Races of *Puccinia graminis* in the United States and Mexico During 1987

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ABSTRACT

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Oat stem rust was present in light amounts throughout most of the United States during 1987, and yield losses were nil. Disease generally developed 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 having resistance genes *Pg-1*, *-2*, *-3*, *-4*, and *-8*. NA-27 made up 93 and 100% of the isolates from the United States and Mexico, respectively. No virulence was found for *Pg-a* or *Pg-16* in the 1987 oat stem rust population. In 1987, wheat stem rust overwintered in trace amounts from southern Texas to southern Georgia and up the Mississippi Valley to the Tennessee border. Overwintering sites were found near Beeville and Victoria in southern Texas in early April. Additional overwintering sites were found in the Mississippi Valley from the Gulf Coast into central Arkansas and along the Red River in southern Oklahoma in late April. Stem rust spread northward into Kansas and Nebraska by late May and into the northern Great Plains by mid-June. No stem rust was found in fields of hard red spring or durum wheat cultivars. Race 15-TNM, virulent on plants with *Sr17*, was the most common virulence combination, making up 99% of the 452 isolates from 172 collections. No virulence was found for wheat lines with "single" genes *Sr13, 22, 24, 25, 26, 27, 29, 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 virtual elimination of the susceptible *Berberis vulgaris* L. from cereal-producing areas of the northern Great Plains, epidemics have been less frequent (7). No major losses have resulted from either oat or wheat stem rust in the United States since the mid 1950s (6). This is partly due to the continuous line of resistant wheat (*Triticum aestivum* L.) cultivars used. These cultivars, e.g., Chris, Era, Marshall, Selkirk, Wells, Leeds, Ward, Waldron, Manitou, Neepawa, Olaf, Vic, and Columbus, have retained resistance throughout the period. The oat cultivars grown during the same period, however, have been susceptible to the most common pathogenic race. The lack of an oat stem rust epidemic could be due to a small amount of inoculum and/or late onset of disease (7,11) or to environmental conditions unfavorable for development of regional epidemics. Another interesting phenomenon is the apparent trend for a single virulence phenotype to make up most of the pathogen population.

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This research was a portion of the continuous effort to monitor changes in virulence combinations present in wheat and oat stem rust in an effort to maintain rust-resistant cultivars in North America.

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. The surveys followed a preselected, generally circular route through areas where small grain cereals are important and rust has been a problem historically. Checks for the presence of rust were made at commercial fields each 32 km or the first field thereafter. Additional checks 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 cultivar or field were collected. These collections were supplemented by others furnished by cooperators throughout North America.

In 1987, field surveys were made in the following areas: southern Texas (late March), northern Texas (late April), Gulf Coast states (early April, late April, and late May), Oklahoma and Kansas (mid-May), Arkansas and Ohio River Valley (early June), Nebraska and South Dakota (mid-June), eastern North and South Dakota and Minnesota (early July), and the North Central states (late July). 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. After 12–14 days, up to four leaves either bearing or pruned to bear a single uredium were saved and reincubated to permit free uredospores to germinate. Uredospores were collected separately 3–4 days later from up to three uredia (each such collection was an isolate); each uredium provided enough spores to inoculate a differential host series.

Spores suspended in a lightweight mineral oil were sprayed on plants, which were placed in a dew chamber overnight at 18 C, then in a greenhouse at 18–28 C. Infection types were observed after 10–14 days.

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

***P. g.* 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. No. 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 ecological areas (Fig. 1A) based on oat production, cultural practices, and geographic separation.

***P. g.* f. sp. *tritici*.** The differential host series consisted of wheat lines with genes for *Sr5, 6, 7b, 8a, 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 *Sr22, 24, 25, 26, 27, 29, 31, 32, 33, 37, Gt*, and *Wld-1* and the cultivars Era, Cando, and Ward; these lines and cultivars have been selected over a period of years as resistant to stem rust. Data were grouped into ecological areas (Fig. 1B) based on wheat production, cultural practices, and geographic separation.

RESULTS AND DISCUSSION

***P. g.* f. sp. *avenae*.** In early April, only traces of oat stem rust were found in southern Texas, Louisiana, and Florida plots and fields. The amount of stem rust was less than normal in this area. The small amount of rust generated less inoculum than normal, which, accompanied by a drier than normal growing season in the northern Great Plains, prevented epidemic development in this, the major oat production area. Traces of stem rust did appear on wild oats (*Avena fatua* L.) in eastern North Dakota and northwestern Minnesota.

Race NA-27 constituted 90% of the 306 isolates collected in the United States (Table 2). This race, virulent on host genes *Pg-1, -2, -3, -4*, and *-8* (and hence almost all commercial cultivars), has predominated in the United States population since 1965 but has caused only one moderately severe epidemic (11). Races NA-3, NA-5, and NA-10 were also isolated frequently, although in small amounts, making up about 1, 6, and 3% of the population, respectively, with 3, 18, and 9 isolates, respectively. NA-10 was exclusively from California, and NA-3 was isolated from a collection made in a South Carolina nursery. NA-3 is avirulent on *Pg-1, -2, -3, -4*, and *-8* but virulent on *Pg-9, -13*, and *-15*, just the reverse of NA-27. Only one collection was received from area 2 and none from area 3 (Ohio Valley and northeastern states, respectively). Virulence on lines with the single genes used for race identification is shown in Table 3. Hosts having genes *Pg-16* and *Pg-a* were resistant to the population sampled from the United States in 1986; virulence to hosts having these genes has occurred in previous years, however. Only race NA-27 was obtained from collections of stem rust from Mexico. The isolates from Canada came from a small area of Ontario.

***P. g.* f. sp. *tritici*.** During 1987, stem rust overwintering sites were found on susceptible cultivars from southern Texas to southern Georgia and up the Mississippi Valley to the Arkansas-Tennessee border. In late April, traces of rust were found in northern Texas fields. By mid-May, traces of stem rust were found in plots from south-central Kansas to northern South Carolina. A single

Table 1. 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*	*8a*	*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.

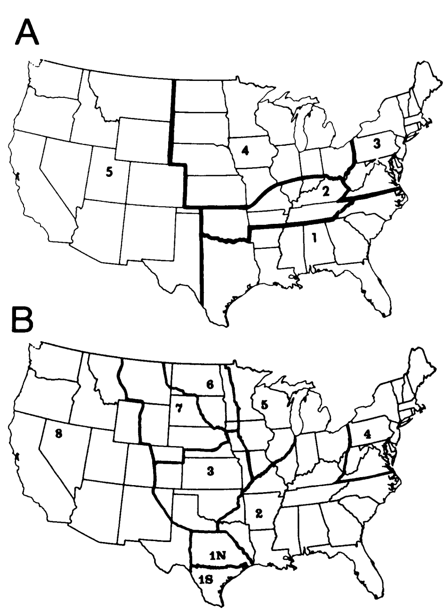

Fig. 1. Ecological areas for *Puccinia graminis* in the United States. **(A)** Areas for oat stem rust: 1 = winter oats, 2 = mixed winter and spring oats, 3 = spring oats and barberry, 4 = major spring oats production, and 5 = widely isolated oat fields. **(B)** Areas for wheat stem rust: 1S = mostly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

Table 2. Frequency of the identified races of *Puccinia graminis* f. sp. *avenae* by area and source of collection in 1987

		Number of:[b]		Percentage of each North American (NA) physiologic race[c]				
Area[a]	Source	Collections	Isolates	3	5	10	25	27
United States	Field	31	79	4	···	···	···	96
	Nursery	89	227	···	8	4	···	88
	Total	120	306	1	6	3	···	90
1	Field	8	24	···	···	···	···	100
	Nursery	74	191	···	8	···	···	92
	Total	82	215	···	7	···	···	93
2	Nursery	1	0	···	···	···	···	···
4	Field	23	55	5	···	···	···	94
	Nursery	10	24	···	···	···	···	100
	Total	33	79	4	···	···	···	96
5	Nursery	4	12	···	25	75	···	···
Canada	Field	11	30	···	···	···	100[d]	···
	Nursery	1	3	···	···	···	···	100
	Total	12	33	···	···	···	91	9
Mexico	Field	2	6	···	···	···	···	100
	Nursery	1	3	···	···	···	···	100
	Total	3	9	···	···	···	···	100

[a] See Figure 1A.
[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 (4).
[d] From aecial and uredial collections from Ontario.

Table 3. Incidence of virulence in isolates of *Puccinia graminis* f. sp. *avenae* to the resistance of the single gene differential lines in the 1987 survey

	Percentage of isolates virulent on *Pg* gene[b]								
Area[a]	*-1*	*-2*	*-3*	*-4*	*-8*	*-9*	*-13*	*-15*	*-16*
1	93	93	100	93	93	0	0	7	0
4	96	96	96	96	96	4	4	4	0
5	0	75	100	0	0	0	0	100	0
United States									
1987	90	93	99	90	90	1	1	2	0
1986[c]	92	90	100	89	93	*[d]	*	7	*
1985[e]	97	98	100	96	96	0	0	3	0

[a] See Figure 1A.
[b] All isolates were avirulent on *Pg-a*.
[c] Roelfs et al (9).
[d] Less than 0.6%.
[e] Roelfs et al (8).

plant of *Aegilops (Triticum) cylindrica* L. was found severely rusted in central Kansas in May. The plant had an 80% disease severity, whereas other plants and the adjacent wheat field were rust-free. The only other report of stem rust in Kansas at the time was of a few isolated uredia 80 km south and east of the infected *Aegilops* plant. It is likely that stem rust overwintered on this plant. During the first week in June, traces of stem rust were found scattered in plots of susceptible plants of northern soft red winter wheat in central Illinois and central Indiana. Wheat stem rust became very severe on plants in a seed-increase field in northeastern Arkansas in late June.

During mid-July, traces of stem rust were found in fields and plots in eastern Washington, Oregon, and northern Idaho. This rust represents a sexual population with great diversity and generally little virulence to wheats bred for stem rust resistance.

The lack of wheat stem rust in area 7 was a major difference between 1986 and 1987. The overwintering of stem rust that occurred in North Dakota in 1986 (12) did not occur in 1987. The collections obtained in 1987 totaled 172 (Table 4), compared with the 5-, 10-, and 25-yr means of 219, 356, and 561, reflecting the lower rust incidence (13).

The most common race in the United States was again 15-TNM, constituting 99% of all isolates (Table 4); all were virulent on the differential host line with *Sr17*. This is the only member of this race cluster identified in 1987.

Race cluster 113-R_Q was represented by two members. Race 113-RTQ, avirulent on *Sr17*, was found on a single isolate from a nursery in Arkansas and from barberry aecial collections made in West Virginia. Race 113-RKQ, virulent on *Sr17*, was isolated four times from three aecial collections obtained in southeastern Minnesota.

The collections from area 8 (Tables 4 and 5) were all from a sexually reproducing population in the Pacific Northwest (2,10). They differed from collections found in other areas in both virulence combinations (Table 4) and incidence of virulence (Table 5), presumably because of frequent sexual recombination and geographical isolation of the population.

An extensive survey detected no wheat stem rust in commercial fields and susceptible trap plots in the Yaqui and Mayo valleys of Sonora, Mexico. These irrigated valleys are the major wheat production areas of Mexico. The major commercial cultivars were Altar durum, resistance genotype unknown, and Seri 82 bread wheat, with at least *Sr31*. The three isolates from Canada represent three collections from Ontario and not the major wheat production area of the prairie provinces.

Associations of virulence/avirulence are common in asexual populations of *P. graminis* (1,2). These associations are important to know and understand when studying virulence or avirulence frequencies (Table 5) or when developing wheats resistant to stem rust. Virulence for *Sr6* remains low, although it is common in commercial cultivars in area 6. The cultivar Siouxland has *Sr24* and *Sr31* in combination (4). Virulence for neither gene is known in North America, although *Sr24* has been used since 1967 in several cultivars. During the survey, no virulence was found to lines having *Sr13, 22, 25, 26, 27, 29, 31, 32, 33, 37, Gt*, or *Wld-1*.

The data reported here are from the southern three-fourths of the range of *P. g.* f. sp. *tritici* in North America. The northern portion of the population is studied annually at the Agriculture Canada Laboratory in Winnipeg. Races

Table 4. Summary of the identified races of *Puccinia graminis* f. sp. *tritici* by area and source of collection in 1987

		Number of:[b]		Percent of isolates/race[c]				
				15	113		151	
Area[a]	Source	Collections	Isolates	TNM	RKQ	RTQ	QSH	Others[d]
United States	Field	33	62	92	6	2	···	···
	Nursery	139	390	100	···	···	···	···
	Total	172	452	99	1	*[e]	···	···
1	Field	3	2	100	···	···	···	···
	Nursery	12	35	100	···	···	···	···
	Total	15	37	100	···	···	···	···
1S	Nursery	19	55	100	···	···	···	···
2	Field	6	16	100	···	···	···	···
	Nursery	62	165	99	···	1	···	···
	Total	68	181	99	···	*	···	···
3	Field	13	19	100	···	···	···	···
	Nursery	12	36	100	···	···	···	···
	Total	25	55	100	···	···	···	···
4	Field	1	4	75	···	25	···	···
	Nursery	1	3	100	···	···	···	···
	Total	2	7	86	···	14	···	···
5	Field	8	17	76	24	···	···	···
	Nursery	7	21	100	···	···	···	···
	Total	15	38	89	10	···	···	···
6	Field	2	4	100	···	···	···	···
	Nursery	26	75	100	···	···	···	···
	Total	28	79	100	···	···	···	···
8	Field	3	7	···	···	···	···	100
	Nursery	2	6	···	···	···	···	100
	Total	5	13	···	···	···	···	100
Canada	Field	3	3	···	33	33	33	···

[a] See Figure 1B.
[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 (see Table 1).
[d] Sexual population from area 8 (Oregon and Washington): eight isolates of 48-BBC, two of 2-LCC, one of 7-QBC, one of -QTH, and one of 10-QFC.
[e] Less than 0.6%.

Table 5. Incidence of virulence in isolates of *Puccinia graminis* f. sp. *tritici* to the resistance of single gene differential lines in the 1987 survey

	Percentage of isolates virulent on *Sr* gene[b]														
Area[a]	*5*	*6*	*7b*	*8a*	*9a*	*9b*	*9d*	*9e*	*10*	*11*	*15*	*16*	*17*	*36*	*Tmp*
1	100	0	100	100	0	0	100	100	100	100	0	100	100	100	100
1S	100	0	100	100	0	0	100	100	100	100	0	100	100	100	100
2	100	*[c]	100	100	*	*	100	99	99	100	*	100	100	100	99
3	100	0	100	100	0	0	100	100	100	100	0	100	100	100	100
4	100	14	100	100	14	14	100	86	86	100	14	100	86	100	86
5	100	10	100	100	10	10	100	89	89	89	10	100	100	100	89
6	100	0	100	100	0	0	100	100	100	100	0	100	100	100	100
8	38	8	0	15	46	8	23	0	100	8	100	85	100	0	0
United States															
1987[d]	100	1	100	100	1	1	100	99	99	99	1	100	100	100	99
1986[e]	99	1	99	99	1	1	100	98	100	98	2	100	98	98	98
1985[f]	100	3	97	98	2	3	99	95	98	92	5	100	89	96	95

[a] See Figure 1B.
[b] All isolates were avirulent on *Sr13*.
[c] Less than 0.6%.
[d] Totals do not include isolates from the sexual population from area 8 (see Table 4).
[e] Roelfs et al (9).
[f] Roelfs et al (8).

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

Cereal Rust Laboratory race	Canadian race[a]	Pgt-race[b]
15-TNM	C53(15B1L)	TRM
113-RKQ	C63(32)	RKR
113-RTQ	C41(32-113)	RTQ
151-QSH	C25(38)	QTR

[a] Green (3).
[b] Roelfs and Martens (14).

were designated differently in 1987 (3), so equivalents are given for races reported here (Table 6). The recently described international system (14) will be used in both areas in 1988, so equivalents for the new system are also provided.

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