Races of *Puccinia graminis* in the United States During 1994

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ABSTRACT

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Wheat stem rust overwintered in southern Louisiana and Texas in the winter of 1993–94. Wheat stem rust caused negligible yield losses in wheat in the U.S. Race Pgt-TPMK was the most common race on wheat, making up 39% from 51 collections, while Pgt-QCCJ was most common from barley, making up 90% from 38 collections. Four collections from *Hordeum jubatum* yielded six isolates of race TMPK, four isolates of race QCCJ, and one each of races RKQQ and RTQQ. No virulence was found to wheat lines with genes *Sr*13, 22, 24, 25, 26, 27, 29, 30, 31, 32, 33, 37, Gt, or Wld-1. Oat stem rust was first found in mid-April in southern Texas and Louisiana. Yield losses due to oat stem rust in 1994 were negligible. Race NA-27, virulent to *Pg*-1, -2, -3, -4, and -8, was again the predominant race in the United States, constituting 87% of the 119 isolates from 41 collections. NA-5 and NA-16 were the two other races identified from the U.S., constituting 3 and 10% of the isolates, respectively. Only race NA-29 was found in 50 collections from central Mexico.

Puccinia graminis Pers.:Pers. has been a major pathogen of many small grains worldwide. Epidemics in the United States have been rare since the virtual elimination of susceptible *Berberis vulgaris* L. from the cereal-producing areas of the northern Great Plains (4). Resistant wheat cultivars (*Triticum aestivum* L.) have also contributed to control of stem rust. No major losses from stem rust have occurred in the United States in spring wheat since the mid-1950s or in winter wheat since the mid-1960s (3; D. L. Long, unpublished). However, *Puccinia graminis* f. sp. *tritici* Eriks & E. Henn. race Pgt-QCCJ (10,11) continues to threaten the barley crop in the Red River Valley of North Dakota, Minnesota, and Manitoba. There have been no major losses to oat stem rust since 1975 (3; D. L. Long, unpublished). The majority of the oat cultivars (*Avena sativa* L.) grown are susceptible to race NA-27, the most common race of *Puccinia graminis* f. sp. *avenae* Eriks. & E. Henn. (1). The lack of oat stem rust epidemics could be due to small numbers of overwintering uredinia and/or to late onset of disease (8,11), small acreage of oats grown or to unfavorable environmental conditions for development of regional epidemics. The trend in recent years is for a single race to make up most of the pathogen population (7).

This research is part of the continuing effort to monitor changes in race combinations present in *P. graminis* in an effort to maintain rust-resistant cultivars in North America.

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

	Sub-set[a]	Infection type produced on host lines with *Sr*			
	1	5	21	9e	7b
Pgt-	2	11	6	8a	9g
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.

MATERIALS AND METHODS

Field surveys were made over a 22,000-km route covering the Great Plains, Ohio River Valley, and Gulf Coast of the United States. The surveys followed a preselected route through areas where small grain cereals are important and rust has historically been a problem. In 1994, field surveys of small grain cereals were made in the following areas: southern and central Georgia (late March through May); eastern and southern Texas (early April); northern Texas and south central Oklahoma (late

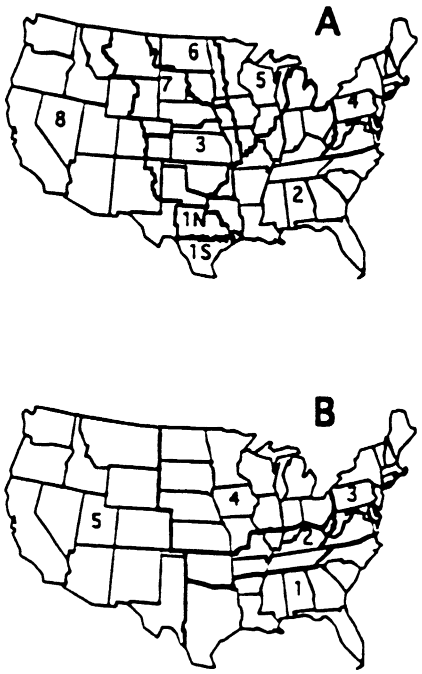

Fig. 1. Ecological areas for *Puccinia graminis* in the United States. **(A)** Areas of wheat stem rust: 1S, fall seeded facultative and spring wheats, overwintering foci; 1N, mixed winter wheat types, rare overwintering uredinia; 2, soft red winter wheat, scattered overwintering foci; 3, southern hard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

April); southeastern Gulf Coast (mid-April to early May); southeastern states (early May); Oklahoma and Kansas (mid-May); the Ohio River Valley (early June); northwestern Kansas, Nebraska, western Iowa, South Dakota, and southern Minnesota (mid-June); and northern Plains states (early July and again in late July). Visual inspections, using the modified Cobb scale (2), for the presence of rust were made at commercial fields (4 to 50 ha in size) 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 (5,6,9). 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.

A portion of each collection was used to inoculate 7-day-old seedlings of a susceptible cultivar (when the rust forma specialis was known) or a group of potentially susceptible host species (if the forma specialis was unknown). Spores suspended in lightweight mineral oil were sprayed on plants, which were then placed in a dew chamber overnight at 18°C. The inoculated plants had been treated with maleic hydrazide to enhance spore production (15). Following 14 h of darkness, VHO fluorescent light was provided for 3 to 4 h while temperature gradually rose to 25°C to enhance fungal penetration. Plants were then placed in a greenhouse at 18 to 28°C, where each culture was maintained in a separate, clear plastic chamber. After 12 to 14 days, up to four host species plants, each bearing a uredinium or pruned to bear a uredinium, were saved and reincubated (free water, 18°C, 3-h minimum) to permit free uredinospores to germinate. About 4 days later, urediniospores were collected from each uredinium (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

Table 2. Frequency of identified races of *Puccinia graminis* f. sp. *tritici* by area and source of collection in 1994[a]

				Percentage of each Pgt physiologic race[d]						
Area[b]	Source	Collections (no.)[c]	Isolates (no.)	QCCJ	QFBS	QFCS	RCRS	RKQQ	RTQQ	TPMK
U.S.	Field	5	14	14	7	7	...	...	...	71
	Nursery	46	131	27	...	28	4	5	1	36
	Total	51	145	26	1	26	3	4	1	39
1N	Nursery	1	2	...	...	...	...	...	...	100
1S	Field	1	3	67	...	...	...	...	...	33
	Nursery	1	3	...	...	...	...	...	...	100
	Total	2	6	33	...	...	...	...	...	67
2	Field	4	11	...	9	9	...	...	...	82
	Nursery	11	33	...	...	...	...	3	...	97
	Total	15	44	...	2	2	...	2	...	93
5	Nursery	5	12	25	...	17	...	25	8	25
6	Nursery	24	70	46	...	41	7	3	...	3
8	Nursery	2	6	50	...	33	...	...	17	...

[a] Includes Hordeum spp.
[b] See Figure 1A. Area 8 not included in U.S. totals.
[c] Uredinia from a single field, plant, or cultivar constituted a collection, from which up to three single uredinia (isolates) were identified.
[d] International Pgt races (14); set four includes *Sr* 9a, 9d, 10, and Tmp.

Table 3. Incidence of virulence in isolates of *Puccinia graminis* f. sp. *tritici* toward single gene differential wheat lines in the 1994 survey

			Percentage of isolates virulent to *Sr* gene[a]															
Area	Source	Isolates	5	6	7b	8a	9a	9b	9d	9e	9g	10	11	17	21	30	36	Tmp
U.S.	Field	14	100	0	71	86	14	0	100	71	100	100	71	93	100	0	71	71
	Nursery	131	100	5	45	69	37	9	100	36	100	95	37	95	100	0	45	36
	Total[b]	145	100	5	48	71	35	8	100	39	100	95	40	94	100	0	48	39
1N		2	100	0	100	100	0	0	100	100	100	100	100	100	100	0	100	100
1S	Field	3	100	0	33	33	0	0	100	33	100	100	33	100	100	0	33	33
	Nursery	3	100	0	100	100	0	0	100	100	100	100	100	100	100	0	100	100
	Total	6	100	0	67	67	0	0	100	67	100	100	67	100	100	0	67	67
2	Field	11	100	0	82	100	18	0	100	82	100	100	82	91	100	0	82	82
	Nursery	33	100	3	100	100	3	3	100	97	100	97	97	97	100	0	100	97
	Total	44	100	2	95	100	7	2	100	93	100	98	93	95	100	0	95	93
3	Nursery	11	100	0	45	100	55	0	100	45	100	100	45	100	100	0	45	45
5	Nursery	12	100	33	58	75	50	33	100	25	100	67	33	67	100	0	58	25
6	Nursery	70	100	3	13	47	51	10	100	3	100	97	3	97	100	0	13	3
8	Nursery	6	100	17	17	50	50	17	100	0	100	83	17	83	100	0	17	0
U.S.	1993[c]		100	*	57	76	19	*	100	57	100	99	57	100	100	0	57	57
U.S.	1992[d]		100	0	31	44	19	0	100	31	100	98	31	100	100	0	31	31
U.S.	1991[e]		100	0	18	32	14	0	100	18	100	100	17	100	100	0	18	17
U.S.	1990[f]		100	*	18	28	19	5	100	18	100	99	14	99	100	0	18	14

[a] * = Less than 0.6%.
[b] See Figure 1A. Area 8 not included in U.S. totals.
[c] Include Hordeum collections (13).
[d] Roelfs et al. (12).
[e] Roelfs et al. (11).
[f] Roelfs et al. (10).

other collections made in the same area and at the same 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 (Table 1). Races were assigned using the International Pgt-code (14). An additional differential set, consisting of lines *Sr*9a, 9d, 10, and *Tmp*, was added. The universally resistant wheat series consisted of lines with 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) based on 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, -15, -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

***Puccinia graminis* f. sp. *tritici*.** There was less wheat stem rust in the United States in 1994 than in 1993. Overwintering sites were found in southern Texas and Louisiana. In the last week of March, dry conditions and cool night temperatures (4 to 5°C) were not conducive to stem rust development in southern Texas. During the first week of March, trace amounts of stem rust were found in a field of winter wheat cultivar Mit, 104 km southwest of Houston, Texas. The collection was identified as Pgt-QCCJ. During the second week of April, trace amounts of stem rust were found in wheat plots at Victoria, Texas, and by the last week of April, trace amounts were found in plots at McGregor and Temple, Texas. Also during late April, trace amounts of race TPMK were found in southern Louisiana.

Table 4. Frequency of identified races of *Puccinia graminis* f. sp. *tritici* from *Hordeum vulgare* by race and source

Area[a]	Source	Collections (no.)[b]	Isolates (no.)	Percentage of each Pgt physiologic race[c]					
				QCCJ	QCCS	QFCS	RKQQ	RTQQ	TPMK
5	Field	2	6	83	...	...	...	...	17
	Nursery	4	10	70	...	...	...	20	10
	Total	6	16						
6	Field	8	24	92	...	...	...	4	4
	Nursery	23	63	92	5	3	...	...	...
	Total	31	87						
7	Nursery	1	3	100	...	...	...	...	...
U.S.	Field	10	30	90	...	...	...	3	7
	Nursery	28	76	89	4	3	...	3	1
	Total	38	106						

[a] See Figure 1A.
[b] Uredinia from a single field, plant, or cultivar constituted 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.

By the first week of May, 5% stem rust severities were observed in fields in east central and central Louisiana and lighter amounts in nurseries in northern Louisiana where wheat was nearing maturity. During late May, light amounts of stem rust were found irregularly across the Mississippi Valley. By the first week of June, trace amounts of stem rust were found on McNair 701 (susceptible host) in a south central Kansas plot, and by the third week 10% severity was observed in plots of the cultivar McNair 701 and trace amounts in fields of the winter wheat cultivar Karl at hard dough. The hot, dry weather in late May and early June was not favorable for stem rust development. By mid-June, the first reports of trace amounts of stem rust from the northern soft red winter wheats from central Indiana and east central Illinois in commercial fields were received.

By mid-July, trace amounts of stem rust were found on the winter wheat cultivar Norstar and in plots of susceptible spring wheat in southeastern North Dakota. In late July, trace amounts were found in plots in west central Minnesota and central and northwestern North Dakota. The commercial spring and durum wheats are resistant to stem rust and occasionally resistant-type uredinia were found in these crops; therefore, losses were negligible.

Seven races were identified from 51 wheat collections in 1994 (Table 2). Race TPMK was predominant, constituting 39% of the wheat isolates, followed by QFCS and QCCJ, each constituting 26% of the isolates. Races RKQQ, RCRS, RTQQ, and QFBS were the other four races identified from wheat. Two wheat stem rust isolates of race NCBG and one each of races QPMQ and QTMQ were identified from four Minnesota *Berberis vulgaris* L. collections. The incidence of virulence to single gene lines used for race identification is shown in Table 3. No virulence was found to wheat lines with genes *Sr*13, 22, 24, 25, 26, 27, 29, 30, 31, 32, 33, 37, Gt, or Wld-1.

From 38 stem rust collections from *Hordeum vulgare* L., 106 isolates of *P.*

Table 5. Incidence of virulence in isolates of *Puccinia graminis* f. sp. *tritici* from *Hordeum vulgare* toward single gene differential wheat lines, 1994 survey

Area	Source[a]	Isolate (no.)	Percentage of isolates virulent to *Sr* gene															
			5	6	7b	8a	9a	9b	9d	9e	9g	10	11	17	21	30	36	Tmp
5	Field	6	100	0	17	17	0	0	100	17	100	100	17	100	100	0	17	10
	Nursery	10	100	20	30	30	20	20	100	10	100	80	30	80	100	0	30	10
	Total	16	100	13	25	25	13	13	100	13	100	88	25	88	100	0	25	13
6	Field	24	100	4	8	8	4	4	100	4	100	96	8	96	100	0	8	4
	Nursery	63	100	0	0	3	8	0	100	0	100	100	0	100	100	0	0	0
	Total	87	100	1	2	5	7	1	100	1	100	99	2	99	100	0	2	1
7	Nursery	3	100	0	0	0	0	0	100	0	100	100	0	100	100	0	0	0
U.S.	Field	30	100	3	10	10	3	3	100	7	100	97	10	97	100	0	10	7
	Nursery	76	100	3	4	7	9	3	100	1	100	97	4	97	100	0	4	1
	Total	106	100	3	6	8	8	3	100	3	100	97	6	97	100	0	6	3

[a] See Figure 1A.

Table 6. Frequency of identified races of *Puccinia graminis* f. sp. *avenae* by area and source collection in 1994

Area[a]	Source	Collections (no.)[b]	Isolates (no.)	Percentage of each North American (NA) physiologic race[c]			
				NA-5	NA-16	NA-27	NA-29
U.S.	Field	11	29	10	0	90	. . .
	Nursery	30	90	. . .	13	87	. . .
	Total	41	119	3	10	87	. . .
1	Nursery	18	54	. . .	22	78	. . .
4	Field	9	23	. . .	. . .	100	. . .
	Nursery	12	36	. . .	. . .	100	. . .
	Total	21	59	. . .	. . .	100	. . .
5	Field	2	6	50	. . .	50	. . .
Mexico	Field	34	92	. . .	. . .	86	14
	Nursery	25	73	. . .	. . .	88	12
	Total	59	165	. . .	. . .	87	13

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

Table 7. Incidence of virulence in isolates of *Puccinia graminis* f. sp. *avenae* toward single gene differential oat lines in the 1994 survey

Area[a]	Source	Isolates	Percentage of isolates virulent to *Pg* gene[b]					
			1	2	3	4	8	15
1	Nursery	54	100	78	100	78	100	. . .
4	Field	23	100	100	100	100	100	. . .
	Nursery	36	100	100	100	100	100	. . .
	Total	59					*	
5	Field	6	50	50	100	50	50	50
U.S.	Field	29	90	90	100	90	90	10
	Nursery	90	100	87	100	87	100	. . .
	Total	119						
Mexico	Field	79	100	100	100	100	100	14
	Nursery	13	100	100	100	100	100	12
	Total	165						
U.S.	1993[c]	. . .	81	91	81	81	81	19
U.S.	1992[d]	. . .	98	91	100	90	98	2
U.S.	1991[e]	. . .	97	93	100	93	97	3
U.S.	1990[f]	. . .	92	84	100	82	92	8

[a] See Figure 1B.
[b] No virulence found on Pg-9, 13, 16, a, from 1990 to 1994.
[c] Roelfs et al. (13).
[d] Roelfs et al. (12).
[e] Roelfs et al. (11).
[f] Roelfs et al. (10).

graminis f. sp. *tritici* were made (Table 4). Combining *H. vulgare* isolates from field and nurseries, race QCCJ constituted 90% of the isolates while other races (TPMK, QFCS, QCCS, RKQQ, and RTQQ) each constituted 3% or less of the isolates. The incidences of virulence from *H. vulgare* are shown in Table 5. Four collections from *H. jubatum*, made from region 6, yielded 12 isolates. Of these, races TPMK (50%), QCCJ (33%), RKQQ (17%) and RTQQ (17%) were present. Race QCCJ is virulent on the *T*-gene, which all presently grown *H. vulgare* cultivars are assumed to possess, while the gene is absent in *H. jubatum*.

***Puccinia graminis* f. sp. *avenae*.** No oat stem rust was observed in late March in southern Texas, along the Gulf Coast, and in Florida. However, by mid-April, trace amounts were found in southern Louisiana nurseries where oats ranged from the early milk to soft dough growth stage. The stem rust developed rapidly and became severe on susceptible cultivars in southern Louisiana by the end of April. At that time it was also found in the nurseries at Beeville, Texas.

By early May, 5% stem rust severities were observed in oat plots at Quincy, Florida, and Fairhope, Alabama, at the hard dough growth stage. In East Baton Rouge, Louisiana, rust developed very late but destroyed most cultivars and the uniform oat trials. In early May, light amounts of stem rust were found on wild oats (*Avena fatua*) in the Central Valley of California.

By late May, light amounts of oat stem rust were found in north central Texas, but none was found in the central plains. During the third week of June, trace amounts were detected in fields in north central Kansas and southwest Nebraska at the late milk growth stage. By early July, trace amounts were found in fields in west central Wisconsin, and by mid-July trace amounts were present in central and east central Minnesota and northeastern South Dakota. In north central South Dakota, traces of stem rust were found on wild oats. During the last week of July, traces of oat stem rust were found in plots in west central and northwest Minnesota and traces in fields in central Minnesota. Trace to 5% severities were found on wild oats in north central North Dakota. Throughout the Great Plains, oat stem rust developed late and caused minor losses except in late maturing fields.

Race NA-27, virulent to *Pg*-1, -2,- 3,- 4, and -8, was predominant, constituting 87% of 119 isolates from 41 collections in 1994 (Table 6). Races NA-5, virulent to *Pg*-3 and -15, and NA-16, virulent to *Pg*-1, -3, and -8, constituted 3 and 10% of the isolates, respectively, from the United States. Race NA-29, virulent to *Pg*-1, -2, -3, -4, -8, and -15, made up 13% of the isolates from Mexico. Terminal severities were light and little loss occurred.

The incidence of virulence to single gene lines used for the race identification is shown in Table 7. Hosts having genes *Pg*-9, -13, -16, and -*a* were resistant to the population samples from the United States. No virulence was detected to the oat lines in the resistant series.

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