Races of *Puccinia graminis* Identified in the United States During 2003

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ABSTRACT

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Stem rust of small grain cereals, caused by *Puccinia graminis*, is a major disease of wheat, barley, and oat. In order to effectively utilize stem rust resistance in the improvement of small grain cereals, it is necessary to monitor the virulence composition and dynamics in the stem rust population. Races of *P. graminis* from barberry, wheat, barley, and oat were surveyed across the United States during 2003. Aecial infections on barberry were primarily due to *P. graminis* f. sp. *secalis*, as inoculations using aeciospores failed to produce infection on wheat and oat. Race QFCS of *P. graminis* f. sp. *tritici* was the most common race identified from wheat and barley. Race QFCS has virulence on stem rust resistance genes *Sr5, 8a, 9a, 9d, 9g, 10, 17*, and *21* that are used for race identification. Race TTTT was identified in 2003. This race possesses virulence to all 16 stem rust resistance genes present in the wheat stem rust differentials and should be targeted in breeding for stem rust resistance. Race QFCN appeared to be a new race in the U.S. stem rust population. Races QCCJ and MCCF were identified, but at low frequencies. Seven races of *P. graminis* f. sp. *avenae* were identified from oat, and races NA-27, NA-29, and NA-67 were the predominant races. Race NA-76 was identified for the first time in the United States.

Stem rust of small grain cereals, caused by *Puccinia graminis*, is a major disease of wheat, barley, and oat. Significant yield losses occurred when the disease developed into epidemic proportions in small grain crops (6). The use of effective resistance in major cereal production regions in the United States, in combination with the interruption of disease cycle (i.e., the eradication of the alternate host), has brought the disease under control. Race surveys, commenced annually throughout major cereal-producing states in the United States and Prairie Provinces of Canada, reveal race composition at a specific time/location in the stem rust population and the changes of races over time. This information, in turn, is used to guide the utilization of stem rust resistance genes in crop improvement. This report summarizes races of *P. graminis* identified on small grain cereals during 2003.

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MATERIALS AND METHODS

Isolation from aecial collections. Leaves of *Berberis* spp. (primarily *B. vulgare*) bearing mature aecia of *P. graminis* were collected and air-dried. Leaves were placed over a wire mesh, covered by two to three layers of moistened paper towel, and suspended over the seedlings of an "identification series" for *forma specialis* (f. sp.) of *P. graminis*. The identification series consisted of stem rust susceptible genotypes of wheat (cv. McNair 701 and Line E), barley (cv. Hiproly), rye (cv. Prolific), and oat (cv. Marvelous). Plants were incubated in a dew chamber for 24 h in the dark and exposed to light in the dew chamber for 4 h. Under a moistened condition during the inoculation period, aecia rehydrated rapidly and aeciospores were released, producing infection on seedlings of cereals. A *forma specialis* was determined based on infection on different plants on the identification series as follows: (i) infection (i.e., producing compatible uredinia) on wheat and barley but not rye and oat was indicative of *P. graminis* f. sp. *tritici* (Pgt); (ii) infection on rye and barley but not wheat and oat was indicative of *P. graminis* f. sp. *secalis* (Pgs); and (iii) infection on oat but not others was indicative of *P. graminis* f. sp. *avenae* (Pga). Line E, one of the wheat lines in the identification series, is generally susceptible to Pgs in addition to its susceptibility to Pgt. Therefore, discriminating between Pgt and Pgs from infection on Line E was done based on infection on McNair 701, because this wheat line is highly resistant to most isolates of Pgs, while it is highly susceptible to a majority of isolates of Pgt.

Isolation from uredinial collections. Annual survey routes, timing, and protocols for sample collections described by previous workers (5,8) were followed. Stem and leaf tissues of wheat, barley, oats, or other grasses bearing uredinia of *P. graminis* were collected from fields and nurseries across the United States. Samples were air-dried and kept in a refrigerator at 3°C. Urediniospores were collected from the samples using a mini-cyclone spore collector, suspended in a lightweight mineral oil, and then inoculated onto seedlings of McNair 701 for samples from wheat and Marvelous for samples from oat and wild oat. Uredinial collections from barley, rye, and other grasses were inoculated onto the identification series first to determine the correct *forma specialis*, following the aforementioned procedure in the isolation of aecial collections.

Determination of races. Two to three single-pustule isolates were derived from each collection and then inoculated onto 7-day-old seedlings of the differential lines. Seedlings were incubated in a dew chamber for 14 h at 18°C in the dark, and then for an additional period of 3 to 4 h under fluorescent light. Plants were further incubated in a greenhouse at 18 ± 2°C with a photoperiod of 16 h. For wheat stem rust, a set of 16 lines with single stem rust (*Sr*) resistance genes used as the differentials of Pgt races were grouped into four subsets in the following order: (i) *Sr5, 21, 9e, 7b*; (ii) *11, 6, 8a, 9g*; (iii) *36, 9b, 30, 17*; and (iv) *9a, 9d, 10, Tmp* (7,9). Infection types, described by Roelfs and McVey (10) and Stakman et al. (11) on designated *Sr* genes, were assessed 14 days postinoculation. Each isolate was assigned to a four-letter race name based on its reaction on the differential lines. Races that appeared to be different from the conventional races were tested against single gene lines with *Sr* genes that have been considered universally resistant and selected cultivars (5,7). The differentials for oat stem rust include single gene lines *Pg1, 2, 3, 4, 8, 9, 13, 15, 16*, and the *Pg-a* complex. Races were assigned following the NA (North America) nomenclature system that assigns a race number chronologically based on the sequence of first appearance as a new race (2,3).

RESULTS AND DISCUSSION

Stem rust on common barberry. In 2003, common barberry bushes in southeastern Minnesota were heavily infected by *P. graminis*. The severity was so high that most of the bushes were defoliated. Aecial collections were made from these bushes as well as from common barberry plants in south central Wisconsin. In the greenhouse inoculation experiments using aeciospores, all collections produced infections on Prolific rye and Hiproly barley on the identification series. Infection on Line E was variable, and no infection was observed on McNair 701 wheat and Marvelous oat. Further inoculations using urediniospores resulting from Prolific, Hiproly, and Line E failed to produce infections on any of the wheat stem rust differential lines. This indicated that aecial infections on the barberries were primarily of *P. graminis* f. sp. *secalis*, and that *P. graminis* f. sp. *tritici* or f. sp. *avenae* was either absent or present at a low level that was undetectable using our sampling technique.

***P. graminis* f. sp. *tritici* identified from wheat.** Wheat stem rust in 2003 was first observed in mid-April in a plot of the susceptible cultivar McNair 701 at Uvalde in southern Texas. Trace amounts of stem rust were also found in cultivar McNair 701 and other susceptible wheat lines in north central Oklahoma and at Baton Rouge, LA. Stem rust was observed on susceptible lines and trap plots of spring wheat throughout the northern Great Plains in mid- to late July, but the incidence was low, likely due to a lack of sufficient inoculum produced in the southern and central Great Plains.

Race QFCS was the most common race of *P. graminis* f. sp. *tritici* identified from wheat samples collected in 2003 (Table 1). This race has been one of the major components in the wheat stem rust population in the United States since the late 1980s. Race QFCS has virulence on *Sr5, 8a, 9a, 9d, 9g, 10, 17*, and *21*. Several hard red winter and soft wheats were found to be susceptible to QFCS based on seedling tests, including Thunderbolt, Onaga, Ankor, Nufrontier, Lakin, Truman, Roane, and Additions (data not shown). However, the majority of wheat cultivars grown in the United States are resistant to race QFCS. Race QCCJ, a race virulent on the *Rpg1* gene in barley, occurred at a very low frequency in comparison with previous years. One collection from a winter wheat in North Dakota was identified as race MCCF.

Table 1. State, source, and frequency of races of *Puccinia graminis* f. sp. *tritici* identified from wheat in 2003

		Number		Number of isolates of Pgt race[a]			
State	Source	Collections	Isolates	QCCJ	QFCS	MCCF	TTTT
Minnesota	Field	1	3		3		
Minnesota	Nursery	5	9	3	6		
North Dakota	Nursery	11	25		24	1	
Oklahoma	Nursery	1	3		3		
South Dakota	Nursery	2	5		5		
Texas	Nursery	5	10		9		1
U.S.	Field	1	3		3		
	Nursery	24	52	3	47	1	1
	Total	25	55	3	50	1	1
	% (of total)			5.5	90.9	1.8	1.8

[a] Pgt race code, after Roelfs and Martens (9), and set four consists of *Sr9a, 9d, 10,* and *Tmp* (7).

Table 2. State, source, and frequency of races of *Puccinia graminis* f. sp. *tritici* identified from cultivated and wild barley (*Hordeum jubatum*) in 2003

		Number		Number of isolates of Pgt race[a]		
State	Source	Collections	Isolates	QCCJ	QFCS	QFCN
Minnesota	Nursery	4	8		8	
	H. jubatum	4	9		8	1
North Dakota	Nursery	6	12	2	9	1
South Dakota	Nursery	1	2		2	
	H. jubatum	6	12	3	9	
U.S.	Nursery	11	22	2	19	1
	H. jubatum	10	21	3	17	1
	Total	21	43	5	36	2
	% (of total)			11.6	83.7	4.7

[a] Pgt race code, after Roelfs and Martens (9), and set four consists of *Sr9a, 9d, 10,* and *Tmp* (7).

Table 3. State, source, and frequency of races of *Puccinia graminis* f. sp. *avenae* identified from cultivated and wild oat in 2003

		Number		Isolates (%) of NA race[a]						
State	Source	Collections	Isolates	5	10	27	29	30	67	76
Alabama	Nursery	3	8			1	4		1	2
California	Nursery	4	9	1	5	3				
Illinois	Nursery	4	12				11		1	
Kansas	Field	1	3				3			
Kansas	Nursery	3	9			5	1		3	
Louisiana	Nursery	4	10			3	3		4	
Minnesota	Field	1	3						3	
Minnesota	Nursery	10	27			4	17		6	
Minnesota	*A. fatua*	1	2				2			
North Dakota	Nursery	6	15				5		8	2
North Dakota	*A. fatua*	2	5				4		1	
Nebraska	Field	4	5			1			4	
South Dakota	Field	1	3				2		1	
South Dakota	Nursery	3	8			2	2		4	
Texas	Nursery	11	32			10	5	2	15	
Texas	*A. fatua*	2	4			2			2	
Wisconsin	Nursery	1	3				1		2	
U.S.	Field	7	14			1	5		8	
	Nursery	49	133	1	5	28	49	2	44	4
	A. fatua	5	11			2	6		3	
	Total	61	158	1	5	31	60	2	55	4
	% (of total)			0.6	3.2	19.6	38.0	1.3	34.8	2.5

[a] NA race number, after Martens et al. (3) and Harder (2).

Table 4. Avirulence and virulence of races of *Puccinia graminis* f. sp. *avenae* identified from U.S. collections in 2003

Race[a]	Avirulence on *Pg* genes	Virulence on *Pg* genes
NA-5	1,2,4,8,9,13,16,a	3,15
NA-10	1,4,8,9,13,16,a	2,3,15
NA-27	9,13,15,16,a	1,2,3,4,8
NA-29	9,13,16,a	1,2,3,4,8,15
NA-30	13,16,a	1,2,3,4,8,9,15
NA-67	16,a	1,2,3,4,8,9,13,15
NA-76	15,16,a	1,2,3,4,8,9,13

[a] NA race number, after Martens et al. (3) and Harder (2).

Race TTTT and its virulence spectrum. Race TTTT was isolated from a collection from Texas in 2003. This race was first identified from a collection in Texas in 2000 and from Minnesota the following year (D. McVey and D. Long, *unpublished*). This race possesses virulence to all 16 *Sr* genes present in the differentials. However, a number of *Sr* genes (namely *Sr13, 22, 24, 25, 26, 27, 29, 31, 32, 33, 35, 37, 39,* and *40*) and most spring wheat cultivars grown in the northern Great Plains were resistant to this race (data not shown). The identities of *Sr* genes conferring resistance to race TTTT in spring wheat are unknown, but *SrWld1* derived from Waldron might be a part of the *Sr* gene complex present in most spring wheat cultivars. On a larger set of designated *Sr* genes, the virulence spectrum of race TTTT does not seem broader than that of TPMK, a race historically significant in the North American stem rust population. Nevertheless, the occurrence of this unique virulence combination is of concern because several important *Sr* genes (*Sr6, 10, 36,* and *Tmp*) utilized for stem rust resistance in many winter wheat cultivars would become ineffective if they were deployed singly. Thus, this race should be a target of breeding for stem rust resistance in winter wheat in the United States. For this reason, race TTTT was used as part of a race-complex to evaluate advanced breeding materials from various breeding programs in the United States (Y. Jin, *unpublished*).

***P. graminis* f. sp. *tritici* identified from barley.** The first report of barley stem rust in 2003 was in early July on susceptible two-rowed cultivars in plots in southern Minnesota. By late July, trace to 40% stem rust severities with very low incidence (<5%) were observed in spring barley varietal plots throughout North Dakota, while traces were observed in fields. In plots in northwestern Minnesota, up to 10% stem rust severities were observed. Most infections were on late tillers.

Similar to samples from wheat, the main race identified from barley and wild barley (*Hordeum jubatum*) samples was QFCS (Table 2). This race is avirulent on barley with the *Rpg1* gene. Race QCCJ, a race virulent on the *Rpg1* gene and causing localized epidemics between 1989 and 1993 (8), was identified from samples from barley and wild barley. Race QFCN, isolated from a barley sample, appeared to be a new race, and it is different from race QFCS by avirulence on *Sr9d*. This is a relatively unusual virulence combination because avirulence on *Sr9d* is not common and has not been found in this race group. A mutation of race QFCS toward avirulence on *Sr9d* would result in QFCN; however this has not been demonstrated experimentally. The virulence of QFCN on *Rpg* genes in barley has not been characterized yet.

***P. graminis* f. sp. *avenae* identified from oats and wild oat.** Oat stem rust was found in southeastern Texas in mid-February, and in Louisiana and Alabama in March and April. Although this was one of the earliest years for initial reporting of oat stem rust, the disease level was less than normal in the southern United States. Stem rust was found on cultivated oat and wild oat (*Avena fatua*) throughout the Great Plains and the Midwest, but severities were relatively low. However, severity up to 100% was observed at some locations. Seven races were identified from collections in 2003 (Table 3), and the avirulence/virulence formula of these races is given in Table 4. Three races, NA-27, NA-29, and NA-67, comprised the majority (94%) of isolates from the survey collections. These three races are widely distributed in the United States and have been predominant in the oat stem rust population in North America in recent years (1,5). Race NA-76 (avirulence/virulence formula: *Pg15, 16, a/1, 2, 3, 4, 8, 9, 13*), first reported in Canada (4) in 1999, was identified in the United States for the first time in 2003. Race NA-76 is similar to NA-67 but avirulent on *Pg15*.

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