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BREEDING AND GENETICS

Bacterial Blight Reactions of Sixty-one Upland Cotton Cultivars

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ABSTRACT

Bacterial blight, caused by *Xanthomonas campestris* pv. *malvacearum* (Smith) Dye (*Xcm*), can be a serious disease in most Upland cotton (*Gossypium hirsutum* L.) growing areas of the world. While blight outbreaks in the USA are infrequent, serious epidemics can occur wherever susceptible cultivars are grown. The purpose of this study was to determine the bacterial blight reactions of 61 Upland cotton cultivars. This information should be useful to breeders interested in incorporating blight resistance into future cotton cultivars. Varying numbers of cultivars (including four checks) were planted each year near Perkins, Oklahoma, over a 3-yr period. The experimental design used each year was a randomized complete block with four replications. Two of the replications were used for testing cultivar reactions to *Xcm* Race 1. The other two replications were used for testing responses to a mixture of races. Significant differences in blight reactions were detected among cultivars each year for both Race 1 and the race mixture. Mean reactions among cultivars varied from immune to fully susceptible. Cultivars included in this study were developed in seven states. The only cultivars among them with resistance or immunity to the array of races used in this study were from Texas and Oklahoma. Cultivars developed elsewhere were moderately to fully susceptible. Large areas of the Cotton Belt will remain vulnerable to outbreaks of bacterial blight unless higher levels of resistance are more widely incorporated into breeding programs than have been in the past.

Bacterial blight, caused by *Xanthomonas campestris* pv. *malvacearum* (Smith) Dye, [which is the same as *X. axonopodis* pv. *malvacearum* (Smith) Vauterin et al. (Vauterin et al., 2000)] can be a serious disease in most Upland cotton (*Gossypium hirsutum* L.) growing areas of the world. Yield losses of 10 to 30% are not unusual in Africa or Asia (Thaxton and El-Zik, 2001). Losses of 50% or more have been noted (Verma, 1986), but generally losses are lower. In recent years, yield losses across the USA have been estimated at less than 1% (e.g., Blasingame, 1990; Ranney, 1995; Blasingame and Patel, 2000). Control has been achieved through the use of resistant cultivars and/or cultural methods, including acid-delinting seed, sanitary practices during ginning and processing, applying fungicides to seed, and the destruction of diseased plant residues following tillage (Thaxton and El-Zik, 2001). In the USA, resistant cultivars have traditionally been developed in the Central and Southwestern areas of the Cotton Belt, but not for the Eastern, Delta (except for Missouri), or Western regions (Bird, 1986). While severe blight outbreaks in the USA are infrequent, under favorable conditions serious epidemics can occur wherever susceptible cultivars are grown.

Pedigree information and/or descriptions of distinguishing characters for cotton cultivars are available from several sources (e.g., Calhoun et al., 1997; May et al., 1995; Metzer and Supak, 1990). Little or no information about blight resistance is available for many of the cultivars developed by private companies, especially those not releasing cultivars specifically adapted to Texas, Oklahoma, or New Mexico, where blight resistance is routinely incorporated into new cultivars.

Bird (1986, p. 48) published lists of cotton cultivars that were developed by public institutions and private companies and released from 1955 through 1985 with "moderate resistance . . . to the bacterial blight pathogen." He defined moderate resistance as that effective in controlling "[R]ace 1, [R]aces 1 and 2, or [R]aces 1 and 2 plus one or two other[s]." Listed (without data) were 28 cultivars from Texas (15), New Mexico (7), Arkansas (3), Oklahoma (2), and Missouri (1). Bird (1986, p. 48) also published lists of cultivars released from 1958

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through 1985 with "high resistance and immunity," defined as effective "against most if not all races known to occur in the USA" up to that time. Listed (also without data) were 26 cultivars from Texas (25) and Missouri (1). Fifteen of the 54 cultivars he identified were also included in this study. More recently, Sagaram et al. (2003, p. 258) determined bacterial blight "disease incidence ... not severity" relative to Race 18 for 54 cotton cultivars over 1 to 3 yr. Only one of the cultivars they identified was included in this study.

The purpose of these experiments was to determine the bacterial blight reaction of 61 Upland cotton cultivars. Information about their blight responses should be useful to breeders interested in incorporating blight resistance into future cotton cultivars.

MATERIALS AND METHODS

Sixty-one Upland cotton cultivars were characterized in this study. An alphabetical list of those cultivars, as well as selected information about them, is provided in Table 1. If available, the previously reported bacterial blight reaction for each cultivar was also included in the table. Those disease ratings are generally unsatisfactory for comparing cultivars because they were derived by many different researchers using a variety of inoculation and scoring methods; different judgment criteria as to what constitutes "tolerance," "resistance," and "immunity"; and diverse testing environments (including races or race mixtures of the pathogen for screening). Also, the blight resistance (or lack thereof) of the cultivar may be inconsistently described in different sources (e.g., see 'PM HS 26' in Table 1).

These experiments were planted on a Teller loam soil (a fine-loamy, mixed, active, thermic Udic Argiustoll) on the Agronomy Research Station near Perkins, Oklahoma. Twenty-seven cultivars were tested in 1989 (Table 2), 24 in 1990 (Table 3), and 18 in 1991 (Table 4). Four cultivars (functioning as checks) were tested all 3 yr (Tables 2 through 5). The experimental design used each year was a randomized complete block with four replications. Two of the replications were used for testing cultivar reactions to *Xcm* Race 1. The remaining two replications were used for testing responses to a mixture of races. A plot consisted of a single row 11.0 m long with 1.0 m between adjacent rows. After emergence, seedlings within rows were thinned by hand to approximate 0.15 m intervals. To enhance disease development, supplemental irrigations were applied each year.

Plants were artificially inoculated at the six to eight true-leaf stage with an aqueous suspension of *Xcm* at a concentration of approximately 5.0×10^5 viable bacterial cells per milliliter. Inoculum was applied to the abaxial side of leaves with a single-nozzle, orchard-type power sprayer at a pressure of 1.4 to 2.1×10^6 Pa. In 1989, the inoculum mixture included Races 1, 2, 7, 10, and an isolate designated as "KM1." Because of difficulties experienced in culturing Race 7, the mixture was modified to include Races 1, 2, 18, and KM1 in 1990 and 1991. In each year, the combination of races (plus isolate KM1) included in the mixture collectively could overcome the individual bacterial blight resistance genes commonly available at that time (Brinkerhoff, 1970; Hillocks, 1992). Races 1, 2, 7, 10, and 18 were obtained from cultures maintained by personnel at Texas A&M University. KM1 is a spontaneous race-change mutant derived by McNally (1990) from Gabriel's strain "H" (Race 1) (Gabriel et al., 1986). It differs from Race 1 in being virulent against the gene B_4.

Approximately 14 d after inoculation, individual plants were graded for their disease reactions using the 0.0 (immune); 0.1, 0.2, 1.0, and 1.2 (resistant); 2.3 (moderately susceptible); and 4.0 (fully susceptible) grading system developed by Brinkerhoff (1963) and divided into disease reaction classes by Brinkerhoff et al. (1984). In recent years (and in this paper as well), grade 1.2 has been reassigned by our group to the "moderately susceptible" category. To facilitate data analyses, the field grades were converted into a whole-number scale of 0 (for the 0.0 grade), 1 (for 0.1), 2 (for 0.2), 3 (for 1.0), 4 (for 1.2), 5 (for 2.3), and 6 (for 4.0), as was done previously (Bayles et al., 2005a; 2005b). Plot means were then obtained for each replication and were reported as 'mean disease index' in Tables 2 through 5.

Separate analyses of variance were conducted on the plot means for the two treatments (i.e., Race 1 and the race mixture) in each year. Differences among cultivar means were determined using Fisher's protected LSD test at $P = 0.05$. Additionally, separate analyses were conducted for the four check cultivars over all 3 yr. If the cultivar by year interaction was not significant at $P = 0.05$, means over years were used; if significant, means from individual years were reported.

Table 1. Cotton cultivars tested for their reactions to *Xanthomonas campestris* pv. *malvacearum*

Cultivar[v]	Originator (or owner)	PVP no.[w]	Crop Science reg. no.	Cluster no.[x]	Year released[y]	Reported blight reaction[z]	Source for information about cultivar
Acala 1517-88	New Mexico AES Las Cruces, NM		CV-93	9	1987	R	Roberts et al. (1988)
Acala BR-110 (ST BR-110)	Ronald D. Thorp Casa Grande, AZ	8600031		1	1985	NT	Metzer and Supak (1990)
All-Tex Quickie	All-Tex Seed Co. Levelland, TX				1986	good T	Metzer and Supak (1990)
Bronco 625	Bronco Seed Co. Stamford, TX	8300124		2	(1983)	poor T	Metzer et al. (1984)
Cascot 2910	Custom Ag. Service, Inc. Loraine, TX				?	high R	Metzer and Supak (1990)
Cascot 5910	Custom Ag. Service, Inc. Loraine, TX				1986 or 1987	high R	B.E. Warrick (2006, personal communication)
Cascot C-13	Custom Ag. Service, Inc. Loraine, TX	8300034		3	(1983)	good T high R	Metzer et al. (1984) Bird (1986)
Cascot L-7	Custom Ag. Service, Inc. Loraine, TX	7700043			(1977)	high R high R	Metzer and Supak (1980) Bird (1986)
CB 232	Chembred, Inc. Phoenix, AZ				1990	?	Holverson (1990)
CB 407	Chembred, Inc. Phoenix, AZ				1990	?	Holverson (1990)
CB 1135	Chembred, Inc. Phoenix, AZ				1990	?	Holverson (1990)
Cencot	Oklahoma AES Stillwater, OK			11	1986	high R	Oklahoma AES (1986)
Coker 139	Coker's Pedigr. Seed Co. Hartsville, SC	8700070		1	1987	S	Anon. (1987)
Coker 320	Stoneville Pedigr. Seed Co. Stoneville, MS	8900290		1	1989	S	Anon. (1989)
Coker 4360	Coker's Pedigr. Seed Co. Lubbock, TX	8200071		1	(1982)	good T	Metzer et al. (1984)
DES 119	Mississippi AFES Stoneville, MS	8500176	CV-88	4	1985	NT	Bridge (1986)
DP 20	Delta & Pine Land Co. Scott, MS	8500110		1	(1985)	NT	Metzer and Supak (1990)
DP 50	Delta & Pine Land Co. Scott, MS	8400154		1	1984	NT	Jones (1998)
DP 77	Delta & Pine Land Co. Casa Grande, AZ	8600073		1	1987	NT	Anon. (1987)
DP 5415	Delta & Pine Land Co. Scott, MS	9100132		1	1991	NT	Burdett (1991)
DP 5690	Delta & Pine Land Co. Scott, MS	9100116		1	1991	NT	Burdett (1991)
DP Acala 90	Delta & Pine Land Co. Memphis, TN	8100143		1	1982	NT	Burdett and Gilbert (1984)
DP SR-383	SeedCo Corp. Lubbock, TX	8200137		8	1984	? mod. T	Carroll (1984) Metzer et al. (1984)
DP SR-482	Delta & Pine Land Co. Lubbock, TX	8200067		3	(1982)	mod. T	Metzer et al. (1984)
GP 74+	G&P Seed Co., Inc. Aquilla, TX	9000019		3	(1989)	high R	PVP application
GP 1005	G&P Seed Co., Inc. Aquilla, TX	8300108		3	(1983)	mod. T	Metzer et al. (1984)

Table 1. Continued

Cultivar[v]	Originator (or owner)	PVP no.[w]	Crop Science reg. no.	Cluster no.[x]	Year released[y]	Reported blight reaction[z]	Source for information about cultivar
GP 1005A	G&P Seed Co., Inc. Aquilla, TX				late 1980s or early 1990s	mod. R	B.E. Warrick (2006, personal communication)
GP 3755	G&P Seed Co., Inc. Whitney, TX	7700019			(1976)	high R high R	Metzer and Supak (1980) Bird (1986)
GP 3774	G&P Seed Co., Inc. Whitney, TX	7700018			(1976)	high R high R	Metzer and Supak (1980) Bird (1986)
Holland 850	Holland Cottonseed Co. Big Spring, TX	9400132 (appl. abandoned)			(1994)	?	PVP application (partial information)
Holland 1379	Holland Cottonseed Co. Big Spring, TX				1988	high R	Bush (1988)
Holland 1919	Holland Cottonseed Co. Big Spring, TX				1989	high R	B.E. Warrick (2006, personal communication)
Holland 4002	Holland Cottonseed Co. Big Spring, TX				1988	high R	Bush (1988)
HS 23	Hyperformer Seed Co. Memphis, TN	9000150		1	(1990)	S	PVP application
Hurdt's 700	Hurdt's Qual. Seeds & Mfg. Lubbock, TX			?	?	good T? high R	Metzer et al. (1984) Bird (1986)
KC311	Stoneville Pedigr. Seed Co. Stoneville, MS	8800197		1	1989	R (nat. infec.) ?	Anon. (1989) Metzer and Supak (1990)
Lankart 142	Cargill Hybrid Seeds Aiken, TX	9000215		11	(1990)	high R	PVP application
Lankart 511	Delta & Pine Land Co. Lubbock, TX	8600086		11	(1986)	excel. T	Metzer and Supak (1990)
Lankart LX 571	Lankart Seed Farm, Ltd. Waco, TX	7200018			(1971)	v. low R	Metzer and Supak (1980)
Lankart PR-75 (Pioneer Br. PR-75)	Paymaster Seeds Aiken, TX	8000135		11	1980	good T high R	Metzer et al. (1984) Bird (1986)
Lockett 77	Lockett Seed Co. Vernon, TX	7500084			(1975)	high R high R	Metzer and Supak (1980) Bird (1986)
PM 145	Cargill, Inc. Minnetonka, MN	8000080			(1980)	good T high R	Metzer et al. (1984) Bird (1986)
PM 147	Cargill Hybrid Seeds Aiken, TX	8900269		5	(1989)	high R	Metzer and Supak (1990)
PM 404	Cargill, Inc. Minnetonka, MN	8000081		5	(1980)	mod. T mod. R	Metzer and Supak (1984) Bird (1986)
PM 505	Cargill Hybrid Seeds Aiken, TX			5	1987?	mod. T	Metzer and Supak (1990)
PM 892	Cargill Hybrid Seeds Aiken, TX	8900270		11	(1989)	high R	Metzer and Supak (1990)
PM HS 26	Delta & Pine Land Co. Lubbock, TX	8600087		8	(1986)	mod. T v. S	Metzer and Supak (1990) Sagaram et al. (2003)
PM HS200	Cargill Hybrid Seeds Aiken, TX	9000216		7	(1990)	high R	PVP application
PR80 (Rosebud PR80)	Pioneer Hi-Bred Int., Inc. Vernon, TX	8000136		3	(1980)	good T high R	Metzer et al. (1984) Bird (1986)
ST 112	Stoneville Pedigr. Seed Co. Stoneville, MS	8500162		4	(1985)	S	Metzer and Supak (1990)
ST 324	Stoneville Pedigr. Seed Co. Stoneville, MS	9200054			(1991)	S	PVP application
ST 453	Stoneville Pedigr. Seed Co. Stoneville, MS	8800173		4	(1988)	S	McDonald (1988)

Table 1. Continued

Cultivar[v]	Originator (or owner)	PVP no.[w]	Crop Science reg. no.	Cluster no.[x]	Year released[y]	Reported blight reaction[z]	Source for information about cultivar
ST 506	Stoneville Pedigr. Seed Co. Stoneville, MS	8100059		4	(1981)	poor-mod. T	Metzer et al. (1984)
Tamcot CAB-CS	Texas AES College Station, TX	8500066	CV-87	3	1985	high R high R	Bird et al. (1986) Bird (1986)
Tamcot CAMD-E	Texas AES College Station, TX	7800073	CV-74		1977	high R high R	Bird (1979b) Bird (1986)
Tamcot CD3H	Texas AES College Station, TX	8600164	CV-94	3	1986	high R	Bird et al. (1988)
Tamcot HQ95	Texas AES College Station, TX	9000092	CV-96	3	1990	high R	El-Zik and Thaxton (1990)
Tamcot SP21S	Texas AES College Station, TX	7800074	CV-73		1977	high R high R	Bird (1979a) Bird (1986)
Tamcot SP37H	Texas AES College Station, TX	7800096	CV-75		1977	high R high R	Bird (1979c) Bird (1986)
Tropical 205	Hyperformer Seed Co. Memphis, TN				1991	good T	Anon. (1991)
Westburn M	Oklahoma AES Stillwater, OK	7700049			1976	high R mod. R	Oklahoma AES (1976) Bird (1986)

[v] **Pedigrees for most of these cultivars are available in Calhoun et al. (1997).**

[w] **The "Objective Description of Variety" portion of the PVP application was used as a source for reported blight reaction when other reports were not available. The PVP application was also used as a source of information for some cultivar names and for some originators (or owners).**

[x] **Cultivar groupings were determined by May et al. (1995) based on their coefficient of parentage.**

[y] **Years of release (which could not be determined from primary sources) were taken from Calhoun et al. (1997). Years listed in parentheses are when the PVP application was submitted.**

[z] **Abbreviations used in this column are as follows: R = resistant (or resistance), T = tolerant (or tolerance), S = susceptible, excel. = excellent, mod. = moderate, v. = very, NT = not tested prior to PVP application, and ? = unknown.**

RESULTS AND DISCUSSION

Significant differences in blight reactions were detected among cultivars in each year. When cultivars were tested with Race 1, grades ranged from 0.0 (immune) to 2.3 (moderately susceptible) in 1989 (Table 2), from 0.0 to 4.0 (fully susceptible) in 1990 (Table 3), and from 0.1 (resistant) to 2.3 in 1991 (Table 4). The race mixture grades ranged from 0.0 to 4.0 in 1989 (Table 2) and from 0.1 to 4.0 in 1990 (Table 3) and 1991 (Table 4). Linear correlations of the mean disease indexes for Race 1 against the race mixture were 0.98, 0.93, and 0.99 in 1989, 1990, and 1991, respectively. All were significant at $P = 0.01$. Cultivars that were susceptible to Race 1 in each year tended to be even more susceptible to the race mixture in that year. Those resistant to Race 1 also tended to be more resistant to the race mixture, but slightly less so. These grades should enable breeders to choose parents more likely to produce blight resistant progeny.

In the analyses of the check cultivars over years, the cultivar by year interaction was not significant for Race 1, so mean values for those cultivars are presented over years in Table 5. The lack of a significant interaction for Race 1 also suggests that the 61 cultivars may be compared directly with each other among Tables 2, 3, and 4 for their reactions to that race of the pathogen. The same analysis for the race mixture detected a significant cultivar by year interaction. As a consequence, mean values over years were not appropriate. Although the race mixture grades for the check cultivars can be found in the individual year tables (Tables 2, 3, and 4), they have been reproduced in Table 5 to clarify the statistical relationships among them in side-by-side comparisons. Statistically, 'DP 77' and 'DP Acala 90' could not be differentiated by their responses to the race mixture in any of the three experiments. Both were more susceptible than 'Holland 4002', which in turn was more susceptible than 'Hurdt's

700' in two of the three experiments. The latter two could not be differentiated in 1991. Because of the significant interaction for the race mixture, cultivars should be directly compared with each other for their reactions to the mixture within tables, but not among them.

Table 2. Reactions of cotton cultivars to *Xanthomonas campestris* pv. *malvacearum*, 1989

Cultivar	Race 1			Race mixture[u]		
	Plants graded (no.)	Mean disease index[v]	Closest grade[w]	Plants graded (no.)	Mean disease index[v]	Closest grade[w]
Bronco 625	46	5.1 ab[x]	2.3	55	5.4 ab[x]	2.3
Cascot 2910	57	1.0 gh	0.1	51	1.2 fg	0.1
Cascot L-7	59	0.5 ij	0.1	43	0.5 ghi	0.1
Cencot	49	1.3 g	0.1	47	1.2 fg	0.1
Coker 4360	53	3.7 c	1.2	49	4.8 bc	2.3
DES 119	61	5.3 a	2.3	64	5.4 ab	2.3
DP 20	58	5.3 a	2.3	57	5.3 ab	2.3
DP 50	56	5.3 a	2.3	54	5.6 a	4.0
DP 77[y]	64	5.3 a	2.3	59	5.6 ab	4.0
DP Acala 90[y]	48	5.1 ab	2.3	65	5.0 abc	2.3
Holland 4002[y]	52	1.0 gh	0.1	56	1.3 f	0.1
Hurdt's 700[y]	51	0.4 j	0.0	51	0.3 hi	0.0
Lankart 511	33	0.6 hij	0.1	19	1.1 fgh	0.1
Lankart PR-75	37	0.5 j	0.1	39	0.7 fghi	0.1
Lockett 77	33	0.5 ij	0.1	40	1.0 fgh	0.1
PM 145	61	0.4 j	0.0	62	0.3 i	0.0
PM 404	45	2.8 de	1.0	23[z]	3.7 de	1.2
PM 505	47	2.5 ef	1.0	45	3.4 e	1.0
PM HS 26	60	3.0 d	1.0	47	4.4 cd	1.2
PR80	55	0.9 ghi	0.1	52	1.1 fg	0.1
ST 112	57	5.1 ab	2.3	53	5.5 ab	4.0
ST 453	54	5.1 ab	2.3	63	5.3 ab	2.3
ST 506	44	4.8 b	2.3	29[z]	5.5 ab	4.0
Tamcot CAMD-E	48	0.7 hij	0.1	26[z]	0.8 fghi	0.1
Tamcot SP21S	50	0.4 j	0.0	20[z]	0.5 fghi	0.1
Tamcot SP37H	48	0.4 j	0.0	47	0.7 fghi	0.1
Westburn M	47	2.1 f	0.2	38	1.2 fg	0.1

[u] The inoculum mixture included Races 1, 2, 7, 10, and "KM1" (which collectively could overcome the individual bacterial blight resistance genes commonly available at that time).

[v] This index ranges from 0 = immune through 6 = fully susceptible (Bayles et al., 2005a; 2005b).

[w] These grades correspond to the 0.0 = immune, 0.1, 0.2, 1.0, 1.2, 2.3, and 4.0 = fully susceptible grading scale derived by Brinkerhoff (1963).

[x] Means within a column followed by the same letter were not significantly different ($P = 0.05$) according to Fisher's protected LSD test. Apparent contradictions in significant vs. nonsignificant differences for some of the same size means were due to rounding.

[y] Check cultivars included in all 3 yr.

[z] Race mixture data on these cultivars could only be obtained from one replication, not both.

Table 3. Reactions of cotton cultivars to *Xanthomonas campestris* pv. *malvacearum*, 1990

Cultivar	Race 1			Race mixture[v]		
	Plants graded (no.)	Mean disease index[w]	Closest grade[x]	Plants graded (no.)	Mean disease index[w]	Closest grade[x]
Acala 1517-88	75	4.4 d[y]	1.2	67	5.4 de[y]	2.3
Acala BR-110	49	5.2 abc	2.3	61	5.8 ab	4.0
All-Tex Quickie	71	0.7 hi	0.1	65	0.9 k	0.1
Cascot C-13	65	0.7 hi	0.1	64	1.2 jk	0.1
Coker 139	33	5.5 ab	4.0	54	5.8 abc	4.0
Coker 320	42	5.6 a	4.0	73	5.8 ab	4.0
DP 77[z]	52	5.6 a	4.0	66	5.9 a	4.0
DP Acala 90[z]	64	5.3 abc	2.3	64	5.8 ab	4.0
DP SR-383	81	4.9 cd	2.3	75	5.4 cde	2.3
DP SR-482	55	5.2 abc	2.3	59	5.7 abcd	4.0
GP 74+	67	0.8 fghi	0.1	63	0.9 k	0.1
GP 1005	66	2.1 e	0.2	71	3.0 g	1.0
GP 3755	55	0.6 i	0.1	65	1.0 k	0.1
GP 3774	56	0.8 ghi	0.1	74	1.0 k	0.1
Holland 1379	69	1.3 fg	0.1	72	1.8 h	0.2
Holland 1919	73	1.3 f	0.1	61	1.4 ij	0.1
Holland 4002[z]	79	1.2 fgh	0.1	74	1.6 hi	0.2
Hurdt's 700[z]	67	0.4 i	0.0	59	1.2 jk	0.1
Lankart LX 571	47	5.0 bc	2.3	53	5.5 bcd	4.0
PM 147	61	1.9 e	0.2	58	5.2 e	2.3
PM 892	62	2.0 e	0.2	66	4.8 f	2.3
Tamcot CAB-CS	67	1.2 fgh	0.1	60	1.4 ij	0.1
Tamcot CD3H	62	0.7 hi	0.1	84	1.1 k	0.1
Tamcot HQ95	58	0.9 fghi	0.1	71	1.2 jk	0.1

[v] The inoculum mixture included Races 1, 2, 18, and "KM1" (which collectively could overcome the individual bacterial blight resistance genes commonly available at that time).

[w] This index ranges from 0 = immune through 6 = fully susceptible (Bayles et al., 2005a; 2005b).

[x] These grades correspond to the 0.0 = immune, 0.1, 0.2, 1.0, 1.2, 2.3, and 4.0 = fully susceptible grading scale derived by Brinkerhoff (1963).

[y] Means within a column followed by the same letter were not significantly different ($P = 0.05$) according to Fisher's protected LSD test. Apparent contradictions in significant vs. nonsignificant differences for some of the same size means were due to rounding.

[z] Check cultivars included in all 3 yr.

The cotton cultivars included in this study were developed by entities located in seven states (Table 6); however, the only cultivars among them with resistance or immunity to the array of races used for screening in this study were developed in Texas and Oklahoma. In this study, the blight resistance of cultivars from New Mexico appear less favorably than is probably warranted. The only cultivar included from New Mexico, 'Acala 1517-88', was previously described as being resistant to Races 1, 2, and 10 of *Xcm* (Roberts et al., 1988). The race mixture used in this study for screening included additional virulent races that lowered that cultivar's apparent overall resistance into the "moderately susceptible" category (Table 6). The New Mexico Agricultural Experiment Station has a history of releasing cultivars with resistance to bacterial blight, e.g., 'Acala 1517-77BR' (Roberts et al., 1984), 'Acala 1517-SR1'

(Malm et al., 1984), 'Acala 1517-SR2' (Malm et al., 1987), 'Acala 1517-SR3' (Cantrell et al., 1992), and others. All were resistant to Races 1, 2, and 10 of *Xcm*. Some were also resistant to the "Tularosa" strain (a local race in New Mexico). Cultivars developed elsewhere in the Cotton Belt were moderately to fully susceptible to Race 1 and the race mixture. This situation in 1989 through 1991 corresponds to the observation made by Bird (1986) that blight resistance is generally ignored in cultivars developed in most parts of the Cotton Belt.

In a 1999 survey, Bowman (2000) reported that the primary source of parental material for private breeders was in-house germplasm lines, so little additional genetic variability will be introduced into such breeding programs for bacterial blight resistance or for other traits. In addition, the transgenic nature of most currently available cultivars precludes their use as parents by outside entities. Unless blight resistance is more widely incorporated into cotton breeding programs than it has been in the past, large areas of the Cotton Belt will remain vulnerable to outbreaks of the disease. Bird (1986, p. 44) pointed out that in 1985 "76% of the acreage [in the USA was] subject to epidemics [of blight] and *they do occur* [italics ours]." The blight situation today is likely very similar to what it was 20 yr ago.

Table 4. Reactions of cotton cultivars to *Xanthomonas campestris* pv. *malvacearum*, 1991

Cultivar	Race 1			Race mixture[v]		
	Plants graded (no.)	Mean disease index[w]	Closest grade[x]	Plants graded (no.)	Mean disease index[w]	Closest grade[x]
Cascot 5910	82	1.1 de[y]	0.1	70	1.1 d[y]	0.1
CB 232	70	5.2 ab	2.3	57	5.5 a	4.0
CB 407	73	5.0 ab	2.3	70	5.0 abc	2.3
CB 1135	69	4.8 b	2.3	64	4.9 c	2.3
DP 77[z]	68	5.1 ab	2.3	55	5.0 bc	2.3
DP 5415	53	5.2 ab	2.3	53	5.4 ab	2.3
DP 5690	71	5.0 ab	2.3	68	4.7 c	2.3
DP Acala 90[z]	70	5.2 ab	2.3	63	5.2 abc	2.3
GP 1005A	75	1.0 de	0.1	63	1.2 d	0.1
Holland 850	75	1.1 de	0.1	65	1.0 d	0.1
Holland 4002[z]	81	1.3 d	0.1	70	1.1 d	0.1
HS 23	76	5.3 a	2.3	76	5.5 ab	4.0
Hurdt's 700[z]	65	0.6 e	0.1	66	1.1 d	0.1
KC311	75	5.2 ab	2.3	71	5.1 abc	2.3
Lankart 142	72	1.1 de	0.1	63	1.0 d	0.1
PM HS200	69	1.1 de	0.1	62	1.0 d	0.1
ST 324	69	5.2 ab	2.3	60	4.9 c	2.3
Tropical 205	74	4.0 c	1.2	61	4.7 c	2.3

[v] The inoculum mixture included Races 1, 2, 18, and "KM1" (which collectively could overcome the individual bacterial blight resistance genes commonly available at that time).

[w] This index ranges from 0 = immune through 6 = fully susceptible (Bayles et al., 2005a; 2005b).

[x] These grades correspond to the 0.0 = immune, 0.1, 0.2, 1.0, 1.2, 2.3, and 4.0 = fully susceptible grading scale derived by Brinkerhoff (1963).

[y] Means within a column followed by the same letter were not significantly different ($P = 0.05$) according to Fisher's protected LSD test. Apparent contradictions in significant vs. nonsignificant differences for some of the same size means were due to rounding.

[z] Check cultivars included in all 3 yr.

Table 5. Reactions of the check cotton cultivars to *Xanthomonas campestris* pv. *malvacearum*, 1989-1991

Check cultivar	Race 1		Race mixture[w]					
	Over years		1989		1990		1991	
	Mean disease index[x]	Closest grade[y]	Mean disease index[x]	Closest grade[y]	Mean disease index[x]	Closest grade[y]	Mean disease index[x]	Closest grade[y]
DP 77	5.3 a[z]	2.3	5.6 a[z]	4.0	5.9 a[z]	4.0	5.0 a[z]	2.3
DP Acala 90	5.2 a	2.3	5.0 a	2.3	5.8 a	4.0	5.2 a	2.3
Holland 4002	1.2 b	0.1	1.3 b	0.1	1.6 b	0.2	1.1 b	0.1
Hurdt's 700	0.5 c	0.1	0.3 c	0.0	1.2 c	0.1	1.1 b	0.1

[w] The inoculum mixture in 1989 included Races 1, 2, 7, 10, and "KM1" (which collectively could overcome the individual bacterial blight resistance genes commonly available at that time). In 1990 and 1991, Races 7 and 10 were replaced in the mixture by Race 18. (The second mixture collectively achieves the same results as the first.)

[x] This index ranges from 0 = immune through 6 = fully susceptible (Bayles et al., 2005a; 2005b).

[y] These grades correspond to the 0.0 = immune, 0.1, 0.2, 1.0, 1.2, 2.3, and 4.0 = fully susceptible grading scale derived by Brinkerhoff (1963).

[z] Means within a column followed by the same letter were not significantly different ($P = 0.05$) according to Fisher's protected LSD test.

Table 6. Relationship between the state of origin for a cotton cultivar and its mean level of bacterial blight reaction

Cultivar	State where developed	Bacterial blight reaction (closest grade)[z]							
		Race 1				Race mixture			
		Immune	Resist.	Mod. susc.	Fully susc.	Immune	Resist.	Mod. susc.	Fully susc.
Acala BR-110	AZ			✓[z]					✓
CB 232	AZ			✓					✓
CB 407	AZ			✓				✓	
CB 1135	AZ			✓				✓	
DES 119	MS			✓				✓	
DP 20	MS			✓				✓	
DP 50	MS			✓					✓
DP 77	MS			✓✓	✓			✓	✓✓
DP 5415	MS			✓				✓	
DP 5690	MS			✓				✓	
DP Acala 90	MS			✓✓✓				✓✓	✓
ST 112	MS			✓					✓
ST 324	MS			✓				✓	
ST 453	MS			✓				✓	
ST 506	MS			✓					✓
Acala 1517-88	NM			✓				✓	
Cencot	OK		✓				✓		
Westburn M	OK		✓				✓		
Coker 139	SC				✓				✓
Coker 320	SC				✓				✓
KC311	SC			✓				✓	
HS 23	TN			✓					✓
Tropical 205	TN			✓				✓	
All-Tex Quickie	TX		✓				✓		
Bronco 625	TX			✓				✓	

Table 6. Continued

Cultivar	State where developed	Bacterial blight reaction (closest grade)[z]							
		Race 1				Race mixture			
		Immune	Resist.	Mod. susc.	Fully susc.	Immune	Resist.	Mod. susc.	Fully susc.
Cascot 2910	TX		✓				✓		
Cascot 5910	TX		✓				✓		
Cascot C-13	TX		✓				✓		
Cascot L-7	TX		✓				✓		
Coker 4360	TX			✓				✓	
DP SR-383	TX			✓				✓	
DP SR-482	TX			✓					✓
GP 74+	TX		✓				✓		
GP 1005	TX		✓				✓		
GP 1005A	TX		✓				✓		
GP 3755	TX		✓				✓		
GP 3774	TX		✓				✓		
Holland 850	TX		✓				✓		
Holland 1379	TX		✓				✓		
Holland 1919	TX		✓				✓		
Holland 4002	TX		✓✓✓				✓✓✓		
Hurdt's 700	TX	✓✓	✓			✓	✓✓		
Lankart 142	TX		✓				✓		
Lankart 511	TX		✓				✓		
Lankart LX 571	TX			✓					✓
Lankart PR-75	TX		✓				✓		
Lockett 77	TX		✓				✓		
PM 145	TX	✓				✓			
PM 147	TX		✓					✓	
PM 404	TX		✓					✓	
PM 505	TX		✓				✓		
PM 892	TX		✓					✓	
PM HS 26	TX		✓					✓	
PM HS200	TX		✓				✓		
PR80	TX		✓				✓		
Tamcot CAB-CS	TX		✓				✓		
Tamcot CAMD-E	TX		✓				✓		
Tamcot CD3H	TX		✓				✓		
Tamcot HQ95	TX		✓				✓		
Tamcot SP21S	TX	✓					✓		
Tamcot SP37H	TX	✓					✓		

[z] **The classes of blight reactions correspond to closest grades [as derived by Brinkerhoff (1963) and defined by our group] as follows: immune (0.0), resistant (0.1, 0.2, and 1.0), moderately susceptible (1.2 and 2.3), and fully susceptible (4.0) The inoculum mixture in 1989 included Races 1, 2, 7, 10, and "KM1" (which collectively could overcome the individual bacterial blight resistance genes commonly available at that time). In 1990 and 1991, Races 7 and 10 were replaced in the mixture by Race 18. (The second mixture collectively achieves the same results as the first.) Each "✓" indicates results from a single experiment. Cultivars with multiple "✓"s are check cultivars.**

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REFERENCES

Anonymous. 1987. New varieties for 1987-88. Cotton Grower 23(1):9, 12.

Anonymous. 1989. 1989-90 varieties. Cotton Grower 25(1):26.

Anonymous. 1991. Texas and Oklahoma cottons will be stronger than ever. Cotton Grower 27(1):40-41.

Bayles, M.B., L.M. Verhalen, W.M. Johnson, and B.R. Barnes. 2005a. Trends over time among cotton cultivars released by the Oklahoma Agricultural Experiment Station. Crop Sci. 45:966-980.

Bayles, M.B., L.M. Verhalen, L.L. McCall, W.M. Johnson, and B.R. Barnes. 2005b. Recovery of recurrent parent traits when backcrossing in cotton. Crop Sci. 45:2087-2095.

Bird, L.S. 1979a. Registration of Tamcot SP21S cotton (Reg. No. 73). Crop Sci. 19:410-411.

Bird, L.S. 1979b. Registration of Tamcot CAMD-E cotton (Reg. No. 74). Crop Sci. 19:411-412.

Bird, L.S. 1979c. Registration of Tamcot SP37H cotton (Reg. No. 75). Crop Sci. 19:412.

Bird, L.S. 1986. Half a century dynamics and control of cotton diseases: bacterial blight. p. 41-48. *In* Proc. Beltwide Cotton Prod. Res. Conf., Las Vegas, NV. 4-9 Jan. 1986. Natl. Cotton Counc. Am., Memphis, TN.

Bird, L.S., K.M. El-Zik, and P.M. Thaxton. 1986. Registration of 'Tamcot CAB-CS' Upland cotton. Crop Sci. 26:384-385.

Bird, L.S., K.M. El-Zik, and P.M. Thaxton. 1988. Registration of 'Tamcot CD3H' cotton. Crop Sci. 28:574-575.

Blasingame, D. 1990. 1989 cotton disease loss estimate committee report. p. 4. *In* Proc. Beltwide Cotton Prod. Res. Conf., Las Vegas, NV. 9-14 Jan. 1990. Natl. Cotton Counc. Am., Memphis, TN.

Blasingame, D., and M.V. Patel. 2000. Cotton disease loss estimate committee report. p. 132-133. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

Bowman, D.T. 2000. Attributes of public and private cotton breeding programs. J. Cotton Sci. 4:130-136 [Online]. Available at http://www.cotton.org/journal/2000-04/2/130.cfm (verified 5 Sept. 2006).

Bridge, R.R. 1986. Registration of 'DES 119' cotton. Crop Sci. 26:646-647.

Brinkerhoff, L.A. 1963. Variability of *Xanthomonas malvacearum*: The cotton bacterial blight pathogen. Tech. Bull. T-98. Oklahoma Agric. Exp. Stn., Oklahoma State Univ., Stillwater, OK.

Brinkerhoff, L.A. 1970. Variation in *Xanthomonas malvacearum* and its relation to control. Annu. Rev. Phytopathol. 8:85-110.

Brinkerhoff, L.A., L.M. Verhalen, W.M. Johnson, M. Essenberg, and P.E. Richardson. 1984. Development of immunity to bacterial blight of cotton and its implications for other diseases. Plant Dis. 68:168-173.

Burdett, L. 1991. New cotton varieties with improved fiber characteristics: Deltapine 6166 Acala, Deltapine 5690, Deltapine 5415, Deltapine 5816 and Deltapine 5461. p. 77. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 6-10 Jan. 1991. Natl. Cotton Counc. Am., Memphis, TN.

Burdett, L.P., and E.L. Gilbert. 1984. Deltapine 90. A new and unique cotton variety. p. 61. *In* Proc. Beltwide Cotton Prod.-Mech. Conf., Atlanta, GA. 11-12 Jan. 1984. Natl. Cotton Counc. Am., Memphis, TN.

Bush, D.L. 1988. Holland 1379 and Holland 4002: two new cotton varieties from Holland Cottonseed. p. 95-96. *In* Proc. Beltwide Cotton Prod. Conf., New Orleans, LA. 3-8 Jan. 1988. Natl. Cotton Counc. Am., Memphis, TN.

Calhoun, D.S., D.T. Bowman, and O.L. May. 1997. Pedigrees of Upland and Pima cotton cultivars released between 1970 and 1995. Bull. 1069. Mississippi Agric. & For. Exp. Stn., Mississippi State Univ., Mississippi State, MS.

Cantrell, R.G., C.L. Roberts, D.D. Davis, C.E. Barnes, and N.R. Malm. 1992. Registration of 'Acala 1517-SR3' cotton. Crop Sci. 32:1295.

Carroll, J.D. 1984. Terra SR-10 and Deltapine SR-383: Two new cotton varieties. p. 58-60. *In* Proc. Beltwide Cotton Prod.-Mech. Conf., Atlanta, GA. 11-12 Jan. 1984. Natl. Cotton Counc. Am., Memphis, TN.

El-Zik, K.M., and P.M. Thaxton. 1990. Registration of 'Tamcot HQ95' cotton. Crop Sci. 30:1359-1360.

Gabriel, D.W., A. Burges, and G.R. Lazo. 1986. Gene-for-gene interactions of five cloned avirulence genes from *Xanthomonas campestris* pv. *malvacearum* with specific resistance genes in cotton. Proc. Natl. Acad. Sci. 83:6415-6419.

Hillocks, R.J. 1992. Bacterial blight. p. 39-85. *In* R.J. Hillocks (ed.) Cotton Diseases. CAB Int., Wallingford, UK.

Holverson, P. 1990. F_2 from hybrid cotton planting seed: CB219, CB232, CB407, and CB1135. p. 111-112. *In* Proc. Beltwide Cotton Prod. Conf., Las Vegas, NV. 10-11 Jan. 1990. Natl. Cotton Counc. Am., Memphis, TN.

Jones, K.R. 1998. Breeding history of Deltapine 16 and Deltapine 50. p. 536-537. *In* Proc. Beltwide Cotton Conf., San Diego, CA. 5-9 Jan. 1998. Natl. Cotton Counc. Am., Memphis, TN.

Malm, N.R., C.E. Barnes, D.D. Davis, and C.L. Roberts. 1984. Registration of Acala 1517-SR1 Upland cotton. Crop Sci. 24:382-383.

Malm, N.R., C.E. Barnes, C.L. Roberts, and D.D. Davis. 1987. Registration of 'Acala 1517-SR2' cotton. Crop Sci. 27:149-150.

May, O.L., D.T. Bowman, and D.S. Calhoun. 1995. Genetic diversity of U.S. Upland cotton cultivars released between 1980 and 1990. Crop Sci. 35:1570-1574.

McDonald, L.D. 1988. Release of Stoneville 453. p. 90. *In* Proc. Beltwide Cotton Prod. Conf., New Orleans, LA. 3-8 Jan. 1988. Natl. Cotton Counc. Am., Memphis, TN.

McNally, K.L. 1990. Useful minimal medium for growth of *Xanthomonas campestris* pv. *malvacearum*, molecular biological analysis of avirulence in *Xcm*, and identification of multiple resistance genes in the segregating *Gossypium hirsutum* line Acala B_5. Ph.D. diss. Oklahoma State Univ., Stillwater, OK. (Abstr. AAT 9119885). Available online at http://proquest.umi.com/pqdweb?index=0&did=746209301&SrchMode=1&sid=3&Fmt=13&VInst=PROD&VType=PQD&RQT=309&VName=PQD&TS=1173801680&clientId=4653 (verified 5 Sept. 2006).

Metzer, R.B., and J.R. Supak. 1980. Characteristics of cotton varieties grown in Texas. Bull. B-1312. Texas Agric. Ext. Serv., Texas A&M Univ., College Station, TX.

Metzer, R.B., and J.R. Supak. 1990. Characteristics of cotton varieties grown in Texas. 3rd ed. Bull. B-1312. Texas Agric. Ext. Serv., Texas A&M Univ., College Station, TX.

Metzer, R.B., J.R. Supak, and E. Grubaugh. 1984. Characteristics of cotton varieties grown in Texas. 2nd ed. Bull. B-1312. Texas Agric. Ext. Serv., Texas A&M Univ., College Station, TX.

Oklahoma Agricultural Experiment Station (AES). 1976. Notice to growers relative to the naming and release of a commercial variety of Upland cotton, 'Westburn M'. Agron. Dep. Mimeo. Rep. Oklahoma State Univ., Stillwater, OK.

Oklahoma Agricultural Experiment Station (AES). 1986. Notice to growers relative to the naming and release of a commercial variety of Upland cotton, 'Cencot'. Agron. Dep. Mimeo. Rep. Oklahoma State Univ., Stillwater, OK.

Ranney, C.D. 1995. Cotton disease losses: Progress and opportunity. p. 237-240. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-7 Jan. 1995. Natl. Cotton Counc. Am., Memphis, TN.

Roberts, C.L., N.R. Malm, D.D. Davis, and C.E. Barnes. 1984. Registration of Acala 1517-77BR Upland cotton. Crop Sci. 24:382.

Roberts, C.L., N.R. Malm, D.D. Davis, and C.E. Barnes. 1988. Registration of 'Acala 1517-88' cotton. Crop Sci. 28:190-191.

Sagaram, U.S., G.L. Schuster, R.A. Thomason, T.A. Wheeler, and J.L. Gannaway. 2003. Performance of commercial cotton cultivars against bacterial blight pathogen in the Texas High Plains. p. 257-260. *In* Proc. Beltwide Cotton Conf., Nashville, TN. 6-10 Jan. 2003. Natl. Cotton Counc. Am., Memphis, TN.

Thaxton, P.M., and K.M. El-Zik. 2001. Bacterial blight. p. 34-35. *In* T.L. Kirkpatrick and C.S. Rothrock (ed.) Compendium of Cotton Diseases. 2nd ed. Am. Phytopathol. Soc., St. Paul, MN.

Vauterin, L., J. Rademaker, and J. Swings. 2000. Synopsis of the taxonomy of the genus *Xanthomonas*. Phytopathology 90:677-682.

Verma, J.P. 1986. Bacterial blight of cotton. CRC Press, Inc., Boca Raton, FL.