Races of *Puccinia graminis* in the United States in 1989

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ABSTRACT

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Oat stem rust was present in light amounts throughout most of the United States in 1989, and yield losses were nil. Disease onset was 1 mo later than the 40-yr average. The principal race in the United States was NA-27, virulent to resistance genes *Pg*-1, -2, -3, -4, and -8. NA-27, NA-5, and NA-16, respectively, made up 97, 1, and 1% of the isolates from the United States. No virulence was found for *Pg*-9, *Pg*-13, *Pg*-a, or *Pg*-16 in the 1989 oat stem rust population. Wheat stem rust overwintered in trace amounts from southern Texas to southern Alabama. A probable overwintering site on winter wheat was found in a northeastern North Dakota plot 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 53% of the 686 isolates from 247 collections. However, if only collections made from wheat were considered, it made up 73% of the isolates. Race Pgt-QCC made up 62% of the isolates from barley and 19% of all isolates. No virulence was found for wheat lines with "single" genes *Sr*13, 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 *Berberis vulgaris* L. from cereal-producing areas of the northern Great Plains, epidemics have been rare (5). Since the mid-1950s, no major losses have resulted from either oat or wheat stem rust in the United States (4). This is partly attributable to the continuous series of resistant wheat (*Triticum aestivum* L.) cultivars used. However, the oat cultivars (*Avena sativa* L.) grown during this period were susceptible to the most common pathogenic race. The lack of an oat stem rust epidemic could be attributable to a small number of overwintering uredinia and/or to a late onset of disease (9,11) or to unfavorable environmental conditions for development of regional epidemics. The trend in recent years is for a single virulence phenotype to make up most of the pathogen population (10).

This research is part of the continuing effort to monitor changes in virulence combinations present in wheat and oat stem rust in an effort to maintain rust-resistant cultivars in North America.

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MATERIALS AND METHODS

Field surveys were made 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 has been a problem. Checks for the presence of rust were made at commercial fields every 32 km or at the first field thereafter. Additional checks were made at experimental nurseries and wheat trap plots along the route. Techniques used in the surveys and their interpretation have been described (7). Whenever rust was observed in a field or nursery, leaves or stems bearing rust uredinia from a single cultivar or field were collected. These collections were supplemented by others furnished by cooperators throughout North America.

In 1989, field surveys were made in the following areas: southern Alabama and Georgia (late January); southern Atlantic Coast states (early April); southern Texas (early April); northern Texas (late April); Gulf Coast states (late April, and mid-May); Oklahoma and Kansas (mid-May); Southeast states (late May); Ohio River Valley (early June); Nebraska, South Dakota, and Minnesota (mid-June); and north central U.S. (early July and early August). Two spore samples were taken from each field uredinial collection received at the laboratory. One portion was used to inoculate 7-day-old seedlings of a susceptible cultivar (when the forma specialis was known) or a group of potentially susceptible host species (if the forma specialis was unknown) treated with maleic hydrazide to enhance spore production (15). 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 was 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 an isolate); each uredinium provided enough spores to inoculate a differential host series.

Spores suspended in light-weight mineral oil were sprayed on plants which were then placed in a dew chamber overnight at 18 C. Plants were then placed in a greenhouse at 18–28 C. Infection types were recorded after 10–14 days. The second sample of spores from each collection was bulked with those from other collections made in the same area and time and used to inoculate a "universally" resistant series.

***P. g.* f. sp. *avenae* Eriks. & E. Henn.** The differential host series consisted of oat lines with resistance genes *Pg*-1, -2, -3, -4, -8, -9, -13, -16, and -a (3). The universally resistant series consisted of the host lines Saia (CI 7010), CI 7221, S.E.S. 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* Guyot, Massenot, & Saccas ex Z. Urban.** The differential host series consisted of wheat lines with genes for *Sr*5, 6, 7b, 8a, 9b, 9e, 9g, 11, 17, 21, 30, and 36. Races were assigned using the International Pgt-code (14). The universally resistant series consisted of lines with the host genes *Sr*13, 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 by ecological areas (Fig. 1B) based on cultural practices, geographic separation, and wheat production.

RESULTS AND DISCUSSION

P. g. avenae. In late March, 5% severities (modified Cobb scale) were common in nurseries from southern Texas to southern Louisiana, where *P. g.*

avenae overwintered. The fungus also overwintered in plots at Raymond, MS, where many of the cultivars were killed. However, in northern Texas, only traces of stem rust developed from exogenous inoculum, as no stem rust overwintered in the area. Dry weather restricted stem rust development on the oat hectarage in the central Great Plains, and stem rust was observed by cooperators in southeastern Kansas fields by early June. By mid-July, stem rust was severe in fields from central Iowa to southern Minnesota and south central Wisconsin to southwestern Michigan. Although many fields escaped damage, some fields were severely damaged. In the Dakotas and western Minnesota, rust was very light on both cultivated and wild oats (*Avena fatua* L.) with losses reported only in late maturing fields.

Race NA-27 constituted 97% of the 617 isolates collected in the United States (Table 1). This race, virulent on most commercial cultivars, has predominated in the United States 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, making up about 1 (six isolates), 0.5 (three isolates), and 1% (nine isolates) of the population. Races NA-5 and NA-10 were exclusively from California, although NA-5 has often been found throughout the United States in previous years. NA-16 was obtained from collections made in Alabama, Florida, Minnesota, Mississippi, and Texas. No collections were received from area 2, only six from area 3, and three from area 5 (Fig. 1A).

Virulence to the single gene lines used for race identification is shown in Table 2. Hosts having genes *Pg*-9, *Pg*-16, and *Pg*-a were resistant to the population sampled from the United States in 1989; however, virulence to hosts having 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 had a role in the disease cycle.

P. g. tritici. In 1989, *P. g. tritici* overwintering sites (6,7) were found on susceptible cultivars from southern Texas to southern Alabama. Scattered infections of wheat stem rust developed in the southern U.S. from the overwintering fungus; however, the amount of inoculum generated was inadequate to initiate an epidemic. In the central Great Plains, scattered infections of wheat stem rust occurred on susceptible cultivars, but dry weather restricted disease development. More stem rust developed on winter wheat in the northern Great Plains than in the previous 2 yr. However, the resistance in the spring and durum wheats prevented losses in these important crops.

In the northern soft red winter wheat region, stem rust was common on susceptible cultivars, but the inoculum arrived too late or in amounts too low to cause significant losses.

During mid-July, traces of stem rust were found on winter wheat in the Pacific Northwest. In most of the area, moisture conditions were unfavorable for rust

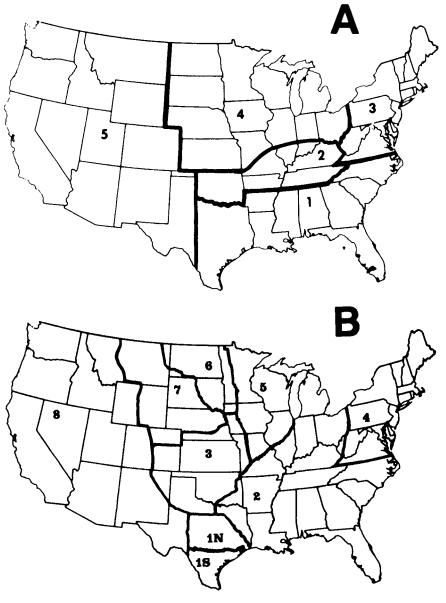

Fig. 1. Ecological areas for *Puccinia graminis* in the United States. **(A)** Areas for oat stem rust: 1) winter oats, occasional overwintering uredinium, 2) mixed winter and spring oats, rare overwintering uredinia, 3) spring oats and barberry, 4) spring oats, and 5) isolated oat fields, overwintering uredinia in southern California. **(B)** Areas of wheat stem rust: 1N) mixed winter wheat types, rare overwintering uredinia, 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. Frequency of identified races of *Puccinia graminis* f. sp. *avenae* by area and source of collection in 1989

Area[a]	Source	Collections[b] (no.)	Isolates (no.)	Percentage of each North American physiologic race[c] 5	10	12	16	25	27	32
U.S.	Field	82	239	1					98	
	Nursery	130	378	1	1		2		96	
	Total	212	617	1	*[d]		1		97	
1	Field	1	3				33		67	
	Nursery	93	270				3		97	
	Total	94	273				3		97	
3	Field	6	16						100	
4	Field	74	217						100	
	Nursery	35	102				1		99	
	Total	109	319				*		100	
5	Field	1	3	100						
	Nursery	2	6	50	50					
	Total	3	9	67	33					
Canada[e]	Field	3	9			22				78
	Nursery	3	9					11	89	
	Total	6	18			11		6	44	39
Mexico	Field	2	4			75			25	
	Nursery	1	1						100	
	Total	3	5			60			40	

[a] See Figure 1A.
[b] Uredinia from a single field, plant, or cultivar received separately was a collection, from which up to three single uredinial isolates were identified.
[c] Martens et al (3).
[d] Less than 0.6%.
[e] Uredinial collections from Ontario.

Table 2. Incidence of virulence in isolates of *Puccinia graminis* f. sp. *avenae* to the resistance of the single gene differential lines in the 1989 survey

Area[a]	Percentage of isolates virulent on *Pg* gene[b] -1	-2	-3	-4	-8	-9	-13	-15
1	100	97	100	97	100	0	0	0
3	100	100	100	100	100	0	0	0
4	100	100	100	100	100	0	0	0
5	0	33	100	0	0	0	0	100
U.S. 1989	99	98	100	97	99	0	0	1
U.S. 1988[c]	90	87	98	83	90	0	0	8
U.S. 1987[d]	90	93	99	90	90	1	1	2

[a] See Figure 1A.
[b] No cultures virulent on *Pg*-a 1986–1989 and *Pg*-16 1987–1989.
[c] Roelfs et al (9).
[d] Roelfs et al (8).

development; however, in east central Oregon, several winter wheat fields were destroyed by stem rust. Most of the cultivars grown in this area have limited resistance to stem rust, and the pathogen frequently passes through the sexual stage.

Overwintering of *P. g. tritici* is unusual in east central North Dakota, but in the last 4 yr, overwintering rust has been found three times. Survey techniques have improved, but the recent increased detection of overwintering in North Dakota is probably related to changes in tillage practices (6,12) and perhaps to cultivars grown.

Two hundred and forty-seven collections were obtained in 1989 (Table 3), compared with the 5-, 10-, and 25-yr means of 219, 356, and 561, respectively, reflecting the near average rust incidence (13). The most common race in the United States in 1989 was Pgt-TPM again, comprising 53% of all isolates (Table 3). It made up 72% of the isolates from collections made from wheat. Avirulence to *Sr*6, 9b, and 2 probably prevents this race from attacking most wheat cultivars. Race Pgt-RCR has often been found in low frequency especially in areas 1N, 1S, 2, and 4 over the years (Fig. 1B). In 1989, 25 isolates were found in collections made in nurseries in area 2.

The collections from area 8 (Tables 3 and 4) were from a sexually reproducing population in the Pacific Northwest (2,10). These collections generally differed from those races found in other areas in both virulence combinations (Table 3) and frequency of virulence (Table 4), presumably because of frequent sexual recombination and geographical isolation of the population.

Two new races were found in the Great Plains in 1989. Pgt-QCC is virulent on *Sr*5, 9d, 9g, 10, 15, 16, and 17 and avirulent on *Sr*6, 7b, 8a, 9a, 9b, 9e, 11, 13, Tmp, and McN (A. P. Roelfs and D. V. McVey, *unpublished*). The 131 isolates of Pgt-QCC came from Idaho, Minnesota, North Dakota, Oregon, and South Dakota. Barley (*Hordeum vulgare* L.) and wild barley (*Hordeum jubatum* L.) were the hosts from which 85 and 10%, respectively, of the isolates of Pgt-QCC were made; therefore, it seems to be primarily a rust of *Hordeum* rather than commercially grown *Triticum* species. This race probably originated in the Pacific Northwest and was first found in the Great Plains in 1989 in a Fillmore County, MN, collection on 10 July.

Pgt-QFC is virulent on *Sr*5, 8a, 9a, 9d, 9g, 10, 15, 16, and 17 and avirulent on *Sr*6, 7b, 9b, 9e, 11, 12, 36, and Tmp (A. P. Roelfs and D. V. McVey, *unpublished*). The 204 isolates of Pgt-QFC were from Alabama, Idaho, Kansas, Michigan, Minnesota, North Dakota, and Wisconsin. Fourteen and 5% of the isolates were found on barley and wild barley, respectively. This race is also typical of the Pacific Northwest stem rust pathogen population; however, because of its presence in collections made in Alabama on 5 May, in Oklahoma on 17 May, and in Kansas on 15 and 20 May, it seems likely that it overwintered east of the Rocky Mountains after arriving in the late summer of 1988. This race had been found in 1988 making up 9% of the isolates from area 6 (9).

Associations of virulence/avirulence are common in asexual populations of *P. graminis* (1,2). These associations are important to understand when studying virulence or avirulence frequencies or when developing wheats resistant to stem rust. Virulence for *Sr*6 remains low, although it is common in commercial cultivars in area 6. The cultivar Siouxland has *Sr*24 and *Sr*31 in combination. Virulence for neither gene is known in

Table 3. Summary of identified races of *Puccinia graminis* f. sp. *tritici* by area and source of collection in 1989

Area[a]	Source	Collections[b] (no.)	Isolates (no.)	Percentage of each Pgt- physiologic race[c]							
				LCC[d]	LCC[e]	QCC	QFC	RCR	RKC	TPM	Other
U.S.[f]	Field	87	236			30	27		1	41	1
	Nursery	160	450			13	21	6		60	
	Total	247	686			19	23	4	*[g]	53	*
1S	Field	1	3							100	
	Nursery	12	36							100	
	Total	13	39							100	
2	Field	9	25				8		8	84	
	Nursery	53	141				4	18		78	
	Total	62	166				5	15	1	79	
3	Field	1	3				33			67	
	Nursery	10	30				17			83	
	Total	11	33				18			82	
4	Field	7	20[h]							85	15
	Nursery	4	9							100	
	Total	11	29							90	10
5	Field	33	93			14	46			40	
	Nursery	13	37			14	43		3	41	
	Total	46	130			14	45		1	40	
6	Field	35	89			61	20				19
	Nursery	68	197			27	35				38
	Total	103	286			37	30				32
7	Nursery	1	3			100					
8	Field	14	7	43	14	43					
	Nursery	4	12	8		8	83				
	Total	18	19	21	5	21	53				

[a] See Figure 1B.
[b] Uredinia from a single field, plant, or cultivar received separately was a collection from which up to three single uredinia (isolates) were identified.
[c] International Pgt- races (14).
[d] Avirulent on *Sr*9a.
[e] Virulent on *Sr*9a.
[f] Totals do not include isolates from the sexual population from area 8.
[g] Less than 0.6%.
[h] Three isolates of Pgt-JCC from a *Berberis canadensis* collection from West Virginia were identified.

Table 4. Incidence of virulence in *Puccinia graminis* f. sp. *tritici* isolates to the resistance of single gene differential lines used in the 1989 survey

Area[a]	Percentage of isolates virulent on *Sr* gene[b]											
	5	6	7b	8a	9b	9g	9e	11	17	21	30	36
1S	100	0	100	100	0	100	100	100	100	100	0	100
2	100	1	95	85	15	100	79	79	100	100	0	94
3	100	0	82	100	0	100	82	82	100	100	0	82
4	100	0	100	100	0	100	100	100	100	100	0	100
5	100	0	100	100	0	100	100	100	100	100	0	100
6	100	0	32	63	0	100	32	32	100	100	0	32
7	100	0	0	0	0	100	0	0	100	100	0	0
8	100	0	0	53	0	100	0	0	100	100	0	0
U.S. 1989[c]	100	0	58	77	4	100	53	53	100	100	0	57
U.S. 1988[d]	100	0	96	98	2	100	94	92	100	100	0	96
U.S. 1987[e]	100	1	100	100	1	100	99	99	100	100	0	100

[a] See Figure 1B.
[b] All isolates avirulent on *Sr*13.
[c] Area 8 not included.
[d] Roelfs et al (9).
[e] Roelfs et al (8).

Table 5. International Pgt- race equivalents for the former Cereal Rust Laboratory (CRL) races of *Puccinia graminis* f. sp. *tritici*

Pgt-race[a]	CRL designation[b]
	JBC[c]
LCC	7-LBC
LCC[d]	7-LCC
QCC	151-QBC
QFC	151-QFC
RCR	11-RCR
RKC	32-RJC
TPM	15-TNM

[a] Roelfs and Martens (14).
[b] Roelfs et al (9).
[c] Yellow urediniospores lost before Pgt- race determined.
[d] Virulent on *Sr*9a.

North America, although *Sr*24 has been used since 1967 in a series of cultivars and currently is widely used in the southern Great Plains. During the survey, no virulence was found to lines having *Sr*13, 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. tritici* in North America. Because races in this area were designated by a different system (9) before 1988, equivalents are given in Table 5.

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