Additional Sources of Resistance to Race 2 of *Fusarium oxysporum* f. sp. *apii*

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ABSTRACT

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Seventy-one lines of *Apium graveolens* var. *dulce* (celery), *A. graveolens* var. *graveolens* (celery), *A. graveolens* var. *rapaceum* (celeriac), and *A. graveolens* var. *secalinum* (smallage) were evaluated for their resistance to race 2 of *Fusarium oxysporum* f. sp. *apii* by growing them in infested soil and rating the plants for incidence of infection and extent of vascular discoloration in the roots, crowns, and petioles 8–10 wk after inoculation. Four lines (three of celeriac and one of smallage) were found highly resistant, and 14 lines were found moderately resistant at an inoculum density of 1×10^6 macroconidia and microconidia per gram of U.C. soil mix.

In 1978, Hart and Endo (3) reported the reappearance in California of Fusarium yellows of celery (*Apium graveolens* L. var. *dulce* DC.) caused by *Fusarium oxysporum* Schlecht. f. sp. *apii* (R. Nels. & Sherb.) Snyd. & Hans. In 1981, Schneider and Norelli (10) reported that the reappearance of the disease was due to the appearance of a new race of the fungus, race 2, which attacked green as well as yellow varieties of celery. Race 2 was identified in Michigan by Elmer and Lacy (2) in 1981 and in New York by Awuah et al (1) in 1982.

According to P. E. Hill, celery breeder (*personal communication*), before 1978, yellows was caused only by race 1, which attacked the old yellow varieties of celery. Race 1 was controlled by the use of green cultivars of celery (e.g., Tall Utah 52-70 R, Florida 2-13, and Florida 6-83) derived by simple selection from Tall Utah 52-70. Tall Utah 52-70 was in turn derived by simple selection from a single plant of the cultivar Chrystal Jumbo. Thus, selection by plant breeders of a narrow range of genotypes ensured that all commercial celery cultivars would be susceptible if a green cultivar-attacking race of the fungus appeared.

Resistance, when available, is the most effective means of controlling vascular wilt diseases. In 1979, we (7) reported that 11 lines of celeriac and three of celery were moderately resistant to a California isolate (H171) of race 2 of *F. oxysporum* f. sp. *apii*. Subsequently, Orton et al (8,9) used one of the resistant celeriac lines, PI 169001, as the Fusarium yellows-resistant parent in a cross with a plant field-resistant to yellows selected out of the highly susceptible Tall Utah 52-70 R. Since celeriac only remotely resembles celery, some difficulty is being encountered in developing a commercially acceptable yellows-resistant cultivar using celeriac as the resistant parent. Progeny tend to be more open and rank and are taller than 5270 R, have more side shoots, and possess petioles that are round, hollow, and off-flavor.

This paper reports additional sources of resistance to isolate H171 of *F. oxysporum* f. sp. *apii* race 2. Since three of the 14 moderately resistant lines are celery (*A. graveolens* var. *dulce*) rather than celeriac (*A. graveolens* var. *rapaceum*), breeding for resistance should be facilitated with these celery lines.

MATERIALS AND METHODS

The isolate (H171) of race 2 used, the method of growing plants, the manner of producing and preparing inoculum, and the procedure used for inoculation have been described in a previous publication (7). Each evaluation was carried out twice using 10 replicates of five plants. Seeds of *A. graveolens* var. *rapaceum* (celeriac), *A. graveolens* var. *graveolens* (celery), and *A. graveolens* var. *secalinum* (smallage) were obtained from 10 sources, mostly from other countries (Table 1).

Since experiments (6) had shown that disease response increased with increasing inoculum density, apparently resistant lines of celery were evaluated at two inoculum densities. A low inoculum level of 1×10^4 macroconidia and microconidia per gram of U.C. soil mix was used in the first test to detect low as well as high levels of resistance. All celery lines were evaluated in this trial. In the second test, a high inoculum level of 1×10^6 macroconidia and microconidia per gram of U.C. soil mix was used to distinguish clearly between the various levels of resistance. Only lines of celery that appeared to possess some degree of resistance in the first test were reevaluated in the second trial. Highly susceptible lines were not included. Tall Utah 52-70 R, Tall Utah 52-70 HK, and PI 176419 (celeriac) were included in each evaluation as the highly susceptible, slightly resistant, and moderately resistant controls, respectively.

Diseased plants were rated for severity on a scale of 0–5 according to the extent of vascular discoloration, since MacHardy and Beckman (5) have emphasized that susceptibility to Fusarium wilt is

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correlated with the amount of vascular discoloration extending into the tops of affected plants. The disease severity classes were as follows: 0 = no vascular discoloration in the roots, crowns, or petioles; 1 = vascular discoloration restricted to less than 50% of the root length, none in the crown or petioles; 2 = vascular discoloration in more than 50% of the root length, sometimes extending into 1–25% of the crown, none in the petioles; 3 = vascular discoloration in the entire length of the roots and extending into 26–50% of the crown, none in the petioles; 4 = vascular discoloration in the entire length of the roots and extending into 51–75% of the crown, none in the petioles; and 5 = vascular discoloration in the entire length of the roots, extending into 76–100% of the crown, and usually present in the petioles. The disease index (DI) was calculated using the formula: $DI = \Sigma i \times j/n$, where n = total number of plants, i = severity class of each plant, and j = number of plants in each class. A disease value of 1 or less was considered highly resistant; 1.1–2, moderately resistant; 2.1–3.0, slightly resistant; 3.1–4.0, susceptible; and 4.1–5.0, highly susceptible.

RESULTS

Seventy-one cultivars and lines of *A. graveolens* var. *dulce* (celery), *A. graveolens* var. *rapaceum* (celeriac), *A. graveolens* var. *graveolens* (celery), and *A. graveolens* var. *secalinum* (smallage) were evaluated (Table 1). In the initial screen employing an inoculum density of 1×10^4 conidia, 39 lines were found to be as highly susceptible as Tall Utah 52-70 R and were eliminated from further testing; 14 lines were rated slightly resistant and 18 lines were rated highly resistant. When the 14 slightly resistant lines and the 18 highly resistant lines were reevaluated at an inoculum density of 1×10^6 macroconidia and microconidia per gram of U.C. soil mix, all the slightly resistant lines tested susceptible and 13 of the 18 highly resistant lines tested moderately resistant. The remaining five highly resistant lines remained highly resistant.

Of the 39 lines rated highly susceptible in test 1, 33 were of the variety *dulce*, four of the variety *secalinum*, one of the variety *rapaceum*, and one of the variety *graveolens*. Of the 14 lines rated slightly resistant in test 1, seven were of the variety *dulce*, two of the variety *secalinum*, four of the variety *rapaceum*, and one of the variety *graveolens*. However, all 14 of the slightly resistant lines were rated susceptible in the more severe test 2. Of the 14 lines rated

Table 1. Disease indices (DI) of 71 cultivars or lines of *Apium graveolens* var. *dulce*, var. *graveolens*, var. *rapaceum*, and var. *secalinum* inoculated with race 2 of *Fusarium oxysporum* f. sp. *apii* in the greenhouse[a]

Line or cultivar[b]	Variety	Inoculum density[c] 1×10^4 DI[d]	1×10^4 SD	1×10^6 DI	1×10^6 SD
a'Couper	*secalinum*	4.6	1.3	···	···
Alabaster	*rapaceum*	0.9	0.4	1.5	0.6
Amsterdam Feiner	*secalinum*	0.4	0.3	0.8	0.4
Apfel	*rapaceum*	0.5	0.2	1.0	1.1
API 7/74	*dulce*	4.8	2.1	···	···
API 8/75	*dulce*	4.4	2.3	···	···
API 9/75	*dulce*	4.5	1.7	···	···
API 56/75	*dulce*	2.6	1.3	3.4	1.1
API 60/76	*dulce*	4.3	2.3	···	···
API 70/74	*dulce*	4.8	1.6	···	···
API 77/74	*dulce*	4.2	1.5	···	···
API 3/75	*graveolens*	4.8	2.3	···	···
API 7/77	*graveolens*	2.3	1.1	3.7	0.9
API 15/75	*rapaceum*	0.4	0.2	1.3	0.5
API 27/76	*secalinum*	4.9	1.4	···	···
API 33/75	*secalinum*	4.8	1.6	···	···
API 34/75	*secalinum*	2.6	1.0	3.1	1.3
Aromatischer Extra Krauser	*dulce*	2.5	1.5	3.8	1.0
Asmer Ely White	*dulce*	4.7	2.6	···	···
Asmer Fenstar	*dulce*	4.4	2.1	···	···
Asmer Multi-Pak	*dulce*	4.3	1.1	···	···
Asmer New Dwarf White	*dulce*	4.6	1.9	···	···
Asmer Nova-Pak	*dulce*	4.9	1.6	···	···
Avon Pearl	*dulce*	0.4	0.4	1.3	0.8
Balder	*rapaceum*	0.3	0.1	1.7	1.4
Bleichsellerie I	*dulce*	0.4	0.2	1.4	1.0
Bleichsellerie II	*dulce*	4.6	2.9	···	···
Cera	*rapaceum*	0.7	0.2	1.5	0.8
Claseed Lathom Self Blanching	*dulce*	4.1	2.3	···	···
Cornell 65-8	*dulce*	4.2	2.7	···	···
De Bologne	*dulce*	4.4	1.5	···	···
D'elne	*dulce*	4.1	1.2	···	···
De Lusia	*dulce*	4.8	2.6	···	···
De Lusia Self Blanching	*dulce*	4.9	2.1	···	···
De Perpignan	*dulce*	4.7	1.4	···	···
De Villeneuve	*dulce*	4.8	1.6	···	···
Dore Briand	*dulce*	2.3	0.9	3.9	0.6
Dresdenent Markt	*rapaceum*	0.4	1.5	1.5	0.8
Earlibelle	*dulce*	4.6	1.9	···	···
Eureka	*rapaceum*	0.3	0.1	1.3	0.7
Festival 68	?	0.4	0.2	2.3	0.4
Florida 6-83 K Strain	*dulce*	4.7	1.3	···	···
Florida 6-83 Lot 5905	*dulce*	4.9	1.8	···	···
Florida 6-83 60-7-6	*dulce*	4.6	1.3	···	···
Green Light 1371	*dulce*	4.4	1.9	···	···
Hopkins Fenlander	*dulce*	4.2	0.9	···	···
Invictus	*rapaceum*	4.9	1.6	···	···
Jemny	*secalinum*	4.8	1.4	···	···
June Belle Lot 5212	*dulce*	4.4	1.1	···	···
Latham Self Blanching	*dulce*	4.7	1.5	···	···
Magdeburger Markt	*rapaceum*	0.2	0.1	0.5	0.3
Nerez	*rapaceum*	0.5	0.2	0.6	0.2
Oderdorfer	*rapaceum*	2.4	1.1	3.6	1.0
Olomoucky	*rapaceum*	0.6	0.3	0.7	0.4
Pascal	*dulce*	0.4	0.5	1.1	0.9
Pomona	*rapaceum*	0.3	0.2	1.4	1.0
Prager Riesen	*rapaceum*	2.6	1.3	3.1	1.9
Prazsky Obrovsky	*rapaceum*	2.1	0.7	3.5	1.4
Processor 34	*dulce*	4.5	2.3	···	···
Rokanova	*rapaceum*	2.7	2.1	3.2	1.3
Slow Bolting Green No. 96	*dulce*	4.9	1.1	···	···
Solid White	*dulce*	2.3	1.6	3.6	1.9
Summer Pascal	*dulce*	2.9	2.1	3.8	2.2
Tellus	*rapaceum*	0.3	0.1	1.3	0.9
Tendercrisp 9436	*dulce*	2.7	1.3	3.7	2.2
Turkis	*dulce*	2.3	1.6	3.5	1.7
Turners Incomparable	*dulce*	4.9	1.2	···	···
Unrivalled Pink	*dulce*	4.6	2.1	···	···
Utah Jumbo	*dulce*	4.5	2.0	···	···
Wiener Markt	*rapaceum*	0.7	0.2	1.4	1.1
Zwdse Krul	*secalinum*	2.1	1.4	3.7	1.5

[a] Disease indices and standard deviations (SD) were calculated with 10 replicates of five plants.

[b] Cultivars were obtained from Asgrow Seed Co.; Asmer Seeds Limited; Claus Seeds; S. Homna, Michigan State University; S. Humaydan, Keystone Seed Co.; National Seed Development Organization Limited; Niagara Seed Co.; Se'lection René Guilland; Sutton Seeds Limited; and Zentralinstitut der Akademie der Wissenschaften der DDR.

[c] Inoculum density: 1×10^4 or 1×10^6 macroconidia or microconidia per gram of U.C. soil mix.

[d] 0 = No vascular discoloration in roots, crowns, or petioles; 1 = vascular discoloration restricted to less than 50% of the root length, none in the crown or petioles; 2 = vascular discoloration in more than 50% of the root length, sometimes extending into 1–25% of the crown, none in the petioles; 3 = vascular discoloration in the entire length of the roots and extending into 26–50% of the crown, none in the petioles; 4 = vascular discoloration in the entire length of the roots and extending into 51–75% of the crown, none in the petioles; and 5 = vascular discoloration in the entire length of the roots, extending into 76–100% of the crown, and usually present in the petioles.

moderately resistant in test 2, three were of the variety *dulce* and 11 of the variety *rapaceum*. Of the four lines rated highly resistant, one was of the variety *secalinum* and three of the variety *rapaceum*. None of the cultivars rated moderately or highly resistant were apparently of domestic origin.

DISCUSSION

Evaluations were first made at the low inoculum density of 1×10^4 conidia per gram of U.C. soil mix to detect slightly resistant lines against race 2. This was done because higher levels of resistance have not been detected in commercial cultivars of celery, and yet such slightly resistant cultivars as Tall Utah 52-70 HK and Tendercrisp have usually yielded satisfactorily in the field in California despite being affected by the disease. Such slightly resistant cultivars are therefore being used by California growers until highly resistant cultivars to race 2 can be developed. Tall Utah 52-70 HK usually performs satisfactorily in the field in Michigan against naturally occurring strains of race 2 according to M. L. Lacy (*personal communication*) and in New York State according to J. W. Lorbeer (*personal communication*). An additional advantage of detecting low levels of resistance is that lines of celery can be combined that possess different degrees of resistance. That the slightly resistant lines of celery possess only a low level of resistance was verified by the fact that all the lines were rated susceptible after inoculation with an inoculum density of 1×10^6 conidia per gram of U.C. soil mix.

In these tests, the inoculum density also determined the resistance response of some celery lines possessing higher levels of resistance. Of 71 lines evaluated at a conidial density of 1×10^4, 18 lines were rated highly resistant. When these 18 lines were reevaluated at an inoculum density of 1×10^6, 14 lines were rated at a lower level of resistance, i.e., moderately resistant. These findings verify the research of Hart and Endo (4), who found that severity of infection in the yellows disease of celery was correlated with the number of infection foci.

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