ARTHROPOD MANAGEMENT

Upland Cotton Susceptibility to *Bemisia argentifolii* (Homoptera: Aleyrodidae) Infestations

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INTERPRETIVE SUMMARY

We field-tested 17 short staple cotton cultivars for susceptibility to whitefly infestations in the Imperial Valley, CA. All cottons were susceptible and without insecticide protection, lint yield was 1 bale or less per acre. With insecticide protection, lint yield was increased 0.35 to eight times. Overall, Deltapine varieties required fewer insecticide applications compared to Louisiana 887 or Stoneville 474 to produce comparable lint yields. In a greenhouse test, we found that when whiteflies had no choice of cultivars, there were no significant differences in whitefly infestations among nine cotton cultivars tested.

ABSTRACT

Seventeen upland cotton (*Gossypium hirsutum* L.) cultivars were evaluated in the field for susceptibility to *Bemisia argentifolii* Bellows and Perring in Imperial Valley, CA, from 1992 to 1996. All cultivars were susceptible. Sticky cotton occurred and lint yields were low. In 1995 and 1996, nine untreated and insecticide-treated cultivars were compared using 4.1 adults per leaf turn as an insecticide-treatment action threshold. Lint yields of the insecticide-treated plots increased from 1.2 to 7.9 times in 1995 and from 0.35 to 4.0 times in 1996 compared to untreated cultivars. Deltapine (DPL) 5409 and 5415 on average required 5.5 insecticide applications; DPL 50, 5461, and 5517 required six applications; and DPL 5432 and 5690 required 6.5 applications. Louisiana (LA) 887 required seven applications and Stoneville (ST) 474 required 7.5 applications. In a no-choice greenhouse trial in 1997, the nine cultivars studied were equally colonized with *B. argentifolii* eggs and nymphs in small leaf cages and adult emergence was not significantly different among cultivars. Results suggest the potential to reduce insecticide applications by selecting appropriate cultivars currently available. Identification of resistance mechanisms and development of breeding programs to incorporate resistance into acceptable upland cultivars appear to be promising approaches for whitefly control.

The sweet potato whitefly (*Bemisia tabaci* Gennadius) has become one of the most serious worldwide economic pests (Basu, 1995). *Bemisia tabaci* was identified in Arizona and southern California cotton as early as 1926 and 1927, respectively, but did not become an economic problem until the early 1980s (Russell, 1957; Johnson et al., 1982; Natwick and Zalom, 1984). A newly described species, *B. argentifolii* Bellows and Perring, appeared about 1990 in the Imperial Valley, CA. Whitefly specimens collected in cotton in 1990 in Imperial Valley, CA (Chu et al., 1994), and examined using a RAPD-DNA technique (randomly amplified polymorphic DNA-polymerase chain reaction) confirmed that the whiteflies were exclusively *B. argentifolii* (Alan C. Bartlett, USDA-ARS Western Cotton Research Laboratory, Phoenix, AZ, 1994, personal communication). *Bemisia argentifolii* was reported to lay significantly more eggs (Bethke et al., 1991), have a broader host range and result in more damage to cultivated crops than the sweetpotato whitefly (Bellows et al., 1994; Zalom et al., 1995). In 1990, plants in a few melon (*Cucumis melo* L.) fields in Imperial Valley, CA, were destroyed by the new species prior to harvest. Melon losses in 1991 increased to include total yields from 4461 ha (Anonymous, 1991). Natwick et al. (1995) reported that in 1991, dead leaves occurred on Pima and upland cotton plants in mid-July as a result of *B. argentifolii* infestations. Also,

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in 1991 overall lower lint yields occurred in the Imperial Valley compared with 1990. Lower yields were associated with high whitefly populations. In 1994, Beltwide cotton losses due to *B. argentifolii* colonization were estimated at ≈ 16 000 bales (Williams, 1995).

In addition to lint yield losses, increases in the occurrence of sticky cotton have occurred because of honeydew contamination (Davidson et al., 1994; Chu et al., 1995a). Berlinger (1986) suggested the development of whitefly-resistant cotton cultivars as one approach to reduce the cotton stickiness problem. Cotton varieties with pubescent leaves have been reported to support higher whitefly populations than smooth leaf varieties (Mound, 1965). Other whitefly resistant cotton characteristics that have been reported are okra leaf shape, glabrous leaf, and high gossypol content (Berlinger, 1986; Butler and Henneberry, 1984). Recent field tests showed differences in the susceptibility of cotton-breeding stocks (Natwick et al., 1995), cultivars (Watson et al., 1994), and genotypes (Flint and Parks, 1990; Leigh et al., 1994) to *B. argentifolii*.

The objective of our studies from 1992 to 1997 was to identify upland cotton cultivars that were less susceptible to *B. argentifolii* colonization under low desert growing conditions. We also evaluated most and least susceptible cultivars in insecticide-treated and untreated choice conditions in the field and untreated no choice greenhouse conditions.

MATERIALS AND METHODS

Relative Susceptibilities of Commercial Cultivars to *Bemisia argentifolii*

Experiments 1 and 2 were conducted at the University of California Desert Research and Extension Center, Holtville, CA, in 1992 and 1993, respectively. The experimental design was a randomized complete block with four replicates. In Experiment 1, each plot was 15 m long and 4 m wide. Rows were spaced 1 m apart. There were two unplanted beds between plots and 6 m alleys that separated blocks. Four upland cotton cultivars evaluated were Deltapine (DPL) 20, 50, and 90, and Chembred (CB) 1135 (Chembred 1992). Seeds were planted and irrigated on 22 April 1992 with plant emergence 7 d later. No insecticides were applied. Samples of four to 10 leaves were taken from third and fifth main terminal nodes, respectively, on 1 and 11 June; 13 July; and 3 and 17 August. Four leaf disks measuring 1 cm^2 each were taken from the base of each leaf and numbers of eggs and nymphs were counted with the aid of a microscope. Seed cotton was machine harvested from all plots on 10 September and ginned to determine lint yields. Lint samples were analyzed for sugar content and stickiness as described by Perkins (1983).

In Experiment 2 (1993), each plot was 15 m long and 8 m wide. Rows were spaced 1 m apart. There were four unplanted rows between plots and 5 m alleys that separated blocks. The eight upland cultivars were DPL 50, 5415, 5461, and 90, CB 232, 333, 1135, and 1233. Seeds were planted and irrigated on 4 April 1993 with plant emergence about 14 d later. All plots were sprayed with a mixture of cyfluthrin (Baythroid, cyano(4-fluoro-3-phenoxyphenyl)methyl 3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate) and methamidophos (Monitor, *O*, *S*-dimethyl phosphoramidothioate), at 0.056 and 0.56 kg AI/ha, respectively, on 22 June; 7, 13, 21, and 27 July; and 3 and 10 August. Five leaf samples were taken from fifth main stem node leaves (Naranjo and Flint, 1994, 1995) from each plot on 1, 11, 18, 29 June; 12, 16, and 23 July; and 2, 6, and 13 August. Two 1.25 cm^2 leaf disks were taken from the base of each leaf and eggs and nymphs were counted. Seed cotton was machine-harvested from plots on 10 September and ginned for lint yields. Lint samples were analyzed for sugars and stickiness was determined with thermodetector readings (Perkins and Brushwood, 1995).

Experiment 3 was conducted at the USDA Irrigated Desert Research Station, Brawley, CA, in 1994. The experimental design was a randomized complete block with 10 replicates. Each plot was 3 by 2 m with rows spaced 1 m apart. There were 3 m fallow areas between blocks. To allow maximum adult migration between cultivars (plots) within a block, there were no skip rows between plots. No insecticides were applied during the season; the five upland cultivars evaluated were DPL 5415, 5429, 5461, and 5690, and Louisiana (LA) 887. Seeds were planted on 14 April 1994 and plants emerged about 7 d later. Five 5th main stem node leaves were sampled weekly for 14 times from each plot from 17 May to 16 August. A 3.8 cm^2 leaf disk was taken from the base of each leaf and the numbers of eggs

Table 1. Mean number of Bemisia argentifolii eggs and nymphs on leaves, lint yield, and percent sugars and stickiness of lint from different upland cotton cultivars at Holtville, CA, 1992.

Cultivar	Leaf disk		Lint		
	Eggs	Nymphs	Yield	Total reducing sugars	Minicard rating
	------------------no./cm²-----------------		kg/ha	%	
CB 1135	195.4 ± 34.9a†	10.9 ± 2.0a	244 ± 65b	1.4 ± 0.1a	3.4 ± 0.1ab
DPL 20	244.9 ± 82.6a	5.2 ± 0.3b	524 ± 29a	1.5 ± 0.0a	3.5 ± 0.0a
DPL 50	176.6 ± 29.8a	8.5 ± 2.9ab	335 ± 78b	1.5 ± 0.0a	3.5 ± 0.0a
DPL 90	136.2 ± 10.6a	5.9 ± 0.6b	469 ± 43a	1.0 ± 0.1b	3.1 ± 0.1b
F, Cultivars	1.52	3.92*	11.38 **	9.61**	4.50*

*, ** Significant at $P \leq 0.05$ and 0.01, respectively.

† Means ± SEM in a column with different letters differ significantly (Student-Neuman-Keul's multiple range test, $P \leq 0.05$).

and nymphs counted as described earlier. Numbers of adults were counted using the leaf turn method (Naranjo and Flint, 1995). Seed cotton was hand picked from all plants in one row from each plot and ginned to determine lint yields.

Action Thresholds and Insecticide Treatments

Experiments 4 and 5 were conducted at the USDA Irrigated Desert Research Station, Brawley, CA. The experimental designs were split-plots with four replicates. Each plot was 12.2 m long and 4 m wide. Rows were 1 m apart. There were four unplanted beds between plots and 9.1 m alleys between blocks. Whole plots were either untreated or insecticide treated. Split plots were nine upland cotton cultivars: DPL 50, 5409, 5415, 5432, 5461, 5517, 5690, LA 887, and Stoneville (ST) 474. Seeds were planted on 14 and 11 March in 1995 and 1996, respectively. Plant emergence occurred about 3 wk later. Leaf samples, as described, were taken weekly from 23 May to 8 August in 1995 and from 7 May to 6 August in 1996. Leaf sampling was identical to that in Experiment 3, except the sample size was increased from 5 to 10 leaves. Insecticide applications were initiated on adult action thresholds of 4.1 or more adults/leaf. The 4.1 adults/leaf action threshold was developed by the authors in 2 yr of study from 1993 to 1994 (Chu et al., 1995c). Insecticide applications were a mixture of fenpropathrin (Danitol, a-cyano-3-phenoxybenzyl 2,2,3,3,-tetramethyl- cyclopopanecarboxylate) and acephate (Orthene, *O*, *S*-dimethyl acetylphosphoramidothioate) at 0.224 and 0.56 kg a.i./ha, respectively. Seed cotton was hand picked from 4 m sections of row in the two center rows of each plot and ginned for lint yield determinations.

No-choice Greenhouse Studies

Experiment 6 was conducted in a heated greenhouse from 28 March to 19 May at the USDA Irrigated Desert Research Station, Brawley, CA, in 1997. Temperature ranged from 21°C (night) to 40°C (day). Relative humidity ranged from 22 to 65%. A no-choice study was conducted with the same nine cultivars used in field tests in 1995 and 1996. The experimental design was a randomized complete block with eight replicates (large cages). Each replicate had nine pots, one cultivar per pot. On 28 March, seed of each of the nine cultivars was planted in 15-cm diameter pots, six seeds per pot. Each pot contained a soil mix (Scotts® Scotts-Sierra Horticultural Products Co., Marysville, OH 43401) and 5 g/pot of slow release fertilizer (14-14-14 Osmocote, Hummert International, Earth City, MO 63045). Nine pots, each with a different cultivar, were placed into a 60 x 60 x 60 cm cage covered with 52 mesh nylon net (BioQuip Products, Gardena, CA 90248). Plants were thinned to two plants/pot at the three true-leaf stage. A small clip cage was used to confine *B. argentifolii* adults on individual leaves. The leaf cage was constructed of a clear plastic petri dish with a diameter of 3.8 cm and 1.8 cm high (Falcon® 3001, Becton Dickinson Labware, Lincoln Park, NJ 07035). The petri dish bottom was cut out and covered with 52 mesh nylon net for air circulation. The petri dish cover had six 3 mm diameter (uncovered) holes to aid in leaf transpiration. On the cage sides a 5 mm diameter hole was drilled for the introduction of adult whiteflies and plugged after the introduction. A large hair clip was glued on the petri dish and hinged at the top and bottom to allow access to the

Table 2. Mean number of *Bemisia argentifolii* eggs and nymphs on leaves, lint yield, and percent sugar and stickiness of lint from different upland cotton cultivars at Holtville, CA, 1993.

Cultivar	Leaf disk: Eggs	Leaf disk: Nymphs	Lint: Yield	Lint: Total reducing sugars	Lint: Thermodetector counts
	------------------no./cm²	------------------	kg/ha	%	
CB 232	57.9 ± 10.5 a†	29.4 ± 5.6 ab	312 ± 51 b	2.7 ± 0.1 a	120 ± 14 a
CB 333	82.7 ± 11.1 a	45.2 ± 6.6 a	226 ± 43 bc	2.5 ± 0.2 a	125 ±7 a
CB 1135	69.1 ± 14.9 a	38.6 ± 6.8 a	218 ± 46 bc	2.6 ± 0.2 a	115 ±8 a
CB 1233	60.7 ± 11.7 a	35.6 ± 4.5 a	260 ± 43 bc	2.0 ± 0.2 a	98 ±7 a
DPL 50	72.6 ± 17.3 a	37.5 ± 8.4 a	292 ± 30 b	2.5 ± 0.2 a	117 ± 11 a
DPL 90	53.7 ±8.8 a	30.1 ± 5.2 ab	253 ± 52 bc	2.2 ± 0.4 a	115 ± 21 a
DPL 5415	42.0 ±8.1 a	19.3 ± 2.8 b	426 ± 9 a	2.2 ± 0.3 a	111 ± 14 a
DPL 5461	60.5 ±7.8 a	33.6 ± 3.9 ab	192 ± 35 c	2.4 ± 0.4 a	111 ± 17 a
F, Cultivars	2.21	2.57*	6.02***	0.98	0.42

***, *** Significant at $P \leq 0.05$ and 0.001, respectively.**

† Means ± SEM in a column with different letters differ significantly (Student-Neuman-Keul's multiple range test, $P \leq 0.05$). All plots treated with a mixture of cyfluthrin and methamidophos.

cage. Cages were clipped on the fourth terminal leaves with the petri dish cover on the top leaf surface and the petri dish bottom on the lower leaf surface. A single cage was installed on each plant in each pot. Six pairs of *B. argentifolii* adults were released into each leaf clip cage. The adults were removed after 24 h and numbers of eggs on the leaves in the caged areas were counted. Numbers of eggs and nymphs were counted after 5 d. Nymphs were recounted after 12 d and newly developed adults were counted after 19 d.

All data were analyzed using analysis of variance (ANOVA), and seasonal averages were separated with Student-Neuman-Keul's multiple range test (Anonymous, 1989). Further analyses were made by combining means of whitefly counts into seasonal averages using the same statistical procedure.

RESULTS AND DISCUSSION

In the absence of insecticides (Experiment 1, 1992), CB 1135 had significantly more nymphs (10.9/cm² of leaf) than DPL 20 and 90, but not DPL 50 (Table 1). There were no significant differences in numbers of whitefly eggs among cultivars. DPL 20 and DPL 90 lint yields were significantly higher than yields of CB 1135 or DPL 50. Percentage of total reducing sugars was lowest for DPL 90 cotton compared with other cultivars. The minicard rating for DPL 90 was significantly lower than for DPL 20 and DPL 50 but CB 1135.

In 1993, with insecticides applied to all plots, nymph populations ranged from 19 to 45/cm² of leaf area (Table 2). DPL 5415 had significantly lower number of nymphs compared with DPL 50, CB 1233, 1235 and 333 but not CB 232, DPL 90, or DPL 5461. DPL 5415 yield was significantly higher than all other cultivars. There were no significant differences among cultivars for numbers of eggs, percentages of total reducing sugar, or thermodetector lint stickiness measurements.

In 1994, when no insecticides were applied, there were no significant differences among cultivars for the numbers of whitefly adults per leaf turn (range 30.1-33.1, Table 3). However, LA 887 had significantly higher numbers of eggs and nymphs compared with other cultivars and the lowest lint yield (62 kg/ha). DPL 5409 and DPL 5461 lint yields were significantly higher than DPL 5415 or DPL 5690.

In 1995, over all cultivars, insecticides applied at action thresholds of 4.1 adults per leaf turn significantly reduced numbers of whitefly eggs,

Table 3. Mean number of *Bemisia argentifolii* eggs, nymphs, and adults on leaves, and lint yield from different upland cotton cultivars at Brawley, CA, 1994.

Cultivar	Leaf disk: Eggs	Leaf disk: Nymphs	Adults	Lint
	-----------no./cm²	----------	no./leaf	kg/ha
DPL 5409	26.4 ± 3.5 b†	7.9 ± 1.1 b	31.1 ± 1.9 a	739 ± 102 a
DPL 5415	28.9 ± 1.5 b	8.2 ± 0.6 b	31.5 ± 1.2 a	412 ±25 b
DPL 5461	21.3 ± 1.7 c	6.7 ± 0.7 b	30.1 ± 1.7 a	598 ±36 a
DPL 5690	20.3 ± 1.5 c	6.4 ± 0.6 b	31.5 ± 1.2 a	426 ±28 b
LA 887	49.4 ± 2.6 a	16.6 ± 1.9 a	33.1 ± 1.1 a	62 ±32 c
F, Cultivars	63.18***	39.80***	0.68	25.74***

***** Significant at $P \leq 0.001$.**

† Means ± SEM in a column with different letters differ significantly (Student-Neuman-Keul's multiple range test, $P \leq 0.05$).

Table 4. Mean number of *Bemisia argentifolii* eggs, nymphs, and adults on leaves, lint yield, percent sugars and stickiness of lint from different upland cotton cultivars at Brawley, CA, 1995

Cultivar	Insecticide applied	Leaf disk Eggs	Leaf disk Nymphs	Adults	Lint Yield	Lint Increase‡	Lint Total reducing sugar	Lint Thermodetector counts
	no.			no./leaf	kg/ha	%	%	
DPL 50	0	12.4 ± 2.3cd†	4.9 ± 1.0cde	20.5 ± 5.0cd	702 ±92e	--	1.8 ± 0.1ab	59 ±1a
DPL 5409	0	21.2 ± 4.5b	8.3 ± 1.8b	22.6 ± 5.6bcd	597 ±64e	--	2.3 ± 0.7a	59 ±6a
DPL 5415	0	15.3 ± 2.4c	6.2 ± 1.3bcd	26.8 ± 7.3ab	479 ± 115ef	--	1.8 ± 0.7ab	34 ± 14b-f
DPL 5432	0	15.5 ± 2.7c	6.8 ± 1.5bc	24.7 ± 6.0bc	524 ±48ef	--	1.5 ± 0.3a-d	25 ± 13c-g
DPL 5461	0	15.8 ± 3.2c	6.7 ± 1.7bc	21.6 ± 6.1bcd	578 ± 117e	--	1.5 ± 0.0a-d	42 ±1a-d
DPL 5517	0	15.9 ± 3.2c	6.6 ± 1.4bc	26.7 ± 7.1ab	688 ±67e	--	2.3 ± 0.0a	46 ±3ab
DPL 5690	0	13.3 ± 2.5cd	4.7 ± 0.9cde	18.5 ± 5.0d	614 ±94e	--	1.2 ± 0.3a-d	40 ±8a-e
LA 887	0	33.2 ± 6.9a	15.7 ± 3.1a	25.6 ± 5.4bc	294 ± 120fg	--	1.7 ± 0.1ab	45 ±1abc
ST 474	0	30.7 ± 5.4a	14.6 ± 3.3a	31.2 ± 7.5a	208 ±39g	--	1.7 ± 0.3abc	55 ±1a
DPL 50	4	5.3 ± 1.2ef	1.9 ± 0.f	4.6 ± 0.7e	1562 ±6bc	122	0.7 ± 0.0bcd	15 ±2fg
DPL 5409	5	10.0 ± 2.2de	2.9 ± 0.6ef	8.9 ± 2.2e	1304 ±13d	118	1.2 ± 0.0bcd	23 ±3d-g
DPL 5415	4	5.2 ± 1.2ef	1.3 ± 0.3f	6.8 ± 2.4e	1848 ± 153a	286	0.9 ± 0.6bcd	12 ±7g
DPL 5432	6	6.6 ± 1.7ef	1.7 ± 0.5f	6.7 ± 1.3e	1673 ±17abc	219	0.7 ± 0.1bcd	18 ±1fg
DPL 5461	5	6.7 ± 1.0ef	1.4 ± 0.3f	7.7 ± 1.7e	1431 ± 142cd	148	0.6 ± 0.1cd	15 ±1fg
DPL 5517	5	4.8 ± 0.5f	1.4 ± 0.3f	7.4 ± 2.1e	1785 ±56ab	159	0.7 ± 0.1bcd	15 ±2fg
DPL 5690	5	6.2 ± 1.0ef	1.9 ± 0.3f	8.0 ± 2.e	1784 ±20ab	191	0.7 ± 0.0 bcd	20 ±3efg
LA 887	6	13.8 ± 3.3cd	3.8 ± 0.8def	8.0 ± 1.4e	1821 ± 109ab	519	0.4 ± 0.1d	12 ±7g
ST 474	7	13.4 ± 1.9cd	3.8 ± 0.6def	10.4 ± 1.e	1848 ±6a	788	0.7 ± 0.2bcd	20 ±3efg
Mean for untreated		19.3 ± 1.4A	8.3 ± 0.7A	24.2 ± 2.0A	520 ±44B	--	1.7 ± 0.1A	45 ±3A
Mean for treated		8.0 ± 0.6B	2.2 ± 0.2B	7.6 ± 0.6B	1673 ±50A	222	0.7 ± 0.1B	17 ±1B
F, cultivars		26.71***		3.65***	2.69*		0.35	2.40
F, insecticide		46.30***	73.16***	65.13***	209.81*		258.25*	384.76*
F, interaction		4.07***	7.81***	1.77	7.53***		0.51	1.68
Etc.								

*, **, *** Significant at $P \leq 0.05$, 0.01, and 0.001, respectively.

† Means ± SEM in a column with different letters differ significantly (Student-Neuman-Keul's multiple range test, $P \leq 0.05$).

‡ Compared to the same untreated cultivar (treated - untreated) x 100 / untreated.

nymphs, and adults; percentage of total reducing sugars; and thermodetector counts (Table 4). Cotton yields increased compared with untreated cottons. Numbers of eggs and nymphs from untreated leaf samples from DPL cultivars were significantly lower than numbers from LA 887 or ST 474. Numbers of adults varied among untreated cultivars with highest numbers found on ST 474, DPL 5415, and DPL 5517, and lowest on DPL 5690. Differences were not significant for all treated cultivars. Numbers of insecticide applications required based on the action threshold were seven for ST 474, six for LA 887 and DPL 5432, five for DPL 5461, 5517, 5690, and 5409, and four for DPL 50 and 5415.

Lint yields among untreated DPL cultivars were not significantly different. All DPL cultivars, except DPL 5415 and 5432, had higher yields than ST 474 and LA 887. For the insecticide-treated cultivars, the highest yields were obtained from DPL 5415 treated four times and ST 474 treated seven times. These treated cultivars were significantly different than DPL 50, 5409 and 5461 treated four, five, and five times, respectively, but not significantly different from DPL 5432, 5517, 5690, and LA 887 treated six, five, five, and six times, respectively. Increased yield in response to insecticide protection for DPL cultivars ranged from 1.2 to 2.9 times. For LA 887 and ST 474, the response was 5.2 and 7.9 times, respectively.

In 1996, results were similar with respect to whitefly eggs, nymphs, and adults on insecticide-treated compared with untreated cultivars and cultivar differences (Table 5). Numbers of insecticide applications required, based on the 4.1 adults per leaf turn action threshold, were eight for ST 474, LA 887, DPL 50, and 5690; seven for DPL 5415, 5432, 5461, and 5517; and six for DPL 5409. Lint yields were significantly increased in insecticide-treated cultivars compared with untreated cultivars. Compared to the untreated plots, yields of insecticide-treated plots of LA 887 and ST 474 were increased 4.0 and 3.6 times, respectively.

Table 5. Mean number of *Bemisia argentifolii* eggs, nymphs, and adults on leaves, lint yield, percent sugars, and stickiness of lint from different upland cotton cultivars at Brawley, CA, 1996.

		Leaf disk			Lint			
Cultivar	**Insecticide applied**	**Eggs**	**Nymphs**	**Adults**	**Yield**	**Increase‡**	**Total reducing sugar**	**Thermodetector counts**
	no.	------------ no./cm² ----------		no./leaf	kg/ha	----------------%----------------		
DPL 50	0	20.9 ± 3.5d†	10.2 ± 1.4c	13.4 ± 3.1b	768 ±83b-e	--	2.0 ± 0.2a	60 ± 4a
DPL 5409	0	33.5 ± 6.5c	15.6 ± 2.1b	16.5 ± 2.5b	558 ±12de	--	2.1 ± 0.4a	63 ± 1a
DPL 5415	0	36.6 ± 8.4bc	14.7 ± 2.4bc	17.9 ± 3.3b	584 ±90de	--	1.5 ± 0.1a	59 ± 5a
DPL 5432	0	29.2 ± 4.6cd	13.9 ± 1.6bc	16.1 ± 2.1b	541 ±35de	--	1.4 ± 0.0a	33 ±13a
DPL 54610	0	30.4 ± 5.8cd	12.9 ± 1.6bc	16.2 ± 2.7b	651 ± 146cde	--	1.2 ± 0.2a	29 ± 1a
DPL 5517	0	30.0 ± 4.7cd	14.7 ± 2.0bc	15.8 ± 2.3b	476 ±76de	--	2.2 ± 0.5a	40 ± 5a
DPL 5690	0	27.5 ± 5.7cd	12.3 ± 1.6bc	14.7 ± 2.1b	680 ±32cde	--	1.6 ± 0.3a	27 ± 2a
LA887	0	51.7 ± 7.6a	28.3 ± 3.9a	29.4 ± 5.1a	287 ±20e	--	1.7 ± 0.4a	46 ± 22a
ST474	0	43.4 ± 5.4b	25.6 ± 3.9a	23.3 ± 3.a	344 ±41e	--	2.4 ± 0.5a	54 ± 11a
DPL 50	8	7.8 ± 1.5e	3.5 ± 0.7d	5.7 ± 1.1c	1035 ± 122a-d	35	1.0 ± 0.1a	14 ±2a
DPL 5409	6	7.9 ± 1.5e	5.2 ± 1.4d	5.6 ± 1.1c	1175 ± 21abc	111	1.4 ± 0.4a	27 ± 10a
DPL 5415	7	6.6 ± 1.1e	4.4 ± 0.6d	5.3 ± 1.2c	1311 ± 183a	124	0.8 ± 0.3a	23 ± 15a
DPL 5432	7	10.0 ± 2.1e	5.4 ± 1.1d	8.1 ± 2.1c	1152 ± 231abc	113	0.9 ± 0.3a	18 ± 13a
DPL 5461	7	7.1 ± 1.5e	2.5 ± 0.3d	5.3 ± 0.8c	1557 ±81a	139	0.9 ± 0.0a	21 ±1a
DPL 5517	7	7.7 ± 1.8e	3.1 ± 0.5d	6.5 ± 1.5c	1529 ±30a	221	1.4 ± 0.6a	41 ± 22a
DPL 5690	8	6.1 ± 1.1e	4.4 ± 1.1d	6.6 ± 1.2c	1269 ±62ad	87	1.1 ± 0.1a	14 ±4a
LA887	8	10.7 ± 2.3e	5.4 ± 1.1d	9.4 ± 1.9c	1422 ± 122a	395	0.7 ± 0.3a	10 ±4a
ST474	8	8.9 ± 1.6e	5.1 ± 0.9d	8.0 ± 1.5c	1594 ±48a	363	0.7 ± 0.1a	9 ±1a
Means for untreated		33.7 ± 2.0A	16.5 ± 0.9A	18.4 ± 1.1A	542 ±40B	--	1.8 ± 0.1A	46 ±4A
Means for treated		8.1 ± 0.6B	4.3 ± 0.3B	6.7 ± 0.5B	1338 ±57A	147	1.0 ± 0.1A	20 ± 3A
F, cultivars		6.73***	17.85***	11.71***	0.99		1.15	1.47
F, insecticide		126.70***	292.17***	44.31***	1.35 x 10^{6}****		25.28	9.00
F, interaction		4.66***	12.08***	5.28***	3.59*		0.69	1.51

*, **, *** Significant at $P \leq 0.05$, 0.01, and 0.001, respectively.

† Means ± SEM in a column with different letters differ significantly (Student-Neuman-Keul's multiple range test, $P \leq 0.05$).

‡ Compared to the same untreated cultivar (treated - untreated) x 100 / untreated.

In DPL cultivars, increased yield response to insecticide protection ranged from 0.35 to 2.2 times. Variation was high in percent total reducing sugars and thermodetector measurements. The differences between the insecticide-treated and the untreated cultivars, or among each group of cultivars, were not significant. Lint yields among untreated DPL cultivars, LA 887 and ST 474 were not significantly different.

In both years, numerous insecticide applications were required across cultivars even at the 4.1 adults per leaf turn action threshold and the cotton lint had unacceptable stickiness.

No-choice Greenhouse Study

In the no-choice greenhouse experiment, there were no significant differences among the nine cultivars for the numbers of eggs laid when adults were confined to leaves for 24 h, numbers of nymphs developed from the eggs, or numbers of emerged adults (Table 6). Why some cottons are more heavily infested with whiteflies than others in the field tests remains unknown. A no-choice field study may reveal the nature of host selection preference among different cultivars.

Results of these studies and others (Butler and Henneberry, 1984; Flint and Parks, 1990; Leigh et al., 1994; Natwick et al., 1995; Watson et al., 1994) indicate a wide range of susceptibility of upland cotton cultivars to whiteflies in the field. Leaf morphology (Chu et al., 1995b) and hairiness (Norman and Sparks, 1997) may be related to cultivar susceptibility. LA 887 and ST 474 were the two most susceptible cultivars in our studies and both have hairy leaves. All the Deltapine cultivars tested are smooth leaf cotton types (Larry Burdett, Delta and Pine Land Co., Yuma, AZ, 1995, personal communication) which may partially explain the lower whitefly populations. Butler et al. (1991) suggested that glabrous, small leaf area, and open

Table 6. Mean number of *Bemisia argentifolii* eggs and nymphs on leaves and adults emerged from different greenhouse grown cotton cultivars at Brawley, CA, 1997.

	No. / 7.1 cm² leaf area			
		Days after eggs laid		
		5	12	19
Variety	**Eggs**	**Eggs + nymphs**	**Nymphs**	**Adults**
DPL 50	65.9 ± 14.1†	44.8 ± 10.5	37.1 ± 10.4	30.4 ±8.7
DPL 5409	68.9 ± 15.9	54.4 ± 15.5	44.8 ± 14.7	37.9 ± 11.0
DPL 5415	76.4 ± 15.6	59.4 ± 13.9	50.1 ± 12.1	45.7 ± 10.8
DPL 5432	82.4 ±8.4	63.4 ± 6.7	54.3 ± 5.4	49.0 ±5.0
DPL 5461	81.8 ±8.7	58.0 ±6.1	53.4 ±5.8	48.1 ± 5.7
DPL 5517	73.9 ± 11.4	53.5 ± 13.2	48.1 ± 11.7	43.4 ±11.3
DPL 5690	64.1 ±8.7	46.0 ±8.1	41.8 ±8.4	36.4 ±7.7
LA 887	91.3 ± 20.4	75.3 ± 19.2	61.8 ± 15.6	53.4 ± 11.9
ST 447	81.6 ± 15.5	63.8 ± 13.6	56.5 ± 12.6	49.8 ±14.0
F, Cultivars	0.81	1.07	0.46	0.59

† Not statistically significantly different between means in any one column.

canopy cotton types could be important characters to use for development of whitefly tolerant cottons. Chu et al. (1995b) indicated that the abundance of vascular bundles was related to *B. argentifolii* densities on different host plant species. Cohen et al. (1996) proposed a geometric model involving the point of whitefly stylet insertion on the leaf surface and the distance to the vascular bundles in leaves. For cotton, the distance from the point of labial contact on the leaf surface to the nearest point on a vascular bundle rarely exceeded 60 mm. In contrast, 50% of the measured distances from the leaf surface to a vascular bundle in lettuce (*Lactuca sativa* L.) was beyond 60 mm and 10% for cantaloupe (*Cucumis melo* var. *cantalupensis* L.). Similar studies have not been conducted comparing vascular tissue accessibility among upland cultivars, but may partially explain the wide range of cultivar susceptibility in the field. Although all cultivars tested supported high whitefly populations, the information reported herein, in conjunction with laboratory and field studies, might provide direction for genetic manipulation to modify leaf morphology for disrupting feeding behavior that would facilitate development of whitefly resistant upland cultivars (Khalifa and Gameel, 1993). Since the no-choice studies showed that the nine cultivars are equally colonized by the insect, the physical limitation of distance between leaf surface and the nearest vascular bundles mentioned earlier may be a more important leaf character for selection than the smooth leaf character. It is unlikely that *B. argentifolii* nymphs or adults can adapt themselves for feeding on leaves by growing longer stylets. This would impose limited access of crawlers to phloem nutrients because crawler stylets are shorter than those of later stages of nymphs or adults (A.C. Cohen, 1998, unpublished data). Crawlers can live only a few hours without food under the southwest desert conditions.

In our 1995 and 1996 studies, lint yields of the insecticide-treated cultivars increased from 1.2 to 7.9 times and from 0.35 to 4.0 times compared to untreated cultivars, for 1995 and 1996, respectively. For the 2 yr, DPL 5409 and 5415 required 5.5 applications of insecticide; DPL 50, 5461, and 5517 required six applications; DPL 5432 and 5690 required 6.5 applications; LA 887 required seven applications; and ST 474 required 7.5 applications. Selection of cultivars less susceptible to *B. argentifolii* has economic advantages in commercial production. Assuming standard rates of 0.224 kg a.i./ha for fenpropathrin and 0.56 kg a.i./ha for acephate, the cost of material was $31.15 and $12.39/ha, respectively (C. R. Waegner, Rockwood Chemical Co., Brawley, CA, November 1995, personal communication). The cost of application was estimated at $27.18/ha for ground application (M. Barrett, Stoker, Co., Imperial, CA, 1995, personal communication). The total cost of each application was $70.72/ha. The difference between four and seven applications to protect yield as occurred in the 1995 study was $212.16/ha which would be a significant saving in production cost.

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