Evaluations of Celery Germ Plasm for Resistance to *Fusarium oxysporum* f. sp. *apii* Race 2 in Michigan

WADE H. ELMER, Former Graduate Research Assistant, MELVYN L. LACY, Professor, Department of Botany and Plant Pathology, and SHIGEMI HONMA, Professor, Department of Horticulture, Michigan State University, East Lansing 48823

ABSTRACT

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Thirty cultivars of celery and celeriac and 71 experimental lines of celery were evaluated for resistance to Fusarium yellows of celery in the greenhouse and under field conditions in naturally infested soil. Disease was assessed by visual disease ratings based on the amount of vascular discoloration in the crown area and by determining dry weights in the greenhouse or fresh trimmed weights of marketable cultivars in the field at harvest. Most commercial celery cultivars were rated highly or moderately susceptible. Deacon and Tall Utah 52-70 HK were the most resistant commercially available lines tested and were rated moderately resistant. Summer Pascal and Golden Spartan also showed some resistance. Several experimental lines showed resistance, but many lacked desirable horticultural characteristics. Breeding lines 83-604 and 68-37 were rated moderately to highly resistant to Fusarium yellows race 2, were horticulturally acceptable, and will be released as the cultivars Companion and Pilgrim, respectively, in 1986.

A recurrence of Fusarium yellows of celery (*Apium graveolens* var. *dulce* L.) incited by *Fusarium oxysporum* Schl. f. sp. *apii* (R. Nels. & Sherb.) Snyd. & Hans. (*F. o.* f. sp. *apii*) was reported in California in 1978 after an absence of almost 25 yr (7). Initially, there was uncertainty about whether the green celery cultivars resistant to *F. o.* f. sp. *apii* race 1 had lost resistance to race 1 or if a new race of the pathogen had appeared. *F. o.* f. sp. *apii* race 1 caused widespread losses in the self-blanching cultivars previously grown in Michigan (14). These cultivars were quickly abandoned in favor of *F. o.* f. sp. *apii* race 1-resistant Tall Utah 52-70 and its decendants. Fusarium yellows was not seen in Michigan celery for 20–25 yr after introduction of complete resistance to *F. o.* f. sp. *apii* race 1 in the cultivar Tall Utah 52-70 in 1952 (1). Virulence tests comparing *F. o.* f. sp. *apii* race 1 with the pathogen isolated from infected plants resistant to *F. o.* f. sp. *apii* race 1 revealed that the disease in California was caused by a new race of *F. o.* f. sp. *apii*, designated race 2 (19). *F. o.* f. sp. *apii* race 2 causes disease on both the older yellow self-blanching cultivars and on the newer green cultivars derived from the race 1-resistant cultivar Tall Utah 52-70 (19). *F. o.* f. sp. *apii* race 2 was reported in Michigan in 1982 (3) and in New York in 1984 (2).

The number of celery fields in Michigan with Fusarium yellows incited by *F. o.* f. sp. *apii* race 2 has increased from one in 1981 to 11 in 1984 (5), and the appearance of the disease in formerly noninfested areas will probably continue. Several attempts to control the disease with soil fungicides have been ineffective (2,10,17).

Because all celery cultivars grown in Michigan were susceptible to *F. o.* f. sp. *apii* race 2 at the time Fusarium yellows was identified (15), a greenhouse and field screening program was initiated at Michigan State University in 1981 to evaluate celery germ plasm for resistance and to compare results of greenhouse screening techniques with those of field evaluations. Commercially available cultivars of celery, experimental lines of celery, and celeriac (*A. graveolens* var. *rapaceum* (Mill.) Gaudich) cultivars were evaluated as potential sources of resistance to *F. o.* f. sp. *apii* race 2. A preliminary report has been given (4).

MATERIALS AND METHODS

Thirty commercial cultivars of celery, six cultivars of celeriac, and one cultivar of parsley (*Petroselinum crispum* (Mill.) Nym. 'Festival 68') were screened for resistance to Fusarium yellows under greenhouse conditions in artificially infested soil. A highly virulent isolate of *F. o.* f. sp. *apii* race 2 (FA3, ATCC 52626) used in this study was isolated from Michigan celery and was maintained in sterile soil culture (13) until it was transferred to agar for increase of inoculum. Colonized wheat straw inoculum was prepared by placing a 4-mm agar plug in 50 g of sterile ground dried wheat straw moistened with 0.025 M asparagine (2 ml/g of wheat straw) (18). After 3 wk of incubation, the wheat straw was air-dried and passed through a 1-mm-mesh sieve. Inoculum contained mycelial fragments, abundant microconidia, and some macroconidia and chlamydospores embedded in the wheat straw tissue. Soil inoculum densities resulting from 1 g of colonized wheat straw per kilogram of soil ranged from 1×10^4 to 5×10^4 cfu/g of soil as determined by diluting soil into Komada's selective medium (9) 24 hr after incorporating inoculum into the soil.

Seeds were germinated in the greenhouse in steamed potting mix under a 16-hr photoperiod at 20–24 C. Seedlings 3–4 wk old were transplanted into pots 10 or 15 cm in diameter containing either steamed muck soil or steamed potting mix (soil:sand:peat, 2:1:1, v/v) and placed on greenhouse benches under sodium vapor lamps providing a 16-hr day with temperatures at 20–24 C. Soils had been infested previously with *F. o.* f. sp. *apii* race 2-colonized wheat straw (1 g of straw per kilogram of soil). Ten replicates (three plants per replicate) of each cultivar were used, and Tall Utah 52-70 R Improved served as the susceptible control. After 5–6 wk, when symptoms were severe in the susceptible control, plants were rated for the amount of vascular discoloration in the roots and crowns by slicing the crown longitudinally and rating on a scale of 1–6, where 1 = no disease, 2 = vascular discoloration in the primary roots only, 3 = vascular discoloration in less than 10% of the crown area, 4 = vascular discoloration in 11–25% of the crown area, 5 = vascular discoloration in 26–75% of the crown area, and 6 = vascular discoloration in 76–100% of the crown or death of the plant. The tops of the plants were severed at the soil level, dried, and weighed. All greenhouse evaluations were repeated at least once.

Field evaluations for resistance to Fusarium yellows were conducted with 9- to 11-wk-old transplants grown in flats in the greenhouse and transplanted into a field at the William Willbrandt farm in North Muskegon, MI, where the disease

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had been severe for at least 5 yr. In addition to commercial cultivars, several experimental lines of celery developed at Michigan State University for resistance to early blight (*Cercospora apii* Fres.) (600 series) (12), to late blight (*Septoria apiicola* Fres.) (C × P series) (8), or to bolting were evaluated in single plots at the same location. The 83–600 series of celery lines consisted of crosses of (Danish celeriac × Cornell 619 celery) × Utah celery, the C × P series (lines 1–7) were the progeny of a cross between celery (Golden Spartan) and parsley (Festival 68) (8), and the slow-bolting line 68-37 had Danish celeriac in its pedigree. The screening program extended over a 3-yr period and involved many greenhouse and field experiments. The soil contained about 73–103 cfu of *F. o.* f. sp. *apii* race 2 per gram according to assays using conventional soil dilution techniques. Representative samples of *F. oxysporum* isolates from soil dilutions were tested for pathogenicity to differentiate between *F. o.* f. sp. *apii* race 2 and nonpathogenic strains of *F. oxysporum*, allowing us to estimate populations of *F. o.* f. sp. *apii* race 2. A randomized block design was employed in field tests with four replicates per cultivar. Each replicate consisted of a 6-m section of row. Plots received the same cultural and chemical treatments as the surrounding commercial plantings. Disease symptoms were monitored periodically during the season. Nine to 10 wk after transplanting, disease ratings were made on a scale of 1–5, where 1 = no disease symptoms (highly resistant); 2 = slight stunting and/or slight vascular discoloration in the primary roots and crown (moderately resistant); 3 = moderate level of stunting, chlorosis in the older petioles, and vascular discoloration in the crown area (moderately susceptible); 4 = severe stunting, chlorosis extending into younger petioles, and extensive vascular discoloration with rotted crowns (highly susceptible); and 5 = plants near death or dead. Trimmed weight yields were taken on all marketable cultivars for the 1983 and 1984 field studies. All data were subjected to analysis of variance (ANOVA), and means were compared using Duncan's multiple range or Student's *t* test.

Table 1. Disease ratings of 30 commercial celery cultivars evaluated in a field naturally infested with *Fusarium oxysporum* f. sp. *apii* race 2

Cultivar	Disease rating[a]
Bishop	MS
Calmario	HS
Camlynn	HS
Clean Cut	HS
Deacon	MR
Earlibelle	HS
Ferry Morse 1217	MR
Florida 2-13	HS
Florida 2-14	HS
Florida 683	HS
Florida 683 K	MS
Florimart 19	HS
Golden Detroit	HS
Golden Spartan	MR
Grande	HS
Green Giant	HS
June Belle	HS
Summer Pascal	MR
Summit	HS
Surepac	HS
Tall Golden Self Blanching	HS-MS
Tall Green Light	HS
Tall Utah 52-70	HS
Tall Utah 52-70 R	HS
Tall Utah 52-70 R Improved	HS
Tall Utah 52-70 HK	MR
Tall Utah 52-75	HS-MS
Tendercrisp	MS-MR
Transgreen	HS
Ventura	HS

[a] MS = moderately susceptible, moderate level of stunting, chlorosis in the older petioles, and vascular discoloration in the crown area; HS = highly susceptible, severe stunting, chlorosis extending into younger petioles, and extensive vascular discoloration with rotted crowns; and MR = moderately resistant, slight stunting and/or slight vascular discoloration in the primary roots and crown.

RESULTS

No celery cultivars tested were rated highly resistant under conditions prevailing in the field used for screening (Table 1). The cultivars Deacon, Tall Utah 52-70 HK, Summer Pascal, and Golden Spartan and the celery line FM 1217 were rated moderately resistant; however, only Deacon and Tall Utah 52-70 HK were horticulturally desirable. Cultivars Tendercrisp, Florida 683 K, and Bishop were rated moderately susceptible because they had more vascular discoloration in the crown area and more stunting than Deacon and Tall Utah 52-70 HK. All other celery cultivars tested were highly susceptible to Fusarium yellows, with severe stunting and rotting of crowns.

Parsley and two of the celeriac lines possessed high resistance (Table 2) to *F. o.* f. sp. *apii* race 2 in as much as no vascular discoloration or stunting could be detected in greenhouse tests. Other celeriac cultivars had higher disease ratings, but there were no significant differences in dry weights between celeriac plants in infested soils and noninfested soils.

Several experimental lines of celery showed resistance to Fusarium yellows in the field. The C × P lines had individual plants that segregated into several disease categories from moderately resistant with slight vascular discoloration and stunting to severely stunted plants near death; however no discernable patterns of segregation were observed. The C × P lines were not considered marketable. Of the 40 early blight-resistant lines (lines 83-601 through 83-640) tested in single plots in a naturally infested field in 1983, two (83-604 and 83-638) were rated moderately resistant. In 1984, another seed lot of the 600 series (lines 84-601 through 84-667) was screened in the field and all lines were rated from highly susceptible to moderately susceptible; however, lines were segregating, with individuals that ranged from moderately stunted to severely wilted and dead. The 83-604 and 83-638 lines screened in 1983 were retested, and only the 83-604 line was rated moderately resistant and was considered to have horticultural value.

Several slow-bolting lines and the 83-604 and 83-638 lines were compared in single plots in another field near Hudsonville, MI, where Fusarium yellows was present. Lines 68-37 and 83-604 were more resistant than Deacon (Table 3). Slow-bolting line 68-37 was compared with other commercial cultivars in the greenhouse in artificially infested soils (Table 4) and was more resistant than Deacon or Tall Utah 52-70 HK, which are presently the most resistant commercial cultivars of celery available.

Table 2. Dry weights and disease reactions of one parsley and six celeriac cultivars to *Fusarium oxysporum* f. sp. *apii* race 2 in artificially infested soils in the greenhouse

Cultivar	Disease rating[x]	Dry weights (g)	
		Noninfested soil	Infested soil
Festival 68 (parsley)	1.00 a[y]	0.91	1.07 ns[z]
Schnittsellerie Amersterdamer	1.00 a	1.08	1.11 ns
Knolselderij Prager	1.00 a	0.71	1.07 ns
Knolselderij Arvi	1.20 a	1.35	1.57 ns
Knolselderij Albatros	1.30 ab	1.03	1.30 ns
Bleichsellerie Improved	2.90 ab	0.99	0.98 ns
Bleichsellerie Alma	2.90 ab	1.01	0.95 ns
Tall Utah 52- 70 R (celery)	4.55 c	2.25	0.57

[x] Based on scale of 1–5, where 1 = no disease, 2 = vascular discoloration in the primary roots only, 3 = vascular discoloration in less than 10% of the crown area, 4 = vascular discoloration in 11–25% of the crown area, 5 = vascular discoloration in 26–75% of the crown area, and 6 = vascular discoloration in 76–100% of the crown area or death of the plant.

[y] Values represent the mean of 10 pots with one plant per pot. Values followed by different letters are significantly different according to Duncan's multiple range test ($P = 0.05$).

[z] ns = Not significantly different from its respective control according to Tukey's test ($P = 0.05$).

DISCUSSION

Generally, dry weights did not correlate well with disease ratings in the greenhouse tests and were not considered as reliable as amount of vascular discoloration in evaluating resistance. In addition, chlorosis of the outer leaves and petioles was not consistently observed in susceptible cultivars grown in the greenhouse and did not provide a good criterion for distinguishing moderately resistant from moderately susceptible ratings. We have also observed in the field that amount of chlorosis is not always a good indicator of disease severity.

Although the *F. o.* f. sp. *apii* race 2-colonized wheat straw soil-infestation technique (18) proved dependable for reproducing Fusarium yellows of celery in the greenhouse, field evaluations were more consistent and therefore more reliable for assessing disease reactions, even though soil inoculum densities were higher in artificially infested soils in the greenhouse. This may have resulted in part from the longer growing period in the field, which allowed the disease to become more severe and aided in detecting differences among cultivars in stunting and symptom severity. Horticultural characteristics also could be better evaluated at harvest in the field along with yield. In addition, environmental conditions in the greenhouse tests may not have been optimal for disease development. Lighting, temperature, and moisture levels are known to affect the development of Fusarium yellows of celery in the greenhouse (6,18,20).

No commercial cultivar tested so far has exhibited the level of resistance to *F. o.* f. sp. *apii* race 2 that was discovered in Tall Utah 52-70 to *F. o.* f. sp. *apii* race 1 (1). Deacon and Tall Utah 52-70 HK were rated as having the highest level of resistance of the horticulturally acceptable commercially available cultivars. Their growth was vigorous and uniform, and vascular discoloration in the crown was slight. These cultivars would be suitable for fresh market when grown in lightly to moderately infested soils and would still be acceptable in heavily infested soils for processing where complete lack of internal crown discoloration is not essential.

Similar disease ratings were observed in California (15) on many of the same cultivars listed, with the exceptions of Golden Spartan, Summer Pascal, and Tall Utah 52-70 HK. These cultivars were rated highly susceptible in California but appeared more tolerant under Michigan conditions, possibly because of differences in inoculum density and/or soil type. Most experimental lines of celery were highly susceptible to *F. o.* f. sp. *apii* race 2; however, since resistance to early blight (12) and late blight (8) was obtained from *F. o.* f. sp. *apii* race 2-resistant celeriac and parsley, respectively, we were not surprised to find that some of the progeny possessed some resistance to Fusarium yellows. The source of resistance to Fusarium yellows that was discovered in the slow-bolting line 68-37 (to be released in 1986 as cultivar Pilgrim) is probably from Emerson Pascal, an early blight-resistant cultivar derived from celery × celeriac (11). This line seems to have great potential for high yield in heavily infested soils (Tables 3 and 4) and has good horticultural traits. Line 83-604 (to be released in 1986 as cultivar Companion) was developed as a line resistant to early blight (*C. apii*) but also proved to have resistance to *F. o.* f. sp. *apii* race 2, probably because of the Danish celeriac in the pedigree.

Orton et al (16) reported that resistance to Fusarium yellows is conferred by a single dominant gene accompanied by a number of quantifying genes; therefore, it is probable that additional breeding could produce a stable genotypic line of celery that would possess resistance to *F. o.* f. sp. *apii* race 2 equal to that found in Tall Utah 52-70 to race 1 of the Fusarium yellows pathogen.

Table 3. Field reactions of several experimental and commercial lines of celery to Fusarium yellows of celery

Celery line	Disease rating[x]	Trimmed weight[y] (lb/1.5-m row)
68-37[z]	HR	23.8
83-604[z]	MR	16.4
Tendercrisp	MR	14.2
Deacon	MR	13.1
83-638[z]	MS	8.6
Florida 683	HS	6.3
Ventura	HS	2.2

[x] HR = highly resistant, no disease symptoms; MR = moderately resistant, slight stunting and/or slight vascular discoloration in the primary roots and crown; MS = moderately susceptible, moderate level of stunting, chlorosis in the older petioles, and vascular discoloration in the crown area; and HS = highly susceptible, severe stunting, chlorosis extending into younger petioles, and extensive vascular discoloration with rotted crowns.

[y] Represents the total trimmed weights of a single plot.

[z] Line 68-37 is a slow-bolting line, and lines 83-604 are early blight-resistant lines developed at Michigan State University.

Table 4. Evaluation of experimental and commercial celery lines for resistance to Fusarium yellows in greenhouse tests

Cultivar or line	Disease ratings[x]	Dry weights (g)	
		Noninfested soil	Infested soil
68-37	1.6 a[y]	3.5	2.9 ns[z]
Deacon	2.0 a	3.2	2.8 ns
Tall Utah 52-70 HK	2.1 a	3.3	2.3 ns
Tall Utah 52-70 R	5.2 b	3.0	1.1
Tall Green Light	5.4 b	3.2	0.2

[x] Based on scale of 1–5, where 1 = no disease, 2 = vascular discoloration in the primary roots only, 3 = vascular discoloration in less than 10% of the crown area, 4 = vascular discoloration in 11–25% of the crown area, 5 = vascular discoloration in 26–75% of the crown area, and 6 = vascular discoloration in 76–100% of the crown area or death of the plant.

[y] Values represent the mean of seven pots with three plants per pot. Values followed by different letters are significantly different according to the Student-Newman-Keuls test ($P = 0.05$).

[z] ns = Not significantly different from its respective control according to Student's t test ($P = 0.05$).

LITERATURE CITED

1. Anonymous, 1956. One hundred years of celery seed. Seedsman 19:14-16.
2. Awuah, R. T., Lorbeer, J. W., and Ellerbrock, L. A. 1984. Occurrence of Fusarium yellows of celery in New York and attempts to control the disease. (Abstr.) Phytopathology 74:826.
3. Elmer, W. H., and Lacy, M. L. 1982. Reappearance of Fusarium yellows of celery in Michigan. (Abstr.) Phytopathology 72:1135.
4. Elmer, W. H., and Lacy, M. L. 1983. Evaluation of celery cultivars for resistance to Fusarium yellows of celery in Michigan. (Abstr.) Phytopathology 73:786.
5. Elmer, W. H., and Lacy, M. L. 1984. Fusarium yellows (*Fusarium oxysporum* f. sp. *apii* race 2) of celery in Michigan. Plant Dis. 68:537.
6. Hart, L. P. 1978. The etiology and biology of Fusarium yellows of celery. Ph.D. dissertation. University of California, Riverside. 148 pp.
7. Hart, L. P., and Endo, R. M. 1978. The reappearance of Fusarium yellows of celery in California. Plant Dis. Rep. 62:138-142.
8. Honma, S., and Lacy, M. L. 1980. Hybridization between Pascal celery and parsley. Euphytica 29:801-805.
9. Komada, H. 1975. Development of a selective medium for quantitative isolation of *Fusarium oxysporum* from natural soil. Rev. Plant Prot. Res. 8:114-125.
10. Lacy, M. L. 1982. The reappearance of Fusarium yellows disease in Michigan celery. Pages 99-105 in: National Celery Workshop, California Celery Research Program, 1980-81, Annual Report. F. Pusateri, ed. Calif. Celery Res. Advisory Board. Publ. 82 pp.
11. Munger, H. M., and Newhall, A. G. 1952. Emerson Pascal, a blight resistant celery. N.Y. State. Agric. Exp. Farm. Res. 18:11.
12. Murakishi, H. H., Honma, S., and Knutson, R. 1960. Inoculum production and seedling evaluation of celery for resistance to *Cercospora apii*. Phytopathology 50:605-607.
13. Nelson, P. E., Toussoun, T. A., and Marasas, W. F. O. 1983. *Fusarium* Species: An Illustrated Manual for Identification. Pennsylvania State University Press, University Park. 193 pp.
14. Nelson, R., Coons, G. H., and Cochran, L. C. 1937. The Fusarium yellows disease of celery (*Apium graveolens* L. var. *Dulce* D.C.). Mich. Agric. Exp. Stn. Tech. Bull. 155:1-74.
15. Opgenorth, D. C., and Endo, R. M. 1979. Sources of resistance to Fusarium yellows of celery in California. Plant Dis. Rep. 63:165-169.
16. Orton, T. J., Durgan, M. E., and Hulbert, S. D. 1984. Studies on the inheritance of resistance to *Fusarium oxysporum* f. sp. *apii* in celery. Plant Dis. 68:574-578.

17. Otto, H. W., Paulus, A. O., Snyder, M. J., Endo, R. M., Hart, L. P., and Nelson, J. 1976. A crown rot of celery. Calif. Agric. 30:10-11.
18. Schneider, R. W. 1979. Etiology and control of Fusarium yellows of celery. Pages 15-26 in: California Celery Research Program, 1977-78, Annual Report. F. Pusateri, ed. Calif. Celery Res. Advisory Board Publ. 66 pp.
19. Schneider, R. W., and Norelli, J. L. 1981. A new race of *Fusarium oxysporum* f. sp. *apii*. (Abstr.) Phytopathology 71:108.
20. Welch, K. E. 1981. The effects of inoculum density and low oxygen tensions on Fusarium yellows of celery. Ph.D. dissertation. University of California, Berkeley. 103 pp.