Races of *Puccinia graminis* in the United States During 1990

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ABSTRACT

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Wheat stem rust overwintered in trace amounts from Louisiana to southern Alabama. No stem rust was found in fields of hard red spring or durum wheat cultivars. Race Pgt-QCCJ was the most common virulence combination, making up 67% of the 643 isolates from 240 collections. However, when only collections made from wheat were considered, the most common races, TPMK and QFCS, each made up 30% of the isolates. Of the isolates of race Pgt-QCCJ, 78% were recovered from barley. No virulence was found for wheat lines with "single" genes *Sr*13, 22, 24, 25, 26, 27, 29, 30, 31, 32, 33, 37, Gt, and Wld-1. Oat stem rust was present in light amounts throughout most of the United States in 1990, and yield losses were negligible. Disease onset was a week 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-16, NA-5, and NA-10 made up 82, 10, 6, and 1%, respectively, of the isolates from the United States. No virulence to *Pg*-9, -13, -16, or -a was found in the 1990 oat stem rust population.

Puccinia graminis Pers.:Pers. has been a major pathogen of many small grain cereals and forage grasses worldwide. Epidemics in the United States have been rare since the virtual elimination of the susceptible alternate host *Berberis vulgaris* L. from cereal-producing areas of the northern Great Plains (5). Since the mid-1950s, no major losses have resulted from oat or wheat stem rust in the United States (4). However, Pgt-QCCJ continues to threaten the barley (*Hordeum vulgare* L.) crop in the Red River Valley of North Dakota and Minnesota. A continuous series of resistant wheat (*Triticum aestivum* L.) cultivars have been used to control stem rust. The oat (*Avena sativa* L.) cultivars grown are susceptible to the most common pathogenic race. The lack of an oat stem rust epidemic could be due to a small number of overwintering uredinia and/or to a late onset of disease (9,11) or to environmental conditions unfavorable 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 endeavor 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 22,000-km route covering the Great Plains and Gulf Coast of the United States. The surveys followed a preselected, generally circular route through areas where small grain cereals are important and rust has historically been a problem. Visual inspections for the presence of rust were made at commercial fields every 32 km, or at the first field thereafter. Additional inspections were made at experimental nurseries and wheat trap plots along the route. Techniques used in the surveys and their interpretation have been described (6,7,12). 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 1990, field surveys were made in the following areas: southern 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); southeastern states (late May); Ohio River Valley (early June); Nebraska, South Dakota, and Minnesota (mid-June); and north central states (early July and early August).

Two spore samples were taken from each uredinial collection received at the laboratory. One portion of each sample 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 not known). Inoculated plants were treated with maleic hydrazide to enhance spore production (15). Spores suspended in lightweight mineral oil were sprayed on plants, which were then placed in a dew chamber overnight at 18 C. Following 14 hr of darkness, VHO fluorescent light was provided for 3–4 hr while temperatures were gradually increased to 25 C to enhance fungal penetration. Plants were then placed in a greenhouse at 18–28 C. Infection types were recorded after 10–14 days. Each culture was maintained in a separate clear plastic chamber. After 12–14 days, up to four leaves of each inoculated host species bearing, or pruned to bear, a single uredinium were saved and reincubated to permit free urediniospores to germinate. About 4 days later, urediniospores were collected from single uredinia (each such collection an isolate); each uredinium provided enough spores to inoculate a differential host series.

The second sample of spores from each collection was bulked with those from other collections made in the same area and time. The bulked spores were sprayed on the "universally" resistant series.

***Puccinia graminis* f. sp. *tritici*.** The differential host series consisted of wheat lines with resistance genes *Sr*5, 6, 7b, 8a, 9b, 9e, 9g, 11, 17, 21, 30, and 36. Races were assigned using the international Pgt code (14). An additional differential set consisting of *Sr*9a, 9d, 10, and Tmp was added. The universally resistant series consisted of lines with the resistance genes *Sr*13, 22, 24, 25, 26, 27, 29, 31, 32, 33, 37, Gt, and Wld-1 and the cultivars Era, Cando, and Ward, which were selected over a period of years as resistant to stem rust. Data were grouped by ecological areas (Fig. 1A) on the basis of cultural practices, geographic separation, and wheat production.

***Puccinia graminis* 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 (3). The universally resistant oat 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, which have been selected over a period of years as resistant to stem rust. Data were grouped by ecological areas (Fig. 1B) on the basis of oat production, cultural practices, and geographic separation.

RESULTS AND DISCUSSION

***P. g. tritici*.** Overwintering stem rust sites were found in southern Texas and

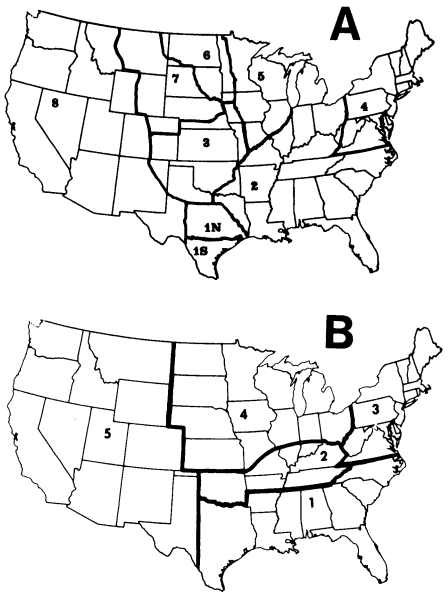

Fig. 1. Ecological areas for *Puccinia graminis* in the United States. **(A)** Areas for wheat stem rust: 1S = fall-seeded facultative and spring wheats, overwintering foci; 1N = mixed winter wheat types, rare overwintering uredinia; 2 = soft red winter wheat, scattered overwintering foci; 3 = southern 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. **(B)** Areas for oat stem rust: 1 = winter oats, occasional overwintering uredinia; 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.

southern Louisiana. The dry summer of 1989 limited oversummering infections that combined with late planting, and a December freeze resulted in a low initial level of fall infection in the area within 75 miles of the Gulf Coast. During the last 2 wk of May, only traces of stem rust were found in plots in north central Texas, west and east central Arkansas, and west central Indiana. In late April, heavy rains throughout Texas and Oklahoma scrubbed urediniospores from the air, washed them from uredinia, and resulted in long periods of high humidity within the canopy, thereby limiting spore release. Thus, only low numbers of spores in the air over affected fields were available for long-distance dispersal.

During the first week in June, stem rust was found in several wheat fields in central Kansas. Incidence and severity of the rust suggested that the inoculum source probably was infected plots in south central Kansas. Several overwintering centers were found in plots of McNair 701 (susceptible host) across Kansas, indicating that conditions had been generally favorable for winter rust survival. In Kansas, rust severity was light in fields of Karl, TAM 107, and 2157, but the level of disease provided inoculum for regions to the north. By mid-June, stem rust was found in fields and plots of susceptible cultivars in northern Kansas and south central Nebraska. In late June, traces of stem rust were found in winter and spring wheat plots in east central North Dakota, east central Minnesota, and east central Washington. By the third week in July, stem rust severities of 20% were found on winter wheats fields in southern Michigan, southeastern North Dakota, and east central Washington. Because most of the wheat in these areas was near maturity, losses were light.

The first reported stem rust on barley in 1990 was from winter barley plots in western Kansas during the second week of June. By the third week in June, traces of stem rust were found in plots and fields in east central Minnesota and in a field in northwestern Minnesota. The initial stem rust lesions were often on the leaves.

For 50 yr, the T-gene had protected barleys from stem rust in the Upper Midwest, with typically only a few pustules developing at maturity on late tillers. The resistance provided by the T-gene in barley is ineffective against race Pgt-QCCJ. During the last week in June, traces of barley stem rust were found in every commercial field surveyed in southeastern North Dakota and west central Minnesota, and by mid-July severities ranged from trace to 60%. This was the most severe and widespread stem rust epidemic on barley since the 1930s. Race Pgt-QCCJ, which was found in 1989 on barley in Minnesota, South Dakota, and North Dakota, was identified in 1990 from collections made on barley in these same states as well as Kansas. Race Pgt-QCCJ has a virulence pattern similar to races found in the Pacific Northwest and is thought to have originated there. This race was frequently found in collections made from winter wheat cultivars Quantum 561 and 2157

Table 1. Frequency of identified races of *Puccinia graminis* f. sp. *tritici* by area and source of collection in 1990

Area[a]	Source	Collections[b] (no.)	Isolates (no.)	Percentage of each Pgt physiologic race[c]											
				GBCD	LCCS	MCCS	QCCJ	QCCQ	QFCQ	QFCS	RCRS	RKRQ	TMLK	TPLK	TPMK
U.S.	Field	122	317	...	...	...	91	...	...	5	1	...	...	...	2
	Nursery	118	326	...	...	...	45	1	1	21	8	1	...	...	22
	Total	240	643	...	...	...	68	*	1	14	5	*	...	...	12
1S	Nursery	3	9	...	...	...	...	...	...	...	89	...	...	...	11
1N	Field	1	3	...	...	...	...	...	...	...	...	...	...	...	100
2	Field	1	3	...	...	...	...	...	...	...	33	...	...	...	67
	Nursery	11	21	...	...	...	...	...	...	14	24	14	...	...	48
	Total	12	24	...	...	...	...	...	...	13	25	13	...	...	50
3	Field	9	14	...	...	...	43	...	...	57	...	...	...	...	...
	Nursery	23	66	...	...	...	16	1	1	46	...	...	...	...	24
	Total	32	80	...	...	...	20	1	1	48	...	...	...	...	20
4	Nursery	2	6	...	...	...	...	...	...	...	...	...	...	...	100
5	Field	12	17	...	...	...	88	...	...	...	...	...	...	...	12
	Nursery	12	33	...	...	...	45	...	...	18	12	...	...	...	24
	Total	24	50	...	...	...	60	...	...	12	8	...	...	...	20
6	Field	99	280	...	...	...	96	...	...	3	1	...	...	...	...
	Nursery	66	188	...	...	...	64	*	2	13	5	...	...	...	16
	Total	165	468	...	...	...	83	*	1	7	2	...	...	...	6
7	Nursery	1	3	...	...	...	...	...	...	67	33	...	...	...	...
8	Nursery	18	40	5	2	8	15	...	8	2	8	...	45	8	...

[a]See Figure 1A. Totals do not include isolates from the sexual population from area 8.
[b]Uredinia from a single field, plant, or cultivar received separately were a collection from which up to three single uredinia (isolates) were identified.
[c]International Pgt races (14); set four includes *Sr*9a, 9d, 10, and Tmp. * = Less than 0.6%.

Table 2. Incidence of virulence in isolates of *Puccinia graminis* f. sp. *tritici* to resistance of single gene differential lines in the 1990 survey

Area[a]	Percentage of isolates virulent on *Sr* gene[b]												
	5	6	7b	8a	9a	9b	9d	9e	10	11	17	36	Tmp
1	100	0	100	100	0	0	100	100	100	100	100	100	100
1S	100	0	100	11	89	89	100	11	100	11	100	100	11
2	100	12	88	75	50	38	100	50	88	50	100	88	50
3	100	0	22	76	55	0	100	22	98	22	100	22	22
4	100	0	100	100	0	0	100	100	100	100	100	100	100
5	100	0	28	32	20	8	100	20	100	20	100	28	20
6	100	0	9	14	10	2	100	6	99	6	100	9	6
7	100	0	33	67	100	33	100	0	100	0	100	33	0
8	95	0	68	18	18	8	85	52	92	52	48	60	52
U.S. 1990	100	*	18	28	19	5	100	14	99	14	99	18	14
U.S. 1989[c]	100	0	58	77	47	4	100	53	99	53	100	57	53
U.S. 1988[d]	100	0	96	98	100	2	100	94	100	92	100	96	92

[a]See Figure 1A. Annual totals do not include isolates from the sexual population from area 8.
[b]All isolates avirulent to *Sr*30 and virulent to *Sr*9g and *Sr*21. * = Less than 0.6%.
[c]Roelfs et al (9).
[d]Roelfs et al (8).

in Kansas in late May and June, where it probably overwintered on these cultivars. Additionally, race Pgt-QCCJ was identified from 72% of the isolates made from wild barley (*H. jubatum* L.) in North Dakota, South Dakota, and Minnesota.

Nine Pgt races (with additional supplemental set, 12 virulence phenotypes) were identified from 240 collections made from wheat in the United States in 1990 (Table 1). Races Pgt-QFCS (151-QFC) and Pgt-TPMK (15-TNM) each composed 30% of the isolates. Races Pgt-TPLK (15-TNMH) and Pgt-TMMK (15-TLMH) were found in an Idaho nursery; these races have been found only in inoculated nurseries since 1987 and therefore are not included in the data reported. Races Pgt-GBCD, -LCCS, -MCCS, and RKRQ were also identified in the 1990 survey, the first three only in area 8.

When compared with the 5-, 10-, and 25-yr means of 219, 356, and 561, respectively, the 240 collections obtained in 1990 (Table 1) reflect a near-average rust incidence (13). The most common race in 1990 was Pgt-QCCJ, which composed 67% of all isolates (Table 1). Pgt-QCCJ is virulent to *Sr*5, 9d, 9g, 10, 15, 16, and 17 and avirulent to *Sr*6, 7b, 8a, 9a, 9b, 9e, 11, 13, Tmp and McN (A. P. Roelfs and D. V. McVey, *unpublished*). The 437 isolates of Pgt-QCCJ came from areas 3, 5, and 6 (the northern Great Plains), and 78 and 8% of the isolates were from barley and wild barley, respectively, indicating a rust primarily 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 a Fillmore County, Minnesota, collection on 10 July 1989.

Pgt-QFCS, virulent to *Sr*5, 8a, 9a, 9d, 9g, 10, 15, 16, and 17 and avirulent to *Sr*6, 7b, 9b, 9e, 11, 12, 36, Tmp (A. P. Roelfs and D. V. McVey, *unpublished*), was the second most common race. This race was rarely found in southern or eastern areas (1S, 1N, 2, or 4) but predominated in areas 3 and 7. Barley and wild barley accounted for 2 and 10% of the isolates, respectively. This race, typical of the Pacific Northwest stem rust pathogen population, made up 9% of the isolates from area 6 in 1988 (9) and 23% of all isolates in 1989. QFCS was the second most common race and was identified from 19% of the isolates from *H. jubatum*. TPMK (15-TNM), the predominant race of the 1970s and 1980s, composed only 12% of the population, partly because of the number of collections from barley, which were primarily Pgt-QCCJ. Of the isolates from wheat, Pgt-TPMK and QFCS each composed 30% of the isolates.

Virulence to *Sr*6 and 9b (Table 2) has remained at low levels for the past 10 yr. This is due to the high frequencies of races Pgt-QCCJ and TPMK. The sharp decrease in virulence to *Sr*9e and 36 is due to the increasing frequency of Pgt-QCC.

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 and when developing wheats resistant to stem rust. The cultivar Siouxland carries both *Sr*24 and *Sr*31. Virulence for neither gene is known in North America even though *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.

P. g. avenae. In late March, overwintering centers of oat stem rust were found in plots in southern Alabama and central Louisiana, and in early April, traces of oat stem rust were found in fields in southern Texas. By mid-May, rust incidence was light and limited to southern states. Traces of oat stem rust were found in fields in eastern Kansas in mid-June and in fields in northeastern South Dakota, central Minnesota, and southern Wisconsin by mid-July. Rust developed about a week later than normal,

Table 3. Frequency of identified races of *Puccinia graminis* f. sp. *avenae* by area and source of collection in 1990

Area[a]	Source	Collections[b] (no.)	Isolates (no.)	Percentage of each North American (NA) physiologic race[c]			
				NA-5	NA-10	NA-16	NA-27
U.S.	Field	50	70	...	...	4	96
	Nursery	64	132	10	2	13	75
	Total	114	202	6	1	10	82
1	Field	3	9	...	...	33	67
	Nursery	35	53	...	...	23	77
	Total	38	62	...	...	24	76
2	Nursery	2	6	...	...	17	83
4	Field	47	61	...	...	...	100
	Nursery	19	51	...	...	...	100
	Total	66	112	...	...	...	100
5	Nursery	8	22	59	14	18	9
Mexico	Nursery	2	6	...	...	...	100

[a]See Figure 1B.
[b]Uredinia from a single field, plant, or cultivar received separately were a collection from which up to three single uredinia (isolates) were identified.
[c]Martens et al (3).

Table 4. Incidence of virulence in isolates of *Puccinia graminis* f. sp. *avenae* to resistance of single gene differential lines in the 1990 survey

Area[a]	Percentage of isolates virulent on *Pg* gene[b]					
	1	2	3	4	8	15
1	100	76	100	76	100	0
2	100	83	100	83	100	0
4	100	100	100	100	100	0
5	27	23	100	9	27	73
U.S. 1990	92	84	100	82	92	8
U.S. 1989[c]	99	98	100	97	99	1
U.S. 1988[d]	90	87	98	83	90	8

[a]See Figure 1B.
[b]No isolates were virulent to *Pg*-a, 9, 13, or 16 during 1988–1990.
[c]Roelfs et al (9).
[d]Roelfs et al (8).

and severities and incidences were lower than normal. Rust became severe only on wild oats (*A. fatua* L.) and in oat fields in northwestern Minnesota and northeastern North Dakota planted in late July, resulting in some losses.

Race NA-27, virulent to *Pg*-1, -2, -3, -4, and -8, constituted 82% of the 202 isolates collected in the United States (Table 3). This race, virulent to most commercial cultivars, has predominated in the United States population since 1965, causing only one moderately severe epidemic (11). In California and Idaho (area 5), NA-27 was not found but NA-5 and NA-10 were isolated as in previous years (9). Race NA-16, virulent to *Pg*-1, -3, and -8, was frequently identified in the area from Texas to Minnesota. Races NA-5, NA-10, and NA-16 were also frequently isolated, although in small numbers (13, 3, and 20 isolates, respectively), making up about 6, 1, and 10% respectively, of the population. Races NA-5 and NA-10 were exclusively from California, although in previous years, NA-5 was often found throughout the United States. NA-16 was found throughout the United States except in area 4, where most cultivars have resistance to it.

Virulence to the single gene lines used for race identification is shown in Table 4. Hosts having genes *Pg*-9, -13, -16, and -a were resistant to the population sampled from the United States in 1990, although virulence to hosts having these genes had been detected in previous years. No virulence was detected to the oat lines of the resistant series.

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