Races of *Puccinia graminis* in the United States and Mexico During 1982

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ABSTRACT

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Stem rust of oats and wheat were generally present in trace amounts in 1982. Oat stem rust was retarded by poor conditions for infection during the early part of the growing season in the principal oat-production area in the north central United States. Wheat stem rust was further restricted by the wide use of resistant cultivars in Mexico and the entire Great Plains of the United States. The principal race of oat stem rust in Mexico and the United States was NA-27, virulent on host genes *Pg*-1, -2, -3, -4, and -8. The 15-TNM was the principal wheat stem rust race in the United States (virulent on *Sr*5, 7b, 8, 9d, 9e, 10, 11, 16, 17, 36, and Tmp). In Mexico, races 113-RKQ (virulent on *Sr*5, 6, 7b, 8, 9a, 9b, 9d, 15, 16, 17, and 36) and 151-QFB (virulent on *Sr*5, 8, 9a, 9d, 15, 16, and 17) were most frequent. No virulence was found in oat stem rust for host genes *Pg*-9, -13, -16, and -a or in wheat stem rust for *Sr*13, 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 worldwide. Since the virtual elimination of susceptible barberry bushes from the north central United States, the frequency of epidemics in this area has been reduced (3). Nevertheless, devastating epidemics occurred on wheat in 1935, 1937, 1953, and 1954 and on oats in 1953 in the United States (2) from windborne uredospores. In order to avoid such epidemics, resistant cultivars were developed that may in turn become susceptible to new pathogen races. Thus, constant monitoring of changes in pathogen virulence has been part of the program to have epidemic-free crops. Data from these surveys also contain information on the effect of changes in host resistance on pathogen frequency and distribution.

MATERIALS AND METHODS

Annual field surveys were made over a 24,000-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 historically been a problem. Stops were made at a commercial field each 32 km or at the first field thereafter. Additional stops were made at experimental nurseries and wheat trap plots along the route. Whenever rust was observed in a field or nursery, a varying number of 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 1982, field surveys were conducted in the following areas: southern Texas (late March), northern Mexico (early April), northern Texas and the Gulf Coast (late April), Oklahoma and Kansas (mid-May), Nebraska and South Dakota (mid-June), eastern Dakotas and Minnesota (early July), and the north central United States (late July). When uredial collections were brought to the laboratory, two spore samples were collected. 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 bearing or pruned to bear a single uredium were saved and reincubated to permit loose uredospores to germinate. Uredospores were collected separately 3–4 days later from up to three uredia (each such collection an isolate); each uredium provided enough spores to inoculate a differential host series.

Spores suspended in lightweight mineral oil were sprayed on plants, which were then placed in a dew chamber overnight at 18 C. This was followed by a 3-hr period of fluorescent light (10,000 lux) as the temperature rose gradually to 30 C. Plants were then placed 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 in the same area at about the same time and was used to inoculate a "universally" resistant series.

***P. graminis* f. sp. *avenae*.** The differential host series consisted of oat lines with genes *Pg*-1, -2, -3, -4, -8, -9, -13, -15, -16, and -a (1). The universally resistant series consisted of the host lines Saia (CI 7010), CI 7221, SES Selection 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 from the United States were grouped 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, Tt-1 (*Sr*36), and Tmp. Races were assigned using the code shown in Table 1. The universally

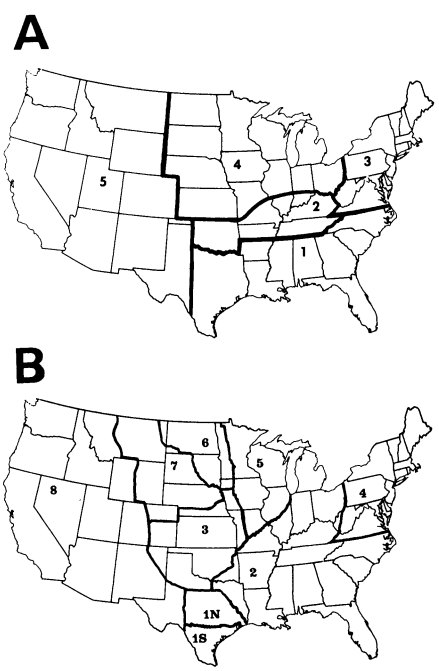

Fig. 1. Ecological areas for *Puccinia graminis* in the United States. **(A)** Areas for oat stem rust: (1) winter oats, (2) mixed winter and spring oats, (3) spring oats and barberry area, (4) major spring oat-producing area, and (5) widely isolated oat fields. **(B)** Areas for wheat stem rust: (1S)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

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resistant series consisted of lines with the host genes *Sr*22, 24, 25, 26, 27, 29, 30, 31, 32, 33, Gt, Tt-2 (*Sr*37), 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 wheat; area 4, mostly soft red winter wheat and scattered barberries; area 5, mixed wheat types; area 6, hard red spring and durum wheat; area 7, northern hard red winter wheat; and area 8, mostly soft winter wheats and spring wheats.

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 first observed in a Beeville, TX, nursery on 30 March, about 2 wk later than the 40-yr mean. Stem rust was light throughout southern and eastern Texas. Scattered infections occurred on oats and wild oats throughout Mexico. These areas provided inoculum for the northern oat-growing region, where rust occurred in most fields in light amounts. Initial infections were sporulating by late May in eastern Minnesota. This early onset would normally result in a serious epidemic (4); however, low temperatures and infrequent dews in June and early July retarded disease development. A second effective input of exogenous inoculum occurred in late June in western Minnesota and the eastern Dakotas. This developed into an epidemic that was terminated by crop maturity before there was much loss, except in a few late-maturing fields.

The principal race in the United States and Mexico was race NA-27, making up 88 and 91% of the isolates, respectively (Table 2). This race has predominated in the U.S. population since 1965. It is virulent on host genes *Pg*-1, -2, -3, -4, and -8, but only *Pg*-2 and -4 are widely used in commercial cultivars. NA-27, however, has caused only one moderately severe epidemic (4). Race NA-16, which has tended to dominate the population obtained from wild oats and susceptible cultivars, was again the second most frequent, and in 1982, it made up 6 and 9%, respectively, of the population in the United States and Mexico. Race NA-5 is avirulent on some of the earliest studied resistance genes, *Pg*-1, -2, -4, and -8, but virulent on *Pg*-15. It was an important component of the pathogen population in Louisiana, Texas, and Idaho. The least common race identified was NA-23, which was widely distributed but in trace amounts. This race is virulent on *Pg*-1, -2, -3, and -8 and continues as a small part of the pathogen population. Virulence for the single genes used for race identification is shown in Table 3. Host gene *Pg*-3 is now universally susceptible to the oat stem rust population in Mexico and the United States; however, avirulence is found in some years from aeciospores or uredospores collected on or near barberry bushes. Host genes *Pg*-13, -16, and -a were resistant to the population we sampled from Mexico and the United States in 1982; however, virulence for these genes has been found in the past.

***P. graminis* f. sp. *tritici*.** Stem rust was found in several commercial barley fields in the state of Coahuila, Mexico, in mid-April and in wheat trap plots at Uvalde, TX, and in Louisiana in late April. Stem rust was not found or reported in central Texas (area 1N), northern Texas, or Oklahoma in 1982, but scattered infections were found in Arkansas and Kansas. The first infections in the northern Great Plains were found in July,

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] 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.

Table 2. Frequency of the identified races of *Puccinia graminis* f. sp. *avenae* by area and source of collection in 1982

Area[a]	Source	Number of[b]		Percentage of each North American (NA) physiologic race[c]			
		Collections	Isolates	5	16	23	27
United States	Field	63	159	···	8	1	91
	Nursery	301	841	5	6	1	88
	Total	364	1000	5	6	1	88
1	Field	16	48	···	6	4	90
	Nursery	226	630	4	7	*[d]	88
	Total	242	678	4	7	*	95
3	Nursery	2	4	···	···	···	100
4	Field	45	119	···	8	···	92
	Nursery	69	181	···	3	4	93
	Total	114	300	···	5	2	93
5	Nursery	6	18	100	···	···	···
Mexico	Field	14	43	···	10	···	90
	Nursery	10	28	···	···	···	100
	Total	15	45	···	9	···	91

[a] Area 1, southern United States; area 3, northeastern United States; area 4, north central United States; and area 5, western United States (Fig. 1A).
[b] Uredia from a single field plant or cultivar received separately was a collection from which up to three single-pustule isolates were identified.
[c] Martens et al (1).
[d] * = Less than 0.6% of the isolates.

Table 3. Incidence of virulence in *Puccinia graminis* f. sp. *avenae* isolates to the resistance of the single-gene differential lines in the 1982 survey

Area[a]	Percentage of isolates virulent on *Pg*-[b]					
	1	2	4	8	9	15
1	96	89	95	96	0	4
3	100	100	100	100	0	0
4	100	95	93	95	0	0
5	0	0	0	0	0	100
United States 1982	95	89	88	89	0	5
United States 1981[c]	99	96	96	99	*[d]	1
United States 1980[c]	91	79	78	91	0	9
Mexico	100	100	100	100	0	0

[a] Area 1, southern United States; area 3, northeastern United States; area 4, north central United States; and area 5, western United States (Fig. 1A).
[b] All isolates were virulent on *Pg*-3 and none were virulent on *Pg*-13, -16, and -a.
[c] Roelfs et al (6,8).
[d] * = Less than 0.6% of the isolates.

but development was restricted because nearly all the acreage was planted to resistant cultivars. The scarcity of wheat stem rust in the United States and Mexico in 1982 was such that only five infected fields were found and these had only a trace of stem rust (one in Idaho, one in Kansas, two in Minnesota, and one in West Virginia). Only 125 collections were obtained in 1982 (Table 4), the fewest since 1980 (5). In 1980, 55 collections were received from commercial fields of wheat, barley, and uncultivated hosts, whereas only 11 such collections were made in 1982 and only one was from a wheat field. The persistance of stem rust is such, however, that enough inoculum was generated to initiate infection in small nurseries of susceptible wheat cultivars in 14 states of the United States and two of Mexico.

The most common race in the United States was again 15-TNM (Table 4); however, 73% of the isolates of this race are now virulent on hosts with *Sr*17. This is the first year that race 15-TNM virulent on *Sr*17 has been the dominant one. It was also found in a nursery at Rio Bravo, Mexico, near Matamoros. Races 151-QFB and -QCB were present in small amounts throughout most of the United States. These races are similar, differing only in virulence on *Sr*8 (151-QFB). Race 151-QFB was present in the barley fields of Coahuila, Mexico. Race 151-QSH has a very different genotype and occurs in trace amounts on cultivars with *Sr*6 and -17 resistance. Races 113-RKQ and 113-RTQ were also found in small amounts. They differ in that 113-RKQ is avirulent on *Sr*11. The race 113-RKQ form that was most common before 1982 was avirulent on *Sr*17; however, in 1982, 58% of the isolates of 113-RKQ were virulent on *Sr*17. Race 56-MBC still exists in trace amounts (three isolates, one collection) and was found in West Virginia.

Associations of virulence or avirulence are common in asexual populations of *P. graminis*. For example, in this survey, virulence to *Sr*9e was always associated

Table 4. Summary of the identified races of *Puccinia graminis* f. sp. *tritici* by area and source of collection in 1982

				Percentage of isolates of each race[c]													
		Number of[b]		15		151			113		11	17		29	56		
Area[a]	Source	Collections	Isolates	TDM	TNM	QCB	QFB	QSH	RKQ	RTQ	RHR	HDL	HNL	HJC	MBC	Others[d]	
United States	Field	11	30	...	57	...	10	7	...	...	7	...	...	...	10	10	
	Nursery	114	324	1	79	3	6	3	4	*[c]	*	*	1	1	...	3	
	Total	125	325	1	78	3	5	3	4	*	1	*	*	1	1	3	
1S	Nursery	13	34	...	79	...	18	...	...	...	3	...	...	...	...	...	
2	Nursery	11	33	...	33	30	21	3	12	...	...	...	...	...	...	...	
3	Field	1	3	...	100	...	...	...	...	...	...	...	...	...	...	...	
	Nursery	3	9	...	78	...	...	...	...	...	...	...	...	22	...	...	
	Total	4	12	...	83	...	...	...	...	...	...	...	...	17	...	...	
4	Field	2	6	...	...	...	17	33	...	...	...	...	...	...	50	...	
	Nursery	4	10	...	30	...	...	...	40	10	...	...	...	20	...	...	
	Total	6	16	...	19	...	6	12	25	6	...	...	...	12	19	...	
5	Field	2	3	...	33	...	...	...	...	...	66	...	...	...	...	...	
	Nursery	8	23	...	87	...	4	4	4	...	...	...	...	...	...	...	
	Total	10	26	...	81	...	4	4	4	...	8	...	...	...	...	...	
6	Field	5	15	...	87	...	13	...	...	...	...	...	...	...	...	...	
	Nursery	68	196	2	93	...	*	*	2	...	...	*	1	...	...	2	
	Total	73	211	1	92	...	1	*	1	...	...	*	1	...	...	1	
7	Nursery	2	4	...	100	...	...	...	...	...	...	...	...	...	...	...	
8	Field	1	3	...	...	...	...	...	...	...	...	...	...	...	...	100	
	Nursery	5	15	...	20	...	...	40	...	...	...	...	...	...	...	40	
	Total	6	18	...	17	...	...	33	...	...	...	...	...	...	...	50	
Mexico	Field	3	7	...	...	...	100	...	...	...	...	...	...	...	...	...	
	Nursery	4	12	...	17	...	...	...	83	...	...	...	...	...	...	...	
	Total	7	19	...	10	...	37	...	53	...	...	...	...	...	...	...	

[a] Area 1S, southern Texas; 2, eastern United States; 3, southern Great Plains; 4, northeastern United States; 5, Wisconsin, Iowa, and eastern Minnesota; 6, Dakotas and western Minnesota; and 8, western United States.
[b] Cereal Rust Laboratory races (see Table 1).
[c] Uredia from a single field plant or cultivar received separately was a collection from which up to three single-pustule isolates were identified.
[d] From Washington: BBC, five isolates; QDC, one; and CBC, three.
[e] * = 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 1982 survey

	Percentage of isolates virulent on *Sr* gene[b]														
Area[a]	5	6	7b	8	9a	9b	9d	9e	10	11	15	16	17	36	Tmp
1S	100	3	82	97	18	3	100	79	18	79	20	100	94	82	79
2	100	15	45	70	64	12	100	33	36	36	67	100	79	45	33
3	83	17	100	100	0	0	100	83	100	83	17	100	100	83	83
4	88	16	81	81	38	44	81	19	62	38	81	100	56	44	38
5	100	15	92	92	26	15	100	81	92	85	81	100	65	92	81
6	98	2	97	98	3	2	98	94	94	93	5	98	65	97	94
7	100	0	100	100	0	0	100	100	100	100	0	100	100	100	100
8	44	33	67	56	0	33	39	17	100	50	83	100	83	17	17
United States 1982	96	9	86	92	12	8	96	78	87	82	22	99	75	84	79
United States 1981[c]	87	4	56	90	46	9	96	37	48	42	63	100	72	54	37
United States 1980[c]	92	8	64	84	39	9	92	48	64	44	49	100	56	61	53
Mexico	100	53	63	10	100	53	100	10	37	10	89	100	100	10	10

[a] Area 1S, southern Texas; 2, eastern United States; 3, southern Great Plains; 4, northeastern United States; 5, Wisconsin, Iowa, and eastern Minnesota; 6, Dakotas and western Minnesota; and 8, western United States.
[b] All isolates were avirulent on *Sr*13.
[c] Roelfs et al (5,7).

with virulence to *Sr*16, -36, and Tmp, and with avirulence to *Sr*6, -9a, -9b, and -15. The association can be complete as with avirulence to *Sr*15 always being associated with virulence to *Sr*9e and vice versa, or directional, as with *Sr*9a avirulence usually but not always being associated with *Sr*9e virulence. These associations are important to know and understand when studying virulence or avirulence frequencies (Table 5). Virulence for *Sr*6 remains low in the United States and Mexico even though this gene was widely used in commercial cultivars. Virulence for *Sr*17, also widely used in North American cultivars, seems to be increasing. Virulence for *Sr*17 had nearly disappeared in the late 1960s and 1970s with the increase in frequency of races 15-TLM, -TDM, and -TNM.

During the survey, no virulence was found for *Sr*13, 22, 24, 25, 26, 27, 29, 31, 32, 33, 37 (Tt-2), Gt, and Wld-1. Virulence for *Sr*30 occurred in only one isolate of 11-RHR from Uvalde, TX. This race has occurred in trace amounts in Mexico and the United States for many years.

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