Fusarium oxysporum f. sp. *niveum* Race 2: A Highly Aggressive Race New to the United States

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ABSTRACT

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In 1981, an isolate of *Fusarium oxysporum* f. sp. *niveum* was isolated from a wilted watermelon plant in south central Texas that was highly aggressive toward several highly wilt-resistant watermelon cultivars. A second highly aggressive isolate was obtained in 1984 from the seed coat of a commercial lot of hybrid watermelon seed grown in north central Texas. Both isolates were highly aggressive in greenhouse tests, causing a mean of 90% wilt of all 17 watermelon cultivars tested, 10 of which are considered highly wilt-resistant. Comparisons with isolates of races 0, 1, and 2 (sensu Cirulli) indicated that the Texas isolates were identical to race 2, first described in Israel in 1973.

Fusarium wilt of watermelon (*Citrullus lanatus* (Thunb.) Natsum. & Nakai) caused by *Fusarium oxysporum* (Schlecht.) f. sp. *niveum* (*F. o.* f. sp. *niveum*) (E. F. Sm.) Snyd. & Hans. was first described by Smith (23,24) in 1894 from South Carolina and Georgia. The pathogen is now well established throughout the watermelon-growing regions of the world. In many areas, it is a limiting factor in production. Where Fusarium wilt has been controlled, it has primarily been with the use of wilt-resistant cultivars. Orton (17) developed the first wilt-resistant watermelon cultivar, Conqueror; however, it was not entirely satisfactory as a commercial type, and its resistance was lost or appreciably decreased when it was introduced into new areas such as Oregon and Iowa (22). Sleeth (22) was perhaps the first to investigate the possible existence of physiologic strains (races) of *F. o.* f. sp. *niveum*. He examined 23 "isolants" from seven states and indicated that they ranged in virulence from avirulent to highly virulent and were therefore different pathogenic strains (22). Reid (21) examined 99 isolates and separated them into a number of cultural races but into only two pathogenic races. McKeen (11) examined several isolates of *F. o.* f. sp. *niveum* from Canada, and on the basis of timing of the wilt symptom and final percentage of wilt, he concluded that there were three distinct strains differing widely in virulence.

In 1963, Crall (4) reported two physiologic races in Florida: one that only caused wilting in susceptible cultivars and one that caused 100% wilting in susceptible cultivars and some wilting in moderately resistant cultivars such as Charleston Gray and Summit. From 1949 to 1959, Armstrong and Armstrong (1) tested 17 isolates from South Carolina to determine if different races were present. They later included Crall's two races from Florida (4) and concluded that differences in virulence existed among the isolates, but there was insufficient evidence to distinguish them as races. Following the genetic model for wilt resistance proposed by Henderson et al (6), Cirulli (3) classified *F. o.* f. sp. *niveum* isolates from Italy into two pathogenic groups: race 0 and race 1. Netzer and Dishon (15) and Netzer (13) reported the existence of a third race in Israel that was highly pathogenic to many cultivars with moderate or high wilt resistance. On the basis of their tests and following the nomenclature suggested by Cirulli (3), they designated the Israeli isolate as race 2. An isolate with similar pathogenicity was also found in Greece (13) and in Turkey (Fantino and Zengen, 1974, cited in 13).

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In 1985, Martyn (9) reported a highly aggressive race of *F. o.* f. sp. *niveum* in Texas. Pathogenicity toward a number of moderately and highly wilt-resistant cultivars suggested the Texas isolate was similar to race 2, although no race number designation was assigned. The purpose of the present study was to compare two Texas isolates of *F. o.* f. sp. *niveum* with the Israeli race 2 along with the two races from Florida (races 0 and 1) and one from South Carolina (race 1) to determine if race 2 sensu Cirulli was present in the United States.

MATERIALS AND METHODS

Source of isolates. Two Texas isolates of *F. o.* f. sp. *niveum* were used. One (TX-X1D) was originally isolated by R. J McLaughlin from the lower stem of a wilted plant of an unknown cultivar from Frio County (south central Texas) in 1981. The second isolate (TX-HC3-13B) was collected by R. D. Martyn in 1984 from the seed coat of a hybrid seedless watermelon seed lot produced in north central Texas. Each isolate was single-spored, tested initially for pathogenicity on a susceptible cultivar, and stored in soil-culture tubes (12). Race 2 (IS-59) was obtained from D. Netzer, Volcani Center, Bet Dagan, Israel. Isolates FL-60-3A(11) and FL-64-2(M59-1), races 0 and 1, respectively, were obtained from J. M. Crall, University of Florida, Agricultural Research Center, Leesburg. A second isolate of race 1 (ATCC 18467) was purchased from the American Type Culture Collection (ATCC), Beltsville, MD. This isolate originated from South Carolina and was deposited with ATCC by G. M. Armstrong. All isolates were single-spored when received, increased, and stored in soil-culture tubes.

Method of inoculation. Unless stated otherwise, all plant inoculations were performed as follows: An active culture of each isolate was obtained by placing several soil granules from a soil-tube culture into a liquid mineral salts medium (5) and incubated on a rotary shaker (100 rpm) at 25 ± 2 C for 48–72 hr under continuous fluorescent light. The cultures were filtered through eight layers of sterile cheesecloth under aseptic conditions, and the predominantly microconidial suspensions were adjusted to either 1×10^5 or 1×10^6 microconidia per milliliter with sterile, deionized water. Captan-treated seeds of watermelon cultivars were obtained from commercial suppliers and planted in flats containing a vermiculite-perlite mix (1:1, v/v). Seed of the Egyptian cultivar Giza was supplied by Mr. Hamza, I.N.R.A.T., Tunis, Tunisia. When the first true leaf was evident (about 2 wk after planting), the seedlings were uprooted and the roots washed under a stream of gently flowing water. Seedlings were root-dipped into the respective inocula for 10–15 sec, swirled several times, and transplanted into 15-cm pots (three or four seedlings per pot) containing a coarse sand-peat-vermiculite soil mix (4:1:1, v/v). Depending on the experiment, there were either five or seven replicated pots per treatment and the inoculum level was either 1×10^5 or 1×10^6 microconidia per milliliter. Control inoculations were made by root-dipping seedlings into sterile water or diluted, sterile mineral salts medium. All plants were maintained in the greenhouse and fertilized regularly after 1 wk with 10-20-10 NPK (two-thirds-strength Miracle Gro) in the irrigation water. Percent wilt of plants was recorded weekly, and final percentage figures were reported for 3 or 4 wk.

Three evaluations of the Texas isolates were made. The first (experiment 1) was conducted in March 1983 and was the original cultivar-screening test of isolate TX-X1D. The second test (experiment 2) was conducted in March 1985, when an isolate of *F. o.* f. sp. *niveum* (TX-HC3-13B) was obtained from watermelon seed. In September 1985, a third test (experiment 3) was conducted in which the two Texas isolates were compared with identified races of *F. o.* f. sp. *niveum* from other areas, including race 2 from Israel.

Table 1. Percent wilt of watermelon cultivars inoculated with different isolates of *Fusarium oxysporum* f. sp. *niveum* (experiment 1)[z]

Cultivar	Isolate		Cultivar mean of all isolates
	ATCC 18467	TX-X1D	
Black Diamond	100 a	100 a	100 a
Sugar Baby	80 a	100 a	90 ab
Jubilee	70 a	67 a	68 abc
Charleston Gray	27 a	40 a	36 c
Calhoun Gray	13 a	52 b	32 c
Crimson Sweet	13 a	100 b	56 abc
Dixielee	7 a	95 b	51 bc
Treatment mean of all cultivars	44 a	79 b	

[z]Inoculum level: 1×10^5 microconidia per milliliter. Percentage figures are the means of five replicated pots (five plants per pot) and are rounded to the nearest whole number. Numbers across a row followed by the same letter are not significantly different ($P = 0.05$) according to Fisher's LSD test. Statistical analysis and mean separation based on arc sine-transformed and weighted data. Statistical letters for cultivar mean separation (down column) have not been included except for the cultivar means of all isolates. All control plants (isolate = water) were rated 0% wilt and data are not included in the table.

Table 2. Percent wilt of watermelon cultivars inoculated with different isolates of *Fusarium oxysporum* f. sp. *niveum* (experiment 2)[z]

Cultivar	Isolate			Cultivar mean of all isolates
	ATCC 18467	TX-X1D	TX-HC3-13B	
Black Diamond	100 a	100 a	100 a	100 a
Black-Seeded Chilean	100 a	100 a	100 a	100 a
Jubilee	93 a	100 a	93 a	95 ab
Charleston Gray	80 a	93 ab	100 b	91 abc
Charleston Gray 133	100 a	60 b	93 ab	84 abc
Peacock	53 a	93 b	93 ab	80 bc
Crimson Sweet	43 a	100 b	100 b	81 abc
Sugarlee	30 a	100 b	93 b	74 bc
Dixielee	13 a	100 b	100 b	71 bc
Summit	13 a	87 b	100 b	67 c
Royal Sweet	13 a	87 b	100 b	67 c
Royal Charleston	27 a	100 b	100 b	76 bc
Royal Jubilee	20 a	93 b	100 b	71 bc
All Sweet	7 a	100 b	100 b	69 c
Calhoun Gray	0 a	100 b	100 b	67 c
Citrullus colocynthis (Texas)	92 a	93 a	87 a	91 abc
Treatment mean of all cultivars	49 a	94 b	98 b	

[z]Inoculum level: 1×10^6 microconidia per milliliter. Percentage figures are the means of five replicated pots (three plants per pot) and are rounded to the nearest whole number. Numbers across a row followed by the same letter are not significantly different ($P = 0.05$) according to Fisher's LSD test. Statistical analysis and mean separation based on arc sine-transformed and weighted data. Statistical letters for cultivar mean separation (down column) have not been included except for the cultivar means of all isolates. All control plants (isolate = water) were rated 0% wilt and data are not included in the table.

RESULTS

The TX-X1D isolate was significantly ($P = 0.05$) more aggressive than ATCC 18467 toward three cultivars: Calhoun Gray, Crimson Sweet, and Dixielee (Table 1). These three cultivars are considered highly wilt resistant to the

common isolates of *F. o.* f. sp. *niveum*, thus the 52, 100, and 95% wilt, respectively, caused by TX-X1D was the first indication of a possible new race. The small amount of wilt exhibited in Calhoun Gray (13%), Crimson Sweet (13%), and Dixielee (7%) with the ATCC 18467 isolate is consistent with earlier results using the same inoculum level (1×10^5 microconidia per milliliter) (10). When each cultivar was analyzed statistically across both isolates, the isolates clearly separated into two distinct reactions (Table 1). The ATCC 18467 isolate caused a mean of 44% wilt of all cultivars, whereas the TX-X1D isolate caused a mean of 79% wilt of all cultivars.

In the second test, the seed isolate was compared with TX-X1D and ATCC 18467. The inoculum level was increased 10-fold to 1×10^6 microconidia per milliliter, and more cultivars were tested. The two Texas isolates reacted similarly to each other on each cultivar, and the mean percentage of wilt for all cultivars was the same (Table 2). There was an increase in percentage of wilt caused by the increase in inoculum level from 1×10^5 to 1×10^6 microconidia per milliliter on the moderately and highly wilt-resistant cultivars with the Texas isolates. Increasing the inoculum level of race 1 (ATCC 18467) resulted in an higher wilt percentage only in the slightly resistant and moderately resistant cultivars Jubilee and Charleston Gray. This is consistent with earlier results (10). Both Texas isolates clearly separated as distinct strains from the ATCC 18467 isolate; they caused a mean of 94 and 98% wilt on all cultivars compared with a mean of 49% wilt induced by ATCC 18467.

Comparisons of wilt percentages caused by the Texas isolates with those caused by the Israeli race 2 (IS-59) (experiment 3) on 17 cultivars suggest that they are identical (Table 3). As with other tests with these isolates, no cultivar was identified as either moderately or highly resistant (≥50% wilt) to race 2. Several cultivars showed less wilt than others when inoculated with the same isolate (i.e., Charleston Gray and Crimson Sweet) but were not significantly different from the others ($P = 0.05$) (Table 3). Again, each of the race 2 isolates was distinct from the other isolates, resulting in a mean of 90% wilt for all cultivars.

The two isolates of race 1, FL-64-2(M59-1) and ATCC 18467, reacted similarly when the means of all cultivars were compared, 36 and 32% wilting, respectively, but there were clear differences between the two isolates on individual cultivars (Table 3). Specifically, the cultivars All Sweet, Dixielee, Summit, and Sugarlee were only moderately resistant to the Florida isolate of race 1 [FL-64-2(M59-1)] but highly resistant to the South Carolina isolate of race 1 (ATCC 18467). Similarly, Charleston Gray 133 reacted differently to the two isolates of race 1.

There were also clear differences between race 0 and race 1. FL-60-3A(11) was pathogenic only to highly susceptible cultivars, which carry no resistance genes, and clearly avirulent on all other moderately or highly wilt-resistant cultivars tested. This was not the case with either isolate of race 1.

DISCUSSION

The results of this work document the existence of a highly aggressive race of *F. o.* f. sp. *niveum* in the United States. On the basis of comparison with the Israeli isolate of race 2, it is concluded that the Texas isolates are race 2. The extent of the distribution of this race in Texas or the United States is not known; however, its occurrence in south Texas and north central Texas suggests that it may be widespread in Texas. Recently, a third isolate of race 2 was confirmed from wilted plants (cultivar Jubilee) grown in northwest Texas (South Plains) near the New Mexico border. At present, no other state has reported the occurrence of race 2. Answers to the questions as to how and when race 2 arrived in Texas are lacking. The original isolation of race 2 in Texas was in 1981, only 7 yr after it was identified in Israel (13). It is most probable that a population of race 2 existed in Texas before 1981, because reports from farmers and extension agents during the late 1970s indicated higher than usual incidences of watermelon wilt.

The significance of this new race in Texas is potentially great. Texas produces almost 25% (24,000 ha) of the nation's watermelons. Although Fusarium wilt has been a long-standing problem to Texas watermelon production, it has generally been kept in check with wilt-resistant cultivars. Many cultivars have high wilt resistance to the common isolates of race 1 (i.e., Calhoun Gray, Crimson Sweet, Dixielee, and Sugarlee) (10), but none of these is resistant to race 2. Additionally, several hybrid watermelons (i.e., Royal Sweet and

Table 3. Percent wilt of watermelon cultivars inoculated with different isolates of *Fusarium oxysporum* f. sp. *niveum* (experiment 3)[z]

Cultivar	Isolate						Cultivar mean of all isolates
	FL-60-3A(11) (race 0)	FL-64-2(M59-1) (race 1)	ATCC 18467 (race 1)	TX-HC3-13B (race 2)	TX-X1D (race 2)	IS-59 (race 2)	
Black-Seeded Chilean	96 a	86 a	100 a	96 a	100 a	100 a	96 a
Black Diamond	79 a	96 a	100 a	100 a	96 a	96 a	95 ab
Giza	92 a	93 a	96 a	89 a	100 a	96 a	94 ab
Sugar Baby	56 a	50 a	81 a	96 a	96 a	100 a	80 bc
Jubilee	27 a	54 ab	86 b	81 b	93 b	89 b	72 cd
All Sweet	0 a	46 b	11 a	100 c	96 c	100 c	59 de
Dixielee	0 a	56 b	4 a	100 c	96 c	100 c	59 de
Summit	0 a	55 b	0 a	90 c	95 c	100 c	57 def
Sugarlee	0 a	56 b	7 a	89 c	96 c	92 c	57 def
Royal Sweet	0 a	0 a	4 a	96 b	92 b	89 b	47 fgh
Charleston Gray 133	4 a	0 a	36 b	88 c	68 bc	86 c	47 fgh
Royal Jubilee	0 a	8 a	0 a	93 b	85 b	89 b	46 fgh
Royal Charleston	0 a	8 a	4 a	86 b	96 b	79 b	46 fgh
Smokylee	0 a	0 a	0 a	95 b	90 b	86 b	45 fgh
Calhoun Gray	4 a	4 a	0 a	89 b	89 b	79 b	44 gh
Charleston Gray	0 a	0 a	18 a	71 b	71 b	79 b	41 h
Crimson Sweet	0 a	4 a	4 a	75 b	88 b	68 b	40 h
Treatment mean of all cultivars	21 a	36 b	32 ab	90 c	91 c	90 c	

[z] Inoculum level: 1×10^6 microconidia per milliliter. Percentage figures are the means of seven replicated pots (four plants per pot) and are rounded to the nearest whole number. Numbers across a row followed by the same letter are not significantly different ($P = 0.05$) according to Fisher's LSD test. Statistical analysis and mean separation based on arc sine-transformed and weighted data. Statistical letters for cultivar mean separation (down column) have not been included except for the cultivar means of all isolates. All control plants (isolate = water) were rated 0% wilt and data are not included in the table.

Royal Jubilee) are becoming increasingly popular because of their wilt resistance. These too, however, are susceptible to the newly described race 2.

Resistance to Fusarium wilt was initially believed to be inherited as a recessive trait (18,20). Bennett (2), concluded that resistance was probably dependent on several factors (genes). Later studies (6,16,26), however, indicated that wilt resistance is controlled by a single dominant gene. Netzer (14) suggested that a nonspecific, polygenic resistance may be effective against race 2.

The status of the search for resistance to race 2 currently is not very encouraging. Netzer (14) screened 65 cultivars of domestic watermelon (*C. lanatus*), 138 *Citrullus* spp. accessions, a wild species of *C. colocynthis* common in Israel, and two wild species native to equatorial Africa (*C. rehmii* and *C. ecirrhosus*) for resistance to *F. o.* f. sp. *niveum* race 2. None of these cultivars or lines expressed resistance to race 2 when tested in the seedling stage. In the present study, a Texas selection of *C. colocynthis* was also susceptible to both race 1 and race 2.

A second significant finding is the detection of race 2 on commercial seed. Isolate TX-HC3-13B was obtained from the seed coat of a commercial seed lot of hybrid seedless watermelon and therefore has potential importance in the dissemination of this new race. *F. o.* f. sp. *niveum* is known to be externally seedborne (7,19,25). Porter (19) demonstrated a 3% infection level of commercial seed obtained from three southern states: Texas, Georgia, and Florida. In the present study, only one isolate of race 2 was obtained from a sample of 100 seeds; therefore, the infection level was $\leqslant 1\%$. Seeds sampled from other lots were negative for *F. o.* f. sp. *niveum*.

A secondary objective of this study was to evaluate watermelon cultivars in an effort to determine which one(s) would serve as the best differentials for separating races of *F. o.* f. sp. *niveum*. Cirulli (3) reported that Sugar Baby, Charleston Gray, and Calhoun Gray would separate races 0 and 1, with Charleston Gray being the key intermediate cultivar resistant to race 0 and susceptible to race 1. In our study, depending on which isolate of race 1 was used, Charleston Gray was either susceptible or resistant (Table 3) and thus may not be the best differential cultivar. When each cultivar was analyzed statistically across all isolates, no one cultivar stood out as a clear choice for the intermediate reaction. Cultivars highly susceptible to all three races were easily identified (Black Diamond, Black-Seeded Chilean, Giza, and Sugar Baby), and cultivars highly resistant to race 0 and both isolates of race 1 were identified (Royal Sweet, Royal Jubilee, Royal Charleston, Smokylee, Calhoun Gray, and Crimson Sweet), but no cultivar was resistant to race 0 and susceptible to both isolates of race 1.

It may be that to separate isolates of *F. o.* f. sp. *niveum* into races will require more than several cultivars and the use of more than one isolate of known races to guard against differences in populations of the fungus. It is also necessary that defined inoculum levels and methods be adopted, because resistance is known to be affected by pathogen inoculum density (10) and inoculation method (8).

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