Thrips (Thysanoptera: Thripidae) Tolerance in Cotton: Sources and Heritability[1]

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ABSTRACT Thrips (Thysanoptera: Thripidae) resistance or tolerance in cotton, *Gossypium hirsutum* L., is often associated with extreme pubescence. This is undesirable because hairy (pubescent) plants tend to have more trash in harvested lint which reduces the price received by growers. Two other possible sources of resistance include gossypol and thick lower epidermal cells, the latter has been found in *G. barbadense* L. Five *G. barbadense* genotypes were mated in a North Carolina Design II to 4 upland cultivars to evaluate combining ability. In addition, 90 converted racestocks were screened for tolerance to thrips. Experiments were designed to evaluate tolerance or resistance by comparing plots with and without thrips. Two *G. barbadense* parents had tolerance to thrips while two upland cultivars also exhibited tolerance. In the F_1 generation, general combining ability was significant for thrips damage ratings among the *G. barbadense* parents. In the F_2 generation, all characters exhibited specific combining ability. Thus, non-additive genetic variance predominates measures of thrips tolerance.

Key Words *Gossypium hirsutum,* L., plant resistance, thrips

Cotton, *Gosspypium hirsutum* L., is grown on nearly 5 million ha across the Cotton Belt of the United States. It is an important cash crop for growers from California to Virginia. Cotton production requires the use of pesticides during much of the growing season. Some of these pesticides are applied prior to insect damage as preventive measures. An example would be the early control strategy for insects such as thrips (Thysanoptera: Thripidae) with soil applied systemic insecticide.

There are as many as 13 species of thrips that attack cotton (Watts 1937a). However, four species composed the major threat to cotton production. These were the flower thrips, *Frankliniella tritici* (Fitch); the tobacco thrips, *F. fusca* (Hinds); the onion thrips, *Thrips tabaci* Lindeman, and, the soybean thrips, *Neohydatothrips variabilis* (Beach). The tobacco thrips was confirmed earlier as

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a pest of cotton by Eddy and Livingstone (1931), and the onion thrips by Eddy and Clarke (1930). The western flower thrips, *F. occidentialis* (Pergande), was confirmed later as a pest by Smith (1942). Of nine species found in a Georgia study in 1955, the two most abundant species were the tobacco thrips and the onion thrips (Beckman and Morgan 1955). The tobacco thrips, flower thrips, and the onion thrips were the predominant thrips found in a study in Alabama (Watson 1965).

In 1991 and 1992, the western flower thrips was the predominant species in a South Carolina study comprising 68% and 69% of the adults (DuRant et al. 1994). The tobacco thrips was next (26%) in occurrence with the flower thrips accounting for the third largest group at 3%. In Louisiana tobacco, the onion thrips and flower thrips were the predominant species in the late 1980s (Micinski et al. 1990).

Thrips are known to cause serious damage to young cotton plants and may even cause floral bud abortion later in development (Terry and Barstow 1988). Thrips are known to attack early in the season when the cotton is 2 to 4 wk old (Brown and Ware 1958). The insects suck juices from the emerging leaves causing distortion and reduction in leaf area (Quisenberry and Rummel 1979). Leaf growth may be retarded which, in turn, stunts overall plant growth resulting in delayed maturity (Hawkins et al. 1966, Hightower 1958). Fletcher and Gaines (1939) reported up to 2 wk delay in flowering from thrips-injured plants; this was also reported by Dunman and Clark (1937) and Ballard (1951). Terminals may abort if infestation levels are severe and excessive branching of the terminal may be observed. In some cases, infestation levels may result in the death of young seedlings. Stunted plants are more vulnerable to seedling disease (Hawkins et al. 1966). Delay in reproduction also causes problems with control of late-season insects. Bloom counts have been shown to be reduced under thrips infestation (Owen 1955). In some instances, depending upon the cultivar and infestation level, final yield may be reduced (Ballard 1951, Brook 1961, Gaines 1934, Watts 1937b).

Genotypic differences for susceptibility to thrips have been known for many years. Wardle and Simpson (1927) discovered smooth leaf Egyptian cottons were more resistant to thrips attack than hairy Indian and American cotton cultivars. This was later confirmed by Watts (1936). Both studies suggested that differences in resistance may not entirely be associated with pubescence but may result from thickness of the epidermis.

Dunman and Clark (1937) examined 40 cultivars of cotton but observed no differences in thrips resistance. Ballard (1951) was one of the first to report cultivar difference within upland cottons with the resistant cultivar possessing heavy pubescence on young leaves; susceptible cultivars had nearly glabrous young leaves. However, intermediate levels of pubescence did not always result in intermediate levels of resistance, and the author noted that resistance may be due to factors other than pubescence.

Hawkins et al. (1966) confirmed the earlier findings of Ballard (1951) regarding resistance of the cultivar 'Empire' and noted resistance or susceptibility in 15 other cultivars. Cultivars having 'Empire' in their pedigree exhibited more resistance than those cultivars not possessing the 'Empire resistance'. Tugwell and Waddell (1964) also reported differences in thrips damage between two cultivars both of which sustained about equal thrips infestation levels. The resistant one possessed Empire in its pedigree and the susceptible one did not.

Rummel and Quisenberry (1979) demonstrated a reduction in thrips injury on pubescent compared to glaborous cottons with significant yield reductions in the latter cottons. Quisenberry and Rummel (1979) found that pilose (heavy pubescence) was associated with a high level of resistance, but that five other morphological traits did not confer resistance. These other morphological traits were okra-leaf shape, red plant color, glandless, nectariless, and smooth leaf.

Pandya and Patel (1964) indicated that thrips resistance in *G. armourianum* Kearn. was the result of thick leaves with a waxy coating. Abdel-Bary et al. (1969) found significantly greater resistance in 'Bahtim' than 'Coker 100'. Bahtim 101 is an Egyptian cotton characterized by heavy pubescence. Gawaad and Soliman (1972) tested 19 cultivars of cotton for resistance to aphids and thrips. Five cultivars showed resistance to both aphids and thrips. The authors concluded that resistance to thrips was not associated with pubescence, but that resistance may be associated with gossypol levels. In a later manuscript (Gawaad et al. 1973), resistant genotypes had a thicker lower epidermis than susceptible genotypes. Zareh (1985) discovered resistant genotypes that possessed heavy pubescence, e.g. 'Darab I', compared to a more glabrous susceptible genotype 'Acala'.

Thrips resistance in cotton genotypes is expressed by heavy pubescence, thicker lower epidermis, and high gossypol traits. Heavy pubescence is undesirable because plant hairs continue to trash in lint. Smooth or near-smooth cottons are desired by the growers and have come to be expected in nearly all new cotton cultivars. Thus, thicker epidermis and high gossypol factors are breeding objectives more likely to achieve thrips resistance and market acceptance.

The objective of this study was to identify other useful sources of resistance to the various species of thrips that attack cotton and to study the inheritance of thrips resistance.

Materials and Methods

In 1991, crosses were made between five lines of *G. barbadense* and four cultivars of upland cotton. The primary purpose of the crosses was to transfer desirable seedling vigor genes from *G. barbadense* to upland cotton; however, previous reports of thrips resistance in *G. barbadense* thought to be due to a thick lower epidermis prompted thrips screening studies the following year. The *G. barbadense* parents were 'Coastland 320', 'Coastland RN-4', 'Coastland RN-45', 'Pima 51', and 'Pima 62'. These genotypes do not possess extreme pubescence. The upland parents were 'Deltapine 20', 'Georgia King', 'MD51ne', and 'Stoneville KC 380'. Deltapine 20 and MD51ne have the T3 smooth-leaf allele while Georgia King and KC 380 possess typical upland pubescence. The crosses were made in the arrangement of an NC Design II. This design allows estimation of general and specific combining ability, i.e., the proportion of additive and non-additive genetic variance. Data were analyzed using the procedures prescribed by Stuber (1970).

In 1992, the parents and their respective F_1 progeny were planted in a three-replicate test at the Border Belt Tobacco Research Station near Whiteville, NC. No in-furrow insecticide was used. Plots were 2 rows spaced 1 m apart and 3 m long. Wheat was planted in the alleys between plot ranges the previous fall to provide a source of thrips for screening. The cotton was planted 12 May to ensure the seedlings were at their most vulnerable stage when the thrips would be leaving the wheat during dry down. One row of each plot was treated with a foliar spray of acephate (Orthene®, Valent USA, Walnut Creek, CA) at a rate of 1.12 kg ha^{-1} A. I. on a weekly basis starting 2 wk after planting for 4 wk to control thrips.

In an adjacent experiment, the parents and their respective F_2 progeny were planted in a 3-replicate test. Plots were 4 rows spaced 1 m apart and 3 m long. Two rows of each plot were treated with acephate similar to the F_1 study. In addition, 2 entries reported to have thrips resistance were included in the test and were 'Pima S-2', a *G. barbadense*, and 'HQ95', an upland cotton. Twenty-four *G. barbadense* lines also were examined for thrips resistance in non-replicated single-row plots.

Thrips ratings on entire plots were taken when sufficient damage was evident (18 June). The rating scale was 1 to 5 with '1' being no damage and '5' being extreme damage (dead plants). Leaf area was measured on 10 random plants at 2 different dates.

In 1993, the F_2 experiment was repeated at 2 locations. The second location was the Central Crops Research Station near Clayton, NC. At the Central Crops location, the test was adjacent to a wheat field which provided the thrips. In lieu of leaf area index, the 10 random plant sample taken from each plot was weighed for fresh green weight in the field because fresh weight is highly correlated with dry weight and dry weight is highly correlated with leaf area (Wells et al. 1988). At each location, plots were two rows with 1 row treated with granular acephate at the rate of 1.12 kg ha^{-1} A.I. in the furrow and 1 row not treated. Instead of rating thrips damage for the entire plot, each individual plant sampled was rated in 1993. Each trial consisted of two replicates.

Sixty converted racestocks were screened at the Central Crops Research Station for thrips resistance in 1993. Two replicates were planted on two different dates. The two planting dates were to ensure adequate thrips numbers during the vulnerable seedling stage.

In 1994, 30 additional converted racestocks were screened at the Central Crops Research Station in the same manner as in 1993. Three replicates were used in 1994.

Results and Discussion

The predominant species of thrips found on young cotton seedlings of North Carolina in surveys conducted by J. R. Bardley (per. commun.) are tobacco thrips (over 50%) with flower thrips and soybean thrips making up the bulk of the rest of the population. Although thrips numbers were not quantified in this study, sufficient numbers existed to cause some entries to have thrips damage rating over 4.0 with a 5.0 indicating dead plants.

Two of the five *G. barbadense* parents appeared to have tolerance to the thrips population experienced in this study. They were 'Coastland RN-4' and 'Coastland 320' (Table 1). Both had low thrips damage ratings and no difference in rate of growth with or without thrips and no significant reduction in leaf area, fresh weight, or dry weight under thrips infestation. 'Coastland RN-45' appeared to be sensitive to thrips based on a low thrips damage rating (1.6) and a significant reduction in leaf area. Seeds were not available for testing this line in 1994. Georgia King and KC 380 exhibited some level of tolerance based on nonsignificant reductions in leaf area, fresh weight, and dry weight caused by thrips infestation. In 1992, Georgia King was rated 1.0 for thrips damage at Whiteville. During that year, Georgia King suffered thrips damage at other variety test locations but always revealed less damage than all other genotypes.

Table 1. Thrips ratings and growth parameters for nine parental cotton genotypes (1992-94).

		Growth rate of leaf area (cm^2)‡		Leaf area (cm^2)		Difference in fresh weight (g)†		Difference in Dry weight†
Line	Thrips rating**	thrips	No thrips	thrips	No thrips	1993	1994	1994
Coastland RN-4	2.2	796	859	1031	1113	3.2	-0.1	0.09
Coastland RN-45	1.6	715	1060	951*	1304	12.5	–	–
Coastland 320	1.9	902	842	1196	1126	0.1	0.7	0.13
Pima 51	2.7	461*	1016	687*	1258	10.9*	1.6*	0.26
Pima 62	2.7	643*	974	880*	1236	7.8	0.5	0.18
MD51 ne	3.1	260*	618	438*	821	6.4*	3.6*	0.24
Deltapine 20	3.0	521	702	724	911	1.2	2.7*	0.45*
Georgia King	2.1	650	699	845	904	-2.4	0.2	0.02
KC 380	2.7	286	392	430	539	0.7	0.4	0.02

*Significantly different from corresponding treatment or significant difference between treated and nontreated at the 0.05 level of probability.
**Thrips damage rating on a scale of 1-5 with 1 = no damage and 5 = severe damage, dead plants.
†Differences in weight (fresh or dry) of 10 random plants between plots with and without thrips.
‡Rate growth or change in leaf area over two sampling dates.

Not included in Table 1 are data for HQ95 and Pima S-2 which had thrips damage ratings of 3.1 and 3.2, respectively. Neither showed thrips resistance or tolerance equal to Coastland RN-4, Coastland 320, Georgia King, or KC 380.

Most of the F_1s did not suffer significant leaf area reductions in 1992 (Table 2). In terms of leaf area difference, KC 380 seemed to have the most desirable progeny, i.e., lowest leaf area difference. The significant negative leaf area differences can not be explained. Acephate is not known to produce a phytotoxic effect on cotton; however, the data would suggest possibility. Thrips damage rating for the F_1s were slightly higher than the lowest parent except for progeny involving Pima 62.

Fresh weight was highly correlated with dry weight (r=0.87). Fresh weight differences were also negatively correlated with thrips damage ratings (r=0.73) indicating that more leaf damage did not necessarily result in less fresh weight. Leaf area differences were not highly correlated with thrips damage ratings or fresh weight differences.

Significant general combining ability for thrips damage ratings was evident among the *G. barbadense* parents (female) in the F_1 generation (Table 3). While in the F_2 generation, all three characters revealed specific combining ability, i.e., significant non-additive genetic variance. Thus, it may be difficult to transfer desirable thrips resistance genes into a pure line.

Of the converted racestocks tested in both 1993 and 1994, four appeared to have tolerance to thrips (T-57, T-60, T-156, and T-257) (Table 4); however, their thrips damage ratings were much higher than Coastland RN-4 and Coastland 320. Of those only tested in 1993, three appeared to have tolerance (T-43, T-158, and T-228) (Table 5), but all three had high thrips damage ratings. Sixteen racestocks that were only tested in 1994 appeared to have tolerance (T-33, T-67, T-76, T-88, T-100, T-101, T-120, T-121, T-124, T-151, T-174, T-197, T-212, T-244, T-1000, and T-1149), although T-244 was the only one with low thrips damage ratings.

Three *G. barbadense* lines tested in 1993 appeared to have resistance to thrips based on low thrips damage ratings and very low fresh weight differences (Table 5). They were Giza No. 7, SA 339 Sea Island, and SA531 Crumpled.

Overall, the *G. barbadense* lines tested had lower thrips damage ratings than either the upland cultivars used as parents or any of the converted racestocks. It is thought that the tolerance or resistance in the *G. barbadense* material is due to a thicker lower epidermis, although this has not been proven. The *G. barbadense* parents used in the NC Design II were smooth leaf and not hairy; thus, pubescence can be ruled out as the source of resistance.

Although the converted racestocks would be more desirable sources of thrips resistance than *G. barbadense,* only one, T-244, showed promise, and it was screened at only one location in one year. T-244 does have very little pubescence which is desirable (McCarty and Jenkins 1992). The predominance of non-additive genetic variance would suggest a long-term effort in transferring desirable genes into agronomically acceptable upland cottons.

Table 2. F_1 performance of a North Carolina Design II arrangement under thrips infestation (1992).

Male Parent	Female Parent	Leaf area diff. (cm^2)**	Thrips rating†
MD 51 ne	Coastland RN-4	-63	2.3
	Coastland RN-45	1	2.7
	Coastland 320	54	2.3
	Pima 51	126	2.7
	Pima 62	33	2.7
Deltapine 20	Coastland RN-4	-113	2.7
	Coastland RN-45	-116	2.7
	Coastland 320	23	2.3
	Pima 51	-19	3.0
	Pima 62	-40	2.3
GA. King	Coastland RN-4	-53	2.0
	Coastland RN-45	27	2.0
	Coastland 320	92	2.3
	Pima 51	-15	3.0
	Pima 62	-87*	3.0
KC 380	Coastland RN-4	-146	2.3
	Coastland RN-45	-47*	2.3
	Coastland 320	-220*	2.3
	Pima 51	-75	2.7
	Pima 62	9	2.0

*Significant difference between treated and nontreated.
**Differences in leaf area of 10 random plants between plots with and without thrips.
†Thrips damage rating on a scale of 1-5 with 1=no damage and 5=severe damage, dead plants.

Table 3. Variance components estimates of thrips resistance for two generations in a North Carolina Design II.

Generation	Character	σ^2 male	σ^2 female	σ^2 mf
F_1 (S_0)	Leaf area	1962	106	-846
	Thrips rating	-0.01	0.02*	0.28
F_2(S_1)	Leaf area	207	233	787*
	Thrips rating	0.04	0.02	0.17**
	Fresh Weight	-21	-26	40*

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

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Table 4. Fresh weight differences and ratings for selected converted racestocks.

Converted racestock	Fresh weight differences (g)**		Thrips rating†	
	1993	1994	1993	1994
T-24	13.3*	1.8*	3.5	3.2
T-30	26.6*	1.9*	3.1	3.7
T-40	24.2*	1.6*	3.5	4.0
T-57	-19.2	1.0	3.0	3.4
T-60	-17.4	1.2	3.4	3.9
T-61	27.1*	0.9	3.5	3.4
T-74	15.4*	4.6*	3.0	3.7
T-87	24.3*	1.6*	3.4	3.1
T-117	-24.0*	0.8	3.5	3.5
T-140	34.1*	1.4	3.4	3.7
T-150	36.9*	2.0*	3.5	3.8
T-156	13.5	0.4	3.1	3.5
T-165	-21.6*	1.4	3.2	3.0
T-182	18.7*	2.8*	3.8	3.7
T-215	6.4*	1.2*	4.0	3.9
T-226	14.2*	2.2*	3.5	3.4
T-247	24.9*	0.9*	3.5	3.9
T-257	5.1	0.7	4.0	3.8
T-326	37.4*	1.7*	4.2	3.4
T-633	20.0*	1.6*	4.3	3.9

*Significant difference between treated and nontreated fresh weights.
**Difference in weight of 10 random plants between plots with and without thrips.
†Thrips damage rating on a scale of 1-5 with 1=no damage and 5=severe damage, dead plants.

Table 5. Differences in fresh weight and thrips damage ratings for selected converted racestocks.

1993			1994		
Converted Racestock	Fresh weight diff. (f)†	Thrips rating‡	Converted Racestock	Fresh weight diff. (f)†	Thrips rating‡
T-2	11.2*	3.4	T-7	1.5*	3.8
T-17	69.2*	3.2	T-33	1.6	4.0
T-31	56.1*	3.4	T-36	1.2*	3.5
T-32	21.1*	3.5	T-45	2.2*	3.5
T-43	4.2	3.4	T-48	2.4*	3.4
T-53	33.2*	3.5	T-55	2.3*	3.7
T-63	62.8*	3.4	T-62	1.6*	3.9
T-68	59.0*	2.9	T-67	1.1	3.6
T-77	47.3*	3.3	T-72	2.0*	3.8
T-78	19.5*	3.5	T-76	1.4	3.2
T-96	22.1*	3.1	T-88	1.8	3.3
T-102	17.2*	3.5	T-91	1.9*	3.8
T-104	22.5*	3.5	T-100	0.6	3.9
T-106	10.2*	3.5	T-101	1.3	3.7
T-119	51.8*	3.4	T-113	2.4*	3.9
T-158	1.4	3.4	T-120	0.9	3.3
T-162	63.3*	3.8	T-121	1.5	3.9
T-164	43.5*	3.5	T-124	0.7	3.7
T-170	29.0*	3.5	T-151	0.8	3.1
T-175	46.4*	3.6	T-154	1.9*	3.8
T-180	28.2*	3.9	T-155	1.5*	3.5
T-206	46.1*	3.5	T-168	1.8*	3.9
T-228	5.4	3.5	T-174	0.6	3.1
T-239	39.7*	3.2	T-197	1.5	3.7
T-243	31.3*	3.5	T-212	1.2	3.8
T-570	52.0*	3.2	T-237	1.9*	3.9
T-612	53.8*	3.5	T-244	0.4	2.6
T-634	35.2*	3.4	T-255	1.6*	3.3
Giza No.7	6.7	1.7	T-641	3.8*	3.3
SA 399 Sea Island	-15.4*	1.3	T-1000	0.9	3.3
SA 531 Crumpled	12.4	1.6	T-1149	0.3	3.4

*Significant difference between treated and nontreated fresh weights.
†Difference in weight of 10 random plants between plots with and without thrips.
‡Thrips damage rating on a scale of 1-5 with 1=no damage and 5=severe damage, dead plants.

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