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Genotype-Environment Interaction Study of Lock Tenacity in Upland Cotton[1]

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ABSTRACT

Sixteen upland cotton (*Gossypium hirsutum* L.) cultivars were grown in replicated experiments under irrigation and on dryland at each of two Oklahoma locations over a 3-year period. The storm resistance trait, measured as "lock tenacity", was studied in genotype × environment interaction analyses over years for all four experiments, for the two irrigated tests, and for the two dryland tests to estimate those interactions and to consider their implications relative to the cotton breeding and cultivar evaluation programs within the state.

A number of genotype × environment interaction mean squares for lock tenacity were significant for both observed and log-transformed data; however, the magnitudes of the interaction variance components were relatively small compared to their respective cultivar components and were concluded to be of minimal importance in the determination of the trait. Classifications into major boll-type categories and selections for the trait in one environment should be relatively stable in other environments. However, because the range of values observed was greater under irrigation than on dryland and because the separation of boll types was more distinct, more effective selections for the trait are probably made under irrigation.

Additional index words: ***Gossypium hirsutum*** **L., Boll type, Storm resistance, Cotton breeding, Cotton cultivar evaluations, Selection in relation to environment.**

COTTON (*Gossypium hirsutum* L.) cultivars with stormproof or storm resistant boll types are widely grown by producers in regions of the Cotton Belt where once-over, stripper-type harvesters are utilized. Those regions include most of Oklahoma and Texas plus parts of other states. These boll types (in contrast to open-boll cottons, which are normally harvested with spindle pickers) substantially decrease preharvest seedcotton loss due to adverse weather and are an important breeding objective in those areas. During those breeding efforts, researchers have noted differences in the degree to which individual cultivars retain their seedcotton over a range of environmental conditions.

The purpose of the present study was to estimate genotype × environment interactions in Oklahoma for "lock tenacity" (a measure of the storm resistance trait) in upland cotton and to consider their implications relative to the cotton breeding and cultivar evaluation programs within the state. This study and a recent one by Quisenberry and Dilbeck (14) are the only genotype × environment interaction studies of the trait to be reported in *G. hirsutum*. Young (16) has published data from such a study in Pima cotton (*G. barbadense* L.).

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Literature Review

In 1926, Cook and Hubbard (4) reported the discovery in Mexico of a wild cotton which exhibited the stormproof boll type. Their report also mentioned previous findings of the trait in Thurberia along with its occasional occurrence in Egyptian cotton (*G. barbadense*) and in hybrids of Egyptian and Hindi cotton. The discovery in about 1935 of this boll type in an upland cotton cultivar, 'Half and Half', and the subsequent development of the first stormproof cultivar, 'Macha', are related by Brown and Ware (1).

Friesen (7) and others have developed instruments to measure the amount of force required to remove a lock of seedcotton from the bur. Young (16) coined the term "lock tenacity" and defined it as "the grams of force required to remove a lock of seedcotton from the bur of a fully open boll." He measured lock tenacity in upland and Pima cottons using a 500-g force gauge with a maximum-hold attachment and an alligator-nosed, electric quick connection. He also conducted a genotype × environment interaction study in Pima cotton for lock tenacity with five entries, 2 years, and three irrigated locations but failed to detect any statistically significant interactions.

Jones and Ray (9) classified the F_2 of crosses between stormproof and "normal" boll types of cotton by measuring the grams of pull required to separate the locks from the bur. Their findings supported the single gene hypothesis of Lynn (10) who had subjectively classified segregating populations by appearance, weathering, and tightness of the locks in the boll. Jones and Ray (9) divided the F_2 into classes of "normal" (defined as requiring less than 130 g of pull), "intermediate" (between 130 and 300 g), and stormproof (more than 300 g). Their F_1 data showed a lack of dominance for the trait and that considerable variation for expression of the trait could be attributed to non-genetic factors. Lynn (10), on the other hand, concluded that the trait was partially dominant.

Mamaghani (11) utilized eight commercial cultivars in a diallel analysis and classified them into four groups based upon their relative lock tenacities. He demonstrated that a logarithmic-transformation of the lock tenacity readings provided a better statistical fit of the data to the diallel assumptions than did the original measurements. In his work, he found no dominance for boll type, detected epistasis, and implied that the trait was influenced by many genes. Narrow-sense heritability estimates from his data ranged from 0.34 to 0.88 indicating the relative ease of selection for different degrees of storm resistance. Earlier, Hintz (8) had concluded that storm resistance in his material was inherited quantitatively. Several intermediate boll types occurred in all the progenies he studied.

Dilbeck and Quisenberry (5) modified the instrumentation developed by Friesen (7) and Young (16) to measure and to conduct a genetic analysis of the stormproof trait. They used visual scores and physical measurements of lock tenacity in the parental, F_1, F_2, and backcross generations from a cross between a non-stormproof and a stormproof cultivar. Visual scores indicated the controlling factor to be a single dominant gene when the stormproof and intermediate classes were combined. We feel that this actually suggests partial dominance because if dominance had been complete, there would have been no intermediate class. The actual lock tenacity readings appeared to follow a normal distribution (frequently an indicator of many genes), but the data better fit the normal curve when transformed into logarithms. Utilizing a joint scaling test, they determined that additive, dominant, and epistatic genetic effects were controlling expression of the trait. Also reported was the observation that differences among various combinations of pulls/boll and bolls/entry were nonsignificant indicating that any reasonable combination of those two factors should give reliable estimates of the trait. In a subsequent paper, Quisenberry et al. (13) reported very high estimates of heritability for the trait even though residual dominance variation persisted into the F_4 generation. They also found that higher tenacity values were correlated with larger seed and longer, stronger fiber, but not with lint yield, node of the first fruiting branch, boll size, seed/boll, lint percentage, lint index, or fiber fineness. In the most recent paper of their series, Quisenberry and Dilbeck (14) reported on six entries grown in seven environments. Assuming a fixed model, they obtained significant entries and entries × environments mean squares in analyses of logarithm-transformed data. Interaction components (which assumes a random model) were not estimated within the paper; but our calculations demonstrate that *if estimated*, they would be extremely large compared to the entries component. The authors also related seasonal mean temperatures and precipitation to lock tenacity values.

MATERIALS AND METHODS

Sixteen cultivars (Table 1) were grown in a randomized complete-block experimental design with four replications over 3 years, 1977–1979, in four experiments/year. Three cultivars in the study were established releases (i.e., 'Westburn M', 'Lankart LX 571', and 'Deltapine 16') representing the stormproof, storm resistant, and open boll-type categories, respectively, and were included as points of reference. The remaining 13 were recent releases at the time this study was initiated.

The experiments were conducted on the Oklahoma Agric. Exp. Stns. near Tipton and Chickasha. Those locations were chosen because irrigated and dryland experiments could be simultaneously conducted at both sites and because they represented a wide range of climatic conditions within the Oklahoma cotton producing area. The soil type at Tipton was a Tipton silt loam (a fine-loamy, mixed, thermic Pachic Argiustoll); that at Chickasha was a Reinach silt loam (a coarse-silty, mixed, thermic Pachic Haplustoll).

Plots were single rows 9.1 m long and spaced 1.0 m apart. Intrarow plant spacing was comparable to that in a commercial field. Cultural practices were uniformly applied to each experiment as judgment dictated. After frost, 15 mature bolls were selected throughout the length of each plot (except in 1977 when one mature boll was selected/plant). The bolls were sampled from near the central portion of the plants using hand clippers to avoid crushing the boll during harvest and to ensure that a portion of the pedicel remained to grasp while measuring the trait.

Table 1. Mean cultivar performance and rank for lock tenacity over years for all, irrigated, and dryland experiments.

	Lock tenacity over years for experiments					
	All		Irrigated		Dryland	
Cultivar	Rank	Mean	Rank	Mean	Rank	Mean
		g force		g force		g force
Westburn M†	1	155	1	174	1	136
Rilcot 90-A	2	147	2	170	2	123
PR-68¶	3	136	3–4	149	3	122
Stripper 31A	4	129	6	142	4	115
Paymaster 792	5	126	3–4	149	7	104
Deltapine SR-4	6–7	122	5	143	11	101
Lankart LX 571‡	6–7	122	7	137	6	106
Paymaster 266	8	121	11	134	5	108
Coker 348	9–10	119	9–10	135	8	103
Paymaster 303	9–10	119	8	136	9–10	102
Dunn 120	11	118	9–10	135	9–10	102
GSA-71	12	98	13	106	12	90
Cascot B-2	13	94	12	107	14	81
Lockett 77	14	93	14	103	13	83
Deltapine 16§	15	84	15	90	15	78
Stoneville 731-N	16	80	16	86	16	75
Mean (over cultivars)		116		131		102
L.S.D.$_{0.05}$		18		21		18

†,‡,§ Stormproof, storm resistant, and open-boll check cultivars, respectively.
¶ Pioneer Brand.

At least 24 hours prior to measurement, the samples were opened in the Cotton Quality Res. Lab. at Oklahoma State Univ. (wherein a temperature of 21.1 C and a relative humidity of 65% are maintained) in an attempt to control extraneous variables. From the 15 harvested bolls, 10 mature, disease-free and insect damage-free bolls were chosen at random from each plot for measurement. The two locks bordering the widest lock were measured on the 10 bolls. If the locks were evenly spaced, one was arbitrarily chosen to be the widest; and the locks bordering it were measured. A 500-g force gauge with a maximum-hold device and a battery clip were used to measure "lock tenacity". This is the same instrumentation as used by Young (16).

To facilitate analyses, plot means were obtained for the 20 measurements (two/boll on 10 bolls) of lock tenacity. Conventional genotype × environment interaction analyses, as outlined by Comstock and Moll (3), were then performed over all experiments on the observed plot means and also on a log-transformation of those means. Similar analyses were performed separately for the two irrigated and for the two dryland locations over years. Cultivars, years, and locations were considered random effects in each analysis. The calculations of the F-statistic and its degrees of freedom for testing the cultivars mean squares were performed according to the method described by Cochran (2).

RESULTS AND DISCUSSION

Mean lock tenacity values for each cultivar over years and experiments are presented in Table 1 for the three analyses. Also presented in the table are the cultivar ranks, means over cultivars, and L.S.D.$_{0.05}$ values for each analysis.

Inspection of the data reveals two fairly clear-cut discontinuities among the cultivars. In the data over all experiments, Westburn M (ranked no. 1 and used as the stormproof check) was significantly higher in lock tenacity than (Pioneer Brand) 'PR-68' (ranked no. 3) while 'Rilcot 90-A' (no. 2) was not significantly different from either. The difference between PR-68 and 'Dunn 120' (ranked no. 11) was not significant; whereas that between Dunn 120 and 'GSA-71' (ranked no. 12) was. Lankart LX 571 (the storm resistant check) was included within the PR-68—Dunn 120 group. Differences among the last five cultivars were not significant. One of those five, Deltapine 16, was our open-boll check cultivar. Significant discontinuities effectively separated all cultivars, except Rilcot 90-A, into distinct categories, each of which contained a check cultivar.

In the data from the irrigated experiments, Rilcot 90-A's lock tenacity was nearly identical to that of Westburn M. The interval between Rilcot 90-A vs. PR-68 and 'Paymaster 792' (tied for no. 3 in rank) was significant at the 0.10 probability level. Again, the cultivars from PR-68 through Dunn 120 formed a coherent group without significant differences among them. Once more, the separation between that group and the last five cultivars was significant; and as before, no significant differences among those five were noted.

In the dryland experiments data, the first three cultivars were not significantly different from each other. Within the storm-resistant group (which contains Lankart LX 571), only one significant difference was detected, viz., between PR-68 and 'Deltapine SR-4'. Within the open-boll group (defined by the Deltapine 16 check), as before, no significant differences were found. However, differences between stormproof (which includes Westburn M) vs. storm resistance categories or between storm-resistance vs. open-boll classifications under dryland conditions were no longer relatively discreet nor statistically significant as they had been under irrigation. This leads us to conclude that distinctions between these boll-type combinations can be made with more confidence under irrigation.

The open-boll cultivar with the highest lock tenacity (i.e., GSA-71 or 'Cascot B-2' depending upon the analysis) was significantly lower than the stormproof cultivar with the lowest lock tenacity (Westburn M or Rilcot 90-A) in every case. The separation between those two boll-type categories was consistent for both irrigated and dryland conditions.

Ranks of cultivars in the three analyses changed slightly; but those changes took place within a boll class and not among classes. A linear correlation coefficient of 0.95 (significant at the 0.01 probability level) between the irrigated and dryland test cultivar means is indicative of the relative consistency of the cultivars' performance for this trait over the range of conditions encountered in these experiments. However, the breeder will readily note that the range of values observed was greater under irrigation and that the separation of similar boll types appears more effective under those conditions than on dryland. The mean lock tenacity values over cultivars were 10, 17, and 33% higher under irrigation than on dryland at Tipton and 91, 31, and 17% higher at Chickasha in 1977, 1978, and 1979, respectively.

Shown in Table 2 are mean squares relevant to the study of genotype × environment interactions for lock tenacity from the analyses of variance over years and over all, irrigated, and dryland experiments, respectively. Data are presented here as both analyses of observed values and of log-transformations of those observed values. Evidence from other workers (5, 11) has suggested that log-transformed data should be used for interpretation of lock tenacity.

The mean squares for cultivars were highly significant in all analyses. Highly significant differences were detected for the cultivars × years interaction in the analyses over all locations, but no differences were detected in the others. It appears that the major source of those interactions was between, rather than within, water-management systems. The only significant mean squares for the cultivars × locations interactions were found in the log-transformations for the overall (0.10 probability level) and dryland analyses. This interaction was partitioned (not shown), in the analyses over all locations, into the components of cultivars × locations (i.e.,Tipton vs. Chickasha), cultivars x water treatments (i.e., irrigated vs. dryland), and cultivars × locations × water treatments. Of these, only the cultivars × water treatments interaction in the observed data and the cultivars × locations interaction in the log-transformed data were significant (0.10 and 0.05 probability levels, respectively). The cultivars × years × locations interactions were highly significant in the observed data in all three analyses and were significant in the log-transformed data in all except the dryland analysis. This interaction was also partitioned into its components in the analyses over all locations (also not shown). Those components found to be significant were the cultivars × locations × years interactions in the observed and log-transformed data and the cultivars × locations × water treatments × years interaction in the observed data (0.10 probability level).

The variance component estimates presented in Table 3 were computed from the mean squares in Table 2. None of the interaction variance components one-half as large as their corresponding cultivar components, and most were not even one-fourth the size of their cultivar components. Several estimates were negative, a result indicative of sampling error in the estimation process. Because variances (and their components) may theoretically only be zero or positive, such values are commonly assumed to be estimates of zero or of relatively small, positive quantities.

Though many of the genotype × environment interaction mean squares (Table 2) and variance components (Table 3) were statistically significant, they were all relatively small compared to their corresponding cultivars component. Thus, they were of little practical importance. Classifications into major boll-type categories and selections for the trait in one environment should be relatively stable in other environments. However, for reasons detailed earlier, the breeder's selections for this trait will likely be more effective under irrigation than on dryland. There are precedents for the viewpoint that selections in cotton for specific traits will be more effective in certain environments than in others (6, 15). In fact, based on a genotype × environment interaction study con-

Table 2. Mean squares pertinent to the study of genotype × environment interactions for lock tenacity over years for all, irrigated, and dryland experiments.

		Lock tenacity over years for experiments					
		All		Irrigated		Dryland	
Source	df†	Observed	Log-trans.	Observed	Log-trans.	Observed	Log-trans.
Cultivars (C)	15	22068**	1.7856**	16071**	1.0848**	7355**	0.7442**
C × years (Y)	30	1832**	0.0855**	1851	0.0778	567	0.0379
C × locations (L)	45	1003	0.0613***	630	0.0438	1021	0.0967*
C × Y × L	90	924**	0.0416*	1320**	0.0511*	866**	0.0435
Error	540	433	0.0321	529	0.0324	338	0.0318

*,**,*** Significant at the 0.05, 0.01, and 0.10 probability levels, respectively.
† Degrees of freedom in the irrigated and dryland location analyses for the mean squares below were 15, 30, 15, 30, and 270, respectively.

Table 3. Variance component estimates for lock tenacity over years for all irrigated, and dryland experiments.

	Lock tenacity over years for experiments					
	All		Irrigated		Dryland	
Component†	Observed	Log-trans.	Observed	Log-trans.	Observed	Log-trans.
σ^2_C	420**	0.0350**	621**	0.0423**	276**	0.0272**
σ^2_{CY}	57**	0.0027**	66	0.0033	−37‡	−0.0007‡
σ^2_{CL}	7	0.0016***	−58‡	−0.0006‡	13	0.0044*
σ^2_{CYL}	123**	0.0024*	198**	0.0047*	132**	0.0029
σ^2_E	433	0.0321	529	0.0324	338	0.0318

*,**,*** Significant at the 0.05, 0.01, and 0.10 probability levels, respectively.
† σ^2_C is the component of variance estimating genetic differences among cultivars; σ^2_{CY}, the cultivar × year component; σ^2_{CL}, the cultivar × location component; σ^2_{CYL}, the cultivar × year × location component; and σ^2_E, the error component.
‡ Negative estimate for which the most reasonable value is zero.

ducted in Oklahoma several years ago (12), the state has been subdivided for some time into irrigated vs. dryland production for purposes of cotton breeding and cultivar evaluation.

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REFERENCES

1. Brown, H. B., and J. O. Ware. 1958. Cotton. McGraw-Hill Book Co., Inc., New York.
2. Cochran, W. G. 1951. Testing a linear relation among variances. Biometrics 7:17-32.
3. Comstock, R. E., and R. H. Moll. 1963. Genotype-environment interactions. p. 164-196. *In* W. D. Hanson and H. F. Robinson (ed.) Statistical genetics and plant breeding. Natl. Acad. Sci.-Natl. Res. Coun., Washington, DC.
4. Cook, O. F., and J. W. Hubbard. 1926. Primitive cottons in Mexico: Characters of native cottons including a wild species. J. Hered. 17:462-472.
5. Dilbeck, R. E., and J. E. Quisenberry. 1979. Stormproof boll in upland cotton. I. Development of instrumentation and an inheritance study. Crop Sci. 19:567-570.
6. Feaster, C. V., E. F. Young, Jr., and E. L. Turcotte. 1980. Comparison of artificial and natural selection in American Pima cotton under different environments. Crop Sci. 20:555-558.
7. Friesen, J. A. 1968. Factors affecting removal of cotton from the boll. Trans. Am. Soc. Agric. Engr. 11:529-531.
8. Hintz, G. D. 1953. Heritable relationships of storm resistance and maturity in three varieties of *Gossypium hirsutum*. M.S. Thesis. Oklahoma A&M College, Stillwater.
9. Jones, D. L., and Levon Ray. 1953. Genetic studies of the stormproof type boll in American upland cotton. Am. Soc. Agron. Abstr., p. 90.
10. Lynn, H. D. 1949. The inheritance of "stormproof" boll type in *Gossypium hirsutum*. M.S. Thesis. Texas A&M College, College Station.
11. Mamaghani, Reza. 1976. A genetic study of storm resistance in upland cotton, *Gossypium hirsutum* L. Ph.D. Thesis. Oklahoma State Univ. (Libr. Congr. Card No. Mic. 7801293). Univ. Microfilms Int., Ann Arbor, Mich. (Diss. Abstr. Int. 38B:3989).
12. Murray, J. C., and L. M. Verhalen. 1970. Genotype by environment interaction study of cotton in Oklahoma. Crop Sci. 10:197-199.
13. Quisenberry, J. E., R. E. Dilbeck, and Bruce Roark. 1980. Stormproof boll in upland cotton. II. Heritability and agronomic relationships. Crop Sci. 20:387-389.
14. ----, and ----. 1981. Stormproof boll in upland cotton. III. Genotype-environment interaction and genetic analysis. Crop Sci. 21:511-514.
15. ----, Bruce Roark, D. W. Fryrear, and R. J. Kohel. 1980. Effectiveness of selection in upland cotton in stress environments. Crop Sci. 20:450-453.
16. Young, E. F., Jr. 1975. Determining lock tenacity in Pima cotton. Crop Sci. 15:59-61.