Inheritance of Resistance to *Pyrenophora teres* in Minnesota Barley

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ABSTRACT

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Four hundred University of Minnesota barley breeding lines and cultivars were evaluated for resistance to net blotch caused by *Pyrenophora teres* f. *teres* in the glasshouse. Most of the barleys were susceptible but 50 were moderately resistant or resistant. The source of resistance was probably line ND B-112, which has been extensively used as a source of resistance because it is reported to be resistant to both spot and net blotches. The resistance appeared to be simply inherited and was probably conditioned by one gene, or perhaps two genes in some parents.

The relative importance of net blotch caused by *Pyrenophora teres* Drechs. in barley (*Hordeum vulgare* L.) has increased during the past decade in the northern barley growing areas of Minnesota (21). This has happened, in part, because spot blotch, caused by *Bipolaris sorokiniana* (Sacc.) Shoemaker, has declined because of the widespread cultivation of resistant cultivars like Morex and Robust (7,8). Unfortunately, these two cultivars are susceptible and moderately susceptible, respectively, to prevalent isolates of *P. teres* in the field (21).

Resistant cultivars are needed to adequately manage net blotch in Minnesota and in many other areas where barley is produced. To begin a resistance breeding program, we prefer, if possible, that the parents be cultivars or breeding lines that are presently in the program to avoid the problems associated with unwanted genes from exotic germ plasm. Fortunately, Sayoud (10) documented sources of resistance in some lines of the Minnesota barley breeding program, and, in addition, resistant lines have been observed in barley nurseries at Crookston and Stephen, MN, where natural epidemics frequently occur.

The objectives of this study were to identify, in the glasshouse, sources of resistance to *P. teres* in some of our breeding lines and to study the inheritance of resistance.

MATERIALS AND METHODS

Four hundred barley genotypes in the Minnesota program, including those listed in Table 1, were evaluated in the glasshouse for net blotch reactions. Heartland and Larker were used as check cultivars because they had consistently been resistant and susceptible in the field, respectively. Heartland also has been resistant in Canada (20). Experiments were made once each fall or winter of 1983, 1984, 1985, 1988, and 1989 with 20–30 plants per genotype. Experiments in 1988 and 1989 were repeated twice.

Inheritance of resistance to net blotch was studied in 12 crosses (Table 2) involving resistant or moderately resistant advanced breeding lines and susceptible or moderately susceptible agronomically elite cultivars Excel or Robust (8,9) or advanced breeding lines M 46 and M 47. Six crosses were evaluated in 1985 and another six in 1988. Resistant parents of two crosses in 1988 were selections from the 1985 test: M 85-425 was from M 81-160/Robust and M 85-424 was from Park/Robust. About 100 F_3 families of each cross were prepared by harvesting, without selection, 100 spikes from single F_2 plants. After evaluation of individual F_3 plants, the F_3 families were grouped by cross into resistant, segregating, and susceptible categories. Goodness-of-fit to the genetic ratio of 1:2:1 was tested using the chi-square test (13).

The possibility that different genes conditioned the resistant reactions of some of the parents used in the inheritance study was tested with eight resistant × resistant crosses (Table 3). From each cross, 300 or more F_2 plants (the number varied with the cross) were evaluated for net blotch reactions in the glasshouse.

Net blotch reactions were evaluated between November and March of 1983, 1984, 1985, 1988, and 1989 in a glasshouse maintained at about 20 C with supplemental light provided by fluorescent tubes (about 198 $\mu E \cdot m^{-2} \cdot s^{-1}$) for 12 hr per day. For each experiment, plants of each genotype, family, or line were inoculated when the third leaf was visible. Inoculated plants were kept moist in the darkness in a mist chamber at 16–20 C for about 24 hr before being returned to the glasshouse.

All experiments included an isolate of *P. teres* f. *teres* that had been isolated at Crookston, MN, in 1982 from the cultivar Morex and stored in liquid nitrogen until needed. After removal from liquid nitrogen, the isolate was stored in soil or silica gel until just before experiments were conducted. Inoculum was prepared by scraping cultures from the surface of 10-day-old cultures grown on V8 juice agar into sterile water containing Tween 20 (one drop per 400 ml of water). The suspension, containing about 20,000 conidia per milliliter, determined with a hemacytometer, was sprayed onto leaf surfaces with an Olympic Polyspray (Olympic Co., Mainland, PA) until they were dripping wet.

Plants were scored for net blotch 7–10 days after inoculation with the numerical qualitative Tekauz scale (16). They were considered resistant when the disease score did not exceed 3 on the scale, moderately resistant when the score was 4 or 5, moderately susceptible when the score was 6 or 7, and susceptible when the score was 8 or more. Plants of F_3 families were evaluated individually and the family was classed as resistant (resistant and moderately resistant plants), susceptible (moderately susceptible and susceptible plants), or segregating (plants of each classification were present in the family).

RESULTS

All plants of the genotypes tested became infected. Resistant plants displayed minute lesions with little or no chlorosis, moderately resistant plants had larger lesions with some chlorosis, moderately susceptible plants had lesions with some netting and chlorosis, and susceptible plants had large lesions with netting and severe chlorosis and necrosis. Barley genotypes that were being used in the breeding program, or were likely to be used for that purpose, or were parents in the inheritance study were grouped into different disease reaction classes (Table 1). Barleys that were similar to resistant Heartland included Park, JR4T-2, M 76-160, M 81-111, M 83-212, M 85-424, M 85-425, M 34, and M 39. Lines M 81-160, M 82-142, and M 60 were intermediate in net blotch reaction and were considered to be moderately resistant to moderately susceptible. The remaining cultivars and lines were

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moderately susceptible to susceptible (Table 1).

Parents that were resistant to the net blotch pathogen and used in the inheritance study were reevaluated for net blotch reactions when progenies of the crosses were tested. Their reactions were similar to those shown in Table 1. The segregation of F_3 families in 11 crosses was consistent with that of a single resistance gene (Table 2); however, with cross Park/Robust, the data did not fit the single gene model.

F_2 plants of the resistant × resistant crosses M 81-160/M 81-111, M 81-160/JR4T-2, Park/M 76-160, and JR4T-2/M 76-160 were resistant or moderately resistant (Table 3). Some F_2 plants of the four remaining crosses were moderately susceptible or susceptible.

DISCUSSION

A major goal of the Minnesota barley improvement program has been to develop disease-resistant cultivars for growers and industrial users (21). Currently released cultivars are resistant to spot blotch and to commonly occurring races of the wheat stem rust pathogen, except race QCC (7–9). Race QCC is virulent on Minnesota genotypes as well as other genotypes that carry the T gene for stem rust resistance (R. D. Wilcoxson et al, *unpublished*). However, Morex does not possess an adequate level of resistance against net blotch to satisfy the needs of the barley industry, and Robust and Excel also may lack enough resistance. Robust, the leading cultivar in Minnesota, has an intermediate level of resistance to net blotch that may be adequate. Excel also has an intermediate level of resistance to the pathogen in Minnesota field trials, but its resistance is not as high as that of Robust. Because Excel has just recently been released, it is too early to speculate about how useful it will be in the management of net blotch.

The present study corroborates a previous study that sources of resistance to *P. teres* are in the current germ plasm pool of the Minnesota barley breeding program (10). Inheritance of resistance was relatively simple and resistance genes were readily transferred to progenies.

Since 1983, four hundred barley genotypes have been evaluated for reaction to *P. teres* in the glasshouse. Most of these genotypes were too susceptible to be useful, but 50 were resistant or moderately resistant. In addition to resistance to the net blotch pathogen, these lines also carry resistance to spot blotch and to the common races of wheat stem rust, except race QCC (R. D. Wilcoxson et al, *unpublished*).

P. teres in Minnesota consists of forma *teres* but forma *maculata* has not been observed; however, forma *maculata* has been reported from Canada and Montana (15).

P. t. teres consists of different pathogenic races in several barley growing regions (10,12,14,17,19). This suggests that the pathogen may rapidly adapt to resistant cultivars after they are released. More thorough studies are needed on the distribution and origin of pathogenic races in the upper midwestern United States to provide basic information about the potential of the pathogen to produce disease, as well as to provide material for breeding resistant cultivars. Limited studies (10,15) indicate that different races of *P. t. teres* occur in Minnesota, but their distribution and ecology are unknown and the mechanism of their origin is poorly understood.

The use of the controlled environments of glasshouses or environmental chambers increases the efficiency of net blotch evaluation programs and should facilitate the development of resistant cultivars. In controlled environments, plants may be inoculated with different isolates of the pathogen and be kept in conditions that favor disease development. After completion of tests in controlled environments, the resistance of survivors may be confirmed under natural conditions in the field. Although we have not made extensive comparisons of cultivars in glasshouse and field experiments, the reactions noted in the glasshouse are often as severe as those observed in the

Table 1. Net blotch reactions of selected barley genotypes and breeding lines in the University of Minnesota breeding program and of check genotypes infected with *Pyrenophora teres* in the glasshouse

Genotype[a]	Pedigree[b]	Reaction[c]
Heartland (CR 2434)	Klondike/BT 146	R
Larker (CI 10648)	Trail//Newal/Peatland//Montcalm	S
Excel (PI 54207)	Robust 2/3//Cree/Bonanza//Manker	MS *
Morex (CI 15773)	Cree/Bonanza	S
Park (CI 15768)	Dickson/3/CI 4738//Trail/UM570/4/ND B133	R *
Robust (PI 476976)	Morex/Manker	MR-MS *
JR4T-2	Not known	R *
M 76-160	M 72-345/M 32	R *
M 81-111	M 77-276/M 39	R *
M 81-160	M 78-825/ND 4028	MR-MS *
M 82-142	M 79-840/M 79-20	MR-MS *
M 83-212	M 46/M 79-267	R-MR *
M 85-424	Park/Robust	R-MR
M 85-425	M 81-160/Robust	R-MR *
M 34	Cree/Bonanza//Manker	R-MR
M 39	Morex/Manker/M 30	MR
M 46	Nordic/Manker/Robust	MS *
M 47	Nordic/Manker/Robust	MS-S *
M 55	Nordic/Manker/2/Robust/3/M 34	MS-S
M 60	Robust/3/Bowers/M 34/Morex	MR-MS
M 64	Excel/Robust/Bumper	MS-S

[a] CR = Canadian Registration number, CI = Cereal Investigation Number, PI = Plant Introduction Number.
[b] More complete pedigrees can be obtained by corresponding with D. C. Rasmusson, Department of Agronomy and Plant Genetics, University of Minnesota.
[c] R = resistant, MR = moderately resistant, MS = moderately susceptible, and S = susceptible. Based on reactions of 20–30 plants tested once in 1983, 1984, and 1985 and in three replications in 1988 and 1989. Asterisks indicate parents for inheritance study.

Table 2. Number of F_3 families that were resistant (R), segregating (seg), or susceptible (S) of crosses between resistant or moderately resistant and moderately susceptible or susceptible barleys when infected with *Pyrenophora teres* in the glasshouse

Cross	Family (no.)	Class			Hypothesis tested	χ^2	*P*
		R	Seg	S			
1985							
Robust/JR4T-2	91	21	49	21	1:2:1	0.54	0.80–0.70
Robust/M 76-160	130	36	62	32	1:2:1	0.52	0.80–0.70
M 76-160/M 46	100	22	45	33	1:2:1	3.42	0.20–0.10
M 81-111/Robust	104	18	61	25	1:2:1	4.06	0.20–0.10
M 81-160/Robust	113	23	65	25	1:2:1	2.63	0.30–0.10
Park/Robust	90	15	55	20	1:2:1	5.00	0.10–0.05
1988							
M 83-212/Robust	105	26	51	28	1:2:1	0.16	0.95–0.90
M 82-142/M 47	94	21	53	20	1:2:1	1.55	0.70–0.50
M 85-425/M 47	195	45	102	48	1:2:1	0.51	0.80–0.70
M 82-142/Excel	97	18	49	30	1:2:1	2.87	0.30–0.20
M 85-424/Excel	181	48	95	38	1:2:1	1.55	0.50–0.30
M 83-212/Excel	97	25	50	22	1:2:1	0.28	0.90–0.80

Table 3. Number of F_2 plants of eight resistant × resistant barley crosses in different net blotch classes when infected with *Pyrenophora teres* in the glasshouse

Cross	Class[a]			
	R	MR	MS	S
M 81-111/JR4T-2	298	29	14	3
M 81-111/Park	300	43	4	0
M 81-160/M 81-111	255	52	0	0
M 81-160/JR4T-2	338	12	0	0
Park/M 81-160	220	82	33	18
Park/JR4T-2	297	37	6	0
Park/M 76-160	348	2	0	0
JR4T-2/M 76-160	359	0	0	0

[a] R = resistant, MR = moderately resistant, MS = moderately susceptible, and S = susceptible.

field. Furthermore, the net blotch reactions of juvenile barley plants are similar to those of adult plants (10).

Resistance to the net blotch pathogen that is present in some lines in the Minnesota program may have originated with line ND B-112 (CI 11531). ND B-112 has been reported to be a source of resistance to both the spot blotch and the net blotch pathogens (6,21). This line and other lines and cultivars that trace to it have been widely used to develop cultivars presently grown in the upper midwestern United States (21).

Barley genotypes M 76-160, Park, and JR4T-2 may be genetically similar for net blotch resistance because, in crosses among these sources, all F_2 plants were resistant or moderately resistant. Genotypes Park, M 81-160, M 81-111, and JR4T-2 may differ genetically for net blotch resistance because in their crosses, F_2 plants were found that were moderately susceptible and susceptible. The relationship among resistance genes of the other sources of resistance is less clear because a few moderately susceptible F_2 plants were identified. It is possible that these moderately susceptible plants were misidentified because it is sometimes difficult to distinguish between moderately resistant and moderately susceptible classes (17). The net blotch reactions of F_2 plants were checked with four F_3 families of each cross derived from single resistant F_2 plants. Between 40 and 90 plants per F_3 family were evaluated. In each family, most plants were resistant, but between two and 10 plants per cross (number varied with the cross) were rated moderately resistant and none were moderately susceptible or susceptible.

Resistance to *P. teres* in breeding lines of the Minnesota Breeding Program is probably conditioned by only a few genes. Data from 11 crosses suggest that a single gene is involved and those from one cross suggested that perhaps at least another gene may be involved. Others also have reported that resistance to net blotch is conditioned by one or two genes and that partial dominance occurs (1–5, 11,12). The incorporation of genes for resistance to isolates of *P. teres* that occur in Minnesota into adapted cultivars should be relatively easy.

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