Races of *Puccinia graminis* in the United States and Mexico During 1985

A. P. ROELFS, Research Plant Pathologist, D. H. CASPER, Research Technician, and D. L. LONG, Plant Pathologist, Cereal Rust Laboratory, ARS, USDA, University of Minnesota, St. Paul 55108

ABSTRACT

Roelfs, A. P., Casper, D. H., and Long, D. L. 1986. Races of *Puccinia graminis* in the United States and Mexico during 1985. Plant Disease 70:1010-1013.

Oat stem rust was present in light amounts throughout most of the United States in 1985, and yield losses were small. Disease development was generally more than a week later than the 40-yr average. The principal race in the United States and Mexico was NA-27, virulent on hosts with resistance genes *Pg*-1, -2, -3, -4, and -8. NA-27 comprised 96 and 100% of the isolates from the United States and Mexico, respectively. No virulence was found in oat stem rust for *Pg*-9, -13, -16, or -a. Wheat stem rust was found in trace amounts in trap plots near Beeville and Victoria in southern Texas in early April. Additional overwintering sites were found in nurseries from Florida through Louisiana and northward into central Arkansas. Stem rust spread northward into the northern Great Plains by early July. Although stem rust occurred on some hard red spring wheat cultivars, they had adequate resistance and losses were nil. Race 15-TNM, virulent on plants with *Sr*17, was the most common virulence combination, making up 77% of the 616 isolates from 225 collections. The second most common race was 15-TDM, which made up 4% of the isolates. No virulence was found for wheat lines with genes *Sr*13, 22, 24, 25, 26, 27, 29, 30, 31, 32, 33, 37, Gt, and Wld-1.

Puccinia graminis Pers. has been a major pathogen of many small-grain cereals and forage grasses worldwide. Since the near elimination of susceptible barberry bushes from cereal-producing areas of the northern Great Plains, epidemics have been less frequent (8). Nevertheless, windborne uredospores resulted in devastating epidemics (7) of stem rust on wheat in 1935, 1937, 1953, and 1954 and on oats in 1953 in the northern Great Plains. Resistant cultivars are continually developed to prevent such epidemics, but they can be susceptible to new pathogen races. Thus, a constant monitoring of changes in pathogen virulence has been part of the program to avoid crop losses. Data from surveys also provide information on the effects of changes in host resistance on pathogen frequency and distribution.

MATERIALS AND METHODS

Field surveys were made over a 21,000-km route covering the Great Plains and the Gulf Coast of the United States. These surveys followed a preselected, generally circular route through areas where small-grain cereals are important and rust historically has been a problem. Assessments for the presence of rust were made at commercial fields each 32 km or at the first field thereafter. Additional assessments were made at experimental nurseries and wheat trap plots along the route. Whenever rust was observed in a field or nursery, leaves or stems bearing rust uredia from a single plant or cultivar were collected. These collections were supplemented by others furnished by cooperators throughout North America.

In 1985, field surveys were made in the following areas: southern Texas (early April), northern Texas (late April), Gulf Coast states (early May), Oklahoma and Kansas (mid-May), Nebraska and South Dakota (mid-June), eastern Dakotas and Minnesota (early July), and north central United States (late July and early August). Two spore samples were taken from each field uredial collection received at the laboratory. One portion was used to inoculate 7-day-old seedlings of a susceptible host (when the forma specialis was known) or a group of potentially susceptible hosts treated with maleic hydrazide to enhance spore production. Each culture was maintained in a separate clear plastic chamber for 12–14 days. Up to four leaves either bearing or pruned to bear a single uredium were saved and reincubated to permit uredospores detached from uredia to germinate. Uredospores within uredia were collected separately 3–4 days later from up to three uredia, each such collection an isolate, and each uredium provided enough spores to inoculate a differential host series.

Spores were suspended in a lightweight mineral oil and sprayed on plants, which were placed in a dew chamber overnight at 18 C. Plants were then placed in a greenhouse at 18–28 C for 10–14 days and assessed for infection types.

The second sample of spores from each collection was bulked with those from other collections made in the same area at about the same time and used for inocula for the "universally" resistant series.

***P. 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 (5). The universally resistant series consisted of the host lines Saia (CI 7010), CI 7221, S.E.S. 52 (CI 3034), X-1588-2 (CI 8457), Kyto (CI 8250), MN 730358, and CI 9139. These lines have been selected over a period of years as resistant to stem rust.

Data derived from collections made in the United States were separated into groups corresponding to five ecological areas (Fig. 1A) based on oat production, cultural practices, and geographic separation.

***P. graminis* f. sp. *tritici*.** The differential host series consisted of wheat lines with genes for *Sr*5, 6, 7b, 8, 9a, 9b, 9d, 9e, 10, 11, 13, 15, 16, 17, 36, and Tmp. Races were assigned using the code shown in Table 1. The universally resistant series consisted of lines with the host genes *Sr*22, 24, 25, 26, 27, 29, 30, 31, 32, 33, 37, Gt, and Wld-1 and the cultivars Era, Cando, Olaf, Leeds, and Ward. These lines and cultivars have been selected over a period of years as resistant to stem rust.

Data were grouped into nine ecological areas (Fig. 1B). Area 1S has mainly fall-sown spring wheats; area 1N, mixed wheat types; area 2, mostly soft red winter wheat; area 3, southern hard red winter wheats; area 4, mostly soft red winter wheat and scattered barberries; area 5, mixed wheat types; area 6, resistant hard red spring and durum wheats; area 7, northern hard red winter wheat; and area 8, mostly highly susceptible soft winter wheats, spring wheats, and scattered barberries.

RESULTS AND DISCUSSION

Data from collections made from commercial fields and naturally occurring hosts were separated from those made in nurseries and plots. No data were included from collections made in or near known inoculated nurseries.

***P. graminis* f. sp. *avenae*.** Rust was severe in South Texas by mid-January. Cold weather in late January delayed further development. By early April, rust

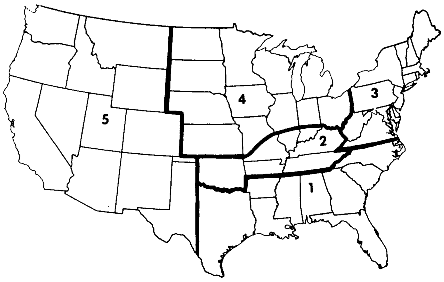
Paper 14,649, Scientific Journal Series, Minnesota Agricultural Experiment Station.

Accepted for publication 1 July 1986 (submitted for electronic processing).

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be hereby marked *"advertisement"* in accordance with 18 U.S.C. § 1734 solely to indicate this fact.

was scattered throughout South Texas fields, and as the season progressed it became severe. By mid-May, rust was found as far north as west central Kansas, a month earlier than the 40-yr mean (11).

A



B

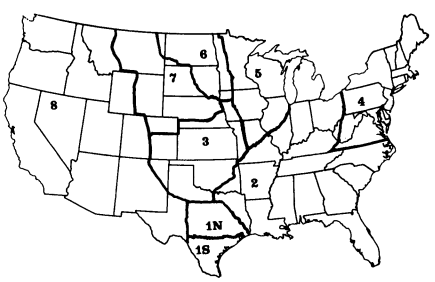


Fig. 1. Ecological areas for *Puccinia graminis* in the United States. **(A)** Areas for oat stem rust: (1) winter oats, (2) mixed winter and spring oats, (3) spring oats and barberry area, (4) major spring oat-producing area, and (5) widely isolated oat fields. **(B)** Areas for wheat stem rust: (1S) mainly fall-sown wheat, (1N) mixed wheat types, (2) soft red winter wheat, (3) southern hard red winter wheats, (4) mostly soft red winter wheat and barberries, (5) mixed wheat types and widely dispersed fields, (6) hard red spring and durum wheat, (7) northern hard red winter wheats, and (8) mostly soft winter wheats, spring wheats, and barberries.

Table 1. A key defining the Cereal Rust Laboratory races of *Puccinia graminis* f. sp. *tritici*

Code[a]	Response of host with *Sr* genes[b]			
Set 1:	5	9d	9e	7b
Set 2:	11	6	8	9a
Set 3:	36	9b	13	10
B	R	R	R	R
C	R	R	R	S
D	R	R	S	R
F	R	R	S	S
G	R	S	R	R
H	R	S	R	S
J	R	S	S	R
K	R	S	S	S
L	S	R	R	R
M	S	R	R	S
N	S	R	S	R
P	S	R	S	S
Q	S	S	R	R
R	S	S	R	S
S	S	S	S	R
T	S	S	S	S

[a] A Combination of host responses from set 1 determines the first letter of code, set 2 the second, and set 3 the third.
[b] R = host not susceptible; S = host susceptible.

In mid-June, rust was found thoughout eastern South Dakota in light amounts. An early spring and extensive dry weather through June to August reduced the potential for losses except for late-planted fields throughout the major oat-growing areas. In Illinois and Wisconsin, where moisture was not limiting, 1985 had the most severe oat stem rust outbreak since the 1950 epidemics.

Race NA-27 constituted 96% of the 1,256 isolates collected in the United States (Table 2). This race, virulent on host genes *Pg*-1, -2, -3, -4, and -8, has predominated in the U.S. population since 1965. However, NA-27 has caused only one moderately severe epidemic (12). Races NA-5, NA-10, and NA-16 were the other frequently isolated races although in small amounts, each making up about 1% of the population (15, 17, and 11 isolates, respectively). NA-10 occurred only in California. Virulence on lines with the single genes used for race identification is shown in Table 3. Hosts with genes *Pg*-9, -13, -16, and -a were resistant to the population sampled from the United States in 1985; however, virulence to hosts with these genes has occurred in previous years. Only race NA-27 was obtained from two collections of stem rust made in Mexico.

***P. graminis* f. sp. *tritici*.** Stem rust was found during early April in wheat trap plots at Victoria and Uvalde, TX. During early May, overwintering foci were found scattered along the Gulf Coast from northwestern Florida to southern Louisiana and north along the Mississippi River Valley into northeastern Arkansas. By mid-May, light severities of stem rust occurred in commercial fields in southern

Table 2. Frequency of the identified races of *Puccinia graminis* f. sp. *avenae* by area and source of collection in 1985

		Number of[b]		Percentage of each North American (NA) physiologic race[c]								
Area[a]	Source	Collections	Isolations	1	5	6	10	16	23	24	27	Other[d]
United States	Field	260	735	···	*[e]	*	···	*	···	···	98	···
	Nursery	193	521	*	2	···	3	1	*	1	92	···
	Total	453	1,256	*	1	*	1	1	*	*	96	···
1	Field	19	56	···	···	···	···	5	···	···	95	···
	Nursery	128	331	1	1	···	···	1	1	*	97	···
	Total	147	387	*	1	···	···	1	*	*	97	···
2	Nursery	1	3	···	···	···	···	···	···	···	3	···
3	Field	11	31	···	10	3	···	6	···	···	81	···
	Nursery	2	5	···	20	···	···	···	···	···	80	···
	Total	13	36	···	11	3	···	5	···	···	80	···
4	Field	229	646	···	···	···	···	*	···	···	100	···
	Nursery	54	160	···	···	···	···	1	···	4	94	···
	Total	283	806	···	···	···	···	*	···	1	99	···
5	Field	1	2	···	100	···	···	···	···	···	···	···
	Nursery	8	22	···	23	···	77	···	···	···	···	···
	Total	9	24	···	29	···	71	···	···	···	···	···
Canada	Field	10	28	···	···	···	···	···	···	4	64	32
	Nursery	18	52	···	···	···	···	2	···	6	44	48
	Total	28	80	···	···	···	···	1	···	5	51	42
Mexico	Nursery	2	4	···	···	···	···	···	···	···	100	···

[a] See Figure 1A for ecological areas in the United States.
[b] Uredia from a single field, plant, or cultivar received separately was a collection from which up to three single-uredial isolates were identified.
[c] Martens et al (5).
[d] From aecial and uredial collections from Ontario.
[e] Less than 0.6% of the isolates.

Table 3. Incidence of virulence in isolates of *Puccinia graminis* f. sp. *avenae* from 1985 survey to the resistance of single-gene differential lines

	Percentage of isolates virulent on *Pg* gene[b]						
Area[a]	-1	-2	-3	-4	-8	-9	-15
1	99	97	99	97	98	0	2
2	100	100	100	100	100	0	0
3	86	80	100	80	86	0	11
4	100	100	100	100	100	0	1
5	0	71	100	0	0	0	92
United States							
1985	97	98	100	96	96	0	3
1984[d]	97	96	100	94	97	0	3
1983[d]	99	96	100	96	99	*[c]	1

[a] See Figure 1A for areas.
[b] No cultures were virulent on *Pg*-13, -16, or -a.
[c] Less than 0.6% of the isolates.
[d] Roelfs et al (9,10).

Oklahoma. By early June, stem rust was present in trace amounts throughout northern Kansas and southern Nebraska in plots of susceptible cultivars, and by mid-June, throughout the northern soft red winter wheat areas from northeastern Indiana to southern Wisconsin. By early July, stem rust was found in trap plots of susceptible cultivars. Disease development was restricted because resistant cultivars were sown in nearly all of the hard red spring and durum wheat area. Disease onset was near normal in the Great Plains (4). More infections were found in commercial fields than since 1983 (9); little if any damage occurred. A few fields in eastern Oregon and scattered fields in the soft wheat region suffered light to moderate losses. A total of 225 collections was obtained in 1985 (Table 4) compared with the 5-, 10-, and 25-yr means of 219, 356, and 561 (9,13–15).

The most common race in the United States was again 15-TNM, constituting 89% of all isolates (Table 4); 95% of these were virulent on the differential host line with *Sr*17. The other members of this race cluster identified were 15-TDM and 15-TLM, both avirulent on *Sr*17.

The second most common race cluster was 32-151-_SH. Race 151-QSH (2%) is virulent to *Sr*6, 11, and 17, which are commonly used host resistances in the commercial wheat cultivars. This race has been a minor component of the population since 1980, comprising a mean of 1.0–6.2% of the isolates in the past 5 and 10 yr, respectively. The oldest existing isolate with this virulence was identified in 1968.

Race 151-QFB (1% of all isolates) is a member of a different asexual cluster than 151-QSH. 151-QCB, the other member of this cluster, was not found in 1985. This cluster is often more abundant in the soft red winter wheats, but its frequency is probably restricted because of avirulence on *Sr*36 and Tmp. The cluster made up 44% of the sampled population in 1981 (14), when most of the isolates were from the soft wheat regions. It has averaged 14% of the population over the past 5 yr.

Race 56-MBC was first isolated in 1928 and has made up part of the population annually since then but has been a minor component since 1968. This race is avirulent on the important *Sr*6, 9d, 9e, 11, and 36 resistant genes but virulent on *Sr*17 and Tmp. Race MBC was found in the southeastern states and in the southern and central Great Plains (Table 4).

Race 11-RCR was confined to southern Texas in 1985. In 1984, this race was present from central Texas northward into the hard red spring wheat area. It was also present in the eastern United States, making up 20% of the isolates in the northeastern states (10).

The collections from area 8 (Tables 4 and 5) were nearly all from a sexual reproducing population in the Pacific Northwest (2,11). They differed from collections found in other areas in both virulence combinations (Table 4) and frequency of virulence (Table 5), presumably because of frequent sexual recombination and geographical isolation of the population. Two aecial isolates from Minnesota were race 34. One isolate from Colorado (48-BBC) seems to be from the northwestern population as well as the 12 isolates of 23-CBC from California based on virulence similarities with that population and extreme virulence dissimilarities with the Great Plains population.

Associations of virulence or avirulence are common in asexual populations of *P. graminis* (1,7,12). These associations are important to know and understand when studying virulence or avirulence frequencies (Table 5) or when developing

Table 4. Summary of the identified races of *Puccinia graminis* f. sp. *tritici* by area and source of collection in 1985

		Number of[b]		Percentage of isolates of each race[c]												
				11	15				56		113			151		
Area[a]	Source	Collections	Isolations	RCR	TDM	TLM	TNM	TNM[d]	MBC	MBC[e]	RKQ[f]	RTQ	RTQ[d]	QFB	QSH	Others[g]
United States[f]	Field	46	116	···	2	···	4	89	···	1	···	2	···	···	1	···
	Nursery	179	500	*[h]	7	*	4	84	···	1	···	*	···	1	2	···
	Total	225	616	*	6	*	4	85	···	1	···	1	···	1	2	···
1	Nursery	1	3	···	···	···	···	100	···	···	···	···	···	···	···	···
1S	Field	3	9	···	···	···	···	100	···	···	···	···	···	···	···	···
	Nursery	39	104	2	21	···	6	66	···	4	···	···	···	···	1	···
	Total	42	113	2	19	···	5	69	···	4	···	···	···	···	1	···
2	Field	14	40	···	···	···	5	92	···	···	···	···	···	···	2	···
	Nursery	37	102	···	3	···	1	94	···	1	···	···	···	1	···	···
	Total	51	142	···	2	···	2	94	···	1	···	···	···	1	1	···
3	Field	10	20	···	15	···	75	···	5	···	5	···	···	···	···	···
	Nursery	16	46	···	···	···	2	91	···	2	···	···	···	2	2	···
	Total	26	66	···	4	···	2	86	···	3	···	2	···	2	2	···
4	Field	1	3	···	···	···	···	100	···	···	···	···	···	···	···	···
	Nursery	1	3	···	···	···	33	67	···	···	···	···	···	···	···	···
	Total	2	6	···	···	···	17	83	···	···	···	···	···	···	···	···
5	Field	12	26	···	···	···	12	77	···	···	···	4	···	···	···	8
	Nursery	15	45	···	2	···	4	87	···	···	···	2	···	4	···	···
	Total	27	71	···	1	···	7	83	···	···	···	3	···	3	···	3
6	Field	6	17	···	···	···	···	94	···	···	···	6	···	···	···	···
	Nursery	61	180	···	4	1	4	86	···	···	···	···	···	*	5	···
	Total	67	197	···	4	1	4	86	···	···	···	*	···	*	4	···
7	Nursery	5	13	···	···	···	···	92	···	···	···	···	···	···	···	8
8	Field	4	12	···	···	···	···	25	···	···	···	···	···	···	···	75
	Nursery	17	46	···	···	···	···	6	···	···	···	···	···	···	···	89
	Total	21	58	···	···	···	···	10	···	···	···	···	···	···	3	87
9	Nursery	1	3	···	···	···	···	100	···	···	···	···	···	···	···	···
Mexico	Nursery	24	42	···	···	···	2	2	2	···	2	12	36	43	···	···

[a] See Figure 1B for description of areas.
[b] Uredia from a single field, plant, or cultivar received separately was a collection from which up to three single-uredial isolates were identified.
[c] Cereal Rust Laboratory races (Table 1).
[d] Virulent on *Sr*17.
[e] Virulent on *Sr*Tmp.
[f] Does not include collections or isolates from the sexual population.
[g] Sexual population from Colorado (area 7): one isolate of 48-BBC; from Idaho, Oregon, and Washington (area 8): 22 isolates of 48-BBC, 10 isolates of 50-BCC, four isolates of 2-LCC, and two isolates of 10-QBC; and from California: 12 isolates of 23-CBC.
[h] Less than 0.6% of the isolates.

Table 5. Incidence of virulence in *Puccinia graminis* f. sp. *tritici* isolates to the resistance of single-gene differential lines used in the 1985 survey

	Percentage of isolates virulent on *Sr* gene[b]														
Area[a]	**5**	**9d**	**9e**	**7b**	**11**	**6**	**8**	**9a**	**36**	**9b**	**10**	**15**	**16**	**13**	**Tmp**
1	100	100	100	100	100	0	100	0	100	0	100	0	100	100	100
1S	100	96	94	99	75	1	95	2	96	3	100	6	100	75	97
2	100	99	98	98	96	1	99	1	98	1	99	7	100	96	98
3	100	97	92	97	91	3	97	3	94	3	97	8	100	92	95
4	100	100	100	100	100	0	100	0	100	0	100	0	100	83	100
5	100	100	94	97	96	3	100	6	97	3	94	6	100	88	94
6	100	100	94	95	96	5	99	1	95	5	99	6	100	91	94
7	92	92	92	92	92	0	92	0	92	0	100	8	100	100	92
8	24	17	10	31	14	3	14	24	10	3	100	90	93	100	10
United States															
1985[c]	100	99	95	97	92	3	98	2	96	3	98	5	100	89	95
1984[d]	99	1	92	88	14	6	99	84	91	85	16	100	90	91	84
1983[d]	94	1	90	90	6	2	94	88	95	88	12	100	77	90	77
Canada	100	100	100	100	100	0	100	0	100	0	100	0	100	100	100
Mexico	100	98	0	57	52	50	98	93	55	50	7	95	100	86	5

[a] See Figure 1B for areas.
[b] All isolates were avirulent on *Sr*13.
[c] Totals do not include isolates from the sexual population in areas 5, 7, and 8.
[d] Roelfs et al (9,10).

Table 6. Canadian race equivalents for Cereal Rust Laboratory races of *Puccinia graminis* f. sp. *tritici*

Cereal Rust Laboratory race	Canadian race[a]
11-RCR	C43(32)
15-TDM	C49(15)
15-TLM	C18(15B-1L)
15-TNM	C33(15B-1L)
15-TNM[b]	C53(15B-1L)
56-MBC	C17(56)
56-MBC[c]	C17(56)
113-RKQ	C35(32-113)
113-RTQ	C41(32-113)
113-RTQ[b]	C52(32-113)
151-QFB	C75(38)
151-QSH	C25(38)

[a] Green (3).
[b] Virulent on *Sr*17.
[c] Virulent on *Sr*Tmp.

wheats resistant to stem rust. Virulence for *Sr*6 remains low although it is widely used in commercial cultivars in area 6. Resistance gene *Sr*17 is present in the commercial wheat cultivars in areas 3 and 6, and virulence has increased greatly in recent years, from 20% in 1975 to 90% in 1984. The reduction of Authur-type wheats in the soft wheat region has reduced the percentage of host population with *Sr*36. The cultivar Siouxland introduces *Sr*31 into the host population for the first time in North America (6).

During the survey, no virulence was found to lines with *Sr*13, 22, 24, 25, 26, 27, 29, 30, 31, 32, 33, 37, Gt, or Wld-1. Virulence to host plants with *Sr*30 has occurred in the North American population of *P. graminis* f. sp. *tritici* but has not been detected since 1982 (15).

The data reported are from the southern three-fourths of the range of *P. graminis* f. sp. *tritici* in North America. The northern portion of the population is studied annually at the Agriculture Canada Laboratory at Winnipeg. This laboratory designates races differently (3), so equivalents are given for races reported in this paper (Table 6).

ACKNOWLEDGMENT

We wish to thank Mark Hughes, who developed the ADP programs and tabulated these data.

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