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Simultaneous Improvement of Yield, Fiber Quality, and Yarn Strength in Upland Cotton

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ABSTRACT

A five-parent half diallel mating design was utilized to determine the potential for the simultaneous improvement in yield, fiber quality, and yarn strength in upland cotton (*Gossypium hirsutum* L.). In addition, fiber traits were measured by standard laboratory instrumentation (SLI) and high volume instrumentation (HVI) to compare their usefulness to breeders in population improvement. The 10 F_1 populations plus the parental lines were grown in a randomized complete-block design in 1983 at two locations each with a different soil type at the Pee Dee Research and Education Center, Florence, SC. Significant general combining ability (GCA), which may approximate additive genetic effects, was detected for 2.5 and 50% fiber span length (SLI measurement), uniformity (SLI measurement), yarn strength, yield, and lint percentage. Therefore, progress from early generation selection could be expected in these populations. There were no significant GCA effects for any of the HVI fiber measurements, and it was concluded that HVI is not as useful to breeders in detecting small genetic differences as HVI is to the textile industry for which it was developed. There was some evidence of nonadditive genetic effects for some of the fiber traits by a general test of heterosis, although it was not detected by the test for specific combining ability. No single parent exhibited high GCA effects for yield and all fiber traits, thus simultaneous improvement in multiple fiber traits and yield probably will require intermating of several parental lines. However, simultaneous improvements in yield and yarn strength could be expected from crosses with PD 3249 and SC-1, thus providing further evidence of the breakup of unfavorable linkages.

A RECENT EMPHASIS in cotton breeding is the simultaneous improvement of yield and fiber strength to meet the demands of the cotton producer as well as the textile industry as it progresses to new spinning technologies and durable press processing. However, cotton breeders have long recognized a negative association between lint yield and fiber strength. This negative association was the case with the introduction of Beasley's triple hybrid [(*G. thurberi* Tod. × *G. arboreum* L.) × *G. hirsutum* L.] (2), which was first utilized as a new genetic source for higher fiber strength. Early breeding and selection with populations derived from this material resulted in germplasm lines with outstanding fiber strength but poor agronomic qualities (6,9).

Miller and Rawlings in 1967 (19) and Meredith and Bridge in 1971 (16) recommended a breeding method that incorporated intermating based on their findings that linkage rather than pleiotropy was the primary cause for the negative genetic correlation between yield and fiber strength. In the years following this proposal, Culp (4), Culp et al. (5,6,7,10), and Harrell et al. (12) reported several breeding successes in combining both high yield potential and superior fiber strength in the Pee Dee germplasm, which is of triple hybrid origin. They attributed this success in simultaneous improvement in yield and fiber strength to the utilization of a breeding program of modified intermating and selection that was initiated in 1946. A shift in phenotypic correlation between yield and yarn strength from $r = -0.93$ to 0.45 was evidence that unfavorable linkages had been broken (9). Further progress in simultaneous improvement of yield and fiber properties may be achieved by knowledge of the combining ability of potential parents for improving yield and fiber traits. In addition, new technologies for measuring fiber properties must be assessed for their utilization in a breeding program. This study was initiated to determine the: (i) importance of general and specific combining ability for yield, fiber traits, and yarn strength; (ii) best parents to utilize for simultaneously improving populations in yield, fiber quality, and yarn strength; and (iii) utility of standard laboratory instrumentation and the new high volume instrumentation for measuring fiber traits.

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MATERIALS AND METHODS

Five parental lines, Coker 201, SC-1, PD 8619, PD 3249, and PD 4461 were crossed in all possible pairs excluding reciprocal crosses to generate a half-diallel. Parents were chosen for yield potential and fiber quality characteristics. The 10 F_1 populations and the five parents were grown in two tests, each consisting of a randomized complete-block design with four replications at the Pee Dee Research and Education Center at Florence, SC. Test 1 was planted on 3 May 1983 on a Wagram loamy sand (loamy, siliceous, thermic Arenic Kandiudult), and Test 2 was planted on 9 May 1983 on a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Kandiudult). Each plot consisted of two rows, 10.6 m long with 96 cm between rows. Seed were hill dropped at planting, and plants were hand thinned to two plants per hill spaced 35 cm apart at the fourth true leaf stage of growth. Standard cultural practices and production recommendations of the Clemson University Cooperative Extension Service were followed.

Prior to mechanical harvest for yield, a 25-boll sample of unweathered open bolls from the middle of the plant's fruiting zone was hand picked from each plot for fiber testing. Samples from Replications 1 and 3, and 2 and 4 were combined at ginning to make two 50-boll samples of each entry per location for fiber and spinning tests. Lint percentage for each 50-boll sample was obtained as the weight of lint expressed as a percent of the weight of the seed cotton sample. Fiber and spinning properties for each sample were determined as follows by the USDA-AMS, Fiber and Spinning Laboratory, Clemson, SC:

Standard laboratory instrumentation (SLI)

a. Fiber length in millimeters measured as 2.5 (2.5 SL) and 50% (50 SL) span length on a Digital Fibrograph.
b. Fiber uniformity (UR) determined as the ratio of 50 and 2.5% span length (50/2.5) expressed as a percentage.
c. Fiber strength (T_1) as force (kN m kg^{-1}) necessary to break the fiber bundle with the jaws of the testing instrument (Stelometer) set 3.2 mm apart.
d. Fiber elongation (E_1) as the percent elongation at the break of the center 3.2 mm of the fiber bundle measured for T_1 strength.

e. Micronaire reading (mic) as fineness of the fiber measured by the micronaire and expressed in standard micronaire units.

f. Yarn strength as force (kN m kg^{-1}) required to break a skein of 27 tex yarn in small scale, ring spun tests as described by Landstreet et al. (13,14).

High Volume Instrumentation (HVI)

g. Upper-half mean length (UHM) as the mean length in millimeters of the half of the fiber, by weight, that contains the long fibers.

h. Uniformity (UR) was determined as the ratio of the mean length to UHM expressed as a percentage.

i. Fiber strength and micronaire were determined similar to the above explanation (c and e) except HVI was used.

An analysis of variance was conducted for each trait measured and the sums of squares were partitioned into:

a. Differences among parental lines.

b. Differences among F_1's, which can be further partitioned into differences due to general combining ability (GCA) and specific combining ability (SCA) (Griffing Model II) (11).

c. The mean of the F_1's vs. the average midparent value, which is a test for average heterosis or nonadditive genetic effects.

General combining ability effects were determined for each parent. The GCA effects were ranked from 1 (lowest) to 5, and correlations were computed among the ranks of all possible pairs of yield and fiber traits.

RESULTS AND DISCUSSION

There were significant differences among the parents and among the F_1's for yield, lint percentage (LP) and all SLI fiber measurements (2.5 SL, 50 SL,. UR, and E_1) except T_1 and mic (Table 1). However, for the HVI fiber measurements, significant differences among parents and among F_1's were detected only for UHM. The F_1's also were significantly different for HVI-mic, yet no differences were detected among parents. Highly significant yarn strength differences (P = 0.01) among parents and F_1's were not reflected by differences in T_1 or HVI-T_1 but by variability in fiber traits other than fiber strength such as length, uniformity, and elongation. This result is significant in that breeders generally must select on fiber strength in early generation with the intention of improving yarn strength.

Significant GCA was detected for SLI measurements of 2.5 SL, 50 SL, UR, E_1, and yarn strength, yield, and LP. No significant GCA effects were detected for any HVI fiber measurements. This result gives conflicting evidence as to whether there are true differences due to additive genetic effects in this population. If it is assumed that both the SLI and HVI instrumentation measure the same corresponding properties, then the conflicting evidence could be explained by concluding the SLI instrumentation is more sensitive to small differences than the HVI instrumentation. Cooper et al. (3) reported that the HVI instrument did not detect significant differences among cottons that differ in fiber strength by 5 to 7%, when measured on the stelometer instrument. Improvements in fiber quality will probably be made as small incremental increases over time, which is often the case for quantitatively inherited traits. Therefore, the present laboratory instrumentation is a minimum standard of precision needed by breeders to detect small improvements.

Specific combining ability was detected for one fiber trait, 50 SL, and yield (Table 1). Yet, the test for average heterosis (parents vs. F_1's) was significant for 2.5 SL, 50 SL, T_1, mic, HVI-length, HVI-mic, yarn strength, yield, and LP. There are previous reports of heterosis for yield in upland cotton (1,15,17,18,20). In addition, Lee et al. (15) reported heterosis for fiber length, and Al-Rawi and Kohel (1) reported heterosis for 2.5 SL, 50 SL, T_1, and E_1. These previous studies did not include HVI fiber measurements.

Significant interactions of F_1's × environment and SCA × environment were found for T_1, and the interaction of parents vs. F_1's (heterosis) × environment was significant for HVI-T_1 (Table 1). There were significant differences among F_1's for T_1 and among the parents for HVI-T_1, at Test Location 2, but differences were not observed when combined over lo-

Table 1. Mean squares from the analysis of variance of parents and F_1's of cotton for fiber traits, yarn strength, yield, and lint percentage combined across two locations at Florence, SC in 1983.

		Fiber traits†												
		SLI						HVI						
	df	2.5SL	50SL	UR	T_1	E_1	Mic	UHM	UR	T_1	Mic	Yarn strength	Yield	LP
Environment (E)	1	12.4	1.5	21.60	19.0*	0.88	2.53	0.03	0.60	2.40	0.02	36.8	1334.68**	7.42**
Genotypes (G)	14	5.3**	4.6**	5.73*	34.2	3.37**	0.99	1.90**	2.78	2.54	1.70*	199.4**	295.58*	2.75**
Parents (P)	4	2.8*	4.6*	5.82*	36.3	3.78**	0.78	1.25*	2.30	4.42	1.37	266.9**	639.78**	4.62**
Parents vs. F_1's	1	3.0**	13.5**	4.41	64.5*	0.19	3.52**	10.00*	3.68	7.50	3.63*	270.0**	513.46**	0.44**
F_1's	9	3.6**	3.8*	5.84*	30.0	3.54**	0.81	1.20*	2.89	1.16	1.63*	161.4**	69.13*	2.18*
GCA	4	4.1**	4.1**	6.27**	42.4	5.06**	1.10	1.55	4.21	1.60	2.31	228.3*	413.27**	4.13**
SCA	5	3.0	3.6**	4.97	05.3	0.50	0.22	0.50	0.25	0.26	0.28	27.8	138.66**	0.91
G × E	14	0.76	1.0	1.78	15.6	0.50	0.43	0.40	1.85	2.97**	0.58	33.8	20.82	0.55
P × E	4	1.5	2.5	3.92	14.2	0.82	0.43*	0.10	0.20	3.82*	0.26	28.0	39.07*	0.57
P vs. F_1 × E	1	0.02	1.0	3.68	01.7	0.00	0.91	0.01	1.88	10.80*	1.08	1.6	72.50	0.01
F_1 × E	9	0.51	0.25	0.61	17.7*	0.41	0.37	0.60	2.58	1.72	0.66	40.0	13.42	0.61
GCA × E	4	0.51	0.25	0.68	14.4	0.46	0.39	0.26	1.64	2.32	0.65	37.8	28.53	0.63
SCA × E	5	1.0	0.25	1.28	24.2*	0.30	0.33	1.30	4.47	0.54	0.69	44.0	10.55	0.45
Residual														
Fiber traits	28	1.02	1.8	3.63	8.73	0.33	0.26	1.30	23.7	1.08	0.31	24.1	–	0.35
Yield	84	–	–	–	–	–	–	–	–	–			11.47	–

*,** Denotes significance at the 0.05 and 0.01 probability levels, respectively.

† SLI = standard laboratory instrumentation; HVI = high volume instrumentation; 2.5, 50SL = 2.5 and 50% fiber span length; UR = uniformity ratio; T_1, T_1 = stelometer fiber strength and HVI fiber strength; E_1 = elongation; Mic, HVI Mic = micronaire; UHM = upper-half mean length; yield = seed cotton yield (kg ha^{-1}); and LP = lint percentage.

Table 2. Estimates of general combing ability effects (gi) and F_1 population means measured at two locations for five cotton parents for fiber traits, yarn strength, yield, and lint percentages.

	Fiber traits†												
	SLI						HVI						
Source	2.5SL	50SL	UR	T_1	E_1	Mic	UHM	UR	T_1	Mic	Yarn strength	Yield	LP
	mm	mm	%	kN m kg⁻¹	%		mm	%	kN m kg⁻¹		kN m kg⁻¹	kg ha⁻¹	%
Coker 201	−0.56*	0.53*	−0.821*	−11.291*	−0.090*	0.097*	0.51*	−0.770*	−0.603*	0.040	−89.1*	162.27*	0.415
SC-1	0.08	0.33*	1.106*	5.719*	0.052	−0.162*	0.46*	0.988*	0.234	−0.253*	39.1*	161.94*	0.087
PD 8619	−0.05	0.00	0.100	−0.687	0.085*	0.097*	0.08	0.318	0.067	−0.023	12.0*	−92.33	−0.523*
PD 3249	0.20*	0.08*	−0.151*	2.511	−0.375	0.114*	0.00	−0.268	0.318	0.216*	38.3*	78.86	0.047
PD 4461	0.36*	0.13*	−0.234*	4.405*	0.295*	0.005	−0.05	−0.268	0.318	0.023	−0.29	−310.75*	0.147
sd (gi)	0.08	0.05	0.150	3.365	0.061	0.056	0.10	0.362	0.430	0.072	17.07	151.08	0.224
F_1 Mean	29.0	13.7	46.7	209.7	5.87	4.1	29.0	82.07	279.5	4.07	1360	5124	37.5

* Significantly ($P = 0.05$) different from zero based on the estimate of the standard deviation.

† SLI = standard laboratory instrumentation; HVI = high volume instrumentation; 2.5, 50SL = 2.5 and 50% fiber span length; UR = uniformity ratio; T_1, T_1 = stelometer fiber strength and HVI fiber strength; E_1 = elongation; Mic, HVI Mic = micronaire; UHM = upper-half mean length; yield = seed cotton yield; and LP = lint percentage.

cations. Large interactions of fiber strength with environment can obscure genotype differences when test data is combined over environments, and thus, hinder selection progress for fiber strength. In this study, yarn strength measurements did not interact with environments. Yarn strength measurements are costly, require a large lint sample, and are generally not obtained until more advanced stages of testing. However, it is necessary to be able to effectively select individual fiber traits in early generations to produce germplasm with yarn strength improvements in later generations.

General combining ability effects were computed for all traits as a method of choosing the best parents for inclusion in a crossing program for population improvement (Table 2). There were fewer significant GCA effects for HVI measurements than for standard laboratory measurements, providing additional evidence that single instrument testing is more useful to the breeder than the HVI instrumentation. The best parents for improvement in yield and LP were Coker 201 and SC-1. There was no single parent that was best for improvement in all fiber properties.

In general, SC-1 and PD 4461 were the best parents for improvement in 2.5 SL, E_1, and T_1. Yet, SC-1 and PD 3249 were the two superior parents for yarn strength improvements. This result might not be expected since PD 8619 had the highest parental mean for yarn strength at 1413 kN m kg^{-1} compared to SC-1 testing at 1354 kN m kg^{-1}, and PD 3249 with a parental mean of 1314 kN m kg^{-1} (Table 3). In three of the four crosses with SC-1 as a parent, the F_1 mean equaled or exceeded that of the high parent for yarn strength. This relationship was true also for PD 3249.

Superiority of the F_1 over the midparent value is further evidence of nonadditive gene effects for yarn strength, although it was not detected by the SCA component in the diallel analysis but by the test for heterosis (parents vs. F_1's) in the analysis of variance for yarn strength. Where nonadditive gene action is important, parental performance per se will not necessarily be indicative of the performance in cross combination, thus making selection of parents more difficult. In this case, a mating scheme such as the diallel can be useful for parental selection. The only significant GCA effect for HVI-T_1 was for Coker 201, which

Table 3. Means of the parents and F_1's from a five parent diallel cotton for fiber traits, yarn strength, yield, and lint percentage.

	Fiber traits†												
	SLI						HVI						
Cross or parent	2.5SL	50SL	UR	T_1	E_1	Mic	UHM	UR	T_1	Mic	Yarn strength	Yield	LP
	mm	mm	%	kN m kg⁻¹	%		mm	%	kN m kg⁻¹		kN m kg⁻¹	kg ha⁻¹	%
Coker 201 × SC-1	28.4	13.7	48.0	207.2	5.8	4.1	28.7	82.5	274.7	3.9	1305	5538	38.9
Coker 201 × PD 8619	28.2	12.9	45.2	195.2	5.8	4.1	28.4	81.2	262.4	4.1	1285	5386	37.3
Coker 201 × PD 3249	28.4	12.7	44.0	199.9	5.6	4.3	28.4	81.0	269.8	4.4	1285	5274	37.8
Coker 201 × PD 4461	29.2	13.5	46.0	202.8	6.0	4.1	28.4	81.2	272.2	4.0	1295	4786	37.2
SC-1 × PD 8619	29.5	14.2	47.5	218.5	6.1	3.8	29.5	83.0	274.7	3.8	1413	5216	36.1
SC-1 × PD 3249	29.5	14.0	47.0	215.8	5.5	4.0	29.2	82.8	277.1	4.0	1442	5144	37.4
SC-1 × PD 4461	29.0	13.7	46.5	214.3	6.3	3.9	29.7	82.0	277.1	3.8	1393	5086	37.3
PD 8619 × PD 3249	29.2	14.0	47.5	208.4	5.6	4.1	29.2	82.8	277.1	4.2	1432	5120	37.0
PD 8619 × PD 4461	29.2	13.5	45.8	212.6	6.3	4.1	28.7	82.2	274.7	4.1	1344	4503	38.0
PD 3249 × PD 4461	29.7	14.2	46.8	222.2	5.7	4.2	29.2	81.0	282.0	4.4	1393	5197	37.5
Coker 201	27.9	12.9	45.5	189.5	5.8	4.3	27.7	81.0	250.2	4.4	1196	5477	37.5
SC-1	28.7	13.5	46.2	207.8	6.1	4.1	28.4	82.2	269.8	4.0	1354	5331	37.5
PD 8619	29.0	14.0	47.8	210.7	5.7	4.1	29.0	82.5	277.1	4.1	1413	4223	36.5
PD 3249	27.9	12.7	44.8	196.2	5.4	4.4	28.2	81.0	272.2	4.4	1314	4298	37.4
PD 4461	27.9	12.7	45.0	209.9	6.1	4.4	28.0	81.0	264.9	4.2	1305	3300	39.4
LSD (0.05)	0.76	0.76	2.0	NS	0.3	NS	0.76	NS	NS	NS	88	692	1.1
CV	1.9	4.7	3.8	3.9	3.8	5.6	2.6	1.5	3.8	4.6	3.6	7.1	1.6

† SLI = standard laboratory instrumentation; HVI = high volume instrumentation; 2.5, 50SL = 2.5 and 50% fiber span length; UR = uniformity ratio; T_1, T_1 = stelometer fiber strength and HVI fiber strength; E_1 = elongation; Mic, HVI Mic = micronaire; UHM = upper-half mean length; yield = seed cotton yield; and LP = lint percentage.

Table 4. Rank correlation (*r*) of general combining ability effects and probabilities for fiber traits with yarn strength measured on cotton at two locations at Florence, SC in 1983.

Trait†	Yarn strength	
	r	*P*‡
2.5SL, mm	0.30	0.62
50SL, mm	0.70	0.18
UR, %	0.90	0.03
T_1, kN m kg^{-1}	0.70	0.19
E_1, %	−0.20	0.74
Mic	−0.20	0.74
HVI − Length, mm	0.90	0.04
HVI − UR, %	0.82	0.09
HVI − T_1, kN m kg^{-1}	0.41	0.49
HVI − Mic	−0.40	0.50

† 2.5, 50SL = 2.5 and 50% fiber span length; UR = uniformity ratio; T_1, HVI T_1 = stelometer fiber strength and HVI fiber strength; E_1 = elongation; Mic, HVI Mic = micronaire; and UHM = upper-half mean length.
‡ Probability of exceeding the correlation assuming no correlation where N = 5.

is the parent that resulted in the greatest overall reduction in fiber strength for the F_1's based on T_1 and HVI-T_1. The use of Coker 201 as a parent resulted in yield improvements in the hybrids but a reduction in fiber and yarn strength. Conversely, PD 3249 and SC-1 contributed both yield and yarn strength improvements to their progeny.

In a prior study during 1971 and 1972 (Culp, unpublished), a similar diallel set was used except that SC-1 was not included as a parent. In that study, Coker 201 again consistently contributed yield improvement to the F_1's, and PD 4461 and PD 3249 contributed yarn and fiber strength improvements; but no single parent contributed both yield and fiber or yarn strength improvements to the progeny. The SC-1 line was released in 1977 as the first commercial cultivar of triple hybrid origin with improved yield and fiber strength (8). Inclusion of this parent in a crossing program can enable simultaneous improvements in yield and fiber quality.

Correlations among the ranks of the GCA effects were computed as an aid to identifying individual fiber traits that would result in yarn strength improvements (Table 4). There were significant correlations of UR and HVI-length with yarn strength (r = 0.9 and r = 0.9, respectively). Correlations of 50% SL and UHM with yarn strength were moderately high (r = 0.70 and 0.82, respectively), yet not significant where N = 5. Correlations of HVI-T_1, and T_1 with yarn strength were 0.41 and 0.70, respectively. Although neither correlation coefficient was significant, there was a closer correspondence of the ranking of GCA effects for T_1 with yarn strength than for HVI-T_1 with yarn strength.

In summary, significant GCA effects were detected for most of the fiber traits measured by laboratory instrumentation, yarn strength, and yield. Therefore, progress from selection for these traits can be expected in these populations. However, there were no significant GCA effects for any of the fiber traits measured by HVI. The inability to detect the same genetic differences with HVI as with SLI indicates that HVI is not sensitive or consistent enough to detect small differences in fiber quality traits, and thus, not as useful to the breeder in improving quantitative traits as it is to the industry for which it was developed. The inability to detect main effect differences in T_1 or HVI-T_1 in the combined analyses and the interaction of T_1 and HVI-T_1 with environment could hinder progress from selection. Finally, simultaneous improvements in yield and yarn strength could be expected from crosses with PD 3249 and SC-1, which is further evidence of the breakup of unfavorable linkages that has enabled the simultaneous improvement of yield, fiber quality, and yarn strength in cotton.

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