Races of *Puccinia graminis* in the United States During 1992

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ABSTRACT

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Wheat stem rust overwintered in southern and east central Texas, southern Louisiana, and southeastern Alabama. Yield losses to stem rust of wheat were traces, but a 1% yield loss in barley occurred in North Dakota. Race Pgt-QCCJ was the most common race, making up 50% of the 450 isolates from 170 collections. If only the 89 collections from wheat were considered, the most common races were Pgt-TPMK, QFCS, and QCCJ, comprising 53, 21, and 16% of the isolates, respectively. Eighty percent of the isolates of QCCJ were from cultivated barley, and 90% 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. Oat stem rust overwintered in southern Texas and southern Louisiana. Yield losses in 1992 were negligible. Race NA-27, virulent to *Pg*-1, -2, -3, -4, and -8 was again the predominant race in the United States comprising 90% of the 279 isolates from 96 collections. NA-16, NA-5, and NA-23 were the other races isolated, comprising 7, 2, and 1% of the population, respectively. No virulence to *Pg*-9, -13, -16, or -a was found in the 1992 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 the 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). However, *Puccinia graminis* f. sp. *tritici* Eriks. & E. Henn. race Pgt-QCCJ (11) continues to threaten the barley crop in the Red River Valley of North Dakota, Minnesota, and Manitoba. A continuous series of resistant wheat cultivars (*Triticum aestivum* 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 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 (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 1992, field surveys of small grain cereals were made in the following areas: southern and central Georgia (late March through late May); eastern and southern Texas (early April); northern Texas and south central Oklahoma (late April); Gulf Coast states (mid-April to early May); southeastern states (early May); north central Texas, Oklahoma, and Kansas (mid-May); the Ohio River Valley (early June); northwestern Kansas, Nebraska, western Iowa, South Dakota, and southern Minnesota (mid-June); and north central states (early July and again in late July).

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). 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 gradually rose 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.

P. g. 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 (11). 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 were 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.

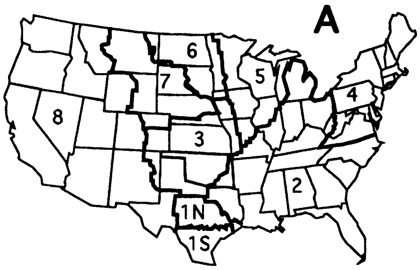
P. g. avenae. The differential host series consisted of oat lines with resistance genes *Pg*-1, -2, -3, -4, -8, -9, -13, -16, and -a. Races were assigned using the NA race nomenclature (1). The universally resistant oat series consisted of the host lines Saia (CI 7010), CI 7221, S.E.S. No. 52 (CI 3034), X-1588-2 (CI 8457), Kyto (CI 8250), MN 730358, and CI 9139, which were 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. tritici. Sites of overwintering stem rust were found on susceptible wheat cultivars in southeastern Alabama, southern Louisiana, and southern and east central Texas plots. By late April, stem rust was severe in these plots (80% severities), while in a northern Texas plot, stem rust severities ranged from 60% at the center (not an overwintering site) to traces 3 miles away. By the second week in May, traces of stem rust were found in plots and fields from north central Texas to south central Kansas. In late May, traces of stem rust were found on the cultivar Voyager in south central and central Kansas as well as on 2157 (susceptible to both race TPMK and QCCJ) in a plot in northern Kansas. By the first week in June, stem rust severities ranged from 1 to 10% in east central Kansas fields. This was the least amount of stem rust found in Kansas since race QCCJ appeared 3 yr ago. By the third week in June, traces of stem rust were found on the cultivar Karl in plots from north central Kansas to central and east central South Dakota. Fewer overwintering sites along the Gulf Coast, cool temperatures, and late freezes all inhibited the spread of stem rust in the central plains.

In early June, traces of stem rust were found in spring-planted winter wheat in a southeastern North Dakota nursery. This was 3 wk earlier than normal for this area. By mid-July, 20% wheat stem rust severities developed in plots of susceptible winter wheat in central Minnesota, and traces developed in southeastern North Dakota plots. Due to cool temperatures, rust increased slowly in the northern plains, resulting in light losses on winter wheat.

In the northern soft red winter wheat area, traces of stem rust were reported in a southeastern Indiana field and in south central Illinois plots the first week in June. Losses were limited to traces in the soft red winter wheat region.



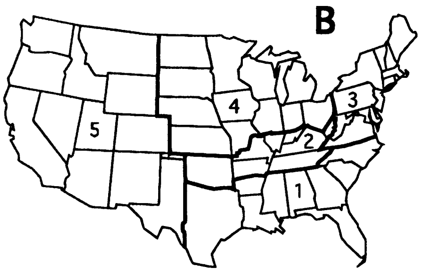


Fig. 1. Ecological areas for *Puccinia graminis* in the United States. **(A)** Areas of wheat stem rust: 1S, fall seeded facultative and spring wheats, overwintering foci; 1N, mixed winter wheat types, rare overwintering uredinia; 2, soft red winter wheat, scattered overwintering foci; 3, southern hard 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 of 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 1. Frequency of identified races of *Puccinia graminis* f. sp. *tritici* by area and source of collection in 1992

Area[a]	Source	Collections[b] (no.)	Isolates (no.)	Percentage of each Pgt physiologic race[c,d]					
				QCCJ	QCCQ	QCCS	QFCS	TPLK	TPMK
U.S.	Field	61	155	70	...	6	10	...	14
	Nursery	109	295	39	3	3	15	*	40
	Total	170	450	50	2	4	13	*	31
	Hordeum[e]	76	211	89	1	1	3	...	6
1N	Field	4	8	...	...	63	...	...	38
	Nursery	9	23	35	...	13	...	...	52
	Total	13	31	26	...	26	...	...	48
1S	Nursery	3	4	...	100	...	...	...	...
2	Field	2	6	...	...	...	50	...	50
	Nursery	10	24	...	13	...	...	4	83
	Total	12	30	...	10	...	10	3	77
	Hordeum	1	3	...	67	...	...	...	33
3	Field	9	18	28	...	6	50	...	17
	Nursery	29	80	21	4	6	19	...	50
	Total	38	98	22	3	6	24	...	44
	Hordeum	5	12	75	...	...	25	...	...
5	Field	9	19	68	...	16	...	...	16
	Nursery	10	22	32	...	...	18	...	50
	Total	19	41	49	...	7	10	...	34
	Hordeum	9	22	91	...	9	...	...	...
6	Field	37	104	88	...	...	3	...	10
	Nursery	48	142	58	...	...	18	...	24
	Total	85	246	71	...	...	11	...	18
	Hordeum	61	174	91	...	...	2	...	6
8	Field	4	12	50	...	33	17	...	...
	Nursery	2	6	...	...	...	100	...	...
	Total	6	18	33	...	22	44	...	...
	Hordeum	4	12	50	...	33	17	...	...

[a] See Figure 1A. Totals do not include isolates from 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] * = Less than 0.6%.
[e] Extracted data for *Hordeum* species.

Traces of stem rust were found on the susceptible spring wheat cultivar Baart in southeastern Minnesota in early July. By the last week in July, stem rust was as high as 60% severity on susceptible spring wheat cultivars in west central Minnesota plots. The commercial spring and durum wheats are resistant to stem rust, so losses were negligible.

Six Pgt races were identified from 170 collections in the United States in 1992 (Table 1). Race QCCJ was the predominant race, comprising 50% of the isolates identified in 1992, compared to 68% in 1991. Eighty percent of the isolates of QCCJ were from cultivated barley. Ninety percent of all isolates from the 74 collections obtained from cultivated barley were QCCJ. Race TPMK, the common race from 1974 to 1989, comprised 31% of the isolates identified in 1992, compared to 17 and 12% for 1991 and 1990, respectively. If only the 89 collections made from wheat were considered, the most common races were TPMK, QFCS, and QCCJ, comprising 53, 21, and 16% 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 stem rust on barley in 1992 was of trace amounts found in north central Texas plots the second week of May. Race QCCJ was identified from these collections. Race QCCJ caused losses in spring-sown barleys in the northern Great Plains in 1990 (9). No barley stem rust was found in southern Texas. In mid-June, barley plots in south central Nebraska had trace to 10% severities on 20% of the plants. During the second week in June, traces of barley stem rust were found in plots and fields in southeastern North Dakota. During the first full week in July, traces of barley stem rust were found in fields from northeastern South Dakota to east central North Dakota and in west central Minnesota plots. In late July, traces of barley stem rust were found in fields and plots in northeastern North Dakota and northwestern Minnesota. Severities of stem rust were the lowest on barley since 1988 due to lower levels of initial inoculum and cool June and July temperatures. Race QCCJ comprised 90% of the isolates identified from barley collections, compared to 65, 90, and 94% in 1989 through 1991, respectively. Collections of QCCJ in 1992 were from Texas, Nebraska, Minnesota, South Dakota, North Dakota, and Idaho (Table 1). Yield losses due to stem rust on barley were estimated from traces in several states to 1% in North Dakota.

P. g. avenae. Sites of overwintering stem rust were found in southern Texas and southern Louisiana. In early May, stem rust severities ranged from 0 to 5% in central Texas fields, while traces were found in southwestern Oklahoma fields. By mid-May, 10% severities were observed on wild oats (*Avena fatua* L.) in north central Texas and central California. By late May, oat stem rust was light

Table 2. Incidence of virulence in isolates of *Puccinia graminis* f. sp. *tritici* to resistance of single gene differential lines in the 1992 survey

	Percentage of isolates virulent to *Sr* gene[b]															
Area[a]	5	6	7b	8a	9a	9b	9d	9e	9g	10	11	17	21	30	36	Tmp
1N	100	0	48	48	26	0	100	48	100	100	48	100	100	0	48	48
1S	100	0	0	0	100	0	100	0	100	0	0	100	100	0	0	0
2	100	0	80	90	20	0	100	80	100	90	80	97	100	0	80	80
3	100	0	44	68	34	0	100	44	100	97	44	100	100	0	44	44
5	100	0	34	44	17	0	100	34	100	100	34	100	100	0	34	34
6	100	0	18	29	11	0	100	18	100	100	18	100	100	0	18	18
8	100	0	0	44	67	0	100	0	100	100	0	100	100	0	0	0
U.S. 1992	100	0	31	44	19	0	100	31	100	98	31	100	100	0	31	31
U.S. 1991[c]	100	0	18	32	14	0	100	18	100	100	17	100	100	0	18	17
U.S. 1990[d]	100	*	18	28	19	5	100	18	100	99	14	99	100	0	18	14

[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 3. Frequency of identified races of *Puccinia graminis* f. sp. *avenae* by area and source of collection in 1992

				Percentage of each North America (NA) physiologic race[c]							
Area[a]	Source	Collections[b] (no.)	Isolates (no.)	NA-5	NA-16	NA-23	NA-24	NA-25	NA-26	NA-27	NA-32
U.S.	Field	50	148	2	4	...	...	...	...	94	...
	Nursery	46	131	2	11	2	...	...	...	85	...
	Total	96	279	2	7	1	...	...	...	90	...
1	Field	6	18	...	6	...	...	...	...	94	...
	Nursery	27	75	...	19	4	...	...	...	77	...
	Total	33	93	...	16	3	...	...	...	81	...
2	Field	1	3	...	...	...	...	...	...	100	...
4	Field	41	124	...	4	...	...	...	...	96	...
	Nursery	13	38	...	...	...	...	...	...	100	...
	Total	54	162	...	3	...	...	...	...	97	...
5	Field	2	3	100	...	...	...	...	...	...	...
	Nursery	6	18	17	...	...	...	...	...	83	...
	Total	8	21	29	...	...	...	...	...	71	...
Mexico	Field	3	53	11	...	...	9	...	...	79	...
	Nursery	1	21	...	...	...	...	...	...	100	...
	Total	4	74	8	...	...	7	...	...	85	...
Canada	Field	3	9	...	...	...	...	33	33	...	33
	Nursery	5	15	...	...	...	...	...	33	...	67
	Total	8	24	...	...	...	...	13	33	...	54

[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 4. Incidence of virulence to isolates of *Puccinia graminis* f. sp. *avenae* to resistance of single gene differential lines in the 1992 survey

	Percentage of isolates virulent to *Pg* gene[b]					
Area[a]	**1**	**2**	**3**	**4**	**8**	**15**
1	100	84	100	81	100	0
2	100	100	100	100	100	0
4	100	97	100	97	100	0
5	71	71	100	71	71	29
U.S. 1992	98	91	100	90	98	2
U.S. 1991[c]	97	93	100	93	97	3
U.S. 1990[d]	92	84	100	82	92	8

[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).

but widely scattered throughout the southern Great Plains, providing inoculum for the northern oat growing areas. In mid-June, traces of oat stem rust were found in south central Nebraska fields and north central Kansas plots. By early July, traces of oat stem rust were found in southeastern Minnesota and west central Minnesota. In late July, 20% severities were observed on plants near maturity in fields in southeastern Minnesota. In general, in the northern plains, oat stem rust appeared late in the season and developed slowly due to cool weather. Race NA-27, virulent to *Pg*-1, -2, -3, -4, and -8, remains the predominant race comprising 90% of the 279 isolates from 96 collections in the United States in 1992 (Table 3). NA-27, virulent to most oat cultivars, has predominated in the United States population since 1965, but has caused only one moderately severe epidemic (7). Races NA-16, NA-5, and NA-23 were the other races isolated, comprising 7, 2, and 1% of the population, respectively. Terminal severities were light and little loss occurred.

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 1992; however, virulence to hosts having these genes has been detected in previous years. No virulence was detected to the oat lines in the resistant series.

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