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BREEDING AND GENETICS

Inheritance and Transfer of Thrips Resistance from Pima Cotton to Upland Cotton

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ABSTRACT

Thrips are one of the most important cotton (*Gossypium* spp.) insect pests in the early growing season and can cause yield losses up to 1% even after one insecticide application. Development of thrips-resistant cultivars represents the most effective strategy for control. The objective of the current study was to investigate the genetic basis of thrips resistance in susceptible Upland (*Gossypium hirsutum* L.) × resistant Pima (*G. barbadense* L.) crosses and to identify thrips-resistant lines from the interspecific hybrids. Among the five tetraploid cotton species, *G. tomentosum* Nutt ex Seem. with the Pilose trait was the most resistant, followed by *G. mustelinum* Miers ex Watt, *G. barbadense*, and *G. darwinii* G. Watt, with Upland cotton being the most susceptible. In 14 F_2 populations of four Pima × four Upland crosses, segregation of thrips resistance in seven populations followed a 3 resistant:1 susceptible ratio, indicating a major dominant thrips-resistance gene (tentatively named as *Thr*) in the Pima parents. Among 146 backcross inbred lines derived from Upland Sure-Grow (SG) 747 × Pima S-7 and 90 recombinant inbred lines derived from Acala 1517-99 × Pima Phy 76, more than 30 lines displayed thrips resistance similar to the Pima parent. This indicates that the thrips resistance in Pima cotton can be successfully transferred into Upland cotton through backcrossing or pedigree selection. Broad-sense heritability estimates for thrips-resistance evaluations in the greenhouse ranged from 0.68 to 0.79, with at least one resistance gene estimated, indicating that the majority of the variation in thrips resistance is determined by genetic factors.

Thrips (*Thrips* and *Frankliniella* spp.) are one of the most important cotton insect pest challenges in the early growing season in the U.S. Infestation on apical meristems and young leaves of cotton seedlings causes malformation of leaves, death of meristems, and reduction of leaf area, plant height, and root growth, all of which can lead to excessive vegetative branching, delayed fruit set, and reduced yield. From 1986 to 2009, 56 to 96% of the cotton acreage in the U.S. was infested with thrips during the seedling growth stage. Even though insecticide applications for thrips were applied 0.19 to 1.1 times per acre, the Beltwide yield losses ranged from 0.12 to 0.88% (Cook et al., 2011).

Genetic variation in thrips resistance among cotton species and genotypes has long been noted (Ballard, 1951; Hawkins et al., 1966; Quisenberry and Rummel, 1979; Rummel and Quisenberry, 1979). Screening of a large number of germplasm accessions for thrips resistance has also been reported (Arnold et al., 2012; Stanton et al., 1992). In general, Upland cotton (*Gossypium hirsutum* L.) is highly susceptible to thrips, so breeding for resistance is one of the objectives of several public breeding programs. Releases of cultivars and breeding lines with moderate levels of thrips resistance have been reported (e.g., Bourland and Jones, 2005; Thaxton and El-Zik, 2004).

Over the years, Pima cotton (*Gossypium barbadense* L.) was noted to be more resistant to thrips in breeding nurseries where both Pima and Upland cotton were grown. This phenomenon also has been reported by others (e.g., Bowman and McCarty, 1997). However, the genetic basis of thrips resistance in Pima cotton is currently poorly understood (Bowman and McCarty, 1997). We initiated the current study to understand the genetic basis of thrips resistance in Pima cotton and to identify advanced breeding lines for thrips resistance in an advanced backcross inbred line (BIL) population and a recombinant inbred line (RIL) population derived from crosses between Upland and Pima cotton.

MATERIALS AND METHODS

Plant Materials: Four greenhouse tests and one field test were conducted in this study as detailed below.

Greenhouse Test 1—Comparison Between Upland and Pima Cotton. Five Upland cotton (*G. hirsutum*, AD1) cultivars or lines and eight Pima cotton

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(*G. barbadense*, AD2) cultivars or lines were grown in 4-in. pots filled with potting soil Metro-Mix 360® (Sun Gro, Bellevue, WA) in the greenhouse in January 2012 and evaluated for thrips resistance on 24 March 2012. The test was arranged in a randomized complete block design with four replications (3 pots/replicate, 3 hills/pot, and 1 seedling/hill).

Greenhouse Test 2—Comparison of Four Tetraploid Species. Ten *G. barbadense* (AD2) cultivars from China and Egypt were grown in January and evaluated for thrips damages on 24 March 2012. The greenhouse experiment was arranged in a randomized complete block design with four replications (1 pot/replicate, 2 hills/pot, and 1 seedling/hill). For comparison purposes *Gossypium tomentosum* Nutt. ex Seem. (AD3), *G. mustelinum* Miers ex Watt (AD4), and *G. darwinii* G. Watt (AD5), each represented by two to six accessions, were also included in this test. These accessions of the three wild species are photoperiodically sensitive and were grown in the greenhouse for many years and trimmed back each year in January. Therefore, only young leaves were evaluated for thrips damages in these wild accessions. The two tests were conducted in the same greenhouse at the same time.

Greenhouse Test 3—Upland × Pima F_2 Populations. Four elite Upland cotton genotypes representing the Southwest and mid-South breeding programs, Acala 1517-08 (Zhang et al., 2011), LA 35RS (Myers et al., 2007), MD25-27Y (Meredith and Nokes, 2011), and UA 48 (Bourland and Jones, 2011) were selected as males to cross with four commercial Pima cotton cultivars grown in the U.S., including Cobalt (PVP 200500112), DP 340 (PVP 200200111), Pima S-7 (Turcotte et al., 1992), and Phytogen (Phy) 830. The thrips resistance of the eight genotypes was not evaluated before the crosses were made. The resulting F_1 hybrids except for DP 340 × UA 48 and Phy 830 × LA 35RS (for which hybrid seed was not produced) were selfed to produce F_2 populations. The 14 F_2 populations and their parental lines were planted in the greenhouse on 18 May 2012 using the same method as described above, with a total of 50 to 87 plants per F_2 population and 36 plants on average for each parent. A completely randomized design was used with parental plants placed in each F_2 population. Evaluation for thrips resistance was conducted in early July 2012.

Greenhouse Test 4—Advanced Breeding Lines. Ninety lines from a pedigree selection process in a cross of Acala 1517-99 (Cantrell et al., 2000) × Pima Phy 76 (PVP 200100120) were divided into three different tests (Test 4a, 4b, and 4c), each of which had 30 lines, both parents, and Acala 1517-08. Seed was sown in 4-in. pots in the greenhouse in January 2012 and seedlings were evaluated for thrips resistance on 24 March 2012. Each of the three tests was arranged in a randomized complete block design with three replications (3 pots/replicate, 3 hills/pot, and 1 seedling/hill).

Field Test—Backcross Inbred Line (BIL) Population. One hundred and forty six BILs, which were derived from a cross of Upland cotton Sure-Grow (SG) 747 (PVP 9800118) × Pima S-7, followed by two generations of backcrossing with SG 747 as the recurrent parent, and three generations of selfing, together with the two parents and Acala 1517-99, were grown in field plots without seed treatment in Las Cruces, NM in early May 2008. The experiment was a randomized complete block design with three replicates (1 row × 9.1-m long plots and seeding rate of 3 seed/30 cm). Thrips damage in each plot was evaluated on 13 June 2008.

Evaluation of Thrips Resistance. Seedling responses to thrips were evaluated under natural infestation conditions in the field or greenhouse. Alfalfa plants (*Medicago sativa* L.) were grown next to the cotton in both the field and greenhouse (where thrips were not controlled) to ensure heavy thrips pressure on cotton plants. A rating scale of 0 to 7 was used to rate individual plants or plots for thrips resistance in the field or greenhouse:

0 no symptom
1 very light symptom, very small mottled dots on leaves
2 light symptom, small mottled appearance of leaf, no wrinkled leaf
3 moderate symptom, malformation and tearing of leaf
4 severe symptom, injury of apical meristem
5 very severe symptom, death of apical meristem, and severely wrinkled leaf
6 nearly dead, death of apical meristem, and defoliation
7 a dead plant

Here, rating 0 is immune, 1 and 2 are resistant, 3 is moderately susceptible, and 4 and above are susceptible in Greenhouse Test 3 where segregation of thrips resistance was evaluated. In some cases, a score between two ratings was given when there was an uncertainty. Although no common susceptible check was predetermined when the tests were conducted, Acala 1517-08 was used as a local standard in all the tests except for Greenhouse Test 2. Thrips damages were monitored on a daily basis in the greenhouse tests and regularly in the field. The dates for thrips evaluation were determined when visual thrips damages were high and consistent between plants within susceptible Upland cotton genotypes and between replications of the genotypes, whereas Pima cotton in the tests showed much lighter thrips damages. However, the plant age was usually between 3 and 5 true leaf stage, depending on tests. The visual scoring for each plant (in the greenhouse) or plot (in the field) on thrips resistance was conducted by the same person in 1 d with assistance from another person in data recording when needed.

Data Analysis. Analyses of variance (ANOVA) were performed (SAS, 2000) for separation of means using the least significant difference (LSD). However, the ANOVA for Greenhouse Test 1 and 2 was performed on an individual plant basis due to no blocking effects detected. Broad-sense heritabilities were estimated based on ANOVA using the following formula:

$$\text{Heritability } (H^2) = \sigma_g^2 / (\sigma_g^2 + \sigma_e^2).$$

Here, σ_g^2 is estimated genetic variance and σ_e^2 is estimated environmental variance.

Minimum number of genes (n) conferring thrips resistance was estimated based on Lande (1981), as follows:

$$n = (P1 - P2)^2 / 8\sigma_g^2.$$

Here, P1 and P2 are means of parents or breeding lines with maximum and minimum values in the same experiment.

RESULTS AND DISCUSSION

Thrips Resistance in Five Tetraploid Cotton Species. As expected (Table 1), Upland cotton as a species was more sensitive to thrips than *G. barbadense* in that the five Upland cotton genotypes (with an average rating of 2.3, ranging from 1.8-3.1) had significantly higher thrips damage than five (with rating below 1.6) of the eight *G. barbadense* cottons (with an average rating of 1.6, ranging from 1.0-2.7). However, two *G. barbadense* cottons (Cobalt and Monseratt SI) were as sensitive as the Upland cotton tested and more sensitive to thrips damage than Upland cotton LA 35RS, which had a similar rating as Pima S-7. Due to the hairy leaves in *G. tomentosum*, no visible thrips damage was observed (Table 2). Pilose cotton was long recognized to confer resistance to thrips (Bowman and McCarty, 1997; Walker et al., 1979). Two other wild tetraploid species, *G. mustelinum* and *G. darwinii*, were also resistant to thrips infestations. The 10 exotic *G. barbadense* cultivars (seven from China and three from Egypt) were consistently resistant to thrips with average ratings ranging from 1 to 1.7, except for three Chinese *G. barbadense* cultivars (Table 2).

Table 1. Average ratings of thrips responses in two cultivated tetraploid cotton species from Greenhouse Test 1, Las Cruces, NM, Jan.-March 2012.

Species	Line	Rating[Z]
Gossypium hirsutum (AD1)	Acala 1517-08	2.1
Gossypium hirsutum (AD1)	UA 48	2.1
Gossypium hirsutum (AD1)	MD 25-27Y	2.3
Gossypium hirsutum (AD1)	DP 393	3.1
Gossypium hirsutum (AD1)	LA S35RS	1.8
Gossypium barbadense (AD2)	Pima S-7	1.6
Gossypium barbadense (AD2)	Phy 830	1.5
Gossypium barbadense (AD2)	Cobalt	2.1
Gossypium barbadense (AD2)	DP 340	1.5
Gossypium barbadense (AD2)	06E2032-11	1.2
Gossypium barbadense (AD2)	Pima 32	1.3
Gossypium barbadense (AD2)	Monseratt SI	2.7
Gossypium barbadense (AD2)	11NM15-Giza	1.1
LSD (0.05)		0.3

[Z] A rating scale of 0 to 7 was used to rate individual plants for thrips resistance, where 0 = no symptom, 1 = very light symptom, 2 = light symptom, 3 = moderate symptom, 4 = severe symptom, 5 = very severe symptom, 6 = nearly dead, and 7 = dead plant.

Table 2. Average ratings of thrips responses in four tetraploid cotton species conducted in Greenhouse Test 2, Las Cruces, NM, Jan.-March 2012.

Species	Line	Rating[Z]
Gossypium barbadense (AD2)	Dandara	2.0
Gossypium barbadense (AD2)	Giza 70	1.3
Gossypium barbadense (AD2)	Giza 83	1.7
Gossypium barbadense (AD2)	Xinhai 16	2.0
Gossypium barbadense (AD2)	Xinhai 20	2.0
Gossypium barbadense (AD2)	Xinhai 24	1.6
Gossypium barbadense (AD2)	Xinhai 25	1.0
Gossypium barbadense (AD2)	Xinhai 30	1.3
Gossypium barbadense (AD2)	Xinhai 35	1.6
Gossypium barbadense (AD2)	Xinhai 36	1.6
Gossypium tomentosum (AD3)		0.0
Gossypium mustelinum (AD4)		1.7
Gossypium darwinii (AD5)		1.0
LSD (0.05)		0.4

[Z] A rating scale of 0 to 7 was used to rate individual plants for thrips resistance, where 0 = no symptom, 1 = very light symptom, 2 = for light symptom, 3 = moderate symptom, 4 = severe symptom, 5 = very severe symptom, 6 = nearly dead, and 7 = dead plant.

Segregation Analysis of Thrips Resistance in Upland × Pima F_2 Populations. Of all 16 possible F_2 populations (except for DP 340 × UA 48 and Phy 830 × LA 35RS) between four Pima and four Upland cotton genotypes, seedling responses to thrips damage in seven interspecific crosses followed a 3 resistant (rating below or equal to 2):1 susceptible (rating higher than 2) ratio (Table 3). The results suggest that Pima cotton carries one major dominant resistance gene to thrips, tentatively designated as *Thr*. In other crosses, escape from thrips injury might have inflated the numbers of resistant plants, resulting in distorted segregations deviating from the expected 3:1 ratio. Only a progeny test will help in determining the exact genetic basis of thrips resistance in these crosses.

Evaluation of Thrips Resistance in Advanced Breeding Lines Derived from Upland × Pima. The success of thrips-resistance transfer from Pima cotton was evaluated in the greenhouse in advanced breeding lines selected for field agronomic performance from the cross of Acala 1517-99 × Pima Phy 76 (Table 4). A total of 21 lines had similar thrips responses to the Pima cotton parent, indicating that the thrips resistance in Pima cotton was transferred into Upland cotton through a pedigree selection process.

Evaluation of Thrips Resistance in BILs Derived from Upland × Pima. Evidence for the transfer of thrips resistance from Pima cotton was further evaluated in a BIL population of 146 lines in a replicated field test (Table 5). The Upland cotton parent SG 747 (rating = 4.67) was more sensitive to thrips than Pima S-7 (rating = 2.67), whereas Acala 1517-99 (with an average rating of 3) was intermediate in response to thrips damage. It appeared that 12 BILs were as resistant as the Pima parent (Table 4), a proportion that was expected based on one major resistance gene in the Pima parent from a BIL population derived from two backcrosses and three selfings. These BILs had significantly lower thrips ratings than the most susceptible BILs (Table 5). The results indicate that the thrips resistance in Pima cotton was indeed transferred into Upland cotton through backcrossing without selection for thrips resistance during the breeding process.

Table 3. Segregation ratio of thrips resistance in 14 Upland × Pima F_2 populations in Greenhouse Test 3, Las Cruces, NM, May-July 2012.

Cross	No. plants with different ratings[Z]											No. R	No. S	Exp. ratio	χ^{2Y}
	0	1	1.5	2	2.5	3	3.5	4	5	6	7				
Cobalt × 1517-08	2	85	0	15	0	5	0	0	0	0	0	102	5	3R: 1S	23.58
Cobalt × LA 35RS	5	75	0	4	0	1	0	0	0	0	0	84	1	3R: 1S	25.73
Cobalt × MD 25-27Y	2	53	0	24	0	12	0	1	0	0	0	79	13	3R: 1S	5.80
Cobalt × UA 48	2	49	0	22	0	13	0	2	0	0	0	73	15	3R: 1S	2.97
DP 340 × 1517-08	3	42	0	29	0	23	0	2	2	0	0	74	27	3R: 1S	0.16
DP340 × LA 35RS	0	27	2	24	11	14	3	6	0	0	0	64	23	3R: 1S	0.10
DP 340 × MD 25-27Y	0	52	0	24	0	9	0	3	0	0	0	76	12	3R: 1S	6.06
Phy 830 × 1517-08	1	48	5	20	2	3	0	1	0	0	0	50	26	3R: 1S	3.46
Phy 830 × MD 25-27Y	0	48	0	27	0	8	0	2	1	0	0	75	11	3R: 1S	6.84
Phy 830 × UA 48	1	53	0	26	0	6	0	1	0	0	0	80	7	3R: 1S	13.34
Pima S-7 × 1517-08	1	21	0	30	0	14	0	10	0	0	0	52	24	3R: 1S	1.75
Pima S-7 × LA 35RS	1	53	6	15	7	2	0	0	0	0	0	75	9	3R: 1S	0.57
Pima S-7 × MD 25-27Y	0	46	0	22	0	8	0	4	0	0	2	68	14	3R: 1S	2.75
Pima S-7 × UA 48	0	16	0	46	0	29	0	3	0	0	0	62	32	3R: 1S	4.10

[Z] A rating scale of 0 to 7 was used to rate individual plants for thrips resistance, where 0 = no symptom, 1 = very light symptom, 2 = light symptom, 3 = moderate symptom, 4 = severe symptom, 5 = very severe symptom, 6 = nearly dead, and 7 = dead plant. Ratings 0-2 were considered resistant and ratings 3-7 susceptible.

[Y] $\chi^2_{(0.05\ df=1)} = 3.84$. $\chi^2_{(0.01\ df=1)} = 6.63$.

Table 4. Thrips resistance in advanced breeding lines derived from Acala 1517-99 × Pima Phy 76 in Greenhouse Test 4, Las Cruces, NM, Jan.-March 2012.

Test 4a		Test 4b		Test 4c	
Line	Rating[z]	Line	Rating	Line	Rating
08N1141	2.21*[X]	08N1635	2.23*	08N1835	2.20*
08N1196	2.50*	08N1595	2.64*	08N1770	2.32*
08N1186	2.60*	08N1653	2.67*	08N1782	2.33*
08N1198	2.63*	08N1589	2.69*	08N1747	2.50*
08N1514	2.66*	08N1599	2.80*	08N1740	2.51*
08N1220	2.67*	08N1592	2.87	08N1773	2.73*
08N1367	2.75	08N1619	2.88	08N1817	2.77*
08N1527	2.78	08N1586	2.93	08N1735	2.80*
08N1184	2.80	08N1563	2.97	08N1547	2.83*
08N1210	3.00	08N1579	2.97	08N1762	2.83*
08N1320	3.02	08N1702	2.97	08N1724	2.91
08N1046	3.03	08N1614	3.06	08N1749	2.91
08N1084	3.09	08N1602	3.23	08N1825	2.91
08N1518	3.19	08N1704	3.27	08N1736	3.07
08N1206	3.22	08N1590	3.30	08N1786	3.10
08N1240	3.32	08N1562	3.31	08N1742	3.20
08N1064	3.34	08N1699	3.32	08N1792	3.20
08N1303	3.38	08N1716	3.36	08N1717	3.23
08N1537	3.38	08N1698	3.43	08N1787	3.23
08N1325	3.40	08N1615	3.43	08N1739	3.25
08N1530	3.46	08N1636	3.51	08N1789	3.25
08N1020	3.47	08N1703	3.51	08N1718	3.47
08N1503	3.47	03N1155	3.54	08N1722	3.50
08N1302	3.53	08N1559	3.58	08N1810	3.53
08N1190	3.64	08N1564	3.58	08N1823	3.58
08N1256	3.67	08N1685	3.60	08N1745	3.59
08N1222	3.68	08N1618	3.61	08N1805	3.61
08N1254	4.00	08N1603	3.72	08N1803	3.67
08N1255	4.07	08N1633	3.78	08N1755	3.73
1517-99	3.49	1517-99	3.36	1517-99	3.02
Pima Phy 76	1.42	Pima Phy 76	1.77	Pima Phy 76	1.75
1517-08	3.48	1517-08	3.28	1517-08	3.47
MSE	0.88	MSE	0.60	MSE	0.69
F[Y]	3.70	F	2.13	F	2.10
LSD (0.05)	1.28	LSD (0.05)	1.05	LSD (0.05)	1.13

[Z] A rating scale of 0 to 7 was used to rate individual plants for thrips resistance, where 0 = no symptom, 1 = very light symptom, 2 = for light symptom, 3 = moderate symptom, 4 = severe symptom, 5 = very severe symptom, 6 = nearly dead, and 7 = dead plant.

[Y] $F_{0.05,\ df1=31/df2=62}=1.64$.

[X] Means with an * were not significantly different from that of Pima Phy 76 at the 0.05 probability.

Table 5. Thrips resistance in selected backcross inbred lines (BILs) derived from SG 747 × Pima S-7 in the field, Las Cruces, NM, May-June 2008.

Most resistant		Most susceptible	
Line	Rating[Z]	Line	Rating
NMHT-61	2.50	NMHT-17	4.83
NMHT-56	2.67	NMHT-71	4.83
NMHT-27	2.83	NMHT-97	4.83
NMHT-38	2.83	NMHT-104	5.00
NMHT-100	3.00	NMHT-70	5.00
NMHT-115	3.00	NMHT-85	5.00
NMHT-116	3.00	NMHT-93	5.00
NMHT-60	3.00	NMHT-128	5.17
NMHT-73	3.00	NMHT-133	5.17
NMHT-80	3.00	NMHT-19	5.17
NMHT-88	3.00	NMHT-123	5.50
NMHT-95	3.00	NMHT-126	5.50
Pima S-7	2.67	SG 747	4.67

LSD (0.05) = 1.27.

[Z] A rating scale of 0 to 7 was used to rate individual plants for thrips resistance, where 0 = no symptom, 1 = very light symptom, 2 = light symptom, 3 = moderate symptom, 4 = severe symptom, 5 = very severe symptom, 6 = nearly dead, and 7 = dead plant.

Heritabilities and Minimum Number of Genes for Thrips Resistance in Upland × Pima. The analysis of variance showed significant genotypic variation at $P = 0.10$ in thrips responses in the BILs tested in the field (Table 5), but the broad-sense heritability estimation was low (0.18). This indicates that larger experimental errors were encountered when evaluating thrips resistance under the natural field infestation conditions in our study. However, in the greenhouse conditions (Table 4), heritabilities for thrips resistance were estimated to be from 0.68 for Test 2 and 3 to 0.79 for Test 1 in the advanced breeding lines derived from pedigree selections in Acala 1517-99 × Pima Phy 76. These results indicate that thrips resistance in the breeding lines derived from Upland × Pima was moderately high, implying that phenotypic selection for thrips resistance is efficient through replicated tests in the greenhouse. After evaluating hybrids from five *G. barbadense* genotypes × four Upland cultivars and 90 converted racestocks for tolerance to thrips, Bowman and McCarty (1997) reported that general combining ability was significant for thrips damage ratings in the F_1 generation among the *G. barbadense* parents, whereas specific combining ability was detected in F_2 progeny, thereby suggesting that thrips resistance was mainly determined by non-additive genetic variance.

The estimates of minimum number of genes conferring thrips resistance in the BIL population of SG 747 × Pima Phy 76 tested in the field were 5.9 based on the difference between the two parents and 2.6 based on the difference between the BILs with the highest and lowest thrips ratings. The minimum number of genes was estimated to be 0.23, 0.47, and 0.27 for Test 4a, 4b, and 4c in the greenhouse, respectively, based on parental differences. The results were 0.18, 0.44, and 0.38, respectively, based on differences between the advanced lines with the highest and lowest thrips ratings. The results were consistent among the three tests and between the two methods of estimation in that there is at least one gene conferring thrips resistance in the advanced breeding lines derived from Acala 1517-99 and Pima Phy 76.

This study was conducted under the natural infestation conditions in the field or greenhouse and the distribution of thrips was relatively uniform even though the number of thrips was not counted. This is evident from the consistent results for Acala 1517-99, 1517-08, and Pima Phy 76 among Greenhouse Tests 4a, 4b, and 4c. This can be further validated based on experimental errors in several experiments. The coefficient of variation (CV) in the BILs tested in the field was 24.4%, whereas the CV in the greenhouse was similar (24.5-29.9%) in the three greenhouse tests. The experimental errors in thrips evaluation were similar to or higher than those reported for cotton yield in variety tests (e.g., results from Regional Breeders Testing Network; see http://www2.msstate.edu/~tpw6/current/home.html). This allowed the detection of significant genotypic variation from the analyses of variance and selection of thrips-resistant breeding lines from Upland × Pima hybrids. However, the high CV in thrips-resistance evaluation certainly demands a better screening method such as artificial inoculation (Arnold et al., 2012) and a more reliable selection method such as marker-assisted selection in breeding.

SUMMARY

This study was performed under natural infestation conditions in the field and greenhouse and relatively uniform thrips infestation was achieved. This allowed for reliable evaluation of cotton seedlings for thrips resistance. Significant genotypic variation was detected in the tests, especially in the greenhouse conditions, in which moderate to high heritabilities for thrips resistance and at least one resistance gene were estimated in advanced breeding lines derived from Upland SG 747 × Pima Phy 76. Further qualitative analysis of 14 F_2 hybrids from four resistant Pima × four susceptible Upland cotton confirmed that there is one major dominant thrips-resistance gene (*Thr*) in seven F_2 populations. Both the quantitative and Mendelian genetics are consistent and corroborated with the identification of more than 30 thrips-resistant lines in the backcross inbred and recombinant inbred line populations. The results indicate that thrips resistance in Pima cotton was successfully transferred into Upland cotton through backcrossing or pedigree selections. Chromosomal location of the thrips resistance gene and the development of its associated molecular markers will facilitate the transfer of the resistance gene to other elite cotton backgrounds.

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