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PLANT BREEDING AND GENETICS

Yarn Performance of Texas Quality Upland Cotton Germplasm

C.Wayne Smith*, Steve Hague, Eric Hequet, and Brendan Kelly

ABSTRACT

Ring and rotor spinning predominate the cotton spinning market with ring spinning dominating globally while United States (U.S.) spinners prefer rotor because of its production speed and high automation level. Newer and faster spinning technologies such as "air jet" spinning, exemplified by Murata Vortex Spinning (MVS), are being deployed. Rotor spinning produces yarn five times faster than ring, and the MVS produces 100 % cotton yarn over 20 times faster than ring spinning. Fiber quality improvements will be necessary for Upland cotton to be competitive with other fibers on MVS. Texas A&M Agrilife Research has released improved fiber quality germplasm lines and cultivars that equal or exceed the fiber quality parameters associated with the New Mexico Acala germplasm pool, which is considered the elite quality among Upland breeding pools. Two improved quality Texas A&M germplasm lines were compared with Acala 1517-08 for High Volume Instrument (HVI) and Advanced Fiber Information System (AFIS) fiber quality parameters plus yarn strength and appearance parameters. These genotypes were grown in 2017 and 2019 at Weslaco, Texas under irrigated culture. The three genotypes were similar in all fiber quality measurements except lengh and fiber strength. TAM 06WE-621 and TAM KJ-Q14 produced stronger yarns with improved yarn appearance when spun on either ring or air jet spinning technologies. Data suggest that the Texas A&M quality germplasm pool can be used to develop Upland cotton cultivars that will produce fibers competitive for the emerging MVS technology.

C.W. Smith* and S. Hague, Dept of Soil and Crop Sciences, 370 Olsen Blvd. MS 2474, Texas A&M University, College Station, TX 88843-2474; E. Hequet and B. Kelly, Texas Tech University, 2911 15th Street, Lubbock, TX 79405-2122.
*Corresponding author: cwsmith@tamu.edu

Cotton, *Gossypium* spp., was domesticated as an Old World textile fiber over 4,000 years before present (YBP) and as a New World textile fiber over 5,000 YBP (Brubaker, et al., 1999). Upland cotton, *G. hirsutum* L., accounts for about 90 % of the world's cotton fiber production while Pima, *G. barbadense* L., accounts for the vast majority of the remaining 10 % with only minor production of the Old World diploid, *G. arboreum* L. Pima fibers are longer, finer, and stronger than Upland cotton fibers. Within Upland varieties, the "Acala" phenotype is considered superior in fiber quality to the remaining Upland commercial phenotypes and is produced on limited acreage in the Southwest United States. A relatively small percentage of Upland production is Acala because of its lower yield potential in production areas outside of the desert Southwest (USDA, 2020).

Cotton traditionally has been considered a highly desirable textile fiber because of its "feel" or comfort compared with other textile fibers and because it absorbs moisture. However, advancements in spinning technologies, manmade fibers, and competition among all fibers mandate continual improvements in Upland cotton fiber quality.

Two types of spinning technologies predominate the yarn market. Ring spinning involves parallelizing fibers and then adding twist to create yarn. The ring method predominates globally because fibers can be spun into a wide range of yarn counts with fewer yarn faults compared with rotor spinning and because of the superior appearance of fabrics produced from it. Rotor spinning was introduced in the 1970s and "wraps" fibers around a core in order to produce yarn. Because much of a yarn's strength or tenacity is the result of fiber to fiber friction, rotor spinning results in yarns that are 10 to 15 % weaker than that produced on ring frames when produced from cotton fibers with the same quality characteristics (Guthrie, et al., 1994). Thus, the cotton cultivar development community developed breeding lines and cultivars with fiber bundle strength approximately 20 % stronger between 1980 and 1993, which allowed spinning mills in the U.S. to take advantage of rotor spinning that is three to five times faster than ring spinning and removes the roving processing step.

The next generation of spinning technology, called air-jet or Murata Vortex Spinning (MVS), will produce yarns at speeds over 20 times faster than the ring method (Gunaydin and Soydan, 2017). Although air jet spinning technology was developed for man-made fibers, the MVS system is capable of utilizing cotton fibers but will require longer, stronger, and finer fibers than required for ring or rotor spinning, again putting pressure on the breeding community to develop cultivars with such fiber characteristics (www.muratec-usa.com/machinery/textiles/vortex-spinning-machine, accessed 29 June 2020; www.cottoninc.com/wp-content/uploads/2017/12/TRI-1001-Air-Jet-Spinning-of-Cotton-Yarns.pdf, accessed 25 January 2021). The MVS-produced yarns have a core of somewhat parallelized fibers that are surrounded by "wrapper" fibers with a direction around the yarn axis similar to ring spun yarn. Thus, fiber friction is reduced in MVS yarn relative to that produced on ring frames and stronger and finer individual fibers will be necessary to produce yarn strengths competitive with ring spinning. MVS requires less maintenance, includes a fully automated piecing system, and eliminates the requirement for the roving process, all, when combined with the increased speed of production, should reduce the cost per unit of yarn produced (International Textile Manufacturers Federation, 2018).

The Cotton Improvement Program of Texas A&M Agrilife Research at College Station has concentrated on developing genotypes with unique and enhanced fiber quality parameters. Several Upland cotton genotypes have been released since 2009 with fiber lengths near or exceeding the minimum for grade 1 Pima or fiber bundle strength (FBS) approximately 25 % higher than the average of current Upland cultivars, other than the Acala types (Smith et al., 2009; Smith et al., 2014, Smith et al. 2018 a,b; Smith et al., 2020). TAM BB-2139 ELSU (Smith et al., 2020) averaged 36.6 mm (Pima = 34.9 mm) across nine locations in eight states in the 2016 USDA Regional High Quality Test (USDA-ARS. 2016. National Cotton Variety Test. https://www.ars.usda.gov/southeast-area/stoneville-ms/crop-genetics-research/docs/national-cotton-variety-test/ (accessed 17 September 2020).

TAM 06WE-621 germplasm with improved Fiber Bundle Strength (FBS) was not different (p=0.05) than 'FM 832LL' in Upper Half Mean Length (UHML) or Micronaire (Mic) when grown at Weslaco, TX in 2009 and 2010 (Smith et al., 2014). However, TAM 06WE-621 averaged 19% stronger FBS and 27% greater 50 Ne ring-spun yarn tenacity. TAM 06WE-621 did exhibit longer (p=0.05) UHML than several other Upland cultivars which may have contributed to its yarn tenacity performance. Gregory et al. (2012) reported that 11 advanced high FBS strains produced stronger (p=0.05) 50 Ne ring spun yarn than two high quality cultivar controls in 2009 and six exhibited stronger yarn in 2010. TAM 11T-08 ELSU-ESU also produced High Volume Instrument FBS that numerically exceeded the strength of Upland cultivars grown in Texas in 2018, except the Acala types in Far West Texas (Smith et al., 2018b).

USTER Technologies, headquartered in Uster, Switzerland, collects and tests yarn samples from around the world to provide globally-accepted benchmarks for textiles. Thus, spinning results can be immediately compared with global averages. These Uster statistics are beneficial to textile mills and for research purposes as a benchmarking process. The Uster Statistics provide a numerical comparison only with no statistical comparison. (https://www.uster.com/en/, accessed 18 September 2020).

The objective of the research reported herein was to determine the performance of the improved quality Texas germplasm pool compared with the New Mexico Acala germplasm pool that traditionally represented the elite Upland quality germplasm in the United States.

MATERIALS AND METHODS

TAM 06WE-621 (Smith et al., 2014), TAM KJ-Q14 (unreleased breeding line), and Acala 1517-08 (Zhang et al., 2011) were grown at the Texas A&M Research and Extension Center in Weslaco, TX in 2017 and 2019. Tamcot 73 (Smith et al., 2011) was added in 2019 to provide a standard Upland comparison. Plots were four rows x 37 m x 1 m, with two replications each year. Soil type was Hildago sandy clay loam. Standard cultural practices for Upland cotton were followed, including furrow irrigation on an as needed basis. Boll samples for HVI and Advanced Fiber Information System (AFIS) analyses were hand harvested from each of the two reps, ginned on a 10-saw laboratory gin, and fiber properties determined on the resulting lint at the Texas Tech University Fiber and Biopolymer Research Institute in Lubbock, TX. Plots were harvested with a spindle type cotton harvester modified for experimental plot harvest. Machine harvested seed cotton was ginned on an industrial gin cut to only 24 saws. The complete gin (Lummus Corporation) setup was:

- Suction unloading telescope
- Inclined 6-cylinder air-fed cleaner
- Gravity-fed extractor-type Little Giant™ 2-saw stick machine
- Model 700™ II extractor feeder
- 24-saw Imperial™ III gin
- Super-Jet centrifugal-type lint cleaner
- Sentinel™ saw-type lint cleaner
- Finally a battery condenser to retrieve the lint.

Analyses of variance (ANOVA) were performed on HVI and AFIS data derived from the hand-harvested boll samples from each plot and each rep in 2017 and 2019. All main effects were considered fixed with years split to genotypes. Means were separated by the Waller LSD at k=100 which approximates the 0.05 probability level.

Carded yarn was spun on both a ring frame (Suessen Elite) and a Murata vortex 870 spinning frame (MVS) in 2017 and 2019 on lint from each entry and each of the two reps. Forty Ne yarn was produced by ring spinning in both years and 30 Ne yarn was produced on the MVS frame. Main effects for the ANOVA were consider fixed with years (Y) split to genotypes (G) which were split to spin type (ST), either ring or MVS. Means were separated by the Waller LSD at k-100 which approximates the 0.05 probability level. USTER 50% statistics are included in the means tables, which is the USTER value at which 50% of the mills worldwide are producing equal or better values for that particular yarn size.

In 2019 only, both combed and carded yarns were produced on both ring and MVS platforms. Thus for 2019 only, the impact of fiber preparation could be evaluated with main effects of G, ST, and preparation (P) included in the ANOVA model and mean separation as noted above.

Data collected and reported herein includes standard HVI properties, selected AFIS fiber properties, three yarn strength parameters, and five yarn appearance measurements (Table 1).

Table 1. Fiber properties measured by High Volume Instrument and Advanced Fiber Information System and selected yarn properties determined on TAM 06WE-621, TAM KJ-Q14, and Acala 1517-08

Trait	Abbreviation	Description
Micronaire	Mic	HVI estimate of fiber fineness and maturity combined.
Upper half mean length	UHML	Mean length by weight of the longest 50% of fibers
Length uniformity index	UI	(Mean fiber length / UHML) * 100
Fiber bundle Strength	FBS	Normalized (by weight) breaking force of the fiber bundle
Elongation before rupture	El	Elongation of the fiber bundle at rupture
Color grade	CGRD	Fiber reflectance and yellowness
Leaf trash	Leaf	Indicator of number of leaf trash per area
Length by number	Ln	Mean fiber length based on number of fibers
Short fiber content by number	SFCn	Percentage of fibers shorter than 12.7 mm based on number of fibers
Immature fiber content	IMC	Percentage of immature fibers
Maturity ratio	MR	Indicator of secondary wall thickening relative to perimeter
Standard fineness	Hs	Fineness (linear density) / MR
Yarn tenacity	Tenacity	Breaking force / linear density
Yarn work to break	YWTB	Area below the force/elongation curve at break
Elongation of yarn before break	YNEL	Elongation of the yarn at rupture
Yarn coefficient of variation	CV	Coefficient of variation of the yarn mass
Neps200	Neps200	Number of entangled fibers that are 200% larger than yarn average diameter
Thin50	Thin50	Number of sites per unit length of yarn that are 50% smaller diameter than average
Thick50	Thick50	Number of sites per unit length of yarn that are 50% thicker diameter than average
Yarn hairiness	Hairiness	Measure of the fiber ends protruding from yarn

RESULTS AND DISCUSSION

Year impacted (p=0.05 to 0.01) all HVI and AFIS fiber characteristics and is reported in Tables 2 and 3. The exceptions were for maturity ratio (MR) and standard fineness (Hs), in which year of production did not differ across these genotypes. Genotypes did not vary for the non-length and non-strength parameters of Mic, Elongation before rupture (El), Color Grade (CGRD), Leaf, Immature Fiber Content (IFC), MR, or Hs. These ANOVA results support the appropriateness of comparing the impact of UHML and FBS on yarn performance when spun on either ring or MVS frames.

HVI and AFIS means reported in Tables 4 and 5 show that TAM 06WE-621, TAM KJ-Q14, and Acala 1517-08 averaged near identical numerical values for Mic, El, CGRD, Leaf, IFC, MR, and Hs when averaged across 2017 and 2019. However, TAM KJ-Q14 exhibited longer (p=0.0001) UHML than TAM 06WE-621 or Acala 1517-08, which were not different at 31.1 and 30.9 mm, respectively. There was a small YxG interaction source of variance for UHML, but it represented only 0.75 % of the total variance and thus was not considered further. Both of the Texas germplasm fiber quality pool lines exhibited better (p=0.01) length uniformity (UI) than Acala 1517-08, and both exhibited stronger (p=0.001) FBS at 366 and 369 kN m kg^{-1} compared with 330 kN m kg^{-1} for Acala 1517-08, a 12% improvement.

Table 2. Mean squares for HVI[z] fiber properties and fiber sample physical condition of TAM 06WE-621, TAM KJ-Q14, and Acala 1517-08

Source	df	Mic	UHML	UI	FBS	El	CGRD	Leaf
Year	1	$2.08^{0.05}$[y]	$7.01^{0.01}$	$2.08^{0.05}$	$15.64^{0.01}$	$7.68^{0.01}$	$1283401^{0.05}$	$44.1^{0.05}$
Error a	2	0.05	0.04	0.11	0.01	0.03	40838	1.4
Genotype	2	0.08	$10.23^{0.0001}$	$4.02^{0.01}$	$19.60^{0.001}$	<0.00	3	1.6
Y x G	2	$3.85^{0.03}$	$0.13^{0.04}$	0.08	0.15	0.02	33003	1.6
Error b	4	0.43	0.02	0.16	0.34	0.01	16335	0.9
%CV		1.4	0.3	0.46	1.6	1.6	11.8	28.0
Mean		4.60	31.75	85.40	355	6.50	34-2	3.4

[z] HVI-high volume instrument; Mic-micronaire; UHML-upper half mean length; UI-uniformity index; FBS-fiber bundle strength; El-elongation before rupture; CGRD-color grade; Leaf-leaf trash in sample.

[y] Superscript = probability of a larger F value; no superscript indicates probability greater than 0.05.

Table 3. Mean squares for selected AFIS[z] fiber properties of TAM 06WE-621, TAM KJ-Q14, and Acala 1517-08

Source	df	Ln	SFCn	IFC	MR	Hs
Year	1	$10.80^{0.01}$[y]	$51.7^{0.01}$	$32.03^{0.01}$	4.08	25.7
Error a	2	0.07	0.3	0.28	1.42	10.0
Genotype	2	$1.91^{0.07}$	$28.3^{0.004}$	3.18	6.25	30.9
Y x G	2	0.68	$12.7^{0.02}$	2.16	6.58	$131.4^{0.018}$
Error b	4	0.34	1.0	1.23	1.42	10.3
%CV		2.2	4.6	7.2	1.3	1.9
Mean		21.67	21.6	4.9	0.95	172

[z] AFIS-advanced fiber information system; Ln-average fiber length averaged over 15000 fibers; SFCn-number of fibers less than 12.7 mm; IFC-immature fiber content; MR-maturity ratio; Hs-standard fineness.

[y] Superscript = probability of a larger F value; no superscript indicates probability greater than 0.05.

Table 4. HVI[z] fiber properties for TAM 06WE-621, TAM KJ-A14, and Acala 1517-08 when grown at Weslaco, TX in 2017 and 2019

Genotype	Mic units	UHML mm	UI %	FBS kN m kg^{-1}	El %	CGRD No unit	Leaf No unit
TAM 06WE-621	4.6 a[y]	31.1 b	85.7 a	366 a	6.4 a	34-2 a	2.8 a
TAM KJ-Q14	4.6 a	33.2 a	86.2 a	369 a	6.5 a	34-2 a	3.5 a
Acala 1517-08	4.6 a	30.9 b	84.3 b	330 b	6.5 a	34-1 a	4.0 a

[z] HVI-high volume instrument; Mic-micronaire; UHML-upper half mean length; UI-uniformity index; FBS-fiber bundle strength; El-elongation before rupture.

[y] Values within columns followed by the same letter are not different at P=0.05.

Table 5. Selected AFIS[z] fiber properties for TAM 06WE-621, TAM KJ-Q14, and Acala 1517-08 when grown at Weslaco, TX in 2017 and 2018

Genotype	Ln mm	SFCn %	IFC %	MR No unit	Hs mtex
TAM 06WE-621	21.5 ab[y]	18.7 b	5.2 a	0.94 a	175 a
TAM KJ-Q14	22.9 a	24.0 a	4.7 a	0.96 a	170 a
Acala 1517-08	21.2 b	22.2 a	4.8 a	0.95 a	171 a

[z] AFIS-advanced fiber information system; CGRD-color grade; Leaf-leaf trash content; Ln-average fiber length by number; SFCn-short fiber content by number; IFC-immature fiber content; MR-maturity ratio; Hs-standard fineness.

[y] Values within columns followed by the same letter are not different at P=0.05.

Advanced Fiber Information System analyses supported the length differences among these lines with TAM KJ-Q14 having Length by number (Ln) longer than Acala 1517-08 but not different than TAM 06WE-621, which was not different than Acala 1517-08 (Table 5). While TAM KJ-Q14 was longer (p=0.0001) than TAM 06WE-621 in UHML and numerically longer in Ln, TAM 06WE-621 exhibited less (p=0.004) Short Fiber Content (SFC) than TAM KJ-Q14 or Acala 1517-08.

These data suggest that TAM 06WE-621 and TAM KJ-Q14 are similar to Acala 1517-08 in fiber quality parameters other than length and/or FBS parameters and that relative differences or similarities in yarn properties should be due to these length and FBS parameters.

Three yarn strength parameters, Tenacity, Yarn Work to Break (YWTB), and Elongation of Yarn before Break (YNEL), are reported herein along with five yarn appearance parameters, CV, Neps200, Thin50, Thick50, and Hairiness (Table 6). Within the yarn strength parameters, the majority of the variance was accounted for by ST, as expected, for Tenacity and YNEL. For YWTB, G accounted for 35 % of the variance, while ST accounted for 52 %. While Y impacted Tenacity, its variance accounted for only 6 % of the total. The proportion of the total variance of the interaction terms in the ANOVA for these yarn strength parameters ranged from less than 1 to 5 %.

The ANOVAs and distribution of total variance were more variable among the appearance parameters (Table 6). Spin type accounted for the largest percentage of total variance for CV, Neps200, Thick50, and Hairiness, with G accounting for 62 % of the total variance for Thin50. A large percentage of total variance for Hairiness was contributed by G at 35 %. Among the interaction terms, ST x G accounted for 18 % and 15 % for Thin50 and Thick50, respectively. Other significant interaction terms were between 1 % and 11 %.

Table 6. Mean squares for selected yarn quality parameters for TAM 06WE-621, TAM KJ-Q14, and Acala 1517-08; grown at Weslaco, TX in 2017 and 2019; ring and vortex spun carded yarns

Source	df	Tenacity	YWTB[z]	YNEL	CV	Neps200	Thin50	Thick50	Hairiness
Year	1	$10.55^{0.05y}$	2.53	0.79	$1.36^{0.05}$	757	2.3	$1300.6^{0.01}$	1.61
Error a	2	0.15	1.92	0.07	0.02	339	1.2	4.9	0.59
Genotype	2	$10.41^{0.01}$	$66.62^{0.01}$	$0.78^{0.05}$	$3.03^{0.01}$	$97^{0.05}$	$388.2^{0.01}$	$458.3^{0.01}$	$12.31^{<0.01}$
Y*G	2	$0.85^{0.05}$	6.28	$0.52^{0.05}$	0.09	7	33.1	29.4	0.66
Error b	4	0.09	1.86	0.06	0.04	6	12.6	8.4	0.17
Spin Type	1	$145.48^{<0.01}$	$98.57^{<0.01}$	$22.79^{<0.01}$	$17.78^{<0.01}$	$1373^{0.02}$	5.1	$6579.5^{<0.01}$	$14.66^{<0.01}$
Y*ST	1	0.18	$8.78^{0.01}$	0.05	$2.74^{<0.01}$	28	$110.5^{0.01}$	$1472.3^{<0.01}$	$1.94^{<0.01}$
G*ST	2	$0.34^{0.01}$	1.34	$0.14^{0.05}$	$0.39^{<0.01}$	19	23.2	$132.6^{<0.01}$	$3.06^{<0.01}$
Y*G*ST	2	0.1	0.43	0.03	$0.16^{<0.01}$	9	41.7	$86.3^{<0.01}$	0.23
Error c	6	0.04	0.71	0.27	0.005	125	9.4	4.8	0.09
% CV		1.12	2.2	1.04	0.43	49.36	23.92	6.35	0.66
Mean		16.95	382	5.04	15.6	716	12.8	346.4	4.6

[z] YWTB-yarn work to break; YNEL-elongation of yarn before rupture; CV-measure of yarn variation as weight per unit length; Neps200-yarn imperfections that are 200% larger than yarn average diameter; Thin50-yarn imperfections that are 50% smaller than yarn average diameter; Thick50-yarn imperfections that are 50% larger than the yarn average diameter; Hairiness-proportion of fiber ends that protrude and are not embedded in the yarn body.

[y] Superscript = probability of a larger F value; no superscript indicates probability value greater than 0.05.

Summarily, ST was the major variance contributor to all appearance measures except Thin50 while G contributed 35 %, 62 %, and 35 % to the total variance for YWTB, Thin50, and Hairiness, respectively.

TAM 06WE-62 and TAM KJ-Q14 yarn exhibited greater ($p \leq 0.05$) carded yarn Tenacity, YWTB, and YNEL than Acala 1517-08 (Table 7). TAM 06WE-621 averaged 13 % stronger yarn when averaged over Y and ST than Acala 1517-08, 15% better YWTB, and 4 % better YNEL. TAM KJ-Q14 was not different ($p \leq 0.05$) than TAM 06WE-621 for these yarn strength characteristics but exceeded the values for Acala 1517-08. Numerically, these relationships were the same regardless of ST, i.e., ring or vortex spinning. Ring spinning produced a stronger ($p \leq 0.01$) yarn than MVS as indicated by these three parameters.

Yarn appearance parameters indicated that TAM 06WE-621 produced a more desirable yarn as indicated by a lower yarn CV, fewer Neps200, fewer Thin50 places per unit of yarn length, fewer Thick50 places, and less Hairiness ($p \leq 0.05$) than yarn produced with Acala 1517-08 when averaged over Y and ST (Table 7). TAM KJ-Q14 was not different than TAM 06WE-621 for Thin50 and Hairiness but was not different than Acala 1517-08 for CV, Neps200, and Thick50. MVS technology, when averaged over Y and G, produced a more desirable yarn appearance with a smaller CV, fewer Neps200, fewer Thin50 places, and fewer Thick50 places. However, ring spinning produced yarn with fewer protruding fibers as indicated by Hairiness.

Table 7. Carded yarn characteristics of TAM 06WE-621, TAM KJ-Q14, and Acala 1517-08 when spun on ring and MVS platforms

Genotype	Tenacity (cN tex^{-1})			YWTB (cN cm)		
	Ring	Vortex	Mean	Ring	Vortex	Mean
TAM 06WE-621	20.3	15.1	17.7 a	427	381	404 a
TAM KJ-Q14	20.1	14.9	17.5 a	416	371	393 a
Acala 1517-08	17.9	13.4	15.6 b	365	334	350 b
Mean	19.4 a^{z}	14.5 b		402 a	362 b	
Uster 50%	16.2	12.4		404	323	

Genotype	YNEL (%)			CV (%)		
	Ring	Vortex	Mean	Ring	Vortex	Mean
TAM 06WE-621	5.5	4.8	5.1 a	15.7	14.2	15.0 b
TAM KJ-Q14	5.4	4.7	5.1 a	16.8	14.6	15.7 a
Acala 1517-08	5.2	4.7	4.9 b	16.9	15.4	16.2 a
Mean	5.4 a	4.7 b		16.5 a	14.8 b	
Uster 50%	5.4	5.3		16.2	15.9	

Genotype	Neps200 (# per unit length)			Thin50 (# per unit length)		
	Ring	Vortex	Mean	Ring	Vortex	Mean
TAM 06WE-621	785	399	592 b	6.3	6.1	6.2 b
TAM KJ-Q14	1094	514	804 a	14.4	9.8	12.1 b
Acala 1517-08	986	517	752 a	19.1	21.1	20.1 a
Mean	955 a	477 b		13.3 a	12.3 a	
Uster 50%	471	265		19	68	

Genotype	Thick50 (# per unit length)			Hairiness (# per unit length)		
	Ring	Vortex	Mean	Ring	Vortex	Mean
TAM 06WE-621	387	138	263 b	4.4	4.6	4.5 b
TAM KJ-Q14	573	160	366 a	4.5	4.7	4.6 b
Acala 1517-08	575	245	410 a	4.8	4.8	4.8 a
Mean	512 a	181 b		4.5 b	4.7 a	
Uster 50%	202	179		5.2	4.3	

^{z} Values within means columns or rows followed by the same letter are not different at P=0.05.

The better ($p \leq 0.05$) yarn performance of TAM 06WE-621 appears to be the result of improved FBS, higher UI, and lower SFC than Acala 1517-08 (Tables 4 and 7). TAM JK-Q14 also had better FBS and UI, but was not different than Acala 1517-08 for SFC. This Texas A&M quality germplasm pool representative produced stronger yarn than Acala 1517-08, but it's appearance was not as distinctly different than Acala 1517-08 as that produced by TAM 06WE-621.

The USTER 50 % statistics in Table 7 indicate that the average Tenacity and YWTB of TAM 06WE-621 and TAM KJ-Q14 exceeded that of over 50% of the yarn produced globally on either ring or MVS frames. The yarn appearance of both TAM lines also exceeded 50% of the global USTER 50 % statistic for CV, Thin50, Thick50, and Hairiness when spun on one or both spinning frames. It should be noted that Uster statistics for MVS are for combed yarns because there are no carded yarns produced on MVS frames today. These Uster statistics indicate that the Texas A&M quality germplasm pool could be used by breeders to develop more globally competitive Upland cotton. The data in Table 7 is encouraging also in that the data are from carded yarn only and the Texas material exceed the Uster 50% based on global performance of combed yarns produced on Vortex.

The data in tables 1 -7 illustrated the desirability of the Texas A&M quality germplasm for spinning carded yarns on either ST but also highlighted that MVS produced yarns from carded cotton were weaker although their appearance were generally superior to ring spun yarns (Table 7). Sample sizes were sufficient in 2019 to both card and comb slivers before spinning and thus provide insights into the generally accepted premise that cotton must be combed in order to spin on the MVS platform. The ANOVA was used to partition the variances associated with yarn strength and yarn appearance due to G, ST, and preparation (P), i.e., combed or carded. The mean squares in table 8 indicate that ST accounting for the majority of the total variance for yarn strength parameters, 78 to 87 %, and that P accounted for 92, 80, 40, 83, and 13 % of the total variation for CV, Neps200, Thin50, Thick50, and Hairiness, respectively. ST and G accounted for the highest proportion of variance for Hairiness.

Table 8. Mean squares for selected yarn quality parameters for TAM 06WE-621, TAM KH-Q14, Acala 1517-08, and Tamcot 73 when grown at Weslaco, TX in 2019 and spun as carded yarn or combed yarn on ring or MVS platforms

Source	df	Tenacity	Work to Break	El^{y}	CV	Neps200	Thin50	Thick50	Hairiness
Genotype	3	24.70$^{0.01z}$	1754.2$^{0.01}$	10.8$^{0.05}$	13.6$^{0.05}$	116.3$^{0.01}$	116.1	71.2$^{0.05}$	4.45$^{0.001}$
Rep	1	0.09	49.4	2.7	0.1	0.1	2.5	0.2	0.03
Error a	3	0.36	40.8	0.5	0.7	3.2	13.7	5	0.02
Spin Type	1	124.32$^{0.001}$	14280.7$^{0.001}$	132.4$^{0.001}$	3.7$^{0.01}$	349.2$^{0.001}$	351.1$^{0.01}$	224.9$^{0.001}$	7.09$^{0.001}$
ST*G	3	0.92	131.4	1.6	1.4$^{0.05}$	12.1$^{0.01}$	58.9$^{0.05}$	20.0$^{0.01}$	3.36$^{0.001}$
Error b	4	0.09	32.2	0.6	0.1	0.4	5.3	1.04	0.01
Preparation	1	7.78$^{0.001}$	518.2$^{0.001}$	0.8$^{0.05}$	573.9$^{0.001}$	3189.8$^{0.001}$	457.5$^{0.001}$	3291.6$^{0.001}$	2.43$^{0.001}$
P*G	3	0.11	14.8	0.6$^{0.05}$	3.2$^{0.001}$	63.0$^{0.001}$	44.0$^{0.001}$	40.6$^{0.001}$	0.56$^{0.001}$
P*ST	1	0.01	<0.0	2.5$^{0.02}$	28.3$^{0.001}$	252.3$^{0.001}$	81.3$^{0.001}$	286.5$^{0.001}$	0.64$^{0.001}$
P*G*ST	3	0.04	3.7	0.2	0.7$^{0.01}$	8.4$^{0.01}$	11.0$^{0.01}$	23.3$^{0.01}$	0.46$^{0.001}$
Error c	8	0.08	10.1	0.2	0.1	0.8	1.7	21	0.02
% CV		1.63	2.32	0.79	0.56	6.58	23.07	10.9	0.79
Mean		17.17	432.7	4.93	13.64	438.02	5.68	132.02	4.98

[z] **El-elongation of yarn before rupture; CV-measure of yarn variation as weight per unit length; Neps200-yarn imperfections that are 200% larger than yarn average diameter; Thin50-yarn imperfections that are 50% smaller than yarn average diameter; Thick50-yarn imperfections that are 50% larger than the yarn average diameter; Hairiness-proportion of fiber ends that protrude and are not embedded in the yarn body.**

[y] **Superscript = probability of a larger F value; no superscript indicates probability value greater than 0.05.**

The interaction variance terms in Table 8 accounted for relatively small percentages of the total variance except for Hairiness ST x G. However, for presentation purposes, Table 9 displays yarn strength and appearance means for G and ST while Table 10 displays means for ST and P. Means in Table 9 for 2019 are similar to those in Table 7 averaged over 2017 and 2019 without a combed component. The ST x G interaction for Tenacity was not significant (Table 8) since all G responded the same to ST. However, the data indicate that TAM 06WE-621 and TAM KJ-Q14 produced MVS yarn with Tenacity numerically similar to that produced on ring for Tamcot 73. Again indicating the value of the Texas A&M quality germplasm in developing cultivars that will be globally accepted for vortex spinning.

Combing impacted yarn performance and appearance as expected (Table 8 and 10). Combed yarns had better (p values ranged from 0.05 to 0.001) strength values and better (p=0.001) appearance values. Combing particularly impacted Neps200, Thin50, and Thick50 parameters. These data suggest that yarn appearance is a major reason to comb slivers prior to spinning Upland cotton on the MVS platform although yarn tenacity is clearly improved.

Table 9. Yarn characteristics of TAM 06WE-621, TAM KJ-Q14, Acala 1517-08, and Tamcot 73 grown at Weslaco, TX in 2019 and spun on either a ring or MVS frame

Genotype	tenacity (cN tex)			Work to break (cN cm)		
	Ring	Vortex	Mean	Ring	Vortex	Mean
TAM 06WE-621	21.0	16.6	18.8 a	546	399	472 a
TAM KJ-Q14	20.8	16.2	18.5 a	555	392	473 a
Acala 1517-08	18.1	14.5	16.3 ab	457	345	401 b
Tamcot 73	16.7	13.5	15.1 b	440	328	384 b
Mean	19.1 a[z]	15.2 b		500 a	366 b	
Genotype	**Break elongation (%)**			**CV (%)**		
	Ring	Vortex	Mean	Ring	Vortex	Mean
TAM 06WE-621	5.22	4.81	5.01 ab	13.06	13.13	13.10 b
TAM KJ-Q14	5.30	4.77	5.04 a	13.58	13.53	13.55 ab
Acala 1517-08	4.95	4.64	4.79 b	13.80	14.08	13.94 ab
Tamcot 73	5.06	4.69	4.87 ab	13.70	14.26	13.98 a
Mean	5.13 a	4.73 b		13.54 b	13.76 a	
Genotype	**Neps200 (# per unit length)**			**Thin50 (# per unit length)**		
	Ring	Vortex	Mean	Ring	Vortex	Mean
TAM 06WE-621	526.2	318.8	422.5 ab	1.13	2.75	1.93 a
TAM KJ-Q14	664.0	407.8	535.9 a	1.63	5.00	3.31 a
Acala 1517-08	656.3	384.0	520.2 a	3.31	11.00	7.15 a
Tamcot 73	323.4	223.8	273.6 b	3.44	17.25	10.34 a
Mean	542.5 a	333.6 b		2.38 b	9.00 a	
Genotype	**Thick50 (# per unit length)**			**Hairiness (# per unit length)**		
	Ring	Vortex	Mean	Ring	Vortex	Mean
TAM 06WE-621	125.6	80.5	103.1 b	5.1	4.5	4.8 b
TAM KJ-Q14	182.7	105.0	143.8 ab	5.0	4.5	4.8 b
Acala 1517-08	207.3	129.5	168.4 a	5.8	4.6	5.2 a
Tamcot 73	118.6	107.0	112.8 ab	5.9	4.5	5.2 a
Mean	158.5 a	105.5 b		5.5 a	4.5 b	

[z] Values within means columns or rows followed by the same letter are not different at P=0.05.

Table 10. Yarn characteristics of carded and combed fiber preparation and spun on either a ring or MVS platform

Spin Type	Tenacity (cN tex)			Work to break (cN cm)		
	Carded	Combed	Mean	Carded	Combed	Mean
Ring	18.66	19.62	19.1 a	486.9	512.2	499.6 a
Vortex	14.70	15.71	15.2 b	353.1	378.8	366.0 b
Mean	16.7 b[z]	17.7 a		420.0 b	445.5 a	
Spin Type	Break elongation (%)			CV (%)		
	Carded	Combed	Mean	Carded	Combed	Mean
Ring	5.14	5.12	5.13 a	15.17	11.90	13.54 b
Vortex	4.68	4.77	4.69 b	14.79	12.71	13.75 a
Mean	4.91 b	4.94 a		14.98 a	12.30 b	
Spin Type	Neps200 (# per unit length)			Thin50 (# per unit length)		
	Carded	Combed	Mean	Carded	Combed	Mean
Ring	947	138	542 a	4.6	0.2	2.4 a
Vortex	561	107	334 b	14.4	3.6	9.0 b
Mean	754 a	123 b		9.47 a	1.91 b	
Spin Type	Thick50 (# per unit length)			Hairiness (# per unit length)		
	Carded	Combed	Mean	Carded	Combed	Mean
Ring	289.9	27.2	158.6 a	5.5	5.4	5.5 a
Vortex	177.0	34.0	105.5 b	4.6	4.4	4.5 b
Mean	233.5 a	30.6 b		5.1 a	4.9 b	

[z] **Values within means or delta columns or rows followed by the same letter are not different at P=0.05**

CONCLUSIONS

The data reported herein show that the two Texas A&M quality germplasm lines produced stronger yarns and yarns with better appearance than yarn produced from Acala 1517-08, the fiber quality standard for Upland cotton in the United States. This relationship held regardless of ST, either ring or MVS platform. When spun in 2019, TAM 06WE-621 and TAM KJ-Q14 produced MVS spun yarn with Tenacity numerically similar to ring spun Tamcot 73, suggesting that progress is being made in developing Upland quality genotypes that will be acceptable for 100% cotton yarns on the faster and more economical MVS frames. These data and the USTER statistics indicate that the Texas A&M quality germplasm pool could be used by breeders to develop more globally competitive Upland cotton.

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