European Journal of Plant Pathology **102:** 855–858, 1996.

Allelism of the *Fcu-1* and *Foc* genes conferring resistance to fusarium wilt in cucumber

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Accepted 28 June 1996

Key words: Fusarium oxysporum f.sp. *cucumerinum*, resistance gene, locus

Abstract

The inheritance of resistance to *Fusarium oxysporum* f.sp. *cucumerinum* race 1 was determined in the cucumber cv. WIS-248 by analyzing segregation of F_1, F_2, and BC populations of crosses with the susceptible cv. Straight-8. Resistance was conferred by a single dominant gene. In an allelism test, it was proven that the *Fcu-1* gene, which confers resistance to *F. oxysporum* f.sp. *cucumerinum* races 1 and 2 in cucumber cv. SMR-18 and the *Foc* gene, which confers resistance to *F. oxysporum* f.sp. *cucumerinum* race 2 in cucumber cv. WIS-248, are indistinguishable.

Introduction

Fusarium oxysporum f.sp. *cucumerinum*, causing fusarium wilt of cucumber (*Cucumis sativus*), is an important pathogen in many parts of the world (Vakalounakis, 1988). Three physiological races, viz. 1, 2 and 3, of *F. oxysporum* f.sp. *cucumerinum* have been identified (Armstrong et al., 1978). Resistance to fusarium wilt in cucumber is due either to a polygenic system found in the cvs Ano 2 and Aofushinari (Kanno et al., 1991; H. Komada, pers. comm.) or to a single dominant gene, *Foc*, found in the cv. WIS-248, which confers resistance to *F. oxysporum* f.sp. *cucumerinum* race 2 (Netzer et al., 1977). Recently, Vakalounakis (1993, 1995) and Vakalounakis and Smardas (1996) identified one dominant gene, *Fcu-1*, in the cvs SMR-18 and WI-2757, which confers resistance to *F. oxysporum* f.sp. *cucumerinum* races 1 and 2 (Table 1).

The objective of the present study was to determine the mode of inheritance of resistance to *F. oxysporum* f.sp. *cucumerinum* race 1 in WIS-248 and investigate the relationship between the *Fcu-1* and the *Foc* genes. In preliminary experiments the simple inheritance of resistance to *F. oxysporum* f.sp. *cucumerinum* race 1 in WIS-248 was observed.

Materials and methods

Inheritance analysis. The inbred line Straight-8 (P_1) was crossed with the inbred line WIS-248 (P_2). Seeds of these lines were obtained from the University of Wisconsin-Madison cucumber breeding program, Dr. T. C. Wehner, Department of Horticultural Science, North Carolina State University, Raleigh, NC, USA, and Dr. H. Komada, Shimane University, Faculty of Agriculture, Matsue, Japan. To determine the genetic basis of resistance to inoculation with *F. oxysporum* f.sp. *cucumerinum* race 1 in WIS-248, the reactions of F_1, F_2, BC(P_1) and BC(P_2) were examined. The backcross and F_2 ratios were tested for deviations from the expected, using the chi square test for goodness of fit (Little and Hill, 1978) with the significance level established at $P < 0.05$.

Allelism test. The inbred line WIS-248 was crossed with the inbred line SMR-18. To investigate the relationship between the dominant gene found in WIS-248, which confers resistance to *F. oxysporum* f.sp. *cucumerinum* race 1 (this study), the *Foc* gene found in WIS-248, which confers resistance to *F. oxysporum* f.sp. *cucumerinum* race 2 (Netzer et al., 1977) and the *Fcu-1* gene found in SMR-18, which confers resistance to *F. oxysporum* f.sp. *cucumerinum* races 1 and 2 (Vakalounakis, 1993, 1995), the reactions of backcross

Table 1. Resistance type to fusarium wilt in cucumber

Resistance type	Resistance gene	Race[a]	Resistance source	References
Polygenic			Ano 2	Kanno et al. (1991)
			Aofushinari	H. Komada, pers. comm.
Monogenic	*Foc*	2	WIS-248	Netzer et al. (1977)
	Fcu-1	1 and 2	SMR-18	Vakalounakis (1993, 1995)
		1 and 2	WI-2757	Vakalounakis and Smardas (1996)

[a] Race of *Fusarium oxysporum* f.sp. *cucumerinum* against of which the resistant gene is effective.

(WIS-248 × SMR-18) × Ashley and F_2 (WIS-248 × SMR-18) (×) to either race 1 and 2 were examined. Ratios of three resistant to one susceptible and 15 resistant to one susceptible in backcross and F_2 progenies, respectively, would have been expected, if resistance to either race in WIS-248 and SMR-18 was conferred by two nonallelic dominant genes.

Inoculum preparation. F. oxysporum f.sp. *cucumerinum* race 1 and race 2 were obtained from Professor P. H. Williams, Department of Plant Pathology, University of Wisconsin-Madison, USA as isolate PHW #231 and from the American Type Culture Collection (ATCC) as isolate #36330, respectively. Cultures of both races were grown separately in potato dextrose broth (PDB) in 200 ml Erlenmeyer flasks in a rotary shaker for 6 days, at 22 °C in the dark. Spores were removed from the substrate, filtered through a double layer of non-sterile cheesecloth and the mycelial mat was washed with distilled water and the suspension centrifuged at 3000 *g* for 10 min. Spores were resuspended in distilled water and the concentration was adjusted to 2×10^6 spores/ml.

Plant inoculation and disease assessment. Seedlings at the cotyledon stage grown in vermiculite were removed from the substrate, washed with tap water and then dipped in the inoculum suspension for 30 min. After inoculation seedlings were transplanted in sterile organic substrate Belplanto and kept in a growth chamber at 26 °C with a 12-h photoperiod for 50 days.

To evaluate the response of seedlings to *F. oxysporum* f.sp. *cucumerinum*, an arbitrary four-point visual scale was used, where 0 = no apparent symptoms; 1 = vascular discoloration of both hypocotyl and epicotyl, stunting; 2 = as 1 with marked stunting, wilting; 3 = dead or almost dead seedlings. When calculating segregation ratios, only plants with a disease rating of 0 were classed as resistant, while those with disease ratings of 1, 2 and 3 were classed as susceptible.

Results and discussion

Inheritance of resistance to Fusarium oxysporum *f.sp. cucumerinum races 1.* The F_1 progenies of the crosses Straight-8 × WIS-248 and WIS-248 × Straight-8 were as resistant to *F. oxysporum* f.sp. *cucumerinum* race 1 as the resistant parent WIS-248 (Table 2). F_2 progenies segregated in a manner consistent with a ratio of three resistant to one susceptible plant. A segregation ratio of one resistant to one susceptible plant was obtained in the backcrosses to the susceptible parent, while backcrosses to the resistant parent gave resistant progenies only (Table 2).

The results of inoculations of F_1, F_2 and BC progenies suggest that resistance to *F. oxysporum* f.sp. *cucumerinum* race 1 in WIS-248 be determined by a single dominant gene.

Allelism test. All progenies of the crosses (WIS-248 × SMR-18) × Ashley and (WIS-248 × SMR-18) (×) showed resistant reactions upon inoculation with *F. oxysporum* f.sp. *cucumerinum* race 1 (Table 3). These results indicate that the dominant gene in WIS-248 which confers resistance to race 1 is allelic to the *Fcu-1* gene found in SMR-18. Similarly, all progenies of the crosses (WIS-248 × SMR-18) × Ashley and (WIS-248 × SMR-18) (×) showed resistant reactions upon inoculation with *F. oxysporum* f.sp. *cucumerinum* race 2 (Table 3). These data indicate that the *Foc* gene in WIS-248, which confers resistance to race 2 is allelic to the *Fcu-1* gene found in SMR-18.

The dominant gene found in this study, which confers resistance to *F. oxysporum* f.sp. *cucumerinum* race 1 in WIS-248 and the *Foc* gene reported by Netzer

Table 2. Inheritance of resistance to *Fusarium oxysporum* f.sp. *cucumerinum* race 1 in the cucumber cv. WIS-248

Pedigree	Generation	Expected ratio[a]	Numbers of screened seedlings							
		R:S	0[b]	1	2	3	R[c]	S	X^2	P
Straight-8	P_1	All S	0	3	10	23	0	36		
WIS-248	P_2	All R	18	0	0	0	18	0		
$P_1 \times P_2$	F_1	All R	20	0	0	0	20	0		
$P_2 \times P_1$	F_1	All R	19	0	0	0	19	0		
$(P_1 \times P_2)$ selfed	F_2	3:1	55	3	5	11	55	19	<0.02	0.95–0.90
$(P_2 \times P_1)$ selfed	F_2	3:1	129	4	7	26	129	37	0.65	0.50–0.25
$P_1 \times (P_1 \times P_2)$	BC_1P_1	1:1	37	4	7	29	37	40	0.12	0.75–0.50
$(P_1 \times P_2) \times P_2$	BC_1P_2	All R	29	0	0	0	29	0		

[a] Assuming a single dominant locus for resistance. X^2 and P indicate the significance of the deviations of observed from expected ratios.
[b] Category of disease index rated on a scale 0–3, see text.
[c] R, resistant; S, susceptible.

Table 3. Allelism test for the *Fcu-1* gene and the dominant genes in WIS-248 conferring resistance to *Fusarium oxysporum* f.sp. *cucumerinum* races 1 and 2

Parents/crosses	Expected ratio[a]					
	Genes nonallelic and unlinked		Both genes allelic		Numbers of screened seedlings	
	Race 1 (R:S)	Race 2 (R:S)	Race 1 (R:S)	Race 2 (R:S)	Race 1 (R:S)	Race 2 (R:S)
Ashley	All S	All S	All S	All S	0:15	0:36
SMR-18	All R	All R	All R	All R	12:0	10:0
WIS-248	All R	All R	All R	All R	12:0	21:0
(WIS-248 × SMR-18) × Ashley	3:1	3:1	All R	All R	156:0	205:0
(WIS-248 × SMR-18) (×)	15:1	15:1	All R	All R	105:0	156:0

[a] R, resistant; S, susceptible.

et al. (1977), which confers resistance to race 2 in WIS-248 appear to be a single gene, which is allelic to the *Fcu-1* gene reported by Vakalounakis (1993, 1995), which confers resistance to *F. oxysporum* f.sp. *cucumerinum* races 1 and 2 in SMR-18. The symbol *Foc* of the resistance gene to both races 1 and 2 of *F. oxysporum* f.sp. *cucumerinum*, however, has priority in publication. Therefore, according to the rules of the gene nomenclature for the Cucurbitaceae (Robinson et al., 1976), we propose this symbol (*Foc*) be adopted for the resistance of cucumber to *F. oxysporum* f.sp. *cucumerinum* races 1 and 2.

Acknowledgements

The author thanks Professor P. H. Williams and Mrs Mary Palmer (Department of Plant Pathology, University of Wisconsin-Madison, USA) as well as the American Type Culture Collection (ATCC) for sending the isolates PHW #231 and #36330 of *Fusarium oxysporum* f.sp. *cucumerinum*, respectively. I gratefully acknowledge Dr. T. C. Wehner (Department of Horticultural Science, North Carolina State University, Raleigh, USA) and Dr. H. Komada (Shimane University, Faculty of Agrticulture Matsue, Japan) for supplying seeds of cucumber cv. WIS-248. I also thank Mrs Helen Petrakis and Mr Petros Kostas for technical assistance.

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