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# Stormproof Boll in Upland Cotton III. Genotype-Environment Interaction and Genetic Analysis[1]

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## ABSTRACT

Stormproofness (lock tenacity) of cotton (*Gossypium hirsutum* L.) was defined as the amount of force required to extract a locule of seedcotton from the bur of a mature boll. Six entries representing the range of variability in stormproofness of Upland cotton were grown in seven environments to study the relationship of the character to temperature and precipitation. In a separate experiment, a complete diallel set of crosses among the six entries was grown for 2 years to estimate general (GCA) and specific combining ability (SCA) associated with the inheritance of the stormproof trait.

In general, stormproofness increased as temperature during the boll maturation period decreased or seasonal precipitation increased. Temperature appeared to influence stormproofness more than precipitation, although responses among the entries varied. 'Acala 1517 BR-2,' TM-1, Contextum, and 'Macha' were more responsive to temperature than to precipitation. Unique Stormproof was about equally influenced by both variables, and 'Lankart Sel. 57' was most responsive to precipitation. Results from the genetic study revealed that significant GCA and SCA effects were associated with the expression of stormproofness, but that the SCA effects were small and hybrids tended to be intermediate between their respective parents. The GCA effects interacted with years primarily as a result of relative changes in lock tenacity between the stormproof and nonstormproof cultivars. A relationship between lock tenacity and the percentage of storm loss (seedcotton that fell on the ground) showed that hybrids between non stormproof cultivars may suffer relatively high storm losses.

Additional index words: *Gossypium hirsutum* L., Seedcotton tenacity, Diallel analysis, Storm loss, Lock tenacity.

THE stormproof boll (i.e., seedcotton held tightly in the boll) is a desirable characteristic in Upland cotton (*Gossypium hirsutum* L.) cultivars developed for production within certain regions of the U. S. Cotton Belt. In those areas, seedcotton is taken from the plant with a once-over, stripper-type harvester to minimize costs and improve production efficiency. Strippers are used in the High and Rolling Plains of Texas, Oklahoma, and New Mexico, as well as the Blacklands, Coastal Bend, and a portion of the Rio Grande Valley of Texas. The percentage of the total U. S. cotton acreage harvested with strippers has expanded from a small fraction in the 1950's to 33% in the 1970's.

In the first paper of this series, we described an instrument that measures stormproofness and reported results of an inheritance study in a cross between a stormproof and a nonstormproof parent (3). Stormproofness seemed to be conditioned by a major gene pair, with partial or complete dominance towards the stormproof parent, when scored subjectively by visual appearance. However, data obtained using the instrument did not fit a simple one-gene model; analysis of means suggested that additive, dominance, and epistatic genetic effects were associated with the expression of the trait. In the second paper, stormproofness as measured with the instrument, was shown to be highly heritable based on the regression of $F_5$ on $F_4$; no detrimental associations were found between the stormproof trait and numerous agronomic and fiber characters (6). The purposes of the study reported in this paper were *i*) to define genotype-environment interactions, if any, for the stormproof trait, and *ii*) to estimate the general (GCA) and specific combining ability (SCA) associated with the inheritance of stormproofness.

## MATERIALS AND METHODS

The experimental material used in this study consisted of six entries of cotton (cultivars or strains). Each entry was chosen to represent different degrees of seedcotton adherence to the bur of the cotton boll. All entries had been inbred for several generations via a plant-to-progeny-row approach. Because of possible variation in the original entry followed by intense inbreeding, the entries that we grew may not be totally representative of the strain or cultivar from which they were derived. The original entries were 'Acala 1517 BR-2,' Texas Marker-1 (TM-1), Contextum, Unique Stormproof, 'Lankart Sel. 57,' and 'Macha'.

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Acala 1517 BR-2 has a large, nonstormproof boll and is representative of the cultivars grown in eastern New Mexico and the San Joaquin Valley of California for their high-quality fiber. TM-1 has a medium-sized, nonstormproof boll and is characteristic of the "deltatype" cultivars grown in the Mississippi Delta, Mid-South, and Gulf Coast regions as well as in Arizona and southern California. Both the Acala and deltatype cultivars have flared, open burs (bolls) without any noticeable fiber attachments to the carpel walls. They are subject to heavy preharvest loss of seedcotton under adverse climatic conditions.

Contextum has a small, stormproof boll. This strain was developed from a strain introduced originally from Mexico (2). The inner surfaces of the mature carpel walls of Contextum have a large number of convolutions, with the ends of numerous fibers caught and held in those convolutions.

Unique Stormproof has a medium-sized boll that is stormproof when the plants are not stressed for moisture. Under stress, however, the locules of seedcotton tend to fall from the bur. Unique Stormproof was derived from the experimental strain Paymaster B8-3502. Its bolls have relatively few convolutions on the inner carpel walls.

Lankart Sel. 57 has a large boll that retains the seedcotton in the bur. This cultivar was selected originally from 'Lone Star,' which it resembles. Lone Star is one of the "Big Boll" or "storm-resistant" types introduced into Texas near the end of the Mexican War (1). The seedcotton tends to fluff more in the Lankart boll than in the other stormproof types.

Macha has a medium-sized, stormproof boll. This cultivar had its origin in a single plant of 'Half and Half' that retained its seedcotton in the boll after a particularly severe windstorm on the Texas High Plains. Macha is the forerunner of the stormproof cotton cultivars as they are defined today.

The above six strains and cultivars appear to represent the range of variation available in stormproofness of Upland cotton. These cottons range from those with essentially no fiber-carpel adherence to those with seedcotton tightly attached to the carpel walls. In some years at Lubbock, Tex., burs of Acala cvs. may lose 50% of their seedcotton; in those same years, burs of Macha will lose less than 1% (3).

Stormproofness was estimated using the Lock Tenacity Instrument (3) that measures the amount of force, in grams, required to extract a locule of seedcotton from the bur. Experimental procedures used in those measurements have been reported previously (3). Prior results suggested that normality of tenacity data improved when these data were transformed into logarithms. In this paper, lock tenacity means are presented in the original units, but mean squares and correlation and regression coefficients are presented in log-transformed units.

*Genotype—Environment Interactions.* The six entries were planted in randomized complete blocks (three replications) in seven environments (Lubbock, Tex., 1974 to 1978 and Big Spring, Tex., 1977 and 1978). For each environment, lock tenacity was measured for 25 bolls from each entry and replication. We determined seasonal mean temperatures during the boll maturation period (July through September) and seasonal precipitation (April to September). The precipitation at Lubbock included a 10cm preplant irrigation in all years and a 10 cm summer irrigation in all years except 1976. Analysis of variance and regression techniques were used to analyze the data.

*Genetic Analysis.* Genetic variances associated with the tenacity values were estimated from a complete diallel set of crosses among the six parental strains (reciprocals included). The parents and $F_1$ hybrids were planted in a randomized complete block design with three replications at Big Spring Tex. in 1977 and 1978. The variances estimated were partitioned into additive, nonadditive, and error components using Griffing's (4) Experimental Method 1, Model II. This model assumes that the GCA source of variation estimates the additive and a portion of the additive-by-additive genetic effects, and that SCA estimates the nonadditive (dominance and epistasis) genetic effects. Since reciprocal $F_1$ hybrids were used, both maternal and reciprocal sources of variation were estimated.

**Table 1. Analyses of variance for lock tenacity of six entries of cotton over seven environments.**

| Source | df | Mean squares |
|---|---|---|
| Environments (E) | 6 | 2.42** |
| Reps/E (R/E) | 14 | 0.04 |
| Entries (Ent.) | 5 | 0.17** |
| Ent. × E | 30 | 0.17** |
| Ent. × R/E | 70 | 0.02 |

** Significant at the 0.01 probability level.

## RESULTS AND DISCUSSION

*Genotype—Environment Interactions.* Mean squares from the analyses of variance of lock tenacity expressed in log-transformed units are shown in Table 1. Lock tenacity was influenced significantly by environments, entries, and the entries by environments interaction. Transformation of the data to logarithms decreased both environmental and interaction effects and increased genetic differences relative to the error mean squares. Since the entries by environment interaction was still significant after the log-transformation, several additional transformations were attempted but none reduced the interaction effect to nonsignificance.

Lock tenacity was significantly lower at Big Spring than at Lubbock in both 1977 and 1978 (Table 2). Tenacity at Lubbock also varied significantly over the 5

**Table 2. Means for observed lock tenacity, seasonal temperatures, and precipitation for six entries of cotton in seven environments.**

| | | Lock tenacity | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Location | Year | Acala 1517 BR-2 | TM-1 | Contextum | Unique Stormproof | Lankart Sel. 57 | Macha | Location-year means | Mean temperature | Precipitation |
| | | g | | | | | | | C | cm |
| Lubbock | 1974 | 67 | 59 | 224 | 183 | 151 | 326 | 168 b* | 20.4 | 45.5 |
| | 1975 | 70 | 85 | 175 | 184 | 183 | 328 | 171 b | 20.5 | 46.1 |
| | 1976 | 69 | 102 | 142 | 340 | 236 | 478 | 230 a | 19.6 | 54.1 |
| | 1977 | 52 | 38 | 86 | 164 | 134 | 203 | 113 c | 23.2 | 39.5 |
| | 1978 | 65 | 55 | 92 | 157 | 123 | 158 | 108 c | 22.7 | 31.5 |
| Big Spring | 1977 | 37 | 39 | 64 | 90 | 143 | 119 | 82 d | 24.8 | 31.9 |
| | 1978 | 55 | 57 | 64 | 80 | 89 | 116 | 77 d | 24.1 | 18.6 |
| Entry means | | 59 c* | 62 c | 121 b | 171 b | 153 b | 246 a | | | |

* Means in the designated column and row followed by different letters were significantly different at the 0.05 probability level, according to Duncan's Multiple Range Test.

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**Table 3. Multiple correlation (R) and standardized partial regression coefficients ($b_1$, $b_2$) for lock tenacity with seasonal temperature and precipitation.**

| | Lock tenacity (Y) | | |
|---|---|---|---|
| | | Temperature ($X_1$) | Precipitation ($X_2$) |
| Entry | R | $b_1$ | $b_2$ |
| Acala 1517 BR-2 | 0.95** | −1.61** | 0.90* |
| TM-1 | 0.87* | −1.31* | 0.56 |
| Contextum | 0.92** | −0.91* | 0.01 |
| Unique Stormproof | 0.94** | −0.40* | 0.58* |
| Lankart Sel. 57 | 0.95** | −0.14 | 1.06** |
| Macha | 0.99** | −0.61** | 0.41* |
| Means | 0.99** | −0.82** | 0.20* |

*,** Significantly different from zero at the 0.05 and 0.01 probability levels, respectively.

years that it was measured. Acala and TM-1 had the lowest tenacity, Macha had the highest, and Contextum, Unique, and Lankart were intermediate.

Standardized partial regression coefficients and multiple correlation coefficients between lock tenacity (Y) and temperature ($X_1$) and precipitation ($X_2$) are shown in Table 3. Because the partial regression coefficients are expressed in standard deviation units, they may be compared directly to estimate the relative importance of temperature vs. precipitation on the expression of lock tenacity. Because temperature was significantly correlated with precipitation ($r = -0.861$), care must be taken in ascribing a specific response to a single environmental variable. Temperatures were averaged over only July, August, and September (i.e., the major period of boll maturation), whereas, precipitation was summed from April through August.

Averaged over entries, temperature was about four times as important as precipitation in its effect upon lock tenacity. However, all entries did not respond similarly. Acala, TM-1, Contextum, and Macha were more responsive to temperature than to precipitation, Unique was affected about equally by both variables, and Lankart was affected more by precipitation than by temperature. Generally, the log-transformation of tenacity values increased the size of the multiple correlation coefficients, suggesting that this transformation reduced experimental error.

Linear correlation and regression coefficients (not shown) of lock tenacity were negative with temperature and were positive with precipitation. The magnitude of the response was generally less in the nonstormproof entries (Acala and TM-1) than in the more stormproof ones. However, Lankart did not respond to temperature as much as expected based on its lock tenacity.

*Genetic Analysis.* The genetic analysis was conducted on a complete 6 × 6 diallel set of parents and hybrids grown in 1977 and 1978 at Big Spring, Tex. General combining ability was significant when estimated across years and also interacted significantly with years (Table 4). The significant GCA effects confirm the results of previous studies (3, 6), i.e., sufficient additive genetic variation exists for selection to be effective for lock tenacity. The GCA × year interaction suggests that the size of the additive effects were not consistent in the 2 years. Reference to parental values from Big Spring (Table 2) shows that

**Table 4. Analysis of lock tenacity in cotton parents and hybrids in 6 × 6 complete diallel tests, Big Spring, Tex., 1977 and 1978.**

| Source | df | Mean squares |
|---|---|---|
| Years (Y) | 1 | 0.14 |
| Reps/Y (R/Y) | 4 | 0.24 |
| Entries (E) | 35 | 0.56** |
| GCA | 5 | 3.42* |
| SCA | 15 | 0.10* |
| Maternal | 5 | 0.12 |
| Reciprocal | 10 | 0.05 |
| E × Y | 35 | 0.09** |
| GCA × Y | 5 | 0.38** |
| SCA × Y | 15 | 0.04 |
| Mat. × Y | 5 | 0.10* |
| Rec. × Y | 10 | 0.04 |
| E × R/Y | 140 | 0.03 |
| GCA × R/Y | 20 | 0.02 |
| SCA × R/Y | 60 | 0.03 |
| Mat. × R/Y | 20 | 0.03 |
| Rec. × R/Y | 40 | 0.02 |

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

**Table 5. Lock tenacity and general (GCA) and specific combining ability (SCA) estimates for six parents and 15 hybrid combinations (reciprocals combined) of cotton in 1977 and 1978 at Big Spring, Tex.**

| | 1977 | | 1978 | |
|---|---|---|---|---|
| Entry | Mean | GCA or SCA estimate | Mean | GCA or SCA estimate |
| | g | | g | |
| Acala (A) | 37 i† | −0.29** | 55 hi | −0.12* |
| TM-1 (T) | 39 i | −0.31** | 57 hi | −0.18* |
| Contextum (C) | 64 f-h | −0.13* | 64 f-i | −0.13* |
| Unique Stormproof (U) | 90 cd | 0.13* | 80 c-f | 0.14* |
| Lankart Sel. 57 (L) | 143 a | 0.34** | 89 cd | 0.11* |
| Macha (M) | 119 b | 0.26** | 116 a | 0.18* |
| A × T | 45 hi | 0.01 | 58 g-i | 0.04 |
| A × C | 50 g-i | −0.04 | 57 hi | −0.03 |
| A × U | 83 c-f | 0.21* | 81 c-f | 0.06 |
| A × L | 72 d-f | −0.17* | 70 e-h | −0.06 |
| A × M | 91 cd | 0.17* | 85 c-e | 0.06 |
| T × C | 51 g-i | 0.01 | 52 i | −0.08 |
| T × U | 67 e-g | −0.01 | 82 c-f | 0.13* |
| T × L | 83 c-f | 0.03 | 64 f-i | −0.08 |
| T × M | 79 c-f | 0.05 | 67 f-i | 0.10 |
| C × U | 81 c-f | 0.01 | 77 c-f | 0.03 |
| C × L | 95 c | −0.01 | 72 d-h | −0.01 |
| C × M | 88 c-e | −0.02 | 76 c-g | −0.03 |
| U × L | 142 a | 0.12 | 109 ab | −0.12 |
| U × M | 97 c | −0.20* | 93 bc | −0.10 |
| L × M | 160 a | 0.11 | 109 ab | 0.09 |

*,** Statistically different from zero at the 0.05 and 0.01 probability levels, based on t-test.

† Means within columns followed by the same letter were not statistically different at the 0.05 probability level, according to Duncan's Multiple Range Test.

the relative differences between the nonstormproof parents (Acala and TM-1) and the stormproof parents (Lankart and Macha) were less in 1978 than in 1977.

Specific combining ability was significant when averaged across years and did not interact with years (Table 4). The nonsignificant SCA × year interaction indicated that the magnitude of the dominance and epistatic effects were consistent across years. Neither maternal nor reciprocal effects were significant. The Mat. × year effect was significant although not large.

Lock tenacity means and general and specific combining abiltiy estimates from each parent and hybrid (reciprocal combined) are shown for 1977 and 1978 in

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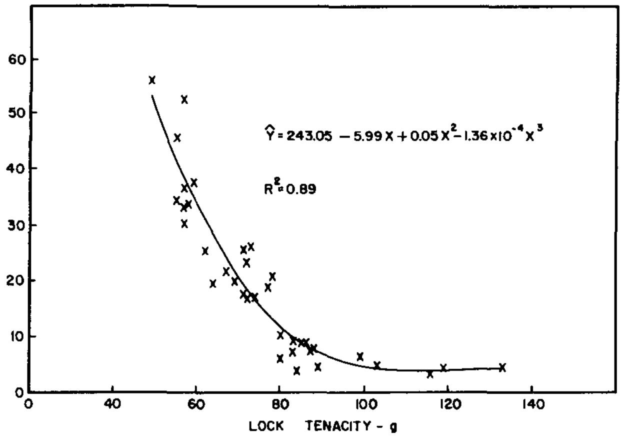


**Fig. 1. Relationship between lock tenacity (X) and percentage storm loss (Y) on 21 Dec. 1978 for six parents and 30 hybrids at Big Spring, Tex.**

Table 5. General combining ability effects were significant for each of the parental lines in both years. GCA estimates were closer to zero in 1978 in Lankart, Macha, Acala, and TM-1. The GCA effects for Unique Stormproof and Contextum remained constant over the 2 years. The changes in the GCA effects from 1977 to 1978 were paralleled by similar changes in the lock tenacity means and accounts for the significant GCA × years interaction shown in Table 4. Significant specific combining ability effects were associated with four hybrid combinations in 1977 and only one combination in 1978. In general, the SCA effects were small and the hybrid means tended to be intermediate between their respective parents.

The relationship between lock tenacity and the percentage of storm loss (seedcotton that fell on the ground) in 1978 is shown in Fig. 1. This relationship demonstrated that lock tenacity was relatively well correlated with stormproofness. A linear relation existed between lock tenacity and percentage storm loss until a threshold was reached. After this threshold, about 80 g in 1978, was reached, additional lock tenacity did not reduce the amount of storm loss.

*Breeding Implications.* A cytoplasmic-genetic system of sterility and restoration is available in cotton (5, 7). If sufficient yield heterosis and cross-pollination can be achieved, then hybrid cotton may become a reality. If hybrid cotton is grown in stripper harvested areas, a stormproof boll will be an essential component of those hybrids. Reference to Table 5 and Fig. 1 shows that hybrids between nonstormproof (Acala and TM-1) and stormproof (Lankart and Macha) cvs. will be intermediate in stormproofness and a certain amount of storm loss should be expected. As an example, a hybrid between TM-1 and Macha had an average lock tenacity of 67 g with a storm loss of 21%. Because of high temperatures and low rainfall at Big Spring in 1978 (Table 2), this amount of storm loss may be higher than would be expected at other locations and in other years. However, this high storm loss demonstrates a potential problem that cotton breeders should be aware of if cotton hybrids are developed for stripper harvested areas.

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