Races of *Puccinia graminis* in the United States and Mexico During 1986

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ABSTRACT

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Oat stem rust was present in light amounts throughout most of the United States in 1986, and yield losses were small except in central Minnesota and northern Wisconsin, where moderate losses occurred on late-planted oats. Disease development was generally more than a week later than the 40-yr average. The principal race in the United States and Mexico was NA-27, virulent on hosts with resistance genes *Pg*-1, -2, -3, -4, and -8. NA-27 constituted 89 and 100% of the isolates from the United States and Mexico, respectively. No virulence for *Pg*-a was found in oat stem rust. Wheat stem rust overwintered in trace amounts within an 80-km band from southern Texas to southern Alabama. Overwintering sites were found near Beeville and Victoria in southern Texas in early April. Additional overwintering sites were found in the Mississippi Valley into central Arkansas and along the Red River in southern Oklahoma in late April. Stem rust spread northward into Kansas and Nebraska by late May and into the northern Great Plains by mid-June. Although stem rust occurred on some hard red spring wheat cultivars resulting in slight losses, the recommended cultivars had adequate resistance and losses were nil. Race 15-TNM, virulent on plants with *Sr*17, was the most common virulence combination, making up 96% of the 1,582 isolates from 581 collections. The second most common race was 15-TNM, avirulent on *Sr*17, which made up 1% of the isolates. No virulence was found for wheat lines with "single" genes *Sr*13, 22, 24, 25, 26, 27, 29, 31, 32, 33, 37, Gt, and Wld-1.

Puccinia graminis (*P. g.*) Pers. has been a major pathogen of many small-grain cereals and forage grasses worldwide. Since the virtual elimination of susceptible barberry bushes from cereal-producing areas of the northern Great Plains, epidemics have been less frequent (8). Nevertheless, windborne uredospores resulted in devastating epidemics (7) of stem rust on wheat in 1935, 1937, 1953, and 1954 and on oats in 1953 in the northern Great Plains. Resistant cultivars are continually being developed to prevent such epidemics, but they in turn may become susceptible to new pathogen races. Thus, monitoring pathogen virulence to detect shifts in the pathogen population has been a part of the program to avoid crop losses. The data from these surveys also provide information on the effects of changes in host resistance on pathogen virulence frequency and distribution.

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MATERIALS AND METHODS

Field surveys were made over a 21,000-km route covering the Great Plains and the Gulf Coast of the United States. The surveys followed a preselected, generally circular route through areas where small-grain cereals are important and rust historically had been a problem. Observations for the presence of rust were made at commercial fields every 32 km or at the first field thereafter. Additional stops were made at experimental nurseries and wheat trap plots along the route. Whenever rust was observed in a field or nursery, leaves or stems bearing rust uredia from a single plant or cultivar were collected. These collections were supplemented by others furnished by cooperators throughout North America.

In 1986, field surveys were made in the following areas: southern Texas (early April), northern Texas (late April), Gulf Coast states (early May), Oklahoma and Kansas (mid-May), Nebraska and South Dakota (mid-June), eastern Dakotas and Minnesota (early July), and north central United States (late July and early

August). Two spore samples were taken from each field uredial collection received at the laboratory. One portion was used to inoculate 7-day-old seedlings of a susceptible host (when the forma specialis was known) or a group of potentially susceptible hosts treated with maleic hydrazide to enhance spore production. Each culture was maintained in a separate clear plastic chamber. After 12–14 days, up to four leaves either bearing or pruned to bear a single uredium were saved and reincubated to permit free uredospores to germinate. Uredospores were collected separately 3–4 days later from up to three uredia (each such collection an isolate); each uredium provided enough spores to inoculate a differential host series.

Spores, suspended in a lightweight mineral oil, were sprayed on plants, which were placed in a dew chamber overnight at 18 C, then in a greenhouse at 18–28 C. Infection types were observed after 10–14 days.

The second sample of spores from each collection was bulked with those from other collections made in the same area on about the same date, and the bulk was used to inoculate a "universally" resistant series.

P. g.* f. sp. *avenae. The differential host series consisted of oat lines with resistance genes *Pg*-1, -2, -3, -4, -8, -9, -13, -16, and -a (5). The universally resistant series consisted of the host lines Saia (CI 7010), CI 7221, S.E.S. No. 52 (CI 3034), X-1588-2 (CI 8457), Kyto (CI 8250), MN 730358, and CI 9139. These lines have been selected over a period of years as resistant to stem rust.

Data derived from collections made in the United States were separated into groups corresponding to five ecological areas (Fig. 1A) based on oat production, cultural practices, and geographic separation.

P. g.* f. sp. *tritici. The differential host series consisted of wheat lines with genes for *Sr*5, 6, 7b, 8, 9a, 9b, 9d, 9e, 10, 11, 13, 15, 16, 17, 36, and Tmp. Races were assigned using the code shown in Table 1. The universally resistant series consisted of lines with the host genes *Sr*22, 24, 25, 26, 27, 29, 31, 32, 33, 37, Gt, and Wld-1 and the cultivars Era, Cando, and Ward. These lines and cultivars have been selected over a period of years as resistant to stem rust.

Data were grouped into nine ecological areas (Fig. 1B). Area 1S has mainly fall-sown spring wheats; area 1N, mixed wheat types; area 2, mostly soft red winter wheat; area 3, southern hard red winter wheats; area 4, mostly soft red winter wheat and scattered barberries; area 5, mixed wheat types; area 6, resistant hard red spring and durum wheats; area 7, northern hard red winter wheat; and area 8, mostly highly susceptible soft winter wheats, spring wheats, and scattered barberries.

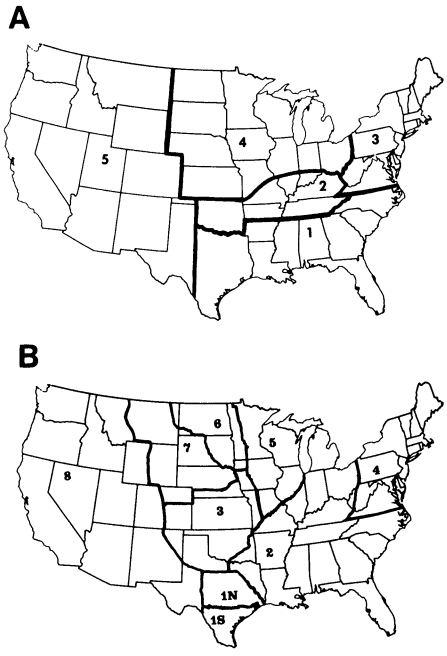

Fig. 1. Ecological areas for *Puccinia graminis* in the United States. **(A)** Areas for oat stem rust: (1) winter oats, (2) mixed winter and spring oats, (3) spring oats and barberry area, (4) major spring oat-producing area, and (5) widely isolated oat fields. **(B)** Areas for wheat stem rust: (1S) mainly fall-sown spring wheat, (1N) mixed wheat types, (2) soft red winter wheat, (3) southern hard red winter wheats, (4) mostly soft red winter wheat and barberries, (5) mixed wheat types and widely dispersed fields, (6) hard red spring and durum wheat, (7) northern hard red winter wheats, and (8) mostly soft winter wheats, spring wheats, and barberries.

RESULTS AND DISCUSSION

Data from collections made from commercial fields and naturally occurring hosts were separated from those made in nurseries and plots. No data were included from collections made in or near known inoculated nurseries.

P. g.* f. sp. *avenae. By early April, rust was scattered throughout South Texas fields, but further development was limited by dry weather. By late April, rust was found into central Texas. No rust was found during the season in north central Texas or Oklahoma, which is unusual (12). In mid-June, traces of rust were found in north central Kansas and southern Nebraska. By early July, traces of rusts were present in South Dakota, Minnesota, and Wisconsin. Although the

Table 1. A key defining the Cereal Rust Laboratory races of *Puccinia graminis* f. sp. *tritici*

Code[a]	Response of host with *Sr* genes			
Set 1:	5	9d	9e	7b
Set 2:	11	6	8	9a
Set 3:	36	9b	13	10
B	R	R	R	R
C	R	R	R	S
D	R	R	S	R
F	R	R	S	S
G	R	S	R	R
H	R	S	R	S
J	R	S	S	R
K	R	S	S	S
L	S	R	R	R
M	S	R	R	S
N	S	R	S	R
P	S	R	S	S
Q	S	S	R	R
R	S	S	R	S
S	S	S	S	R
T	S	S	S	S

[a] A combination of host responses from set 1 determines the first letter of code, set 2 the second, and set 3 the third.
[b] R = host not susceptible; S = host susceptible.

Table 2. Frequency of the identified races of *Puccinia graminis* f. sp. *avenae* by area and source of collection in 1986

		Number of[b]		Percentage of each North American (NA) physiologic race[c]								
Area[a]	Source	Collections	Isolations	5	12	16	23	25	26	27	39	Other[d]
United States	Field	137	268	*[e]	*	3	···	···	···	97	···	*
	Nursery	96	279	11	···	2	1	1	···	82	1	1
	Total	233	547	6	···	2	1	*	···	89	1	1
1	Field	4	12	···	···	25	···	···	···	75	···	···
	Nursery	60	173	2	···	3	2	···	···	89	···	2
	Total	64	185	2	···	5	2	···	···	88	···	2
4	Field	133	256	*	···	2	···	···	···	98	···	*
	Nursery	24	70	···	···	···	···	···	···	100	···	···
	Total	157	326	*	···	1	···	···	···	98	···	*
5	Nursery	12	36	80	···	···	···	···	···	8	8	3
Canada	Field	7	19	···	26	···	···	68	5	···	···	···
	Nursery	9	16	···	···	···	···	37	···	62	···	···
	Total	16	35	···	14	···	···	54	3	28	···	···
Mexico	Nursery	11	29	···	···	···	···	···	···	100	···	···

[a] See Figure 1A for ecological areas in the United States.
[b] Uredia from a single field, plant, or cultivar received separately was a collection from which up to three single-uredial isolates were identified.
[c] Martens et al (5).
[d] From aecial and uredial collections from Ontario.
[e] Less than 0.6% of the isolates.

disease was 2 wk later in onset than the 47-yr average in central Texas, it was near normal to later than normal in the rest of the Great Plains. Less disease than normal at maturity probably resulted from cool nights and low levels of initial infection, except in central Minnesota and southern Wisconsin, where a few late-planted fields were severely rusted.

Race NA-27 constituted 89% of the 547 isolates collected in the United States (Table 2). This race, virulent on host genes *Pg*-1, -2, -3, -4, and -8, has predominated in the U.S. population since 1965. However, NA-27 has caused only one moderately severe epidemic (12). Races NA-5, NA-16, NA-23, and NA-39 were the other frequently isolated races, though in small amounts, making up about 6, 2, 1, and 1% of the sampled population, respectively (33, 13, 4, and 3 isolates, respectively). NA-5 and NA-39 were common in California, and NA-39 occurred only there. No collections were received from areas 2 and 3 (Ohio Valley and northeastern States). Virulence on lines with the single genes used for race identification is shown in Table 3. Hosts with gene *Pg*-a were resistant to the population sampled from the United States in 1986; however, virulence to hosts with this gene has occurred in previous years. Only race NA-27 was obtained from two collections of stem rust made in Mexico during both the spring and fall growing period.

***P. g.* f. sp. *tritici*.** Stem rust overwintered in wheat trap plots at Fairhope, AL, Alexandria, Crowley, Jeannette, and St. Joseph, LA, and at Victoria and Beeville, TX. It is likely that stem rust overwintered in at least some commercial fields in this area. Commercial fields in which rust probably overwintered were observed in southern Oklahoma. Stem rust also occurred at Jay, FL, and Plains, GA, in early May. Growers with over 1,200 ha south of Houston, TX, lost their entire crop because of wheat stem rust. This resulted from fall infection of a susceptible cultivar. By mid-May, light (trace to 1%, modified Cobb scale) severities of stem rust occurred in commercial fields in southern Oklahoma to southeastern Nebraska. This was the greatest incidence of rust in this area since 1965. In Kansas, a few growers with very susceptible cultivars suffered moderate losses. By mid-June, stem rust was common with wheat in the milk stage

Table 3. Incidence of virulence in isolates of *Puccinia graminis* f. sp. *avenae* isolates to the resistance of the single-gene differential lines in the 1986 survey

	Percentage of isolates virulent on *Pg* gene[b]								
Area[a]	-1	-2	-3	-4	-8	-9	-13	-15	-16
1	97	92	100	90	98	0	0	3	0
4	99	98	100	98	100	*[c]	*	1	0
5	8	11	100	8	8	0	0	83	3
United States									
1986	92	90	100	89	93	*	*	7	*
1985[d]	97	98	100	96	96	0	0	3	0
1984[d]	97	96	100	94	97	0	0	3	0

[a] See Figure 1A for areas.
[b] No cultures were virulent on *Pg*-a.
[c] Less than 0.6% of the isolates.
[d] Roelfs et al (9,10).

Table 4. Summary of the identified races of *Puccinia graminis* f. sp. *tritici* by area and source of collection in 1986

				Percentage of isolates of each race[c]										
		Number of[b]		11		15		29	56	113		151		
Area[a]	Source	Collections	Isolations	RCR	RHR	TNM	TNM[d]	HJC	MBC[e]	RTQ	QCB	QFB	QSH	Others[f]
USA[g]	Field	204	533	...	...	1	97	...	...	...	...	*[h]	*	...
	Nursery	377	1,049	*	*	2	96	1	*	*	*	...	*	*
	Total	581	1,582	*	*	1	96	*	*	*	*	*	*	*
1N	Field	24	56	...	...	...	100	...	...	...	...	...	...	...
	Nursery	51	139	...	1	...	97	...	1	...	...	...	...	...
	Total	75	195	...	1	...	98	...	1	...	...	...	...	...
1S	Nursery	7	15	...	...	...	100	...	...	...	...	...	...	...
2	Field	12	31	...	...	...	100	...	...	...	...	...	...	...
	Nursery	66	169	...	...	...	95	3	...	...	2	...	...	*
	Total	78	200	...	...	...	96	3	...	...	2	...	...	*
3	Field	50	139	...	...	...	99	...	...	...	...	...	1	...
	Nursery	63	183	...	...	...	98	*	...	...	...	...	2	...
	Total	113	322	...	...	...	98	*	...	...	...	...	1	...
4	Nursery	5	14	...	...	...	100	...	...	...	...	...	...	...
5	Field	46	114	...	...	2	98	...	...	...	...	...	...	...
	Nursery	20	59	...	...	...	100	...	...	...	...	...	...	...
	Total	66	173	...	...	1	99	...	...	...	...	...	...	...
6	Field	66	181	...	...	2	94	...	...	...	...	1	1	2
	Nursery	137	389	1	...	4	95	*	...	*	...	*	...	...
	Total	203	570	*	...	3	94	*	...	*	...	*	*	*
7	Field	6	12	...	...	...	92	...	...	...	...	...	...	8
	Nursery	26	77	...	...	4	96	...	...	...	...	...	...	...
	Total	32	89	...	...	3	96	...	...	...	...	...	...	1
8	Field	8	19	...	...	...	...	...	...	...	...	...	...	100
	Nursery	51	149	...	...	...	3	...	...	...	...	...	...	97
	Total	59	168	...	...	...	2	...	...	...	...	...	...	98
Canada	Nursery	2	6	...	...	...	100	...	...	...	...	...	...	...

[a] See Figure 1B for description of areas.
[b] Uredia from a single field, plant or cultivar received separately was a collection, from which up to three single uredia isolates were identified.
[c] Cereal Rust Laboratory races (Table 1).
[d] Virulent on *Sr*17.
[e] Virulent on *Sr*Tmp.
[f] Sexual population from area 8 (Oregon and Washington): 94 isolates of 48-BBC, 2 isolates of -LBC, 37 isolates of 2-LCC; 3 isolates of 10-GCC, 7 isolates of 7-QBC, 3 isolates of -SDC; and 18 isolates of -QFC.
[g] Does not include 57 collections or 164 isolates from the sexual population.
[h] Less than 0.6% of the isolates.

Table 5. Incidence of virulence in *Puccinia graminis* f. sp. *tritici* isolates to the resistance of single-gene differential lines used in the 1986 survey

Area[a]	Percentage of isolates virulent on *Sr* gene[b]														
	5	9d	9e	7b	11	6	8	9a	36	9b	10	15	16	17	Tmp
1	100	99	98	100	98	1	98	1	99	1	100	2	100	100	99
1S	100	100	100	100	100	0	100	0	100	0	100	0	100	100	100
2	98	100	96	98	96	3	98	2	96	0	99	4	100	100	96
3	100	100	98	99	100	2	100	0	98	1	100	2	100	100	98
4	100	100	100	100	100	0	100	0	100	0	100	0	100	100	100
5	100	100	100	100	100	0	100	0	100	0	100	0	100	99	100
6	100	100	98	98	98	1	99	1	98	1	99	2	99	97	98
7	100	100	99	99	99	0	100	0	99	0	100	1	99	97	99
8	42	21	2	2	2	0	15	34	2	0	100	98	78	100	2
United States															
1986[c]	99	100	98	99	98	1	99	1	98	1	100	2	100	98	98
1985[d]	100	99	95	97	92	3	98	2	96	3	98	5	100	89	95
1984[d]	99	99	84	92	85	1	88	14	91	6	91	16	100	90	84
Canada	100	100	100	100	100	0	100	0	100	0	100	0	100	100	100

[a] See Figure 1B for areas.
[b] All isolates were avirulent on *Sr*13.
[c] Roelfs et al (9,10).
[d] Totals do not include isolates from the sexual population in area 8.

Table 6. Canadian race equivalents for Cereal Rust Laboratory races of *Puccinia graminis* f. sp. *tritici*

Cereal Rust Laboratory race	Canadian race[a]
11-RCR	C43(32)
11-RHR	No equivalent
15-TNM	C33(15B-1L)
15-TNM[b]	C53(15B-1L)
29-HJC	C5(29-1)
56-MBC[c]	C17(56)
113-RTQ	C41(32-113)
151-QCB	C56(38-151)
151-QFB	C75(38)
151-QSH	C25(38)

[a] See Green (3).
[b] Virulent on *Sr*17.
[c] Virulent on *Sr*Tmp.

throughout the northern soft red winter wheat areas from northeastern Indiana to southern Wisconsin, and the disease was present on hard red winter wheat northward into southern Minnesota. Disease development was restricted because resistant cultivars were sown in nearly all of the hard red spring and durum wheat area. Disease losses, however, were moderate (about 10%) on susceptible winter wheat in western North Dakota (A. P. Roelfs and D. L. Long, *unpublished*). Disease onset was 7–10 days earlier than normal in the Great Plains (4). More infections were found in commercial fields than since 1976 (13), but losses in commercial fields were limited. However, a number of commercial cultivars developed at considerable cost will be removed from production.

A total of 581 collections was obtained in 1986 (Table 4) compared with the 5-, 10-, and 25-yr means of 219, 356, and 561 collections in earlier surveys. The most common race in the United States was 15-TNM, constituting 96% of all isolates (Table 4); 99% of these were virulent on the differential host line with *Sr*17. Race 15-TNM, avirulent on *Sr*17, was the second most common race but made up only 1% of all isolates. These were the only members of this race cluster identified in 1986.

The second most common race cluster was 29-32-_JC. Race 29-HJC (eight isolates) is virulent to *Sr*6 and 17, which are commonly used resistance genes in commercial wheat cultivars. This race has been a minor component of the population for 50 yr.

Race 151-QFB (three isolates) and 151-QCB (three isolates), members of the 151-Q_B cluster, were found only in areas 2 and 6, respectively.

Race 56-MBC (two isolates) was isolated only from Texas. This race was avirulent on the important *Sr*6, 9d, 9e, 11, and 36 resistant genes but virulent on *Sr*17 and Tmp. These *Sr* resistance genes are among the most common ones in commercial cultivars.

Race 11-RCR (three isolates) was identified only from North Dakota in 1986. Race 11-RHR, though somewhat similar in virulence but isozymatically quite different (2), was found only in area 1.

The collections from area 8 (Tables 4 and 5) were nearly all from a sexually reproducing population in the Pacific Northwest (2,11). These isolates differed from isolates found in other areas in both virulence combinations (Table 4) and frequency of virulence genes (Table 5), presumably because of frequent sexual recombination and geographical isolation of the population.

Associations of virulence or avirulence are common in asexual populations of *P. graminis* (1,2). These associations are important to know and understand when studying virulence or avirulence frequencies (Table 5) or when developing wheats resistant to stem rust. Virulence for *Sr*6 remains low although it is widely used in commercial cultivars in area 6. Resistance gene *Sr*17 is present in the commercial wheat cultivars in areas 3 and 6, and virulence has increased greatly in recent years from 20% in 1975 to 98% in 1986. The reduction of Arthur-type wheats in the soft wheat region has reduced the percentage of the host population with *Sr*36. The cultivar Siouxland now provides *Sr*24 and *Sr*31 in combination (6). Virulence for neither gene is known in North America.

During the survey, no virulence was found to lines with *Sr*13, 22, 24, 25, 26, 27, 29, 31, 32, 33, 37, Gt, or Wld-1.

The data reported are from the southern three-fourths of the range of *P. g.* f. sp. *tritici* in North America. The northern portion of the population is studied annually at the Agriculture Canada Laboratory at Winnipeg. This laboratory designates races differently (3), so equivalents are given for races reported in this paper (Table 6).

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