Races of *Puccinia graminis* in the United States During 1991

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ABSTRACT

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Wheat stem rust overwintered in southern Texas, southern Louisiana, and southwestern Georgia. Yield losses caused by stem rust in wheat and barley were light, although losses up to 10% occurred in some barley fields in east central North Dakota. Race Pgt-QCCJ was the most common race, making up 68% of the 1,279 isolates from 487 collections. However, when only collections made from wheat were considered, the most common races were QCCJ, TPMK, and QFCS, comprising 38, 36, and 25% of the isolates, respectively. Of the isolates of race Pgt-QCCJ, 67% were from cultivated 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, occurring only in the Gulf Coast area, northern Great Plains, and California (an isolated population). Yield losses were negligible. The principal race was NA-27, virulent to resistance genes *Pg*-1, -2, -3, -4, and -8. NA-27, NA-16, and NA-5 made up 94, 4, and 2%, respectively, of the isolates from the United States. No virulence to *Pg*-9, -13, -16, or -a was found in the 1991 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 *Berberis vulgaris* L. from cereal-producing areas of the northern Great Plains (4). Since the mid-1950s, no major losses have resulted from oat or wheat stem rust in the United States (3). However, race 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 majority of the oat (*Avena sativa* L.) cultivars grown are susceptible to the most common pathogenic race, NA-27. 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 (11).

This research is part of the continuing endeavor to monitor changes in virulence combinations present 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 (5,6,10). 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 1991, field surveys of small grain cereals were made in the following areas: southern Georgia (early March through late May); southern Texas (early April); northern Texas and southwestern Oklahoma (late April); Gulf Coast states (mid-April to early May); southeastern states (early May); Oklahoma and Kansas (mid-May); Ohio River Valley (early June); northwestern Kansas, Nebraska, South Dakota, and Minnesota (mid-June); and north central states (early July and late July through early August).

Two single-uredinium 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 not known). Inoculated plants were treated with maleic hydrazide to enhance spore production (13). 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 (free water, 18 C, 3 hr 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.

***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 (12). An additional differential set, consisting of lines with *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 (11). 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 (1). 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 (11). Data were grouped by ecological areas (Fig. 1B) on the basis of oat production, cultural practices, and geographic separation.

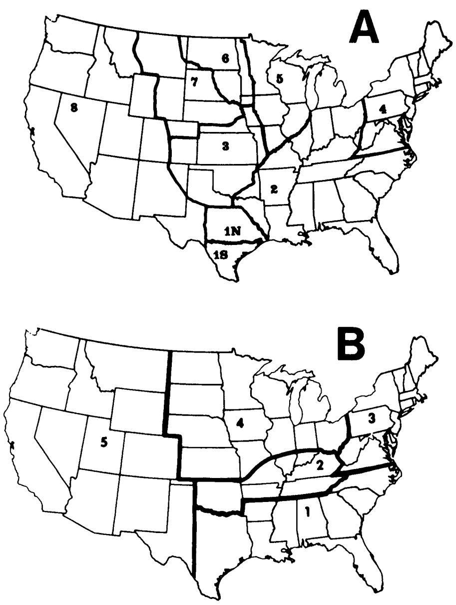

Fig. 1. Ecological areas for *Puccinia graminis* in the United States. **(A)** Areas for wheat stem rust: 1S = fall seeded facultative and spring wheats, overwintering foci; 1N = mixed winter wheat types, rare overwintering uredinia; 2 = soft red winter wheat, scattered overwintering foci; 3 = southern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

RESULTS AND DISCUSSION

P. g. tritici. Overwintering stem rust sites were found on susceptible cultivars in southern Texas, southern Louisiana, and southwestern Georgia. By late April, stem rust was severe in these plots, but none was found in plots of susceptible cultivars in northern Texas. By mid-May, stem rust was found at 20% severities in fields in southwestern Oklahoma and north central Texas, where stem rust overwintered, and at trace amounts in demonstration plots in southern Kansas and northwestern Arkansas. In late May, plots of the cultivar 2157 (susceptible to both Pgt-TPMK and QCCJ) were lightly rusted (10–15% incidence) across the northern tier of Kansas counties. Stem rust was more widely spread than in 1990 in the central Great Plains, when it developed from a point source in south central Kansas (11). Although severities in the central Great Plains were slightly less than in 1990, conditions were favorable for rust infection in May and the inoculum that was carried northward was deposited over the spring grain area during late May.

By early June, stem rust was present across Kansas and eastern Colorado. Most cultivars in plots in Kansas were lightly rusted (less than 1% severity). The exception was cultivar 2157, which had 50% severity in a north central Kansas location. By the third week in June, cultivars 2157 and Quantum 542 had 20% stem rust severities in north central and northwestern Kansas plots. This was the second consecutive year that stem rust had been so widely distributed in Kansas. Stem rust appeared earlier than normal throughout this area because the inoculum (race Pgt-QCCJ) produced in south central Oklahoma and adjacent areas in Texas was more abundant than normal. The weather was very favorable for rust in early April and early May but less favorable in late April.

Several centers of stem rust (race Pgt-TPMK) with 20% severities were found in southern Illinois fields during the first week in June. Traces of stem rust were also found in fields in northwestern Illinois (race Pgt-QFCS), and plots in west central Indiana (race Pgt-TPMK).

In most of the northern Great Plains locations, stem rust was first detected 1–2 wk earlier than normal. In mid-June, the rains and warm nights (15–18 C) created a favorable environment for spore deposition, infection, and increase. By the last week in June, trace to 40% severity occurred in plots of susceptible spring and winter wheat cultivars from east central North Dakota to southeastern Minnesota. In early July, foci of 30% severity were observed in winter wheat plots in northwestern North Dakota and northeastern Montana. Plots of susceptible winter wheat in southeastern North Dakota had foci of 40% severity, but only traces of rust were found in northeastern North Dakota. Since most winter wheat was near maturity, losses were light. By the last week in July, stem rust severities were as high as 60% on susceptible spring wheat cultivars in northeastern North Dakota plots, but no stem rust was found in spring or durum wheat fields in northern North Dakota. The commonly

Table 1. Frequency of identified races of *Puccinia graminis* f. sp. *tritici* by area and source of collection in 1991

Area[a]	Source	Collections[b] (no.)	Isolates (no.)	Percentage of each Pgt physiologic race[c]					
				HFLG	QCCJ	QFCS	RTQQ	RTRQ	TPMK
U.S.	Field	184	505	...	84	10	...	...	6
	Nursery	303	774	1	58	16	...	...	25
	Total	487	1,279	*	68	14	...	...	17
1S	Nursery	4	12	50	50	...	...	...	...
1N	Field	1	0	...	...	...	...	...	...
2	Field	3	8	...	...	...	...	...	100
	Nursery	31	78	...	4	...	...	...	96
	Total	34	86	...	4	...	...	...	96
3	Field	41	120	...	70	22	...	...	8
	Nursery	84	221	...	58	23	...	...	20
	Total	125	341	...	62	22	...	...	16
5	Field	15	41	...	58	34	...	...	7
	Nursery	48	74	...	51	16	...	...	32
	Total	63	115	...	54	23	...	...	24
6	Field	124	336	...	94	3	...	...	2
	Nursery	127	364	...	70	18	...	...	12
	Total	251	700	...	82	11	...	...	7
7	Nursery	9	25	...	72	8	...	...	20
8	Nursery	11	33	...	67	33	...	...	...
Mexico, D. F.	Nursery	1	2	...	...	...	50	50	...

[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 (12); 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 1991 survey

Area[a]	Percentage of isolates virulent on *Sr* gene[b]												
	5	6	7b	8a	9a	9b	9d	9e	10	11	17	36	Tmp
1S	100	0	0	0	0	0	100	0	100	0	100	0	0
1N	0	0	100	100	0	0	100	0	0	0	0	100	0
2	100	0	96	96	0	0	100	96	100	96	100	96	96
3	100	0	16	38	22	0	100	16	100	16	100	16	16
5	100	0	24	46	23	0	100	24	100	24	100	24	24
6	100	0	7	18	11	0	100	7	100	7	100	7	7
7	100	0	20	28	8	0	100	20	100	20	100	20	20
8	100	0	0	33	33	0	100	0	100	0	100	0	0
U.S. 1991	100	0	18	32	14	0	100	17	100	17	100	18	17
U.S. 1990[c]	100	*	18	28	19	5	100	14	99	14	99	18	14
U.S. 1989[d]	100	0	58	77	47	4	100	53	99	53	100	57	53

[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 (11).
[d]Roelfs et al (7).

Table 3. Frequency of identified races of *Puccinia graminis* f. sp. *avenae* by area and source of collection in 1991

Area[a]	Source	Collections[b] (no.)	Isolates (no.)	Percentage of each North American (NA) physiologic race[c]					
				NA-5	NA-16	NA-25	NA-26	NA-27	NA-32
U.S.	Field	21	56	...	...	...	...	100	...
	Nursery	44	106	3	6	...	...	92	...
	Total	65	162	2	4	...	...	94	...
1	Field	1	3	...	...	...	...	100	...
	Nursery	27	60	...	3	...	...	97	...
	Total	28	63	...	3	...	...	97	...
4	Field	20	53	...	...	...	...	100	...
	Nursery	16	43	...	9	...	...	91	...
	Total	36	96	...	4	...	...	96	...
5	Nursery	1	3	100	...	...	...	...	...
Canada	Nursery	3	7	...	...	43	29	...	29
Mexico	Nursery	6	9	...	...	...	...	100	...

[a]See Figure 1B. Canadian collections from Ontario, Mexican collections from Sonora and Chihuahua.
[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 (2).

grown spring and durum wheats remain resistant to stem rust, and no significant losses occurred in 1991. Wheat stem rust developed slowly in the Pacific Northwest and was light on susceptible winter and spring wheats in late July.

Four Pgt races were identified from 487 collections in the United States in 1991 (Table 1). Race Pgt-QCCJ was the predominant race, comprising 68% of the isolates, compared with 67% in 1990. Of the isolates of Pgt-QCCJ, 67% were from cultivated barley; 95% of all isolates from cultivated barley were Pgt-QCCJ. Pgt-TPMK, the common race from 1974–1989, comprised 17% of the isolates identified in 1991, compared with 12% in 1990. When only collections made from wheat were considered, the most common races were QCCJ, TPMK, and QFCS, comprising 38, 36, and 25% of the isolates, respectively.

The incidence of virulence to the single gene lines used for race identification is shown in Table 2. 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.

The first report of barley stem rust in 1991 was in southern Texas plots at Uvalde during the third week in April. Race Pgt-QCCJ was identified from these Texas collections. Pgt-QCCJ caused losses in spring-sown barley in the northern Great Plains in 1990 (11). During early May in 1991, barley stem rust was common in an eastern Virginia barley nursery, and at maturity the susceptible cultivars in this nursery were severely rusted. By late May, traces of stem rust were found in barley fields in central Kansas. During the second week in June, traces of stem rust were reported in spring barley plots in southern Minnesota and southeastern North Dakota.

During the last week in June, traces of barley stem rust were found in each barley field surveyed in the Red River Valley of Minnesota and North Dakota. By the second week in July, severities ranged from 0.1 to 20% in fields and nurseries surveyed from western Minnesota to northeastern Montana. The most severe rust, and the only area where significant damage occurred, was in east central North Dakota and adjacent Minnesota. Overall losses were light, but a few growers lost up to 10% in yield. Rust severities that reduce grain plumpness, an important factor in malting quality (and thus price), are lower than those that significantly affect yields (1).

In early June, traces of stem rust were found on wild barley (*H. jubatum* L.) from northwestern Iowa to east central Nebraska, on little barley (*H. pusillum* Nutt.) growing along fields in southeastern Nebraska and northeastern Kansas, and on goat grass (*T. cylindricum* Ces.) in north central Kansas. These species are susceptible to Pgt-QCCJ. By late July, severities ranged from 0.1 to 40% on wild barley growing along roadsides from west central Minnesota to north central North Dakota. Race Pgt-QCCJ comprised 94% of the isolates identified from *Hordeum* spp. in the United States. Race Pgt-QCC has now survived the winter in Kansas during 1989–1990 and in Texas through Kansas during 1990-1991, so it is likely to remain a part of the *P. graminis* population. Because of its abundance in the population, mutants with a wider host range are expected to occur.

P. g. avenae. In late March, overwintering sites of oat stem rust were found in southern Georgia and southern Louisiana nurseries. In early April, traces of oat stem rust were present in oat fields and on wild oats (*A. fatua* L.) in southern Texas. By late April, stem rust was severe in southern Georgia and Louisiana and light in central Louisiana plots. By late May, the northern limits of stem rust were plots in southeastern Kansas. During the first week in June, traces of oat stem rust were found in west central Kansas, southeastern Nebraska, and east central Wisconsin. Stem rust was severe in a field in northeastern South Dakota during the second week in July, and traces were found in plots in west central

Table 4. Incidence of virulence in isolates of *Puccinia graminis* f. sp. *avenae* to resistance of single gene differential lines in the 1991 survey

Area[a]	Percentage of isolates virulent to *Pg* gene[b]					
	1	2	3	4	8	15
1	100	97	100	97	100	0
4	100	96	100	96	100	0
5	0	0	100	0	0	100
U.S. 1991	97	93	100	93	97	3
U.S. 1990[c]	92	84	100	82	92	8
U.S. 1989[d]	99	98	100	97	99	1

[a] See Figure 1B.
[b] No isolates were virulent to *Pg*-a, 9, 13, or 16 during 1989–1991.
[c] Roelfs et al (11).
[d] Roelfs et al (7).

Minnesota and north central South Dakota. In late July, light (1–3%) severities were observed on oats in plots and fields in northeastern North Dakota and northwestern Minnesota; stem rust severities on wild oats were lower than normal in this area. Losses to oat stem rust in 1991 in the northern oat-growing area were lower than in the previous 2 yr.

Race NA-27, virulent to *Pg*-1, -2, -3, -4, and -8, remained the predominant race east of the Rockies, comprising 94% of the 162 isolates collected in the United States in 1991 and 100% of isolates from field collections (Table 3). NA-27 is virulent to most commercial cultivars, has predominated in the United States population since 1965, but has caused only one moderately severe epidemic (9). Races NA-5 and NA-16 were the other races isolated (one and six isolates, respectively), making up about 2 and 4%, respectively, of the population. Race NA-5 was from California but has often been found throughout the country in previous years. NA-16 was found in Texas, Minnesota, and North Dakota.

The incidence of 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 1991, although virulence to hosts having these genes has been detected in previous years. No virulence was detected to the oat lines of the resistant series.

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