Races of *Puccinia graminis* in the United States in 1988

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ABSTRACT

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Oat stem rust was present in light amounts throughout most of the United States in 1988, and yield losses were nil. Disease development was a month later than the 40-yr average. The principal race of the pathogen was NA-27, which is virulent on hosts having resistance genes *Pg-1, -2, -3, -4,* and *-8.* NA-27 accounted for 83% of the isolates and NA-16 for 7%. No virulence was found for *Pg-a* or *Pg-16* in the 1988 oat stem rust population. Wheat stem rust overwintered in trace amounts from southern Texas to southern Georgia. A probable overwintering site was found in a plot in northeastern North Dakota leeward of a shelterbelt. Stem rust inoculum spread northward, but little disease developed because of a severe drought throughout the central and northern Great Plains. No stem rust was found in fields of hard red spring or durum wheat cultivars. Race Pgt-TPM was the most common virulence combination, making up 92% of the 148 isolates from 54 collections. No virulence was found for wheat lines with "single" genes *Sr13, 22, 24, 25, 26, 27, 29, 30, 31, 32, 33, 37, Gt,* or *Wld-1.*

Puccinia graminis Pers.:Pers. has been a major pathogen of many small-grain cereals and forage grasses worldwide. Since the virtual elimination of the susceptible host *Berberis vulgaris* L. from cereal-producing areas of the northern Great Plains, epidemics have been rare (6). Since the mid-1950s, no major losses have resulted from either oat or wheat stem rust in the United States (5), partly because of the continuous series of resistant wheat (*Triticum aestivum* L.) cultivars used. However, the oat (*Avena sativa* L.) cultivars grown during this period have been susceptible to the most common pathogenic race. The lack of oat stem rust epidemics could be the result of a small amount of inoculum and/or late onset of disease (8,11) or of environmental conditions unfavorable for the development of regional epidemics. The trend for a single virulence phenotype to make up most of the pathogen population continues (9).

The research reported here was part of an ongoing project to monitor changes in virulence combinations present in wheat and oat stem rust fungi in an effort to maintain rust-resistant cultivars in North America.

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MATERIALS AND METHODS

Fields were surveyed over a 19,000-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. Commercial fields were checked for the presence of rust every 32 km, or at the first field thereafter. Additional checks were made at experimental nurseries and wheat trap plots along the route. In 1988, fields in the following areas were surveyed: southern Texas (early and late March), northern Texas (late April), Gulf Coast states (early April, late April, and late May), Oklahoma and Kansas (mid-May), Arkansas and the Ohio River Valley (early June), Nebraska and South Dakota (mid-June), and the north-central states (mid-July).

Whenever rust was observed in a field or nursery, leaves or stems bearing rust uredinia were collected from a single cultivar or field. These collections were supplemented by others furnished by cooperators throughout North America.

Two spore samples were taken from each field uredinial collection received at our 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 (14). Each culture was maintained in a separate clear plastic chamber. After 12–14 days, up to four leaves of each host species either bearing or pruned to bear a single uredinium were saved and reincubated to permit free urediniospores to germinate. Urediniospores were collected separately 3–4 days later from up to three uredinia (each such collection was an isolate). Each uredinium provided enough spores to inoculate a differential host series.

Spores suspended in a lightweight mineral oil (14) were sprayed on plants, which were then placed in a dew chamber

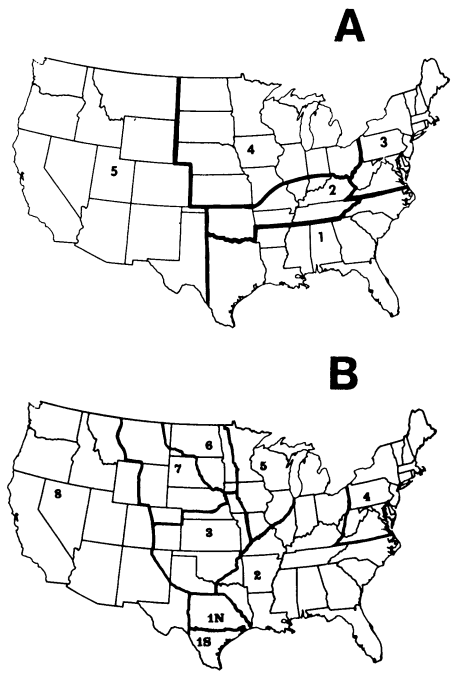

Fig. 1. Ecological areas for *Puccinia graminis* in the United States. **(A)** Areas for oat stem rust: 1 = winter oats, 2 = mixed winter and spring oats, 3 = spring oats and barberry, 4 = spring oats, and 5 = isolated oat fields. **(B)** Areas for wheat stem rust: 1N = mixed winter wheat types, 1S =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

Table 1. International Pgt race equivalents for the former Cereal Rust Laboratory (CRL) races of *Puccinia graminis* f. sp. *tritici*

Pgt race[a]	CRL designation[b]
TPM	15-TNM
RCR	11-RCR
QFC	151-QFB

[a] Roelfs and Martens (13).
[b] Roelfs et al (9).

overnight at 18 C. Plants were then placed in a greenhouse at 18–28 C. Infection types (13) 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 at the same time and 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* (4). 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 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 *Sr5, 6, 7b, 8a, 9b, 9e, 9g, 11, 17, 21, 30*, and *36*. Races were assigned using the international Pgt code (13). Races were designated differently in 1987 (9), so equivalents are given in Table 1 for races reported here. The "universally" resistant series consisted of lines with the host genes *Sr13, 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 ecological areas (Fig. 1B) based on cultural practices, geographic separation, and wheat production.

RESULTS AND DISCUSSION

***P. g.* f. sp. *avenae*.** In early April the only oat stem rust found was in a southern Texas nursery. The amount of stem rust was much less than normal in this area. The small amount of rust generated little inoculum, which, accompanied by a severe drought in the northern Great Plains, prevented epidemic development in this area, the major oat production area. Traces of stem rust appeared on wild oats (*A. fatua* L.) in eastern North Dakota (three collections) and Minnesota and Wisconsin (one collection each).

Race NA-27 accounted for 83% of the 245 isolates collected (Table 2). This race, which is virulent on almost all commercial cultivars, has predominated in the U.S. oat stem rust fungus population since 1965, causing only one moderately severe epidemic (11). Races NA-5, NA-10, and NA-16 were the other races isolated frequently, although in small amounts, accounting for about 4% (10 isolates), 4% (nine isolates), and 7% (17 isolates), respectively, of the population. NA-5 was isolated from a nursery collection from California and from a field in West Virginia. NA-10 was exclusively from California. NA-16 was obtained from collections made in Kansas, Louisiana, and Texas. Only one collection was received from area 2 (Ohio Valley) and none from area 3 (northeastern states). A collection from Oregon (three isolates) and another from West Virginia (two isolates) yielded isolates that produced an infection type 2 or less on all the differential host lines and the "susceptible" host, Marvelous.

Virulence on lines with the single genes used for race identification is shown in Table 3. Hosts with genes *Pg-9, -16*, and *-a* were resistant to the population sampled in 1988; however, virulence to hosts with these genes has occurred in previous years.

The isolates from Canada came from a small area of Ontario, where stem rust from barberry may have played a role in the disease cycle.

***P. g.* f. sp. *tritici*.** During 1988, stem rust overwintering sites (7) were found on susceptible cultivars from southern Texas to southern Georgia. By mid-May, traces of stem rust were found in plots from south-central Kansas to northern South Carolina.

During late July, traces of stem rust were found in fields and plots in eastern Washington, Oregon, and northern Idaho. The rust from this area represents a sexual population (2,10) with great diversity and generally little virulence to wheats bred for stem rust resistance.

Fifty-four collections were obtained in 1988 (Table 4), compared to the 5-, 10-, and 25-yr means of 219, 356, and 561, reflecting the low rust incidence (12). The most common race in 1988 was again Pgt-TPM, which made up 92% of all isolates (Table 4).

A single collection from area 4, identified as race RCR, has often been found in low frequency, especially in areas 1N, 1S, 2, and 4 over the years. The collections from area 8 (Tables 4 and 5) were from a sexually reproducing population in the Pacific Northwest (2,10). These collections differed from those found in other areas in both virulence combinations (Table 4) and frequency of

Table 2. Frequency of the identified races of *Puccinia graminis* f. sp. *avenae* by area and source of collection in 1988

Area[a]	Source	Number of[b]		Percentage of each North American (NA) physiologic race[c]							
		Collections	Isolates	?	5	10	12	16	25	27	32
United States	Field	35	88	2	5	7	...	...	...	86	...
	Nursery	57	157	2	4	2	...	11	...	82	...
	Total	92	245	2	4	4	...	7	...	83	...
1	Nursery	39	111	...	...	...	...	14	...	86	...
2	Field	1	3	...	...	...	...	...	...	100	...
4	Field	32	79	3	5	...	...	...	...	92	...
	Nursery	14	34	...	...	...	...	3	...	97	...
	Total	46	113	2	4	...	...	1	...	94	...
5	Field	2	6	...	...	100	...	...	...	...	...
	Nursery	4	12	25	50	25	...	...	...	...	...
	Total	6	18	17	33	50	...	...	...	...	...
Canada[d]	Field	3	9	...	...	...	100	...	...	...	...
	Nursery	10	30	...	...	...	17	...	27	47	10
	Total	13	39	...	...	...	36	...	21	36	8

[a]See Figure 1A.
[b]Uredinia from a single field, plant, or cultivar received separately were counted as a collection, from which up to three single-uredinia isolates were identified.
[c]Martens et al (3).
[d]Uredinial collections from Ontario.

Table 3. Incidence of virulence in isolates of *Puccinia graminis* f. sp. *avenae* toward the resistance of the single-gene differential lines in the 1988 survey

Area[a]	Percentage of isolates virulent on *Pg* gene[b]								
	-1	*-2*	*-3*	*-4*	*-8*	*-9*	*-13*	*-15*	*-16*
1	100	86	100	86	100	0	0	0	0
2	100	100	100	100	100	0	0	0	0
4	95	94	98	94	95	0	0	4	0
5	0	50	83	0	0	0	0	83	0
United States									
1988	90	87	98	83	90	0	0	8	0
1987[c]	90	93	99	90	90	1	1	2	0
1986[d]	92	90	100	89	93	*[e]	*	7	*

[a]See Figure 1A.
[b]No cultures were virulent on *Pg-a*, 1986–1988.
[c]Data from Roelfs et al (9).
[d]Data from Roelfs et al (8).
[e]Less than 0.6%.

Table 4. Summary of the identified races of *Puccinia graminis* f. sp. *tritici* by area and source of collection in 1988

Area[a]	Source	Number of[b]		Percentage of isolates/Pgt race[c]			
		Collections	Isolates	TPM	RCR	QFC	Others[d]
United States	Field	4	9	67	33	...	...
	Nursery	50	139	94	...	4	...
	Total	54	148	92	2	4	...
1N	Nursery	2	3	100	...	...	...
1S	Nursery	1	3	100	...	...	...
2	Field	21	57	100	...	...	...
3	Field	1	3	100	...	...	...
	Nursery	3	8	100	...	...	...
	Total	4	11	100	...	...	...
4	Field	1	3	...	100	...	...
5	Field	1	0	...	...	...	...
	Nursery	2	4	100	...	...	...
	Total	3	4	100	...	...	...
6	Field	1	3	100	...	...	...
	Nursery	20	63	90	...	10	...
	Total	21	66	91	...	9	...
7	Nursery	1	1	100	...	...	...
8	Field	2	6	...	...	...	100
	Nursery	11	33	...	...	...	100
	Total	13	19	...	...	100	...

[a]See Figure 1B.
[b]Uredinia from a single field, plant, or cultivar received separately were counted as a collection, from which up to three single-uredinia isolates were identified.
[c]International Pgt races (13).
[d]Sexual population from area 8 (Idaho, Oregon, and Washington), three isolates of Pgt-GCC, four isolates of Pgt-QCC, two isolates of Pgt-QFB, and 30 isolates of Pgt-QFC, not included in U.S. totals.

Table 5. Incidence of virulence in isolates of *Puccinia graminis* f. sp. *tritici* toward the resistance of single-gene differential lines in the 1988 survey

Area[a]	Percentage of isolates virulent on *Sr* gene[b]											
	5	*6*	*7b*	*8a*	*9b*	*9g*	*9e*	*11*	*17*	*21*	*30*	*36*
1	100	0	100	100	0	100	100	100	100	100	0	100
1S	100	0	100	100	0	100	100	100	100	100	0	100
2	100	0	100	100	0	100	100	95	100	100	0	100
3	100	0	100	100	0	100	100	100	100	100	0	100
4	100	0	100	0	100	100	0	0	100	100	0	100
5	100	0	100	100	0	100	100	100	100	100	0	100
6	100	0	91	100	0	100	91	91	100	100	0	91
7	100	0	100	100	0	100	100	100	100	100	0	100
8	92	0	100	82	0	100	0	0	95	100	0	0
United States												
1988[c]	100	0	96	98	2	100	94	92	100	100	0	96
1987[d]	100	1	100	100	1	100	99	99	100	100	0	100
1986[e]	99	1	99	99	1	100	98	98	98	100	1	98

[a]See Figure 1B.
[b]All isolates were avirulent on *Sr13*.
[c]Excluding area 8.
[d]Roelfs et al (9).
[e]Roelfs et al (8).

virulence (Table 5), presumably because of frequent sexual recombination and geographic isolation of the population.

No wheat stem rust was observed in commercial fields or susceptible trap plots in the Yaqui and Mayo valleys of Sonora, Mexico. These irrigated valleys are the major wheat production areas of Mexico. The major commercial cultivars were Altar durum, resistance genotype unknown, and Seri 82 bread wheat, with at least *Sr31*.

Associations of virulence and avirulence are common in asexual populations of *P. graminis* (1,2). These associations have important implications for studies of virulence or avirulence frequencies and for the development of wheats resistant to stem rust. Virulence for *Sr6* remains low, although it is common in commercial cultivars in area 6. The cultivar Siouxland has *Sr24* and *Sr31* in combination (4). Virulence for neither gene is known in North America, although *Sr24* has been used since 1967 in a series of cultivars. During the survey no virulence was found to lines with *Sr13, 22, 24, 25, 26, 27, 29, 30, 31, 32, 33, 37, Gt*, or *Wld-1*.

The data reported here are from the southern three-fourths of the range of *P. g.* f. sp. *tritici* in North America.

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