Short Communication

Foliar Reaction to *Phytophthora infestans* in Inoculated Potato Field Trials in Michigan

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ABSTRACT

Late blight, caused by *Phytophthora infestans*, is the most important disease of potato worldwide and foliar resistance is an important component of managing late blight in the field. The objective of this research was to identify germplasm for use in breeding cultivars with foliar resistance to *P. infestans*. More than 500 clones were tested from 1997 to 2002 in inoculated (US8 genotype) field experiments conducted at the Michigan State University Muck Soils Research Farm in Bath, Michigan. All of the current commercial cultivars tested were classified as susceptible to *P. infestans*. The most resistant clones were A90586-11, AWN86514-2, B0718-3, Jacqueline Lee (MSG274-3), MSI152-A, MSJ307-2, MSJ317-1, MSJ453-4Y, MSJ456-2, MSJ456-4, MSJ461-1, MSK101-2, MSK128-1, NY121, LBR8, LBR9, Tollocan, and Torridon. Some of these resistant selections were from crosses with B0718-3, Jacqueline Lee, and Tollocan suggesting that the resistance to *P. infestans* was transmissible. These resistant clones will provide the opportunity to breed late-blight-resistant cultivars from a diverse pool of cultivated germplasm. Consistent foliar reaction to *P. infestans* over years suggested that the Michigan State University Muck Soils Research Farm is a valuable location for North American breeders to assess the reaction of potato germplasm to the US8 genotype of late blight.

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INTRODUCTION

Potato late blight, caused by *Phytophthora infestans* (Mont.) de Bary, re-emerged in the mid-1980s and 1990s as a threat to cultivated potato (*Solanum tuberosum* L.) production (Fry and Goodwin 1997). The most prevalent genotype of *P. infestans* in the USA is currently US8 (Fry and Goodwin 1997); however, genotypes such as the original, metalaxyl-sensitive US1 and the metalaxyl-resistant US11 also are found, particularly in California, Washington, and Oregon (Dorrance and Inglis 1998). Currently, in the eastern USA, the US8 genotype dominates, although US11 was identified in Michigan in 1996 (Kirk unpublished data) and US17 in 1997 (Mayton et al. 2000).

One of the major goals of potato-breeding programs is to introduce new market-quality cultivars with levels of late blight resistance that exceed what is currently available (Douches et al. 1998). These cultivars also must possess agronomic qualities such as high yield, early or moderate maturity, unblemished internal flesh, high specific gravity, and be attractive in appearance (Dean 1994).

Field screening can be an effective method to evaluate foliar reaction to *P. infestans*. The Muck Soils Research Farm, located at Bath, Michigan, is the designated location for potato late blight research at Michigan State University (Figure 1). This location has been an ideal testing site for foliar reaction to *P. infestans* because (1) of its isolation from potato-production regions, (2) of a humid microclimate that is conducive to the development and spread of late blight disease, and (3) of consistent *P. infestans* infection levels over years. The purpose of this paper is to report on six years of evaluating foliar reaction to *P. infestans* in advanced potato germplasm

(advanced breeding clones and cultivars) from various potato breeding programs using the US8 genotype of *P. infestans*.

MATERIALS AND METHODS

Germplasm

More than 500 clones were evaluated between 1 and 6 years. The germplasm included (1) clones from National Late Blight Trial (Haynes et al. 1998); (2) susceptible commercial cultivars; (3) European cultivars with reported resistance to late blight; (4) advanced breeding clones from North American university breeding programs; and (5) International Potato Center (CIP) R gene-free late-blight-resistant selections obtained from the NRSP-6 US Potato Genebank, Sturgeon Bay, Wisconsin.

FIGURE 1.
Michigan State University Muck Soils Research Farm, Bath, Michigan, (star) shown in relation to major potato production areas in the state. Counties with 1000 acres of potato production (2000-2001 mean acres planted, NASS) or greater are shaded.

Preparation of P. infestans Inoculum

Isolates of *P. infestans* were collected from foliar tissue sent by growers to the Michigan State University Late Blight Pathology Laboratory for examination. Michigan *P. infestans* isolates 95-7, 97-2, 98-2, 99-9, 00-4 (all US8, A2 mating type, insensitive to metalaxyl [Goodwin et al. 1995]) were maintained on rye agar at 18 C. These Michigan isolates, used for inoculation in each year of the field study, overcame R genes either alone, or in combination (Table 1), as determined in laboratory detached-leaf tests (data not shown). A zoospore suspension of the selected isolates of *P. infestans* was prepared from cultures grown for 14 days on rye agar plates (Deahl et al. 1995) in the dark at 18 C. Prior to inoculation, the concentration was adjusted to 1 x 10^6 zoospores mL^{-1} based on hemacytometer readings. The inoculum suspension was administered (100 mL 7.5 m^{-1} row) through the field's irrigation system in late July (See Table 1 for inoculation dates).

Field Evaluation

Field tests were conducted from 1997 to 2002 at the Michigan State University Muck Soils Research Farm, Bath, Michigan. Planting date, inoculation date, and trial size are summarized in Table 1. Advanced breeding clones and cultivars were arranged in a randomized complete block design with three replications. Each 1.5-m plot contained four plants at 30-cm spacing, with eight plots per row. Following inoculation, plants were mist-irrigated frequently with a sprinkler system to prevent foliage from drying and to promote humidity within the canopy.

Percent foliar infection was visually assessed every 2 to 4 days following inoculation. Each year the evaluations continued for 28 to 39 days, concluding when the susceptible lines reached 100% infection. To compare the reactions of the potato lines across years, the relative area under the disease progress curve (RAUDPC) was calculated for each line.

TABLE 1—*Overview of late blight field trial experiments conducted at the MSU Muck Soils Research Farm, Bath, MI.*

Year	Planting date	Date of inoculation	No. of clones evaluated	Length of rating period (days)	Isolates used and avr genes absent	
1997	3 June	23 July	170	33	95-7*	1,2,3,4,5,6,7,10,11
1998	5 June	22 July	150	28	95-7, 97-2	1,3,4,5,8,11
1999	27 May	22 July	170	28	95-7, 98-2	1,2,3,4,5,7,10,11
2000	9 June	26 July	214	39	95-7, 99-9	1,2,3,4,5,6,7,8,9,10
2001	14 June	28 July	206	34	95-7, 00-4	1,2,3,4,5,6,7,8,9,10,11
2002	7 June	26 July	160	36	95-7	1,2,3,4,5,6,7,10,11

* 95-7 used each year. The avr genes of additional isolates are described.

RAUDPC is the area under the disease progress curve (AUDPC [Shaner and Finney 1977]) divided by the maximum AUDPC (100 X the total number of days after inoculation). Low RAUDPC values indicate low levels of infection over the evaluation period. Mean comparisons of RAUDPC values were accomplished using Fisher's protected least significant difference (LSD, $\alpha = 0.05$) in the general linear models procedure of SAS (SAS 2000). The LSD values are based on all entries in the trial for each year.

RESULTS AND DISCUSSION

Six years of field studies identified numerous advanced selections and cultivars with foliar resistance to *P. infestans*. In these trials, potato clones with RAUDPC values consistently less than 10 were considered resistant. These results are summarized in Table 2. Figure 2 shows resistant and susceptible plots in the late blight field trial approximately 30 days after inoculation with *P. infestans*. Some clones were tested over all six years, while other clones were evaluated one year. Efforts were made to test resistant lines at least three years; however, tuber availability limited further testing. In other cases, highly susceptible clones were discarded from the breeding programs.

The mean RAUDPC for each of the susceptible cultivars is an indication of the intensity of the late blight infection for the testing year. The years with the greatest late blight infection were 1998 and 2000, while 1997 was the lowest. Resistant clones were able to be consistently differentiated from susceptible ones each year.

The RAUDPC values for the late blight differential lines are found in Table 2. Except for LBD-LBR8 and LBD-LBR9, the differentials tested from 1998-2001 were susceptible. Similar results were obtained in other late blight testing locations (Haynes et al. 1998). The majority of the CIP R-free clones tested in 2001 were considered highly resistant; however, some clones exhibited susceptibility. The CIP clones, flowering until the frost in late September, had late maturity in comparison to commercial varieties.

The majority of the cultivars and advanced lines from public breeding programs demonstrated susceptibility to foliar *P. infestans* infection in the trials; however, cultivars such as Jacqueline Lee, Robijn, Libertas, Bzura, Tollocan, and Torridon had low RAUDPC values. Jacqueline Lee (MSG274-3) is a recent release with Tollocan as a resistance source (Douches et al. 2001). The "MS" lines in Table 2 are selections from the Michigan State University breeding program that have Brodick, B0718-3, Jacqueline Lee, Tollocan, or Torridon as a resistant parent. Many of these "MS" selections have foliar resistance to *P. infestans* combined with acceptable vine maturities and tuber characteristics under Michigan potato

FIGURE 2.
Late blight field trial ~30 days post inoculation with *P. infestans* at the Michigan State University Muck Soils Research Farm, Bath, Michigan.

TABLE 2—*RAUDPC values of select clones evaluated in inoculated late blight field trials from 1997 to 2002 at the Michigan State University Muck Soils Research Farm, Bath, MI.*

	RAUDPC (x100) Year					
Entry	1997	1998	1999	2000	2001	2002
Potato cultivars exhibiting foliar susceptibility to late blight						
Atlantic	16	35	24	32	25	23
Dark Red Norland	14	-*	29	32	30	24
Desiree	17	-	-	-	-	-
Dorita	3	19	14	-	-	-
Hampton	16	-	-	-	-	-
Lady Claire	-	-	29	33	-	-
Legend Russet	5	-	13	-	-	-
Onaway	18	37	31	43	31	27
Picasso	-	26	-	-	-	-
Pike	16	27	20	37	-	24
Ranger Russet	-	-	21	27	28	-
Russet Burbank	20	33	19	24	24	21
Russet Norkotah	24	38	18	31	25	23
Shepody	16	40	21	-	25	-
Snowden	11	35	19	27	16	18
Superior	-	39	25	36	25	25
Yukon Gold	19	36	24	28	14	17
Mean of Susceptible Cultivars	15	33	22	32	24	22
Late blight differentials (LBD)						
LBD-LBR0	2.8	8.4	-	-	-	-
LBD-LBR1	-	-	-	-	18.7	-
LBD-LBR1R2R3R4	4.1	19.9	20.6	15.7	-	-
LBD-LBR1R2R4	4.6	-	-	-	-	-
LBD-LBR1R3R4	3.9	-	-	-	-	-
LBD-LBR2	-	24.3	16.8	-	24.4	15.2
LBD-LBR3	6.6	27.3	18.4	-	17.4	12.6
LBD-LBR4	-	27	21.9	-	22.5	14.4
LBD-LBR5	-	18.2	17.6	17.1	13.2	9.6
LBD-LBR7	-	21.7	10.7	13.6	-	-
LBD-LBR8	0.9	0.6	3.4	0.3	0.0	0.0
LBD-LBR9	-	1.1	3.7	-	0.0	0.0
LBD-LBRMULTI	0.5	-	-	-	-	-
Potato cultivars exhibiting foliar resistance to late blight						
Bertita	2.9	20.5	-	-	-	-
Bzura	6.0	10.1	-	-	-	-
Greta	5.7	20.7	-	-	-	-
Jacqueline Lee (MSG274-3)	1.9	3.8	3.8	0.7	0.7	0.0
Libertas	6.4	-	-	-	-	-
Robijn	5.3	12.1	7.2	-	-	-
Stobrawa	5.0	17.4	-	-	-	-
Tollocan	-	-	2.0	-	-	-
Torridon	-	-	7.0	1.8	0.4	1.1
Zarevo	5.7	16.2	15.3	-	-	7.3
Elba	6.3	17.1	-	-	-	-
Lily	9.1	26.1	-	-	-	-
Matilda	11.5	28.7	-	-	-	-
Advanced potato breeding lines exhibiting foliar resistance to late blight†						
A90586-11	-	-	8.7	3.2	0.7	6.3
AWN86514-2	0.3	5.2	5.2	-	0.4	1.1
B0288-17	0.8	14.1	7.9	-	-	-
B0692-4	0.1	4.9	-	2.5	1.0	0.2
B0718-3	1.9	8.2	7.4	-	0.8	0.7

production conditions (Bisognin and Douches 2002). Some clones have shown tuber resistance in laboratory studies, but the level of tuber resistance has varied between seasons (data not shown). The "WTS" lines are advanced selections from the University of Wisconsin that have *S. bulbocastanum* as a resistance source (Naess et al. 2000). Strong resistance was identified, but further backcrossing of the "WTS" lines may be necessary to achieve commercial tuber types. A90586-11 is a long russet selection from AWN86514-2. Some cultivars with reported resistance to late blight were also evaluated (Bertita, Bzura, Greta, Libertas, Zarevo, Elba, Island Sunshine, Lily, and Matilda). In some years, reduced susceptibility was observed in these cultivars. Cultivars and advanced breeding lines with reduced susceptibility are candidates to be considered for fungicide-management studies to determine the best strategy to protect the foliage and reduce fungicide usage (Kirk et al. 2001). Based upon the pedigrees of the resistant and reduced-susceptibility germplasm evaluated, a diverse pool of cultivated germplasm is available for breeding late-blight-resistant cultivars.

Field screening can be an effective method to evaluate foliar resistance to late blight of advanced breeding lines and cultivars. Currently, Toluca Valley, Mexico, is a center of diversity for *P. infestans* and is viewed by potato breeders and plant pathologists as an ideal location to assess foliar resistance to *P. infestans*. One of the difficulties of effectively using the Toluca Valley site is overcoming the phytosanitary require-

TABLE 2—*Continued.*

Entry		RAUDPC (x100) Year 1997	1998	1999	2000	2001	2002
B0767-2		0.6	-	3.8	1.3	0.1	0.1
B1865-2		-	-	9.4	3.3	-	-
MSI058-4		-	-	-	8.6	-	-
MSI152-A		-	-	-	4.3	2.0	-
MSJ018-2		-	-	-	1.9	-	-
MSJ031-6		-	-	-	-	5.1	-
MSJ307-2		-	-	-	1.4	1.7	2.7
MSJ317-1		-	-	-	5.0	1.5	2.9
MSJ319-1		-	-	-	3.1	1.5	4.0
MSJ319-7		-	-	-	2.3	1.9	2.8
MSJ334-1Y		-	-	-	8.3	6.2	-
MSJ343-1		-	-	-	3.0	1.6	-
MSJ453-4Y		-	-	-	2.5	0.4	0.4
MSJ456-2		-	-	-	4.5	2.7	0.0
MSJ456-4		-	-	-	1.0	0.4	0.4
MSJ457-2		-	-	-	0.9	0.2	0.1
MSJ458-2		-	-	-	4.4	2.1	0.9
MSJ459-3		-	-	-	1.9	-	-
MSJ459-4		-	-	-	0.9	0.3	-
MSJ461-1		-	-	-	1.8	0.2	0.0
MSJ464-1		-	-	-	6.8	-	-
MSJ464-5		-	-	-	-	0.5	-
MSK034-1		-	-	-	6.8	6.2	6.1
MSK101-2		-	-	-	1.4	2.3	0.1
MSK106-A		-	-	-	-	-	0.0
MSK106-B		-	-	-	-	-	0.1
MSK123-5		-	-	-	-	-	3.5
MSK128-1		-	-	-	0.1	1.6	0.8
MSK128-A		-	-	-	-	-	0.3
MSK136-2		-	-	-	4	1.2	5.9
MSL211-3		-	-	-	-	-	2.8
MSL757-1		-	-	-	-	-	2.5
MSL766-1		-	-	-	-	-	0.0
ND6947B-15		-		9.6	-	-	-
NY121	(Q237-25)	-	5.1	4.5	1.7	-	-
WTS1212-1		-	-	-	-	0.1	-
WTS1212-6		-	-	-	-	0.2	-
WTS1216-4		-	-	-	-	0.8	-
WTS1217-3		-	-	-	-	1.7	-
WTS1217-4		-	-	-	-	0.6	-
WTS1217-7		-	-	-	-	0.3	-
International Potato Center (CIP) entries							
CIP 382178.14	LBR-01	-	-	-	-	0.3	-
CIP 386209.10	LBR-02	-	-	-	-	0.2	-
CIP 387004.13	LBR-03	-	-	-	-	0.1	-
CIP 387015.12	LBR-04	-	-	-	-	1.6	-
CIP 387015.13	LBR-05	-	-	-	-	1.6	-
CIP 387326.2	LBR-07	-	-	-	-	0.6	-
CIP 387348.20	LBR-08	-	-	-	-	0.6	-
CIP 387410.7	LBR-09	-	-	-	-	16.4	-
CIP 387411.40	LBR-10	-	-	-	-	7.9	-
CIP 387411.41	LBR-11	-	-	-	-	8.5	-
CIP 387413.21	LBR-12	-	-	-	-	1.5	-
CIP 387413.54	LBR-13	-	-	-	-	1.4	-
CIP 387415.6	LBR-14	-	-	-	-	24.4	-
CIP 387415.7	LBR-15	-	-	-	-	21.3	-

ments for U.S. to Mexico shipments. This requirement limits what material can be sent for testing on a yearly basis. In addition, the photoperiod, irradiation, light quality and resulting plant maturity differences may have a direct effect on the epidemiology of late blight (Harrison 1992).

The Muck Soils Research Farm, located in Bath, Michigan, has been an ideal testing site for foliar reaction to *P. infestans* because (1) of its isolation from potato production regions which allows timed inoculations to be done during the season, (2) of a humid microclimate that is conducive to the development and spread of late blight disease, and (3) of consistent *P. infestans* infection levels over the past 8 years. The Muck Soils Research Farm can complement the Toluca Valley as a late-blight-testing site. Germplasm that is identified as resistant to late blight in Michigan can then be targeted for future characterization in Toluca Valley. This two-tiered system may allow breeders to make more efficient progress in their efforts to breed late blight resistant cultivars.

TABLE 2—*Continued.*

Entry		RAUDPC (x100) Year 1997	1998	1999	2000	2001	2002
CIP 387415.26	LBR-16	-	-	-	-	0.9	-
CIP 387415.32	LBR-17	-	-	-	-	4.2	-
CIP 387315.27	LBR-18	-	-	-	-	0.2	-
CIP 381400.22	LBR-19	-	-	-	-	2.1	-
CIP 387205.5	LBR-20	-	-	-	-	0.2	-
CIP 387411.49	LBR-23	-	-	-	-	4.7	-
CIP 387415.40	LBR-24	-	-	-	-	1.6	-
CIP 387415.47	LBR-25	-	-	-	-	14.2	-
CIP 387415.49	LBR-26	-	-	-	-	14.2	-
CIP 386209.1	LBR-29	-	-	-	-	0.2	-
CIP 387002.11	LBR-32	-	-	-	-	19.6	-
CIP 387004.4	LBR-33	-	-	-	-	0.8	-
CIP 387006.5	LBR-34	-	-	-	-	1.7	-
CIP 387132.2	LBR-37	-	-	-	-	0.2	-
CIP 387136.14	LBR-38	-	-	-	-	0.4	-
CIP 387143.22	LBR-39	-	-	-	-	0.5	-
CIP 387164.4	LBR-40	-	-	-	-	0.1	-
CIP 387170.9	LBR-43	-	-	-	-	0.0	-
CIP 387312.2	LBR-46	-	-	-	-	1.8	-
CIP 387334.5	LBR-47	-	-	-	-	18.0	-
CIP 387338.3	LBR-50	-	-	-	-	0.2	-
$LSD_{0.05}$		11.5	6.6	8.4	8.0	10.2	7.0

Mean separation by Fisher's protected LSD, $\alpha = 0.05$. LSD values are based on all entries in the trial for each year.

* - not tested

†Advanced breeding lines were from the following sources: A: USDA-ARS, ID; B: USDA-ARS, MD; MS: Michigan State University; ND: North Dakota State University; NY: Cornell University; WTS: University of Wisconsin.

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