Specific Virulence of *Puccinia recondita* f. sp. *tritici* in the United States from 1978 Through 1983

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ABSTRACT

Long, D. L., Schafer, J. F., and Roelfs, A. P. 1985. Specific virulence of *Puccinia recondita* f. sp. *tritici* in the United States from 1978 through 1983. Plant Disease 69:343-347.

Puccinia recondita f. sp. *tritici* was identified from wheat leaf collections made by cooperators throughout the United States and from cereal rust field surveys of the Great Plains and Gulf Coast from 1978 through 1983. Testing of 1,928 isolates for virulence to 12 single-gene resistant tester lines showed 33 virulence combinations, which were categorized into 12 Unified Numeration (UN) races. Ninety-five percent of the isolates were classified into six UN races. No virulence was found to *Lr*16 or 19.

Additional key words: wheat leaf rust

Wheat leaf rust, caused by *Puccinia recondita* Rob. ex. Desm. f. sp. *tritici*, is currently an important disease worldwide (11). For example, in 1982 in the southeastern United States, state average leaf rust loss estimates ranged from 3 to 15% (D. L. Long, *unpublished*). To select effective resistance genes in breeding cultivars for resistance to this pathogen, continual monitoring of virulence and combinations of virulence in the pathogen population is needed. Data from such surveys also provide an insight into the epidemiological patterns by monitoring the changes and movement of virulence combinations. The objective of this study was to characterize the virulence of the *P. recondita* population in the United States by regions. This information provides a data base needed by wheat breeders, epidemiologists, and modelers. Results are presented in a form to provide historical continuity with the Unified Numeration (UN) designation proposal of Johnston (4) and Basile (1).

MATERIALS AND METHODS

Leaf rust urediniospore collections were made by cooperators throughout the United States and by personnel of the Cereal Rust Laboratory during annual field surveys. These surveys were conducted over a 24,000-km route covering the Gulf Coast and the Great Plains of the United States (Fig. 1, areas 1, 4, 5, and 6). The surveys followed a predetermined, generally circular route through selected areas where small-grain cereals are important. Stops were made at commercial fields each 32 km or at the first field thereafter. Additional stops were made at nurseries and trap plots along the route. At least one rust collection was made in each locality visited during 1978–1981 and from each rusted field or nursery observed during 1982–1983. A collection consisted of a varying number of leaves bearing urediniospores from a single plant or cultivar.

When collections were received at the Cereal Rust Laboratory, urediniospores from them were used to inoculate 7-day-old seedlings of wheat (*Triticum aestivum* L. 'Thatcher,' CI 10003) treated with maleic hydrazide to enhance spore production. After 12–15 days, up to three leaves, each bearing a single uredinium or pruned to a single uredinium, were saved for inoculum. Six to 8 days later, sufficient urediniospores were collected from a single uredinium per collection in 1978 and 1979 and separately from two uredinia per collection in 1980 through 1983 to provide isolates to inoculate a differential host series. Spores suspended in a lightweight mineral oil were sprayed onto plants, which were placed in a dew chamber overnight at 18 C. Plants were then placed in a greenhouse at 18–28 C. Observations were recorded 10–14 days later on a dichotomous high or low virulence basis, following the susceptible and resistant host classes described by Levine et al (5). Wheat single-gene isolines known to possess resistance genes *Lr*1, 2a, 2c, 3, 3ka, 9, 10, 16, 17, 18, and 19 were included in the host series to evaluate these isolates (9). *Lr*24 was included in

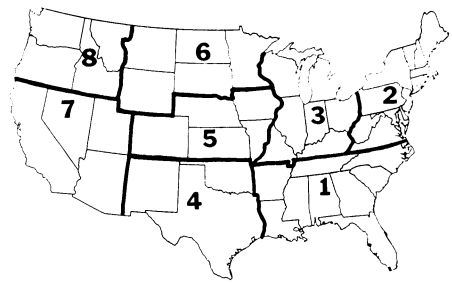

Fig. 1. Agroecological areas for *Puccinia recondita* f. sp. *tritici* in the United States: Area 1, mainly southern-adapted soft red winter wheats; 2 and 3, both planted to northern-adapted soft red winter wheat and white winter wheats, but appear to be epidemiologically separated by geographic features; 4, a mixture of wheat types but largely hard red winter; 5, hard red winter wheat; 6, mixed wheat types but largely hard red spring; 7, spring wheats planted in late fall; and 8, mixed wheats but largely soft white winter types.

Table 1. UN race designation of *Lr* virulence/avirulence character of *Puccinia recondita* f. sp. *tritici* isolates

UN race number	Virulence (V) or avirulence (A) to *Lr* gene			
	1	2a	2c	3
1	A	A	A	A
2	A	A	A	V
10	A	A	V	A
3	A	A	V	V
12	A	V	V	A
17	A	V	V	V
11	V	A	A	A
5	V	A	A	V
14	V	A	V	A
6	V	A	V	V
9	V	V	V	A
13	V	V	V	V

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the cultivar Agent (3).

Isolates were grouped by eight agro-ecological geographic source areas (Fig. 1) on the basis of the locations of collections: area 1, mainly southern-adapted soft red winter wheats; areas 2 and 3, both planted to northern-adapted soft red winter and white winter wheats but appear to be epidemiologically separated by geographic features; area 4, a mixture of wheat types but largely hard red winter; area 5, hard red winter wheat; area 6, a mixture of wheat types but largely hard red spring wheat; area 7, spring wheats planted in late fall; and area 8, a mixture of wheats but largely soft white winter types.

RESULTS AND DISCUSSION

The data are grouped by modified UN numbers based on the reactions of *Lr*1, 2a,

Table 2. Virulence combinations of isolates of *Puccinia recondita* f. sp. *tritici* from collections made in the United States from 1978 through 1983 as determined by the reactions of 12 wheat lines containing single genes for resistance (commonly found UN races)

	Number of isolates per virulence formula grouped by UN races[a]																				
	UN 2 (3)					UN 17 (2a,2c,3)	UN 5 (1,3)					UN 13 (1,2a,2c,3)			UN 3 (2c,3)			UN 6 (1,2c,3)			
Year	0	10	3ka 9	24	10 24	10	10	10 17	3ka 17	10 24	10 17 18	0	17 18	10 17 18	3ka 9	3ka 18	3ka 9 10	3ka 9	3ka 10	10 17	10 17 18
											Area 1[b,c]										
1978	...	2	3	...	...	1	1	...	...	2	...	...	...	...	...	...	1	...	...	...	...
1979	...	1	3	...	1	...	...	...	...	...	...	...	1	...	...	...	11	...	...	...	...
1980	23	4	6	...	2	1	...	...	...	...	4	1	...	...	...	...	34	4	4	...	...
1981	...	19	19	...	2	6	1	...	...	...	4	10	...	...	3	...	15	...	...	...	...
1982	16	28	9	...	...	5	2	4	...	2	15	7	...	4	59	6	43	...	...	...	1
1983	27	18	2	...	...	4	18	...	...	...	1	10	...	7	64	...	...	11	4	...	9
											Area 2										
1978	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1979	1	...	...	...	...	...	...	...	...	...	3	...	...	...	...	...	...	...	...	...	2
1980	...	7	...	...	...	4	...	...	...	...	7	...	...	...	...	...	8	...	...	...	2
1981	...	1	...	...	...	...	...	...	...	...	2	...	...	...	...	...	7	...	...	...	2
1982	1	1	...	...	...	...	1	...	...	1	1	...	...	...	17	...	...	...	...	2	4
1983	...	4	...	...	...	...	6	7	4	...	2	...	...	1	4	...	...	15	5	...	12
											Area 3										
1978	2	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1979	...	...	6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1980	...	2	6	...	...	5	...	...	...	...	3	...	...	...	...	...	20	...	...	...	...
1981	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...
1982	1	4	...	...	1	2	1	2	...	...	...	1	...	...	13	...	...	...	...	1	2
1983	...	...	...	...	...	2	1	...	...	...	...	...	...	...	...	...	...	1	...	...	5
											Area 4										
1978	...	3	...	...	...	1	1	...	...	4	...	3	...	...	...	...	...	...	...	...	...
1979	1	1	...	...	...	10	...	...	...	5	...	2	4	...	...	...	...	...	...	...	...
1980	...	2	...	...	...	17	...	...	...	5	1	...	...	...	...	...	8	...	...	...	...
1981	...	26	1	...	2	23	...	...	...	1	...	3	...	1	...	...	6	...	...	...	1
1982	7	47	6	...	4	54	23	2	...	8	13	...	...	3	27	...	...	...	...	...	...
1983	5	13	3	...	1	30	67	...	...	11	4	...	...	2	2	...	...	...	...	...	...
											Area 5										
1978	2	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1979	3	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...
1980	...	...	...	...	...	19	...	...	...	...	2	...	...	...	...	...	1	...	...	...	...
1981	...	22	2	...	...	25	...	...	...	1	1	...	...	...	...	...	1	...	...	...	2
1982	3	11	...	...	...	25	30	1	...	2	...	1	...	2	2	...	...	...	...	...	...
1983	...	2	...	...	...	3	22	...	...	...	...	...	...	...	...	...	...	...	...	...	...
											Area 6										
1978	7	10	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1979	...	...	2	...	...	22	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...
1980	...	3	...	...	...	29	3	...	...	1	7	...	...	...	...	...	5	...	...	...	...
1981	1	12	...	...	1	38	4	...	...	4	6	...	...	1	...	...	6	...	...	...	...
1982	1	4	...	2	2	51	53	6	...	6	3	...	...	...	27	2	...	...	...	2	...
1983	...	2	...	...	...	29	15	...	...	...	...	...	...	...	...	...	...	...	...	...	...
											Area 7										
1978	...	1	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...
1979	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1980	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1981	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1982	...	...	...	...	...	...	...	...	...	...	...	2	...	...	...	...	...	...	...	...	...
1983	...	4	...	...	...	7	3	...	...	...	...	...	...	1	...	...	...	...	...	...	...
											Area 8										
1978	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1979	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1980	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1981	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1982	...	...	...	...	...	...	2	...	...	...	...	...	...	...	...	...	...	...	...	...	3
1983	...	4	...	...	...	...	1	...	...	...	1	...	...	...	...	...	...	...	...	...	...
Total	103	266	69	2	16	413	255	22	4	54	81	40	5	22	218	8	168	31	13	5	45

[a] Specific virulence of designated UN race to *Lr* genes is in parentheses. Additional virulence to other single-gene *Lr* lines is indicated in columns below.
[b] Areas are based on host types and geographic isolation (Fig. 1).
[c] Total isolates per area per year are listed in Table 3.

2c, and 3, historical differential host materials. Basile (1) proposed 27 UN races based on five differential cultivars: Malakof, Webster, Loros, Mediterranean, and Democrat. Soliman et al (12) subsequently showed that in North America, the resistance provided by both Mediterranean and Democrat is conditioned by a single gene, *Lr*3; thus for North American race identification purposes, one may be dropped. The differential cultivars of Basile (1) were replaced by Samborski (8) with Thatcher isolines of *Lr*1, 2a, 2c, and 3. In North America in recent years, *Lr*2c has been susceptible whenever *Lr*2a is susceptible (3). These four differential lines thus distinguish only 12 races in North America, generally corresponding to 12 of Basile's UN races. To facilitate comparisons, the UN numbers of Basile (1) for which Mediterranean and Democrat provide a similar response are used in the present report. These are

Table 3. Virulence combinations of isolates of *Puccinia recondita* f. sp. *tritici* from collections made in the United States from 1978 through 1983 as determined by the reactions of 12 wheat lines containing single genes for resistance (infrequently found UN races)

	Number of isolates per virulence formula grouped by UN races[a]												
	UN 1		UN 12 (2a,2c)	UN 11 (1)			UN 9 (1,2a,2c)		UN 10 (2c)		UN 14 (1,2c)		Total per area per year[b]
Year	0	9	17	17	17 18	10 17 18	17	10 17	18	10 17	10	10 18	
							Area 1[c]						
1978	...	...	...	...	...	...	...	...	...	...	...	...	10
1979	1	...	...	...	...	...	...	...	...	...	...	...	18
1980	...	...	...	...	...	...	...	...	...	...	...	...	83
1981	...	...	...	...	...	...	...	...	...	...	...	...	79
1982	...	...	...	...	...	...	...	...	...	...	17	...	218
1983	1	...	...	...	...	...	...	...	...	...	16	...	192
							Area 2						
1978	...	...	...	...	...	...	...	...	...	...	...	...	2
1979	...	...	...	...	...	...	...	...	...	...	...	...	6
1980	...	...	...	...	...	...	...	...	...	...	...	...	28
1981	...	...	...	...	...	...	...	...	...	...	...	...	12
1982	2	...	...	...	...	2	2	...	2	...	...	...	36
1983	...	...	...	3	17	...	...	...	...	...	5	...	85
							Area 3						
1978	2	...	...	...	...	...	...	...	...	...	...	...	7
1979	...	...	...	...	...	...	...	...	...	...	...	...	6
1980	...	...	...	...	...	...	...	...	...	...	...	...	36
1981	...	2	...	...	...	...	...	...	...	...	...	...	4
1982	1	...	...	...	...	1	...	...	...	...	...	...	30
1983	...	...	...	...	...	...	...	...	...	...	...	...	9
							Area 4						
1978	...	...	...	...	...	...	...	...	...	...	...	...	12
1979	...	...	...	...	...	...	...	...	...	...	...	...	23
1980	...	...	...	...	...	...	...	...	...	...	...	...	33
1981	...	...	...	...	...	...	...	...	...	...	...	...	64
1982	...	...	...	...	...	...	...	2	...	...	...	...	196
1983	...	...	...	...	...	...	...	...	...	1	...	...	139
							Area 5						
1978	...	...	...	...	...	...	...	...	...	...	...	...	6
1979	...	...	...	...	...	...	...	...	...	...	...	...	5
1980	...	...	...	...	...	3	...	...	...	...	...	...	25
1981	...	...	...	...	...	...	...	...	...	...	...	...	54
1982	...	...	...	...	...	...	...	...	...	...	...	...	77
1983	...	...	...	...	...	...	...	...	...	...	...	...	27
							Area 6						
1978	...	...	...	...	...	...	...	...	...	...	...	...	17
1979	...	...	...	...	...	...	...	...	...	...	...	...	25
1980	...	...	...	...	...	2	...	...	...	...	...	...	50
1981	...	...	1	...	...	...	...	...	...	...	...	...	74
1982	...	...	...	...	...	...	...	...	...	...	...	...	159
1983	...	...	...	...	...	...	...	...	...	...	...	...	46
							Area 7						
1978	...	...	...	...	...	...	...	...	...	...	...	...	2
1979	...	...	...	...	...	...	...	...	...	...	...	...	0
1980	...	...	...	...	...	...	...	...	...	...	...	...	0
1981	...	...	...	...	...	...	...	...	...	...	...	...	0
1982	...	...	...	...	...	...	...	...	...	...	...	...	2
1983	...	...	...	...	...	...	...	...	...	1	...	...	16
							Area 8						
1978	...	...	...	...	...	...	...	...	...	...	...	...	0
1979	...	...	...	...	...	...	...	...	...	...	...	...	0
1980	...	...	...	...	...	...	...	...	...	...	...	...	0
1981	...	...	...	...	...	...	...	...	...	...	...	...	0
1982	...	...	...	...	...	...	...	...	...	...	...	...	5
1983	...	...	...	...	...	...	...	...	...	...	...	4	10
Total	7	2	1	3	17	8	2	2	2	2	38	4	1,928

[a] Specific virulence of designated UN race to *Lr* genes is in parentheses. Additional virulence to other single-gene *Lr* lines is indicated in columns below.
[b] For Tables 2 and 3.
[c] Areas are based on host types and geographic isolation (Fig. 1).

Table 4. Percentage of isolates of *Puccinia recondita* f. sp. *tritici* virulent to the single-gene differential lines used in the surveys from 1978 through 1983 by areas

Year	Isolates virulent to *Lr* genes (%)[a]									
	*Lr*1	*Lr*2a	*Lr*2c	Lr3	*Lr*3ka	*Lr*9	*Lr*10	*Lr*17	Lr18	*Lr*24
					Area 1[b]					
1978	30	10	20	100	40	40	70	0	0	20
1979	6	6	67	94	78	78	72	6	6	6
1980	16	2	53	100	58	53	59	5	5	2
1981	19	20	43	100	47	47	59	5	5	3
1982	24	7	65	92	54	51	56	11	12	9
1983	40	12	69	96	45	42	42	4	9	0
Total[c]	27	10	60	94	50	48	52	7	9	2
					Area 2					
1978	0	0	0	100	0	0	0	0	0	0
1979	83	0	33	100	0	0	83	83	83	0
1980	32	14	50	100	29	29	100	32	32	0
1981	33	0	75	100	58	58	100	33	33	0
1982	36	5	75	78	47	47	39	31	19	3
1983	91	1	49	71	33	22	49	54	38	0
Total	64	4	56	80	36	30	60	44	34	1
					Area 3					
1978	0	0	0	71	0	0	43	0	0	0
1979	0	0	0	100	100	100	0	0	0	0
1980	8	14	69	100	72	72	69	8	8	0
1981	0	0	25	50	50	50	75	50	50	0
1982	27	10	63	93	43	43	40	20	10	3
1983	78	22	89	100	11	11	89	56	56	0
Total	20	11	58	93	52	54	53	15	12	1
					Area 4					
1978	67	33	33	100	0	0	75	0	0	33
1979	48	70	70	100	0	0	70	17	17	22
1980	18	52	76	100	24	24	100	3	3	15
1981	9	42	53	100	11	11	94	3	3	5
1982	26	30	44	99	17	17	80	10	2	6
1983	60	23	25	99	4	4	93	5	4	9
Total	36	33	43	99	11	11	86	7	3	9
					Area 5					
1978	0	0	0	100	0	0	67	0	0	0
1979	0	0	20	100	20	20	40	0	0	0
1980	20	76	80	88	4	4	100	20	20	0
1981	7	46	52	100	6	6	50	6	6	4
1982	47	36	39	100	3	3	92	4	3	3
1983	81	11	11	100	0	0	100	0	0	0
Total	35	39	42	98	4	4	80	6	5	2
					Area 6					
1978	0	0	0	100	0	0	59	0	0	0
1979	4	88	88	100	0	0	92	0	0	12
1980	26	58	68	96	10	10	100	24	18	2
1981	20	54	62	99	8	8	97	11	9	7
1982	44	32	52	100	17	18	80	7	3	6
1983	33	63	63	100	0	0	100	0	0	0
Total	31	46	57	99	11	10	88	8	6	5
					Area 7					
1978	50	0	0	100	0	0	100	50	50	0
1979	0	0	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	0	0	0	0
1982	100	100	100	100	0	0	0	0	0	0
1983	25	50	56	94	0	0	100	12	6	0
Total	35	50	55	95	0	0	90	15	10	0
					Area 8					
1978	0	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0	0	0
1981	100	0	60	100	0	0	100	60	60	0
1982	60	0	40	60	0	0	100	10	10	0
1983	0	0	0	0	0	0	0	0	0	0
Total	73	0	47	73	0	0	100	27	27	0
U.S. total[d]	34	25	53	95	26	25	73	11	10	4

[a] No virulence was observed for *Lr*16 or 19.
[b] Area description in text and Figure 1.
[c] Percentage of total isolates from the area for the 6-yr period.
[d] Percentage of total isolates from the United States for the 6-yr period.

designated in Table 1.

The virulence formulas for the 1,928 isolates, based on the 12 lines each possessing a single gene for resistance, are shown in Tables 2 and 3. The arrangement of the 12 UN race categories places populations together that have apparent developmental or geographic relationships.

Virulence to either *Lr*16 or 19 was not identified during this period of years in the U.S. survey. These results are similar to data of Samborski (10) for Canada and Statler et al (15) for North Dakota. Virulence to *Lr*16, resistance that is present in Exchange and Selkirk, was previously common in Canada (7) and North Dakota (14) when Selkirk and related cultivars were grown and has been found in the Pacific Northwest (6). *Lr*16 is not currently present in common cultivars in the United States (2,3), and the corresponding virulence characteristic has become rare in recent years (10,15). Rare reports of virulence to *Lr*19 have not been verified by subsequent retained cultures. This resistance probably has not been used commercially.

In contrast, virulences to *Lr*3 (95%) and to *Lr*10 (73%) were widespread in the U.S. population of *P. recondita* f. sp. *tritici* (Table 4). These two genes for resistance are carried by numerous widely grown cultivars (3,13).

Because of their patterns of occurrence, virulences to the other differential lines are considered in the context of the UN races. The six UN races with virulence to *Lr*3 (UN 2, 3, 5, 6, 13, 17), constituting 95% of the isolates identified, are the major populations of these surveys. UN 3 and 6 were more prevalent in the south and east (primarily areas 1 and 2 but also 3 and 4) (Table 2), although a large sample of UN 3 (27 isolates) was collected in area 6 in 1982. UN 3 and 6 are characterized by virulence to *Lr*2c and avirulence to *Lr*2a. Much of the virulence to *Lr*3ka and *Lr*9 occurs in these populations, but these virulences were also found to a lesser extent in a small portion of the UN 2 population, otherwise only virulent to *Lr*3 (largely in area 1), in which these two virulence characters again occur together (69 isolates, Table 2). *Lr*9 was incorporated into soft red winter wheat cultivars (3), which were widely grown in the South and East (2). Usage of *Lr*3ka is not known. UN 6, which includes virulence to *Lr*1 compared with UN 3, increased considerably in 1983 (Table 2) and was found mainly in areas 1 and 2.

UN 2, 17, and 5, the most numerous elements of the pathogen population, were most prevalent in the south and central regions (areas 1, 4, 5, and 6) (Table 2), in comparison to the more easterly orientation of UN 3 and 6. UN 17 and 5 appear similar to UN 2 with the addition of virulence to *Lr*2a and 2c in UN 17 and virulence to *Lr*1 in UN 5. They were proportionately more prevalent in

the north than UN 2. *Lr*2a is possessed by several commonly grown hard red spring wheat cultivars (3,13) in area 6 (2), and *Lr*1, by Newton (3), a recent extensively grown hard red winter cultivar in area 5. UN 17 has a unique virulence uniformity and was found mainly in areas 4, 5, and 6 (very little in area 1). Virulence to *Lr*24 occurred in very low frequency only in UN 2 and 5, and in this survey sample, never in combination with virulence to *Lr*2a, 2c, 3ka, or 9. It was most prevalent in area 4. Several cultivars possessing *Lr*24 (3) were grown in limited amounts in the Southeast (area 1) and the hard red winter wheat region (areas 4 and 5) (2).

UN 13 occurred primarily in the South (mostly in area 1) (Table 2). This contrasts with the UN 3 and 6 populations and the UN 2 and 5 populations, which were found not only in the South but also farther north in the eastern and central areas, respectively.

Virulences to *Lr*17 and 18 appeared to occur randomly at low frequencies in most elements of the pathogen population as otherwise evaluated and described but were not found in widely distributed UN 2 and 17. Neither virulence was found in combination with virulence to *Lr*9 or 24. *Lr*17 and 18 have not been used in any widely grown North American commercial cultivars (2,3,13).

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