Races of *Puccinia graminis* in the United States During 1993

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ABSTRACT

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Wheat stem rust overwintered in southern Texas, southern Louisiana, and southern Georgia. Yield losses in wheat to stem rust were traces, but several hundred hectares southwest of Houston were destroyed. Race Pgt-TPMK was the most common race overall, making up 61% of the 895 isolates from 311 collections. From *Hordeum* spp., 112 collections were made, in which the most common race was Pgt-QCCJ, comprising 56% of the isolates. Eighty-eight percent of the isolates of QCCJ were from cultivated barley, and 56% of all isolates from cultivated barley were race QCCJ. No virulence was found to wheat lines with "single" genes *Sr*13, 22, 24, 25, 26, 27, 29, 30, 31, 32, 33, 37, Gt, or Wld-1. Little oat stem rust overwintered in the southern states in 1993. Yield losses in 1993 were negligible. Race NA-27, virulent to *Pg*-1, -2, -3, -4, and -8, was again the predominant race in the United States, comprising 81% of the 93 isolates from 33 collections. NA-5 and NA-10 were the other races isolated, comprising 9 and 11% of the population, respectively. No virulence to *Pg*-9, -13, -16, or -a was found in the 1993 oat stem rust population.

Puccinia graminis Pers.:Pers. is 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 *Berberis vulgaris* L. from cereal-producing areas of the northern Great Plains (3). Since the mid-1950s, no major losses have resulted from oat or wheat stem rust in the United States (2). *Puccinia graminis* f. sp. *tritici* Eriks. & E. Henn. race Pgt-QCCJ (11) may threaten the barley crop in the Red River Valley of North Dakota, Minnesota, and Manitoba when adequate inoculum levels are present. A continuous series of resistant wheat cultivars in the northern Great Plains (*Triticum aestivum* L., *T. turgidum* L.) has been used to control stem rust. The majority of the oat cultivars (*Avena sativa* L.) grown are susceptible to the most common pathogenic *Puccinia graminis* f. sp. *avenae* Eriks & E. Henn. race NA-27 (1). 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 (7,10) 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 (6).

This research is part of the continuing effort to monitor changes in virulence combinations in *P. graminis* 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 (4,5,8). 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.

In 1993, field surveys of small grain cereals were made in the following areas: southern and central Georgia (late March through late May); southern Texas (late March); northern Texas and south central Oklahoma (late April); Gulf Coast states (late March to late April); southeastern states (early June); central Oklahoma, and Kansas (mid-May); Ohio River Valley (early June); northwestern Kansas, Nebraska, western Iowa, eastern South Dakota, and southern Minnesota (late June); and north central states (mid-July and again in early August).

Table 1. A key for defining the Pgt-code races of *Puccinia graminis* f. sp. *tritici*

	Subset[a]	Infection type produced on host lines with *Sr*			
	1	5	21	9e	7b
	2	11	6	8a	9g
Pgt code	3	36	9b	30	17
B		Low	Low	Low	Low
C		Low	Low	Low	High
D		Low	Low	High	Low
F		Low	Low	High	High
G		Low	High	Low	Low
H		Low	High	Low	High
J		Low	High	High	Low
K		Low	High	High	High
L		High	Low	Low	Low
M		High	Low	Low	High
N		High	Low	High	Low
P		High	Low	High	High
Q		High	High	Low	Low
R		High	High	Low	High
S		High	High	High	Low
T		High	High	High	High

[a] Pgt code consists of the designation for subset 1 followed by that for subset 2, etc.

Two single-uredinial samples were taken from each uredinial collection received. A 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 unknown). Inoculated plants were treated with maleic hydrazide to enhance spore production (12). Urediniospores suspended in lightweight mineral oil were sprayed on plants, which were then placed in a dew chamber overnight at 18°C. Following 14 h of darkness, VHO fluorescent light was provided for 3 to 4 h while temperatures gradually rose to 25°C to enhance fungal penetration. Plants were then placed in a greenhouse at 18 to 28°C. Infection types were recorded after 10 to 14 days. Each culture was maintained in a separate clear plastic chamber. After 12 to 14 days, up to four leaves of each inoculated host species bearing or pruned to bear a single uredinium were saved and reincubated (free water, 18°C, 3-h minimum) to permit free urediniospores to germinate. About 4 days later, urediniospores were collected from single uredinia (each considered 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.

***P. g.* 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 (Table 1). An additional differential set, consisting of lines with *Sr*9a, 9d, 10, and Tmp, was added. The universally resistant wheat 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 have been selected over a period of years as resistant to stem rust (10). Data were grouped by ecological areas (Fig. 1A) based on cultural practices, geographic separation, and wheat production.

***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. Races were assigned using the NA race nomenclature (1). The universally resistant oat series consisted of the host lines Saia

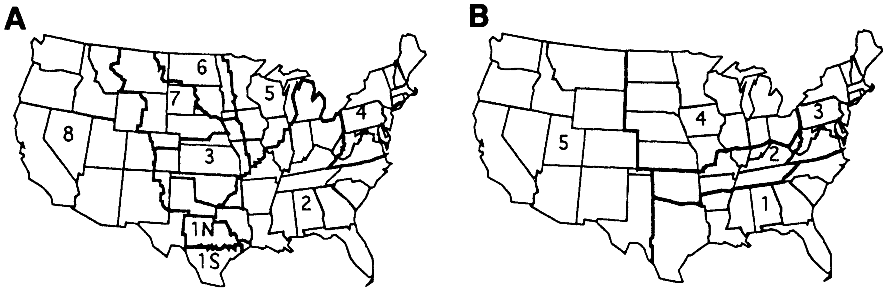

Fig. 1. Ecological areas for *Puccinia graminis* in the United States. **(A)** Areas of wheat stem rust: 1S, fall seeded facultative and spring wheats, overwintering foci; 1N, mixed winter wheat types, rare overwintering uredinia; 2, soft red winter wheat, scattered overwintering foci; 3, southern hard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

Table 2. Frequency of identified races of *Puccinia graminis* f. sp. *tritici* by area and source of collection in 1993

				Percentage of each Pgt physiologic race[c]								
Area[a]	Source	Collections[b] (no.)	Isolates (no.)	GCCD	QCCJ	QCCN	QCCQ	QFCQ	QFCS	RCRS	RKRQ	TPMK
U.S.	Field	91	260	*	32	...	*	*	16	*	...	51
	Nursery	220	635	...	19	...	...	...	15	...	1	65
	Total	311	895	*	22	...	*	*	15	*	*	61
	Hordeum[d]	112	315	...	56	...	...	...	18	...	...	26
1N	Field	4	7	...	...	...	14	...	86	...	...	...
	Nursery	4	11	...	...	...	...	...	...	...	...	100
	Total	8	18	...	...	...	6	...	33	...	...	61
1S	Field	5	15	7	...	...	...	...	20	...	...	73
2	Field	14	39	...	...	...	...	...	...	2	...	97
	Nursery	54	157	...	4	...	...	...	...	...	...	96
	Total	68	196	...	3	...	...	...	...	*	...	96
	Hordeum	2	5	...	...	...	...	...	...	...		100
3	Field	17	51	...	16	...	...	...	14	...	...	70
	Nursery	37	103	...	11	...	...	...	17	...	...	72
	Total	54	154	...	12	...	...	...	16	...	...	71
	Hordeum	3	9	...	22	...	...	...	...	...	...	78
4	Field	1	3	...	...	...	...	...	100	...	...	...
5	Field	20	60	...	47	...	...	2	10	...	...	42
	Nursery	41	120	...	22	...	...	...	28	...	3	47
	Total	61	180	...	30	...	...	*	22	...	2	45
	Hordeum	22	57	...	65	...	...	...	14	...	...	21
6	Field	30	85	...	54	...	...	...	19	...	...	27
	Nursery	80	232	...	32	...	...	...	18	...	...	50
	Total	110	317	...	38	...	...	...	18	...	...	44
	Hordeum	70	199	...	57	...	...	...	14	...	...	28
7	Nursery	3	9	...	...	...	...	...	11	...	...	89
	Hordeum	1	3	...	...	...	...	...	...	...	...	100
8	Field	6	18	...	67	...	...	...	33	...	...	...
	Nursery	20	58	...	33	5	...	...	59	...	...	3
	Total	26	76	...	41	4	...	...	53	...	...	3
	Hordeum	14	42	...	55	...	...	...	45	...	...	...

[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 (11); set four includes *Sr*9a, 9d, 10, and Tmp.
[d] Extracted data for *Hordeum* species.

(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 (10). Data were grouped by ecological areas (Fig. 1B) based on oat production, cultural practices, and geographic separation.

RESULTS AND DISCUSSION

***P. g.* f. sp. *tritici*.** Wheat stem rust overwintering sites were found in the southern portions of Texas, Louisiana, and Georgia. During the last week in March, stem rust was severe in fields southwest of Houston. Conditions were similar to 1986, when stem rust spread from soft red winter wheat fields south of Houston to the southern Great Plains. In late April, in central Texas, traces of stem rust were found scattered throughout fields of the cultivar Wintex, and 5% severities were found in plots of the cultivar McNair 701. By the third week in May, traces of wheat stem rust were found in southwestern Oklahoma fields and south central Kansas and northeastern Missouri plots. In southeastern Kansas fields, during the last week in May, rust was scattered and in trace amounts. Spore movement was limited because frequent rains kept the infected leaves wet and scrubbed the air of spores.

Stem rust was severe in southwestern Arkansas by late May, and heavy losses occurred in fields of cultivar CK 9835. Traces of stem rust were found in northeastern Missouri plots of cultivar Cardinal and of the old cultivars Knox and Riley 67. This was the most severe and widespread stem rust in this area in 5 years. During the second week in June, stem rust foci were found in fields in southern Illinois, southern Indiana, and western Kentucky. In Illinois and Indiana, Clark was the most severely rusted commercial cultivar. By late June, traces of stem rust were reported in a few fields in central and southern Wisconsin. Traces of stem rust were found in western New York plots in early July.

During the third week in June, traces of stem rust were found in north central Kansas and south central Nebraska fields. In this area, 5% severities were found in plots of cultivar Karl, and a 1-m-diameter focus with a 10% severity was found in a Karl plot in the Nebraska panhandle. Traces of stem rust were observed on some of the other hard red winter wheat cultivars, while 20% severities were found on the soft red winter wheat cultivars Clark and Cardinal in these plots. In northwestern Kansas plots, 10% severities were observed on both cultivars 2157 (susceptible to Pgt-QCCJ race) and McNair 701 (susceptible to races other than QCCJ). In a south central Nebraska irrigated winter wheat plot, 10 or more stem rust pustules per flag leaf were common. This infection was presumably due to a heavy spore shower in mid-June.

In mid-June, traces of stem rust were found in a winter wheat nursery in southeastern Minnesota. By early August, 10 to 40% severities were found in east central and northwestern North Dakota plots of susceptible cultivars. During the fourth week in June, traces of stem rust were found in susceptible spring wheat plots in southeastern North Dakota and south central Minnesota, which is normal for the first observation of rust at these locations. The cool weather and frequent rain slowed the spread of stem rust. During the second week in July, traces of wheat stem rust were found on susceptible spring wheats in central and north central North Dakota. Commercial spring and durum wheat cultivars in this area have a high level of stem rust resistance, so losses to stem rust were negligible. In mid-July, wheat stem rust increased in eastern Washington and caused some damage in late-maturing susceptible spring wheat cultivars.

Race Pgt-TPMK continues to be the most common race on wheat in the Great Plains (Table 2). Pgt races QCCQ and QCCS, which do not infect barley, were identified from collections made in south Texas in early spring. The barley-attacking race Pgt-QCCJ was found in areas 2, 3, 5, 6, and 8.

The first report of barley stem rust was in a southwestern Georgia nursery in late May. The next report of barley stem rust was during the fourth week in June, when traces of stem rust were found in plots in south central Nebraska and south central Minnesota. In mid-July, 1% severities were observed in southeastern Minnesota and south central Wisconsin fields. Trace to 5% stem rust severities were observed in clumps of wild barley (*Hordeum jubatum* L.) throughout northeastern South Dakota and southeastern North Dakota. During the first week in August, traces of barley stem rust were found in fields from northwestern North Dakota to northwestern Minnesota. Stem rust was reported at several Idaho sites in early August. In both 1992 and 1993, there was less rust reported on barley than in the previous 4 years. This can be related to lower levels of initial inoculum and cool June and July temperatures. Losses were limited to stands that were thin.

Pgt races TPMK, QCCJ, and QFCS made up 98% of the wheat stem rust isolates collected in 1993. Thus, the frequencies of these three races in areas 1 to 8 mainly determine the virulence frequencies in those areas (Table 3). For example, Pgt races TPMK, QCCJ, and QFCS are all virulent to *Sr5*, 9d, 9g, 10, 17, and 21 and avirulent to *Sr6*, 9b, and 30. Consequently, virulence to *Sr5*, 9d, 9g, 10, 17, and 21 was very common and virulence to *Sr6*, 9b, and 30 was absent or very rare. As these three races have been common for the past 3 years, there has been little change in virulence to the chosen differential hosts. No virulence was found to the universally resistant wheat series.

***P. g.* f. sp. *avenae*.** In early March, oat stem rust was reported in a northeastern Mexico field. The only stem rust observation in Texas was of traces in the nursery

Table 3. Incidence of virulence in isolates of *Puccinia graminis* f. sp. *tritici* to resistance of single gene differential lines in the 1993 survey

Area[a]	Percentage of isolates virulent to *Sr* gene[b]															
	5	6	7b	8a	9a	9b	9d	9e	9g	10	11	17	21	30	36	Tmp
1N	100	0	61	94	39	0	100	61	100	94	61	100	100	0	61	61
1S	93	0	73	93	20	0	93	73	100	100	73	100	100	0	73	73
2	100	0	97	96	*	*	100	96	100	100	96	100	100	0	97	96
3	100	0	71	88	16	0	100	71	100	100	71	100	100	0	71	71
4	100	0	0	100	100	0	100	0	100	100	0	100	100	0	0	0
5	100	2	47	70	25	2	100	45	100	97	45	100	100	0	47	45
6	100	0	44	62	18	0	100	44	100	100	44	100	100	0	44	44
7	100	0	89	100	11	0	100	89	100	100	89	100	100	0	89	89
8	100	0	3	55	57	0	96	3	100	100	3	100	100	0	3	3
U.S. 1993	100	*	57	76	19	*	100	57	100	99	57	100	100	0	57	57
U.S. 1992[c]	100	0	31	44	19	0	100	31	100	98	31	100	100	0	31	31
U.S. 1991[d]	100	0	18	32	14	0	100	18	100	100	17	100	100	0	18	17

[a] See Figure 1A. Annual totals do not include isolates from the sexual population from area 8.
[b] * = Less than 0.6%.
[c] Roelfs et al. (10).
[d] Roelfs et al. (9).

Table 4. Frequency of identified races of *Puccinia graminis* f. sp. *avenae* by area and source of collection in 1993

Area[a]	Source	Collections[b] (no.)	Isolates (no.)	Percentage of each North America (NA) physiologic race[c]		
				NA-5	NA-10	NA-27
U.S.	Field	12	35	17	...	83
	Nursery	21	58	3	17	79
	Total	33	93	9	11	81
1	Nursery	6	15	...	...	100
2	Nursery	2	6	...	...	100
4	Field	10	29	...	...	100
	Nursery	9	25	...	...	100
	Total	19	54	...	...	100
5	Field	2	6	100	...	...
	Nursery	4	12	17	83	...
	Total	6	18	44	56	...

[a] See Figure 1B. Canadian collections from Ontario, Mexican collections from central Mexico.
[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. (1).

Table 5. Incidence of virulence to isolates of *Puccinia graminis* f. sp. *avenae* to resistance of single gene differential lines in the 1993 survey

Area[a]	Percentage of isolates virulent to *Pg* gene[b]					
	1	2	3	4	8	15
1	100	100	100	100	100	0
2	100	100	100	100	100	0
4	100	100	100	100	100	0
5	0	56	0	0	0	100
U.S. 1993	81	91	81	81	81	19
U.S. 1992[c]	98	91	100	90	98	2
U.S. 1991[d]	97	93	100	93	97	3

[a] See Figure 1B.
[b] No isolates were virulent to *Pg*-a, -9, -13, or -16 during 1989–1992.
[c] Roelfs et al. (10).
[d] Roelfs et al. (9).

at Beeville in late March. This was less rust than usual at this time of the year. Late planting and perhaps less inoculum in the fall were the main factors in the low level of disease. By late April, oat stem rust was increasing rapidly at Beeville, Texas, and was severe within 75 miles of the Gulf Coast in nurseries at Quincy, Florida; Fairhope, Alabama; and Baton Rouge, Louisiana. By the second week in May, oat stem rust was severe on a few lines in the southern Georgia nursery at Plains. In late May, stem rust was severe on wild oats (*Avena fatua* L.) growing in fields in California's Sacramento Valley. During the first week in June, stem rust was heavy in oat plots in eastern Tennessee at Knoxville. The first report of oat stem rust in the northern oat-growing area was traces in southern Wisconsin fields in mid-June. By mid-July, 1 to 5% severities were found in southeastern Minnesota and south central Wisconsin fields. In late July, 10 to 20% severities were reported in south central Minnesota. In general, in the northern plains, oat stem rust appeared late in the season and developed slowly because of cool weather. Rust severities were light, and little loss occurred. Race NA-27, virulent to *Pg*-1, -2, -3, -4, and -8, remains the predominant race of the population (Table 4).

Only three races were identified, and two of these were found only in area 5 (California). Thus in areas 1, 2, and 4, no variation was observed in the incidence of virulence to the differential *Pg* genes used (Table 5). The difference between 1993 and 1991 to 1992 was due to the presence of only race NA-27 in areas 1, 2, and 4 and to the greater proportion of isolates from California in 1993 (19%) than in 1991 to 1992 (2% and 8%). No virulence was found to the universally resistant oat series.

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