Races of *Puccinia graminis* in the United States During 1995

D. V. McVey, Research Plant Pathologist, and D. L. Long, Plant Pathologist, Cereal Rust Laboratory, Agricultural Research Service, USDA, University of Minnesota, St. Paul 55108, and J. J. Roberts, Research Plant Pathologist, Cereal Rust Research, Agricultural Research Service, USDA, Georgia Agricultural Experiment Station, Experiment 30212

ABSTRACT

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Wheat stem rust overwintered in southern Louisiana, southern Texas, southwestern Georgia, northeastern Arkansas, and southwestern South Carolina in the winter of 1994-95. Wheat stem rust caused negligible yield losses in wheat in the United States. Races Pgt-TPMK and QCCJ made up 39 and 31% of all isolates, respectively. Race TPMK comprised 67% of isolates from farm fields. Race Pgt-QCCJ was most common from barley, making up 93% from 47 collections. Six collections from *Hordeum jubatum* yielded six isolates each of races QCCJ and QFCS, and one isolate of race TPMK. No virulence was found to wheat lines with genes *Sr6*, *9b*, *13*, *22*, *24*, *25*, *26*, *27*, *29*, *30*, *31*, *32*, *33*, *37*, *Gt*, or *Wd1-1*. Oat stem rust overwintered in plots at Beeville and Temple, Texas, in a field near San Antonio, and in southern Louisiana. Yield losses due to oat stem rust in 1995 were negligible. Race NA-27, virulent to *Pg-1*, *-2*, *-3*, *-4*, and *-8*, was again the predominant race in the United States, comprising 82% of the 225 isolates from 80 collections. NA-5 and NA-16 were the two other races identified from the United States, comprising 11 and 19% of the isolates. Only race NA-29 was found in four collections from Mexico.

Puccinia graminis Pers.:Pers. is 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 (5). The use of resistant wheat cultivars (*Triticum aestivum* L.) 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in the United States in spring wheat since the mid-1950s or in winter wheat since the mid-1960s (4; D. L. Long, unpublished). However, *P. graminis* f. sp. *tritici* Eriks. & E. Henn. race Pgt-QCCJ (11,12) continues to threaten the barley crop in Minnesota, Manitoba, and the Red River Valley of North Dakota. There have been no major losses to oat stem rust since 1975 (4; 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 *P. graminis* f. sp. *avenae* Eriks. & E. Henn. (1). The lack of oat stem rust epidemics could be due to small numbers of overwintering uredinia or to late onset of disease (9,12), small area of oats grown, or unfavorable environmental conditions for development of regional epi-

demics. The trend in recent years is for a single race to make up most of the pathogen population (8).

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.

MATERIALS AND METHODS

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 1995, 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 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 and Nebraska, western Iowa and South Dakota, and southern Minnesota (mid-June); and northern Plains states (early July and again in late July).

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

Pgt-code	Subset ^a	Infection type produced on host lines with Sr				
		1	5	21	9e	7b
	2	11	6	8a	9g	
	3	36	9b	30	17	
	4	9a	9d	10	Tmp	
B		Low	Low	Low	Low	Low
C		Low	Low	Low	Low	High
D		Low	Low	Low	High	Low
F		Low	Low	Low	High	High
G		Low	High	Low	Low	Low
H		Low	High	Low	Low	High
J		Low	High	High	High	Low
K		Low	High	High	High	High
L		High	Low	Low	Low	Low
M		High	Low	Low	Low	High
N		High	Low	Low	High	Low
P		High	Low	Low	High	High
Q		High	High	Low	Low	Low
R		High	High	Low	Low	High
S		High	High	High	High	Low
T		High	High	High	High	High

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

Corresponding author: D. V. McVey, USDA, Agricultural Research Service, Cereal Rust Laboratory, University of Minnesota, St. Paul 55108; E-mail: donm@puccini.crl.umn.edu.

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Table 2. Frequency of identified races of *Puccinia graminis* f. sp. *tritici* from wheat by area and source of collection in 1995

Area ^a	Source	Collections (no.) ^b	Isolates (no.)	Percentage of each Pgt physiologic race ^c					
				QCCJ	QCCS	QCMS	QFCS	RCMS	TPMK
1N	Nursery	2	6	50	...	...	...	...	50
1S	Field	3	9	...	...	...	...	67	33
	Nursery	4	8	...	...	...	38	50	13
	Total	7	17	...	...	...	18	59	24
2	Field	3	9	...	...	...	...	...	100
	Nursery	14	41	7	...	...	...	7	85
	Total	17	50	6	...	...	...	6	88
3	Nursery	4	10	20	...	...	40	...	40
	Nursery	2	6	...	...	...	...	...	100
5	Nursery	6	18	50	...	...	33	6	11
6	Nursery	21	63	54	5	...	37	...	5
7	Nursery	1	3	67	...	...	...	...	33
8	Field	1	3	...	...	...	...	...	100
	Nursery	8	22	5	23	18	14	...	41
	Total	9	25	4	20	16	12	...	48
U.S.	Field	6	18	...	...	...	...	33	67
	Nursery	54	155	34	2	...	23	5	35
	Total	60	173	31	2	...	21	8	39

^a See Figure 1A. Area 8 not included in U.S. totals.^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 (15); set four includes *Sr9a*, 9d, 10, and *Tmp*.**Table 3.** Incidence of virulence in isolates of *Puccinia graminis* f. sp. *tritici* from wheat toward single gene differential wheat lines in the 1995 survey

Area ^a	Source	Isolates	Percentage of isolates virulent to <i>Sr</i> gene															
			5	6	7b	8a	9a	9b	9d	9e	9g	10	11	17	21	30	36	<i>Tmp</i>
U.S.	Field	18	100	0	100	67	33	0	100	67	100	100	67	100	100	0	100	67
	Nursery	155	100	0	41	59	30	0	100	35	100	100	35	100	100	0	41	35
	Total	173	100	0	47	60	31	0	100	39	100	100	39	100	100	0	47	39
1N	Nursery	6	100	0	50	50	0	0	100	50	100	100	50	100	100	0	50	50
1S	Field	9	100	0	100	33	67	0	100	33	100	100	33	100	100	0	100	33
	Nursery	8	100	0	63	50	88	0	100	13	100	100	13	100	100	0	63	13
	Total	17	100	0	82	41	76	0	100	24	100	100	24	100	100	0	82	24
2	Field	9	100	0	100	100	0	0	100	100	100	100	100	100	100	0	100	100
	Nursery	41	100	0	93	85	7	0	100	85	100	100	85	100	100	0	93	85
	Total	50	100	0	94	88	6	0	100	88	100	100	88	100	100	0	94	88
3	Nursery	10	100	0	40	80	40	0	100	40	100	100	40	100	100	0	40	40
4	Nursery	6	100	0	100	100	0	0	100	100	100	100	100	100	100	0	100	100
5	Nursery	18	100	0	17	44	39	0	100	11	100	100	11	100	100	0	17	11
6	Nursery	63	100	0	5	41	41	0	100	5	100	100	5	100	100	0	5	5
7	Nursery	3	100	0	33	33	0	0	100	33	100	100	33	100	100	0	33	33
U.S.	1994 ^b		100	5	48	71	35	8	100	39	100	95	40	94	100	0	48	39
U.S.	1993 ^c		100	* ^d	57	76	19	*	100	57	100	99	57	100	100	0	57	57
U.S.	1992 ^e		100	0	31	44	19	0	100	31	100	98	31	100	100	0	31	31
U.S.	1991 ^f		100	0	18	32	14	0	100	18	100	100	17	100	100	0	18	17

^a See Figure 1A. Area 8 not included in U.S. totals.^b 1994 McVey et al. (2). Does not include *Hordeum* collections.^c 1993 Roelfs et al. (14). Includes *Hordeum* collections.^d * = Less than 0.6%.^e 1992 Roelfs et al. (13).^f 1991 Roelfs et al. (12).**Table 4.** Frequency of identified races of *Puccinia graminis* f. sp. *tritici* from *Hordeum vulgare* and *H. jubatum* by race and source

Area ^a	Source	Collections (no.) ^b	Isolates (no.)	Percentage of each Pgt physiologic race ^c				
				QCCJ	QCCS	QFCS	RCMS	TPMK
2	Nursery	1	3	...	...	...	...	100
5	Nursery	4	12	83	...	...	17	...
6	Field	20	58	100	...	...	...	...
	Nursery	22	65	92	3	3	2	...
	Total	42	123	96	2	2	1	...
U.S.	Field	20	58	100	...	...	...	...
	Nursery	27	80	88	3	3	4	4
	Total	47	138	93	1	1	2	2

^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 (15); set four includes *Sr9a*, 9d, 10, and *Tmp*.

Visual inspections for the presence of rust, using the modified Cobb scale (3), were made at commercial fields (4 to 50 ha) every 32 km, or in 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 interpretations have been described (6,7,10). Whenever rust was observed in a field or nursery, leaves or stems bearing rust uredinia from a single cultivar or field were collected. Addi-

tional collections were furnished by co-operators.

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 light-weight 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 (16). Following 14 h of darkness, VHO fluorescent light was provided for 3 to 4 h while the 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 re-incubated (free water, 18°C, 3-h minimum) to permit free urediniospores 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 collection of spores was made from each uredinium and bulked with those from other collections made in the same area and at the same time. The bulked spores were sprayed on the "universally" resistant series.

***P. 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 (15). 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 (12). Data were grouped by ecological areas (Fig. 1A) based on cultural practices, geographic separation, and wheat production.

***P. graminis* f. sp. *avenae*.** The differential host series for identifying races of *P.*

graminis f. sp. *avenae* 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), Kyo (CI 8250), MN 730358, and CI 9139, which were selected over a period of years as resistant to stem rust (11). Data were grouped by ecological areas (Fig. 1B) based on oat production, cultural practices, and geographic separation.

RESULTS AND DISCUSSION

***P. graminis* f. sp. *tritici*.** Overwintering sites were found in southern Texas, Louisiana, southwestern Georgia, northeastern Arkansas, and southwestern South Carolina. During the last week of March, trace amounts of stem rust were found in winter wheat fields southwest of Houston, southeast of San Antonio, and in a nursery at Beeville, Texas. In mid-April, trace to 5% severities were found in commercial fields of the cultivars CK9835 and Savannah in central Louisiana. By late April, traces were found in winter wheat plots from central Texas to southwestern South Carolina. In early May, stem rust was severe on susceptible cultivars in southern and central Texas nurseries. By mid-May, light severities surrounded overwintering sites in the cultivar CK9835 in northeast Arkansas, and susceptible cultivars in plots in northeastern South Carolina. By the third week of May, severe stem rust was found in plots of the cultivars Saluda and Chisholm, respectively, in northeastern Arkansas and southwestern Oklahoma, and a week later in southwestern Missouri. In the second week of June, wheat stem rust was observed in fields of soft red winter wheat in southern Illinois and wheat plots in southwestern Indiana. By mid-June, traces were found in west central Indiana.

By late June, 10% stem rust severities were reported in northeastern and northwestern Kansas in trap plots of susceptible winter wheat cultivar McNair 701 at hard dough. On 19 June, traces of stem rust were found on the susceptible spring wheat cultivar Baart (trap plots) in southern Min-

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 barley; 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 barley. (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 barley; 4, spring oats; and 5, isolated oat fields, overwintering uredinia in southern California.

Table 5. Incidence of virulence in isolates of *Puccinia graminis* f. sp. *tritici* from *Hordeum vulgare* and *H. jubatum* toward single gene differential wheat lines in the 1995 survey

			Percentage of isolates virulent to <i>Sr</i> gene															
Area ^a	Source	Isolates	5	6	7b	8a	9a	9b	9d	9e	9g	10	11	17	21	30	36	<i>Tmp</i>
U.S.	Field	58	100	0	0	0	0	0	100	0	100	100	0	100	100	0	0	0
	Nursery	80	100	0	8	6	9	0	100	4	100	100	4	100	100	0	8	4
	Total	138	100	0	4	4	5	0	100	2	100	100	2	100	100	0	4	2
2	Nursery	3	100	0	100	100	0	0	100	100	100	100	100	100	100	0	100	100
5	Nursery	12	100	0	17	0	17	0	100	0	100	100	0	100	100	0	17	0
6	Field	58	100	0	0	0	100	0	100	0	100	100	0	100	100	0	0	0
	Nursery	65	100	0	2	3	8	0	100	0	100	100	0	100	100	0	2	0
	Total	123	100	0	1	2	4	0	100	0	100	100	0	100	100	0	1	0
U.S.	1994		100	3	6	8	8	3	100	3	100	97	6	97	100	0	6	3

^a See Figure 1A.

nesota. In early July, traces of stem rust were found in a hard red winter wheat plot in southeastern North Dakota. By mid-July, traces were found in trap plots of the susceptible cultivar Baart in east central South Dakota, southeastern North Dakota, and west central Minnesota.

The stem rust population overwintering north of Texas was smaller than normal. Cool dry weather conditions in late winter in the southern Plains and hot dry weather in late May and early June in the central Plains were not favorable for stem rust development or spread northward. The commercial spring and durum wheats are resistant to stem rust. Incidence of resistant type uredinia was low and losses were negligible.

Six races were identified from 60 wheat collections in 1995 (Table 2). Races

TPMK, QCCJ, and QFCS consisted of 39, 31, and 21% of the isolates, respectively. Only races TPMK (67%) and RCMS (33%) were identified from seven (25 isolates) field (areas 1S, 2, and 8) collections. The other four races identified were QCCS, QCMS, QFCS, and RCMS. Races RCRS, RKQQ, and RTQQ, detected in 1994, were not detected in 1995. Wheat stem rust races BBBB, BFBJ, and RCMS were identified from Minnesota *B. vulgaris* collections, and RCMS was identified from an unknown grass collection. The incidences of virulence to single gene lines used for race identification are shown in Table 3. No virulence was found to wheat lines with *Sr6*, 9b, 13, 22, 24, 25, 26, 27, 29, 30, 31, 32, 37, *Gt*, and *Wld-1*.

Forty-one stem rust collections from *Hordeum vulgare* L. and six from *H.*

jubatum yielded 138 isolates of *P. graminis* f. sp. *tritici* (Table 4). Race QCCJ constituted 93% of the isolates from fields and nurseries, while the other races (TPMK, QCCS, QFBS, and RCMS) constituted 2% or less of the isolates. The incidences of virulence of *P. graminis* f. sp. *tritici* from *H. vulgare* and *H. jubatum* are shown in Table 5. Six collections from *H. jubatum* from region 6 yielded six isolates each of races QCCJ and QFCS, and one of TPMK. Race QCCJ is virulent on *Rpg-1* (T-gene), which all *H. vulgare* cultivars presently grown are assumed to possess. *Rpg-1* is absent in *H. jubatum*.

P. graminis f. sp. *avenae*. Overwintering sites were observed (trace to 20%) in experimental plots at Beeville and Temple, Texas, and in a field 80 km southwest of San Antonio. In late February, oat stem rust was also observed in experimental plots in southern Louisiana. In general, there was less oat stem rust and it was slower to develop in this area than last year because of cool weather in early February and March. In the last week of April, trace to 20% severities were reported in plots in central and north central Texas, and stem rust was severe in the plots by the first week of May. The relative lack of oat production in the Great Plains interrupted the potential for an epidemic farther north. During the last week of June, 2% severity was found on oats in northeastern Indiana.

The first detection of oat stem rust in the north central Plains was in the first week in July, when traces were found on wild oats (*A. fatua*) growing alongside a road in southeastern North Dakota. In mid-July, traces of oat stem rust were in plots in east central Minnesota, but none was found during the disease survey through eastern South and North Dakota.

Table 6. Frequency of identified races of *Puccinia graminis* f. sp. *avenae* by area and source of collection in 1995

Area ^a	Source	Collections (no.) ^b	Isolates (no.)	Percentage of each North American (NA) physiologic race ^c		
				NA-5	NA-16	NA-27
1	Field	3	9	...	22	78
	Nursery	59	164	...	16	84
	Total	62	173	...	16	84
2	Nursery	1	3	...	...	100
3	Field	1	3	...	...	100
4	Field	4	12	...	25	75
	Nursery	9	25	...	4	96
	Total	13	37	...	11	89
5	Field	1	3	100	...	...
	Nursery	2	6	100	...	...
	Total	3	9	100	...	...
U.S.	Field	9	27	11	19	70
	Nursery	71	198	3	14	83
	Total	80	225	4	14	82

^a See Figure 1B.

^b Uredinia from a single field, plant, or cultivar received separately constituted a collection from which up to three single uredinia (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 1995 survey

Area ^a	Source	Isolates	Percentage of isolates virulent to <i>Pg</i> gene ^b					
			1	2	3	4	8	15
1	Field	9	100	78	100	78	100	0
2	Nursery	3	100	100	100	100	100	0
3	Field	3	100	100	100	100	100	0
4	Field	12	100	75	100	75	100	0
	Nursery	25	100	96	100	96	100	0
	Total	37	100	89	100	89	100	0
5	Field	3	0	0	100	0	0	100
	Nursery	6	0	0	100	0	0	100
	Total	9	0	0	100	0	0	100
U.S.	Field	27	89	70	100	70	89	11
	Nursery	34	82	79	100	79	82	18
	Total	61	85	75	100	75	85	15
U.S.	1994 ^c	...	98	97	100	97	98	2
U.S.	1993 ^d	...	81	91	81	81	81	19
U.S.	1992 ^e	...	98	91	100	90	98	2
U.S.	1991 ^f	...	97	93	100	93	97	3

^a See Figure 1B.

^b No virulence found on *Pg*-9, -13, -16, -a, from 1990 to 1995.

^c McVey et al. (2).

^d Roelfs et al. (14).

^e Roelfs et al. (13).

^f Roelfs et al. (12).

Race NA-27, virulent to *Pg*-1, -2, -3, -4, and -8, was predominant, consisting of 82% of 225 isolates from 80 collections in 1995 (Table 6). Races NA5, virulent to *Pg*-3 and -15, and NA16, virulent to *Pg*-1, -3, and -8, constituted 4 and 14% of the isolates, respectively, from the United States. Only race NA29, virulent to *Pg*-1, -2, -3, -4, -8, and -15, was identified from four collections 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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