytesting.tamu.edu/cotton/). To address this issue, ELSU and LSU strains have been developed by the Cotton Improvement Lab at Texas A&M AgriLife Research (Smith, et al., 2008; 2009) without the introgression of *G. barbadense*. In addition to the development of ELSU and LSU quality fiber phenotypes, Smith et al. (2014) have developed Extra Strength Upland (ESU) strains without *G. barbadense* introgression that exhibit Str values equal to or greater than 343 kN m kg^{-1}. These descriptions or types are internal to the Texas A&M AgriLife Research cotton breeding program and ELSU is defined as an upland phenotype with UHML equal to or greater than the minimum UHML for grade 1 pima, i.e., 34.9 mm; LSU is defined as an UHML of 32 to 34.8 mm; and ESU is defined as HVI Str of at least 343 kN m kg^{-1}. TAM 94L-25 (Smith, 2003) is a common parent among the five families of ELSU strains released by Smith (2009) and is considered the progenitor of the ELSU trait. The source of the improved Str in the TAM material is not as well defined and appears to have resulted from an incremental improvement using pedigree breeding, recurrent selection breeding, and multiple parents since about 1970 (Smith et al., 2014).

The objectives of the research reported herein were to [1] compare the seed cotton yield and LP of Texas A&M AgriLife Research strains exhibiting the ELSU, LSU, and/or ESU fiber traits with current cultivars and strains and [2] determine if strains exhibiting the ELSU, LSU, and ESU traits performed as well as standard cultivars and strains relative to UHML and Str characteristics in two environments, i.e., Weslaco under irrigated culture and Corpus Christi under dryland culture. The seed cotton yield and LP were compared to confirm that the strains exhibiting the ELSU, LSU, and/or ESU traits did not exhibit those traits as a result of extremely low productivity. Other HVI fiber quality traits are reported but not discussed since these traits in the elite fiber quality TAM strains do not differ from current standard medium staple cultivars.

MATERIALS AND METHODS

Entries in this study included TAM 11K-13 ELSU, TAM 11T-08 ELSU/ESU, and TAM 11L-24 LSU, developed as part of the elite fiber quality breeding program at Texas A&M AgriLife Research; TAM 07V-45, TAM 08WZ-78, and TAM 08WZ-83, developed as part of the cotton cultivar development breeding program at Texas A&M AgriLife Research; and 10 commercial cultivars that were entered into the official cotton cultivar trials for central and south Texas in 2013 and 2014 (Table 1). These 16 genotypes were grown at Weslaco, TX with irrigation at the Texas A&M AgriLife Research and Extension Center and at Corpus Christi, TX without irrigation at the Research and Extension Center in 2013 and 2014. Soil type at Weslaco is a Hidalgo sandy clay loam, a fine-loamy, mixed, active, hyperthermic Typic Calciustolls and at Corpus Christi a Houston black clay, a fine smectitic, thermic Udic Haplustert. The experimental design at both locations was a randomized complete block design with four replications. Plots were two rows, 10.7 m long on 1.0 m centers, at both locations. Irrigation at Weslaco was applied in furrow with frequency determined subjectively by experienced research technicians. Rainfall amounts and average daily high and low temperatures at these sites are shown in Table 2. All other cotton production practices for these locations were per extension-recommended guidelines. One row of each plot was harvested with a one row picker, modified for research plot harvest. Thirty open bolls, normal in appearance, from the middle of the fruiting zone were hand harvested from two reps and ginned on a 10-saw laboratory gin at the Cotton Improvement Laboratory at Texas A&M. Lint samples were forwarded to the Fiber and Biopolymer Research Institute at Texas Tech University for determination of High Volume Instrument (HVI) fiber properties: UHML, Mic, Str, length uniformity index (UI), and elongation (Elong). Lint percent was determined from the hand-harvested boll sample as ((lint wt./seed cotton wt.) *100).

Table 1. Genotypes and their origin planted at Weslaco under full irrigation and Corpus Christi, TX under dryland culture in 2013 and 2014.

Genotype	Abbreviation	Reference
DP 0912 B2RF	DP 0912	200900057 PVP
DP 1044 B2RF	DP 1044	201000260 PVP
DP 1359 B2RF	DP 1359	201100414 PVP
NG 1511 B2RF	NG 1511	-
PHY 339 WRF	PHY 339	20140137281, publication #
PHY 499 WRF	PHY 499	20130117875, Publication #
PHY 575 WRF	PHY 575	DowAgro, 2013
PHY 725RF	PHY 725	DowAgro, 2007
SSG UA 103	SSG UA 103	Bourland, 2013
SSG UA 222	SSG UA 222	Bourland, 2012
TAM 07 V-45	TAM 07 V-45	Experimental
TAM 08 WZ-78	TAM 08 WZ-78	Experimental
TAM 08 WZ-83	TAM 08 WZ-83	Experimental
TAM 11 K-13 ELSU	TAM 11 K-13 ELSU	Experimental
TAM 11 L-24 LSU	TAM 11 L-24 LSU	Experimental
TAM 11 T-08 ELSU/ESU	TAM 11 T-08 ELSU/ESU	Experimental

Table 2. Rainfall accumulations and average daily high and low temperatures for Weslaco (irrigated site) and Corpus Christi (non-irrigated site) from January through August for 2013 and 2014.

Month	Weslaco		Corpus Christi		Average daily high and low	
	2013	2014	2013	2014	Weslaco	Corpus Christi
	---------------- mm ----------------		---------------- mm ----------------		--------------------------- C ---------------------------	
January	20	8	29	16	22/9	17/8
February	0	6	29	13	23/11	21/11
March	0	9	2	26	27/14	24/13
April	7	0	74	8	30/18	28/17
May	44	40	27	65	32/22	31/21
June	5	0	33	4	34/24	33/23
July	44	5	70	2	36/24	34/24
August	29	17	33	22	36/24	34/24
Total	149	85	297	156	-	-

Although the two locations, Weslaco and Corpus Christi, are separated by approximately 250 km, both are described as sub-tropical sub-humid climates. Table 2 verifies that the two sites received little rainfall during the two growing seasons of this study and that they have similar long term average daily highs and lows during the growing season, thus providing the opportunity to compare the UHML and Str performance of the three elite fiber quality strains in two locations with growing conditions differing primarily in moisture, i.e., irrigated at Weslaco and no irrigation at Corpus Christi.

The GLM procedure of SAS 10.1 was used for determining differences in fiber properties, seed cotton yield, and lint percent (LP) with year (Y), location (L), and genotypes (G) considered fixed effects. Seed cotton yields were compared rather than lint yield to avoid discriminating against the yield potential of the elite quality strains because of their lower LP. The change in genotype performance when grown at Corpus Christi without irrigation versus growth with irrigation at Weslaco in south Texas was determined as (((Weslaco value – Corpus Christi value)/ Weslaco value) * 100) and reported as delta, Δ. LSD values were calculated for the Δ values as LSD = $t_{.05, 60}$ * $(4*MSE/r)^{-1/2}$, since four means are required in comparing any two Δs (Smith, 1978). Comparisons between the Δ values facilitate the explanation of the genotype x location interaction term in the ANOVA. Evaluation of the genotypes that do not respond the same to the two locations in the study allows the comparison of the performance of the genotypes with the ELSU, LSU, and ESU traits with genotypes that possess current levels of UHML and Str. The interactions for yield and LP were compared using the Δ concept to show that the ELSU, LSU, and ESU traits were not artifacts of differences in yield response. Additionally, the Δ for specific traits of interest, i.e., UHML and Str, were separated to examine those interactions.

RESULTS AND DISCUSSION

According to the National Cotton Council, upland cotton requires from 635 mm of water for optimum production in the humid rainbelt to over 1100 mm in the desert Southwest (National Cotton Council of America, 2016). Table 2 provides in-season rainfall amounts from January through August for the Weslaco and Corpus Christi sites in south Texas showing that the moisture requirements for maximum production at these sites were not met by natural precipitation. Irrigation at Weslaco was provided by furrow and actual amounts were not recorded. The precipitation amounts recorded plus the irrigation provided at Weslaco clearly set up two contrasting moisture environments for this study at these two locations.

Year significantly affected all traits measured except LP; location significantly affected all traits measured except Mic; and genotypes varied significantly for all traits measured (Table 3). Location x year was a significant source of variation for all traits except yield; while genotypes responded the same across years—genotype x year—for all traits except Mic. These results generally were expected because of the natural precipitation and the application of irrigation at one site. Since the objective was to evaluate the performance of the genotypes, and thus the ELSU, LSU, and ESU traits, for UHML and Str performance, the genotype and the genotype x location terms from Table 3 are the variance terms of most interest. The location and genotype x location variance terms in the analysis of variance were significant for all traits measured. A three way genotype x location x year interaction existed for Mic but will not be addressed in the discussion below.

Data in Table 4 are means across both years of the study. All genotypes produced more seed cotton per ha when grown at Weslaco under irrigation in 2013 and 2014. No significant differences in yield among the genotypes were observed when grown at Corpus Christi without irrigation, with yields ranging from 607 kg ha^{-1} for TAM 08WZ-78 to 810 kg ha^{-1} for PHY 575WR. The ELSU, ESU, and LSU entries were not different (p=0.05) in yield than all other genotypes tested during these two years when grown without irrigation at Corpus Christi. When grown at Weslaco with irrigation TAM 11K-13 ELSU, TAM 11L-24 LSU, and TAM 11T-08 ELSU/ESU were not lower yielding than the numerically highest yielding cultivar, PHY 499WR, which was significantly higher yielding than TAM WA-78, SSG UA103 and NG1511B2. The elite-trait Texas A&M AgriLife Research genotypes exhibited lower LP than all other genotypes when grown at Weslaco with irrigation but were not lower in LP than PHY 575WR, DP 1044B2, SSG UA103, TAM 07V-45, SSG UA 222, and PHY 725RF when grown at Corpus Christi without irrigation. Thus, the elite fiber trait genotypes included in this study are similar in seed cotton yield potential to the commercial genotypes included in the study but LP remains lower than desirable or competitive at the commercial level.

Table 3. Means squares for seedcotton yield, lint percent, and high-volume instrument (HVI) fiber properties for 16 genotypes of upland cotton, grown at Weslaco, TX under irritated culture and Corpus Christi, Tx under non-irrigated culture in 2013 and 2014.

Source	df	Yield[Z]	df	LP	Mic	UHML	UI	Str	Elong
Year (Y)	1	1738.2***	1	5.29	1.61***	75.10***	211.9***	1142.8**	5.29**
Error a	6	35.3	2	1.63	0.21	1.93	1.12	311.5	1.62
Location (L)	1	118679.6***	1	136.93***	0.11	953.10***	675.74***	10145.5	136.94***
L x Y	1	23.8	1	87.54***	0.42**	40.08***	186.97***	1878.5***	87.54***
Error b	6	61.3	2	1.54	0.02	0.21	0.02	0.7	1.54
Genotype (G)	15	75.3**	15	40.75**	0.65***	33.52***	5.14***	3568.0***	40.75***
G x Y	15	38.4	15	2.77	0.08*	0.54	0.74	139.2	2.77
G x L	15	66.5**	15	4.78**	0.08*	1.21*	1.63*	387.2***	4.78**
G x Y x L	15	34.7	15	1.00	0.08*	0.41	0.34	129.8	1.00
Error C	179	31.1	60	1.61	0.04	0.62	0.78	97.9	1.61

*,**,*** Significant at p=0.05, 0.01, and .001, respectively.

[Z] Yield = seedcotton yield, LP = lint percent, Mic = micronaire, UHML = upper half mean length, UI= length uniformity index, Str = fiber bundle strength, Elong = elongation.

Table 4. Seedcotton yield , Lint percent (LP) and high volume instrument (HVI) fiber properties of 16 genotypes grown at Weslaco, TX under irrigated culture and Corpus Christi, TX under non-irrigated culture in 2013 and 2014.

Genotype	Weslaco						Corpus Christi					
	Yield[Z]	LP	Mic	UHML	UI	Str	Yield	LP	Mic	UHML	UI	Str
	Kg ha $^{-1}$	%	units	mm	index	kN m kg^{-1}	kgha^{-1}	%	units	mm	index	kN m kg^{-1}
TAM 11K-13ELSU	5367	35.7	4.1	36.6	86.1	340	642	36.0	4.2	29.7	81.3	331
TAM 11T-08ELSU/ESU	5362	35.8	4.3	35.4	86.5	357	615	35.9	4.4	28.6	82.4	368
TAM 11L-24LSU	5320	35.4	4.3	33.5	86.4	329	712	35.6	4.5	28.1	82.1	327
PHY 725RF	5298	36.9	4.5	31.6	85.4	351	633	36.4	4.4	26.2	81.4	329
TAM 08WZ-83	5209	41.0	5.0	31.2	85.4	323	766	38.5	4.9	25.3	80.4	286
SSG UA103	4878	39.7	4.9	31.1	85.0	329	699	37.7	4.7	26.6	82.5	321
SSG UA222	6113	41.0	4.6	31.1	85.1	312	694	36.5	4.9	25.0	80.0	303
PHY 575WR	6084	40.5	4.5	30.9	85.0	302	810	37.9	4.5	26.5	81.3	281
TAM 08WZ-78	5308	42.5	4.7	30.5	84.5	316	607	41.0	4.8	24.2	80.1	268
PHY 339WR	6131	41.2	4.7	30.2	85.8	314	723	39.9	4.6	24.3	79.9	299
DP 1359B2	5402	43.8	5.0	29.9	83.6	312	759	39.5	5.0	24.9	79.8	289
TAM 07V-45	5765	39.5	4.7	29.6	84.4	312	708	36.9	4.7	24.8	80.2	297
PHY 499WR	6291	44.5	5.3	29.1	85.7	314	683	41.2	5.0	24.0	79.9	302
NG 1511B2	4593	43.2	5.0	29.1	84.9	322	689	39.5	4.8	24.1	79.7	292
DP 1044B2	5668	40.1	4.6	29.0	84.5	300	690	37.8	4.7	23.9	79.5	281
DP 0912B2	5679	40.6	5.3	28.4	85.2	297	773	38.1	4.9	23.5	79.5	270
LSD$_{K=100}$[Y]	1049	0.9	0.3	0.8	1.3	10	ns	2.5	0.3	1.2	1.3	16
% CV	20.1	1.8	4.4	2.0	1.0	2.6.5	22.7	4.4	4.6	3.6	1.1	3.8
Mean	5529	40.1	4.7	31.1	85.2	320	700	38	4.7	25.6	80.6	303

[Z] Yield = seedcotton yield, LP = lint percent, Mic = micronaire, UHML = upper half mean length, UI = length uniformity index, Str = fiber bundle strength.

[Y] Values within a column are different according to Waller LSD at k=100, approximates p=0.05, if they differ by more than the LSD value at base of column.

Averaged over 2013 and 2014, TAM 11K-13 ELSU and TAM 11 T-08 ELSU/ESU exhibited longer UHML than the minimum pima length of 34.9 mm and TAM 11L-24 LSU averaged greater UHML than the 32 mm requirement for LSU designation when grown with irrigation at Weslaco (Table 4). These three lines exhibited significantly longer UHML than all other strains or cultivars evaluated under irrigated culture at Weslaco. When grown without irrigation at Corpus Christi and averaged over 2013 (severe drought) and 2014 (moderate drought), these three lines again outperformed ($P \leq 0.05$) all other genotypes relative to UHML. TAM 11K-13 ELSU, TAM 11T-08 ELSU/ESU, and TAM 11L-24 LSU all produced UHML well above 25.4 mm and above the minimum 27 mm UHML value for non-discount upland cotton fiber in the United States and above the 27.8 mm minimum for international trade. Only three commercial cultivars averaged over 25.4 mm, SSG UA 103, PHY 575WR, and PHY 725RF, at 26.6, 26.5, and 26.2, respectively.

At Weslaco, under irrigated culture, the ESU genotype, TAM 11T-08 ELSU/ESU, produced stronger fibers according to HVI analysis than all genotypes except PHY 725RF, an Acala type upland (Table 4). When grown without irrigation at Corpus Christi, TAM 11T-08 ELSU/ESU had significantly higher Str than all other genotypes tested. These data confirm that the elite-trait genotypes used in this study carry alleles for significant improvements in UHML and Str.

Since genotypes did not respond the same ($P \leq 0.05$) to these locations in south Texas for UHML or Str, differences (Δ) were calculated. The purpose was to determine if the longer UHML and/or the greater Str traits found in TAM 11K-13 ELSU, TAM 11T-08 ELSU/ESU, and TAM 11L-24 LSU responded differently to these two locations or environments that differed primarily in moisture regimes, i.e., irrigated at Weslaco and not irrigated at Corpus Christi, than the medium staple and standard Str traits found in the comparison genotypes. The genotypes also did not respond the same to location for LP or yield according to the analysis of variance (Table 3).

SSG UA222 exhibited a significantly greater reduction, Δ, in LP than any of the three elite quality TAM germplasm lines but was not different than all other comparison genotypes in the study (Table 5). However, TAM 11T-08 ELSU/ESU and TAM 11K-13 ELSU were not different than all other genotypes except SSG UA 222 while TAM 11L-24 LSU exhibited significantly lower reduction in LP when expressed as a percent change from Weslaco irrigated culture to Corpus Christ non-irrigated culture than SSG UA 222 and DP 1359 B2. While the ANOVA indicated that the genotypes responded differently in seed cotton yield to the two locations, that interaction appears to have been caused by the magnitude of differences rather than direction of response differences (Table 4). This conclusion is supported by the Δ analysis for difference in yield in Table 5. The Δ values for yield were not significantly different, indicating stability for seed cotton yield among all genotypes, including the elite-trait TAM strains, across these two locations.

Based on Δ, TAM 11K-13 ELSU, TAM 11T-08 ELSU/ESU, and TAM 11L-24 LSU responded similarly ($p=0.05$) to the two locations for UHML as the medium staple cultivars at 18.9 %, 19.2 %, and 16.1 % reduction, respectively (Table 6). No significant differences were noted in the UHML Δ that ranged from 14.2 % change from irrigated culture at Weslaco to non-irrigated culture at Corpus Christi for PHY 575 WRF to 20.7 % change for TAM 08 WZ-78. These data confirm that the UHML of the ELSU, LSU, and ESU traits were not affected differently across these two locations that differed primarily in moisture in south Texas. These data confirm observational data that while the ELSU and LSU traits will result in longer UHML under drought conditions that will prevent length discounts under the United States Department of Agriculture (USDA) classing protocols, genotypes with this trait responds similar to other upland cultivars under production in south Texas.

Averaged over 2013 and 2014, TAM 11T-08 ELSU/ESU averaged greater Str than all other genotypes in this study when grown at Weslaco with irrigation and at Corpus Christi without irrigation, except for PHY 725 RF (Table 4). This ESU strain averaged 357 kN m kg^{-1} with irrigation at Weslaco and 368 kN m kg^{-1} without irrigation at Corpus Christi. TAM 11K-13 ELSU exhibited Str greater than 13 of the 16 comparison genotypes at Weslaco and greater than 11 of 16 when grown at Corpus Christi. TAM 11L-24 LSU averaged lower Str than TAM 11T-08 ELSU/ESU under both moisture regimes but was significantly stronger than nine comparison genotypes at Weslaco and 11 at Corpus Christi.

Table 5. Mean values and stability estimates (Δ) for seedcotton yield and lint percent of genotypes with the ELSU, LSU, and ESU[Z] traits compared with cultivars and germplasm lines with normal length and strength levels when grown at Weslaco, TX under irrigated culture and Corpus Christi, TX under non-irrigated culture averaged over 2013 and 2014.

Genotypes	Yield			Lint percent		
	W[Y]	CC	Δ	W	CC	Δ
	------------- kg ha^{-1} -------------		------ % ------	---------------- % ----------------		------ % ------
SSG UA222	6113	694	89	41.0	36.5	10.98
DP 1359B2	5402	759	86	43.8	39.5	9.82
NG 1511B2	4593	689	85	43.2	39.5	8.56
PHY 499WR	6291	683	89	44.5	41.2	7.42
TAM 07V-45	5765	708	88	39.5	36.9	6.58
PHY 575WR	6084	810	87	40.5	37.9	6.42
DP 0912B2	5679	773	86	40.6	38.1	6.16
TAM 08WZ-83	5209	766	85	41.0	38.5	6.10
DP 1044B2	5668	690	88	40.1	37.8	5.74
SSG UA103	4878	699	86	39.7	37.3	5.04
TAM 08WZ-78	5308	607	89	42.5	41.0	3.53
PHY 339WR	6131	723	88	41.2	39.9	3.16
PHY 725RF	5298	633	88	36.9	36.4	1.36
TAM 11T-08ELSU/ESU	5362	615	89	35.8	35.9	-0.28
TAM 11K-13ELSU	5367	642	88	35.7	36.0	-0.84
TAM 11L-24LSU	5320	712	87	35.4	35.6	-1.92
$LSD_{0.05}$[X]			ns			10.08

[Z]ELSU=extra long staple upland; LSU=long staple upland; ESU=extra strength upland.

[Y]W=Weslaco; CC=Corpus Christi.

[X]Values within a column are different at p=0.05, if they differ by more than the LSD value at base of column.

Table 6. Mean values and stability estimates for UHML and Str of genotypes possessing the ELSU, LSU, an ESU[Z] traits compared with cultivars and germplasm lines with current UHML and Str levels when grown at Weslaco, TX under irrigated culture and Corpus Christi, TX under non-irrigated culture averaged over 2013 and 2014.

Genotypes	UHML			Str		
	W[Y]	CC	Δ	W	CC	Δ
	------------------------ mm % ------------------------			----------- kN m kg^{-1} -----------		------ % ------
TAM08WZ-78	30.5	24.2	20.7	316	269	14.9
TAM08WZ-83	31.2	25.3	18.9	323	285	11.6
NG1511B2RF	29.1	24.1	17.2	322	292	9.1
DP0912B2RF	28.4	23.5	17.3	297	271	8.9
DP1359B2RF	29.9	24.9	16.7	313	288	7.8
PHY575WRF	30.9	26.5	14.2	302	281	6.8
DP1044B2RF	29.0	23.9	17.6	300	280	6.5
PHY725RF	31.6	26.2	17.1	351	329	6.4
PHY339WRF	30.2	24.3	19.5	315	299	5.0
TAM07V-45	29.6	24.8	16.2	312	297	4.7
PHY499WRF	29.1	24.0	17.5	315	302	4.0
SSGUA222	31.1	25.0	19.6	312	303	2.8
TAM11K-13 ELSU	36.6	29.7	18.9	340	331	2.5
SSGUA103	31.1	26.6	14.5	329	321	2.4
TAM11L-24 LSU	33.5	28.1	16.1	330	327	0.9
TAM11T-08 ELSU/ESU	35.4	28.6	19.2	357	368	-3.0
LSD[X]			ns			8

[Z]ELSU=extra long staple upland; LSU=long staple upland; ESU=extra strength upland.

[Y]W=Weslaco; CC=Corpus Christi.

[X]Values within a column are different at p=0.05, if they differ by more than the LSD value at base of column.

A Δ of zero would mean numerical stability, i.e., the same performance at both locations, in any comparison across production regimes or sites, whether comparing locations, moisture, or any other variable. Assuming that zero Δ indicates such stability, any response within the LSD value from zero would be stable. Thus, data in table 6 suggest that 12 of the 16 genotypes tested expressed stability for Str across the two locations. Two TAM lines, TAM 08WZ-78 and TAM 08WZ-83, along with NG 1511 B2RF were significantly variable and likely the main contributor to the significant GxL interaction, i.e., these genotypes exhibited reductions in Str when grown at Corpus Christi compared with Weslaco greater than zero Δ. The phenomena that has been observed with these ELSU, LSU, and ESU genotypes in Texas is that they produce lint with Str values equal to zero Δ when grown in environments with moderate to severe droughts compared with locations that receive sufficient rainfall or irrigation (data not shown). That phenomenon was observed in these data as well with TAM 11T-08 ELSU/ESU averaging numerically higher Str at Corpus Christi without irrigation than at Weslaco under irrigated culture. TAM 11 L-24 LSU and TAM 11K-13 ELSU averaged only 0.9 % and 2.5 % lower Str when grown at Corpus Christi compared with the Weslaco location, respectively.

CONCLUSIONS

Evaluation of the interaction term of GxL in the ANOVA in this study by separating the Δ values revealed that the ELSU, LSU, and ESU upland fiber quality traits developed at Texas A&M AgriLife Research were as consistent in performance for UHML, Str, seed cotton yield, and LP as standard fiber quality genotypes when grown at Weslaco with irrigation and at Corpus Christi without irrigation. These data suggest that further improvement in UHML and Str of upland cotton will not be detrimental to the stability of these traits in south Texas regardless of moisture conditions.

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