Virulence Patterns of *Puccinia recondita* f. sp. *tritici* in Nebraska During 1992 and 1993

J. E. Watkins, Professor, and **S. S. Rutledge,** Research Technologist, Department of Plant Pathology, and **P. S. Baenziger,** Professor, Department of Agronomy, University of Nebraska, Lincoln 68583-0722

ABSTRACT

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One hundred sixty-four urediniospore isolates of *Puccinia recondita* were collected in 1992 and 134 in 1993 from four wheat-growing regions in Nebraska. These were characterized for virulence to 16 near-isogenic, single-gene differentials in a Thatcher genetic background. Thirty-seven virulence combinations were identified from the isolates collected in 1992 and 46 were identified from those collected in 1993. Twenty-two new virulence phenotypes were detected in 1993 that were not found in 1992. Virulence was high during both years in all regions to *Lr1, Lr2a, Lr2c, Lr3, Lr10, Lr11, Lr18, Lr21, Lr24,* and *Lr30.* The virulence frequency was moderate to *Lr26,* and was low to *Lr3ka, Lr9, Lr16, Lr17,* and *Lr19* during both years. The most prevalent virulence phenotypes were TFH-10,18,21 (virulent on *Lr1, Lr2a, Lr2c, Lr3, Lr24, Lr26, Lr11, Lr30, Lr10, Lr18,* and *Lr21*) in 1992 and TFH-10,18 (virulent on *Lr1, Lr2a, Lr2c, Lr3, Lr24, Lr26, Lr11, Lr30, Lr10,* and *Lr18*) in 1993. Eighty-three percent of the 1992 isolates and 74% of the 1993 isolates had the *Lr1, Lr2a, Lr2c,* and *Lr3* virulence phenotype. Virulence to resistance genes *Lr3ka, Lr9,* and *Lr16* was only detected in 1993. *Lr19* was resistant to all rust isolates collected both years. Combinations of these last four genes could provide resistance to Nebraska's current leaf rust population.

Additional keywords: near-isogenic lines, wheat leaf rust

Wheat leaf rust, incited by *Puccinia recondita* Roberge ex Desmaz. f. sp. *tritici* occurs annually throughout the wheat-growing regions of North America (4,8, 17). It is one of the most important wheat diseases worldwide and is a potential threat to wheat production in the central Great Plains. The rust typically overwinters in Texas, Kansas, and Oklahoma, and urediniospores are carried by southerly winds to Nebraska in mid-May. With moderate temperatures and frequent rains, severe rusting occurs by mid-June. In Nebraska losses from leaf rust in hard red winter wheat (*Triticum aestivum* L.) were estimated at 4.0 ($10.3 million), 2.5 ($4.8 million), 2.0 ($3.6 million) and 4.0% ($8.8 million) in 1990, 1991, 1992, and 1993, respectively (D. L. Long, *unpublished*). Since the late 1980s, some hard red winter wheat cultivars grown in the Great Plains contain resistance genes *Lr24, Lr26,* or both (2,5,9–11). These genes have become ineffective because of the shift of rust races to virulence to *Lr24* and *Lr26.*

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Physiological races of *P. recondita* were first reported in 1921 by Mains and Jackson (12). Initially, they used the wheats Kanred and Malakof to separate *P. recondita* isolates, and then later used a differential series of 11 wheat cultivars to describe physiological races. In 1989 Long and Kolmer (6) reported on a North American system of nomenclature for *P. recondita* proposed by the North American Wheat Leaf Rust Workers Committee. This system is the standard for characterizing virulence of the North American leaf rust population in annual surveys conducted in the United States and Canada.

Virulence of the natural leaf rust population is monitored through annual surveys in the United States (7–11) and Canada (2–5) and in the Great Plains through periodic surveys in North Dakota (18), Nebraska (15), Minnesota (14), and Texas (13). These survey data are used to estimate the relative prevalence and distribution of rust races, and to detect shifts toward virulence to resistance genes being used in wheat breeding programs.

The objectives of this study were to characterize virulence of *P. recondita* in Nebraska during 1992 and 1993, compare these results with those of other surveys, and detect new virulence phenotypes. A preliminary report of some of the data has been published (15).

MATERIALS AND METHODS

In 1992 uredinial collection trips were made on 5, 12, 20, and 27 May; 2, 10, 14, and 19 June; 8, 14, and 27 October; and 3 November. Wheat growth stages for the May and June collections ranged from Growth Stage 8 (ligule of last leaf just visible) to 11.1 (milky ripe) on the Feekes scale. Uredinial collection trips in 1993 were made 20, 25, and 27 May and 3, 10, 14, 15, 16, 18, 21, and 22 June; these collections had growth stages ranging from Growth Stage 10 (boot) to 11.1 (milky ripe). Collections were made approximately every 32 km or at the first field thereafter by driving predetermined routes through selected wheat-growing areas. Surveys were conducted in four wheat-growing regions in Nebraska (Panhandle, west central, central, and east), and the total number of leaves collected varied in each region. The four regions differ somewhat in environmental characteristics and planting time, and to a lesser extent in cultivars grown. Elevation ranges from approximately 300 m in the southeast to 1,800 m in the Panhandle, and annual precipitation varies from 76 cm in the southeast to 38 cm in the Panhandle. Winter wheat is generally planted 1–15 September in the Panhandle, 15–25 September in the west central, 15 September to 1 October in the central, and 20 September to 10 October in the east. In 1993, the cultivars Arapahoe, AgriPro Thunderbird, Centura, Siouxland, Redland, AgriPro Abilene, and Buckskin occupied approximately 76% of the total Nebraska winter wheat acreage. By geographic area, the predominant cultivars were Arapahoe, Centura, Siouxland, and Buckskin in the Panhandle, Arapahoe, AgriPro Thunderbird, Siouxland, and Redland in the west central, and Arapahoe, AgriPro Thunderbird, Redland, and AgriPro Abilene in the central and east. A collection consisted of four to eight leaves bearing uredinia from five to ten plants. Uredinia-bearing leaves were placed in glycine bags and stored in a cooler on ice until transported to the laboratory in the Department of Plant Pathology, University of Nebraska-Lincoln. In the laboratory, they were transferred to plastic bags and stored at 3 C for 1–5 wk.

Each collection was then increased on 7-day-old seedlings of the wheat cultivar Thatcher (CI 10003). Inoculated plants were set in a dew chamber at 100% relative humidity at 20 C for an 18- to 24-hr dark period. The plants were then placed in a greenhouse at 20–25 C in which natural daylight was supplemented with 400 W metal halide lights to provide a 14-hr

photoperiod. Ten to 12 days after inoculation the leaves were trimmed so that only one pustule remained on each plant. Urediniospores from single pustules were removed with a spatula and transferred to a microscope slide containing one drop of Tween 20. After the spores were mixed with the Tween 20, the slide was wiped onto the leaves of Thatcher to increase each single-pustule isolate. The single uredinial isolates were increased through one uredinial generation on Thatcher be-

Table 1. Virulence of the 1992 and 1993 wheat leaf rust (*Puccinia recondita* f. sp. *tritici*) populations in Nebraska to 16 near-isogenic wheat differentials

	Virulence frequency[a] of leaf rust isolates by geographic region									
	East		Central		West central		Panhandle		Mean	
Lr gene	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
1	100	100	100	100	100	100	100	100	100	100
2a	88	79	88	71	88	74	75	83	85	77
2c	90	85	86	79	88	74	75	83	85	80
3	100	100	100	100	100	100	100	100	100	100
3ka	0	16	0	21	0	5	0	17	0	15
9	0	0	0	0	0	5	0	0	0	1
10	100	100	100	100	100	100	100	100	100	100
11	73	83	74	79	80	71	64	61	73	74
16	0	0	0	0	0	5	0	0	0	1
17	13	6	5	17	10	16	7	0	9	10
18	100	92	100	83	100	97	100	94	100	92
19	0	0	0	0	0	0	0	0	0	0
21	63	42	52	33	51	18	61	22	57	29
24	87	68	74	38	83	55	82	78	82	60
26	52	40	50	29	54	42	57	50	53	40
30	58	64	43	67	56	63	54	56	53	63

[a] Represents the percentage of isolates collected from that specific region.

Table 2. Virulence phenotypes of *Puccinia recondita* f. sp. *tritici* isolates collected in Nebraska in 1992

		Number and percentage of isolates from indicated area									
		East		Central		West central		Panhandle		Total	
Prt code[a]	Virulence formula[b]	No.	%	No.	%	No.	%	No.	%	No.	%
MBB-10,18	1,3,10,18,21	0	0	1	2.5	0	0	0	0	1	0.6
MBD-10,18	1,3,17,10,18	0	0	0	0	0	0	1	5	1	0.6
MBG-10,18	1,3,11,10,18	2	3.5	1	2.5	0	0	0	0	3	1.8
MBQ-10,18	1,3,11,30,10,18	1	1.8	0	0	0	0	0	0	1	0.6
MCG-10,18,21	1,3,26,11,10,18,21	0	0	1	2.5	0	0	0	0	1	0.6
MDG-10,18	1,3,24,11,10,18	0	0	2	5.0	1	2.1	0	0	3	1.8
MDG-10,18,21	1,3,24,11,10,18,21	1	1.8	0	0	1	2.1	0	0	2	1.2
MDH-10,18	1,3,24,11,30,10,18	1	1.8	0	0	0	0	1	5	2	1.2
MDH-10,18,21	1,3,24,11,30,10,18,21	1	1.8	0	0	0	0	0	0	1	0.6
MFB-10,18,21	1,3,24,26,10,18,21	0	0	0	0	1	2.1	0	0	1	0.6
MFH-10,18,21	1,3,24,26,11,30,10,18,21	0	0	1	2.5	4	8.5	2	10	7	4.3
RCG-10,18,21	1,2a,3,26,11,10,18,21	0	0	2	5	0	0	0	0	2	1.2
RFB-10,18	1,2a,3,24,26,10,18	1	1.8	0	0	1	2.1	0	0	2	1.2
TBB-10,18	1,2a,2c,3,10,18	1	1.8	0	0	1	2.1	0	0	2	1.2
TBB-10,18,21	1,2a,2c,3,10,18,21	1	1.8	0	0	0	0	0	0	1	0.6
TBG-10,18	1,2a,2c,3,11,10,18	0	0	3	7.5	0	0	0	0	3	1.8
TBH-10,18	1,2a,2c,3,11,30,10,18	0	0	0	0	3	6.4	0	0	3	1.8
TBK-10,18,21	1,2a,2c,3,11,17,30,10,18,21	0	0	0	0	1	2.1	0	0	1	0.6
TCB-10,18,21	1,2a,2c,3,26,10,18,21	2	3.5	1	2.5	0	0	0	0	3	1.8
TCD-10,18,21	1,2a,2c,3,26,17,10,18,21	0	0	0	0	0	0	1	5	1	0.6
TCG-10,18,21	1,2a,2c,3,26,11,10,18,21	0	0	1	2.5	0	0	0	0	1	0.6
TCH-10,18,21	1,2a,2c,3,26,11,30,10,18,21	1	1.8	0	0	1	2.1	2	10	4	2.4
TDB-10,18,21	1,2a,2c,3,24,10,18,21	2	3.5	3	7.5	3	6.4	2	10	10	6.1
TDC-10,18	1,2a,2c,3,24,30,10,18	1	1.8	0	0	2	4.3	0	0	3	1.8
TDD-10,18,21	1,2a,2c,3,24,17,10,18	0	0	0	0	1	2.1	0	0	1	0.6
TDG-10,18	1,2a,2c,3,24,11,10,18	0	0	2	5	3	6.4	1	5	6	3.7
TDG-10,18,21	1,2a,2c,3,24,11,10,18,21	4	7.0	2	5	1	2.1	1	5	8	4.9
TDH-10,18	1,2a,2c,3,24,11,30,10,18	3	5.3	3	7.5	1	2.1	3	15	10	6.1
TDH-10,18,21	1,2a,2c,3,24,11,30,10,18,21	5	8.8	1	2.5	1	2.1	0	0	7	4.3
TDK-10,18,21	1,2a,2c,3,24,11,17,30,10,18,21	6	10.5	0	0	0	0	0	0	6	3.7
TFB-10,18	1,2a,2c,3,24,26,10,18	0	0	1	2.5	2	4.3	2	10	5	3.0
TFG-10,18	1,2a,2c,3,24,26,11,10,18	4	7.0	3	7.5	1	2.1	1	5	9	5.5
TFG-10,18,21	1,2a,2c,3,24,26,11,10,18,21	4	7.0	0	0	5	10.6	0	0	9	5.5
TFH-10,18	1,2a,2c,3,24,26,11,30,10,18,21	5	8.8	4	10.0	0	0	0	0	9	5.5
TFH-10,18,21	1,2a,2c,3,24,26,11,30,10,18,21	8	14.0	8	20.0	9	19.1	3	15	28	17.1
TFK-10,18,21	1,2a,2c,3,24,26,11,17,30,10,18,21	3	5.3	0	0	3	6.4	0	0	6	5.7
Total		57		40		47		20		164	

[a] *Prt* code (5) plus *Lr10, Lr18, Lr19*, and *Lr21* near-isogenic supplemental differentials.

[b] *Lr* genes on which that isolate is virulent.

fore inoculating the set of differentials. During this increase the inoculated Thatcher plants were isolated in the greenhouse to prevent mixture of single-pustule isolates. After 10–12 days, the urediniospores of each single-pustule isolate were collected and stored in 00 gelatin capsules in a desiccator at 3 C. To inoculate the differentials, 4 mg of urediniospores were suspended in 30 ml of Tween 20 and atomized onto the primary leaves of 7-day-old differential host set consisting of near-isogenic, single-gene lines of wheat possessing leaf rust resistance genes *Lr1, Lr2a, Lr2c, Lr3, Lr3ka, Lr9, Lr10, Lr11, Lr16, Lr17, Lr18, Lr19, Lr21, Lr24, Lr26,* and *Lr30* in a Thatcher background (6). Infection types were recorded 10–12 days after inoculation. An infection type of 0, ;(fleck), 1, or 2 indicated avirulent reactions, and infection types 3 and 4 virulent reactions. Each single-pustule isolate was assigned a three-letter virulence phenotype or *Prt* code based on the virulence formula to the standard set of 12 differentials (*Lr1, Lr2a, Lr2c, Lr3, Lr3ka, Lr9, Lr11, Lr16, Lr17, Lr24, Lr26,* and *Lr30*) (6). Each three-letter virulence code is followed by a hyphen and a listing of ineffective host genes in the supplemental differential host set consisting of *Lr10, Lr18, Lr19,* and *Lr21.*

RESULTS AND DISCUSSION

In 1992 leaf rust was observed first in southeast Nebraska in early May, and by mid-June it had become widespread throughout the eastern, central, and west central wheat production areas of the state. In a fungicide evaluation trial in Clay County, NE, an average 76% leaf rust severity was recorded at Growth Stage 11, Feekes scale, on non-fungicide-treated TAM 107 (1). Rust severity was an estimate of the severities on five flag leaves from four replicated plots. The leaf rust epidemic of 1993 was the most severe outbreak of the disease in the last 5 yr. Initially, leaf rust development was slowed by cool temperatures in May in which the average daily high and low temperatures for central Nebraska were 21 C and 9 C, respectively. With warmer temperatures in early June (average daily high and low of 27 C and 14 C for central Nebraska), it developed rapidly and occurred in all wheat-growing areas of Nebraska. The

Table 3. Virulence phenotypes of *Puccinia recondita* f. sp. *tritici* isolates collected in Nebraska in 1993

		Number and percentage of isolates from indicated area									
		East		Central		West central		Panhandle		Total	
Prt code[a]	Virulence formula[b]	No.	%	No.	%	No.	%	No.	%	No.	%
MBB-10,18	1,3,10,18	0	0	1	4.2	0	0	0	0	1	0.7
MBC-10,18	1,3,30,10,18	0	0	0	0	1	2.6	0	0	1	0.7
MBG-10,18	1,3,11,10,18	1	1.9	1	4.2	2	5.1	0	0	4	3.0
MBH-10,18	1,3,11,30,10,18	0	0	2	8.3	0	0	0	0	2	1.5
MBH-10,18,21	1,3,11,30,10,18,21	1	1.9	0	0	0	0	0	0	1	0.7
MCH-10,18	1,3,26,11,30,10,18	1	1.9	0	0	1	2.6	0	0	2	1.5
MDB-10	1,3,24,10	1	1.9	0	0	1	2.6	1	5.3	3	2.2
MDH-10,18,21	1,3,24,11,30,10,18,21	1	1.9	0	0	0	0	1	5.3	2	1.5
MDJ-10,18	1,3,11,17,10,18	1	1.9	0	0	1	2.6	0	0	2	1.5
MFB-10,18	1,3,24,26,10,18	0	0	0	0	1	2.6	0	0	1	0.7
MFC-10,18	1,3,24,26,30,10,18	1	1.9	1	4.2	1	2.6	0	0	3	2.2
MFG-10,18	1,3,24,26,11,10,18	1	1.9	0	0	1	2.6	0	0	2	1.5
MFH-10,18	1,3,24,26,11,30,10,18	1	1.9	0	0	1	2.6	0	0	2	1.5
MFR-10,18,21	1,3,24,26,3ka,11,30,10,18,21	0	0	0	0	0	0	2	10.5	2	1.5
PBC-10,18	1,2c,3,30,10,18	1	1.9	0	0	0	0	0	0	1	0.7
PCG-10,18	1,2a,3,26,11,10,18	2	3.8	1	4.2	0	0	0	0	3	2.2
PDC-10,18,21	1,2c,3,24,30,10,18,21	1	1.9	1	4.2	0	0	0	0	2	1.5
TBB-10,18	1,2a,2c,3,10,18	1	1.9	0	0	2	5.1	1	5.3	4	3.0
TBC-10,18,21	1,2a,2c,3,30,10,18,21	0	0	1	4.2	0	0	0	0	1	0.7
TBD-10	1,2a,2c,3,17,10	1	1.9	1	4.2	0	0	0	0	2	1.5
TBG-10,18	1,2a,2c,3,11,10,18	3	5.8	2	8.3	1	2.6	0	0	6	4.4
TBH-10,18	1,2a,2c,3,11,30,10,18	0	0	1	4.2	3	7.7	0	0	4	3.0
TBH-10,18,21	1,2a,2c,3,11,30,10,18,21	1	1.9	1	4.2	5	12.8	0	0	7	5.2
TBK-10	1,2a,2c,3,11,17,30,10	2	3.8	3	12.5	0	0	0	0	5	3.7
TBR-10,18	1,2a,2c,3,3ka,11,30,10,18	2	3.8	0	0	0	0	0	0	2	1.5
TCB-10,18	1,2a,2c,3,26,10,18	0	0	0	0	0	0	1	5.3	1	0.7
TCC-10,18	1,2a,2c,3,26,30,10,18	0	0	0	0	1	2.6	0	0	1	0.7
TCG-10,18,21	1,2a,2c,3,26,10,18,21	1	1.9	0	0	0	0	0	0	1	0.7
TCH-10,18	1,2a,2c,3,26,11,30,10,18	1	1.9	0	0	0	0	0	0	1	0.7
TCR-10,18	1,2a,2c,3,26,3ka,11,30,10,18	0	0	1	4.2	2	5.1	1	5.3	4	3.0
TDB-10,18	1,2a,2c,3,24,10,18	0	0	0	0	0	0	1	5.3	1	0.7
TDB-10,18,21	1,2a,2c,3,24,10,18,21	1	1.9	0	0	0	0	0	0	1	0.7
TDC-10,18	1,2a,2c,3,24,30,10,18	2	3.8	0	0	2	5.1	1	5.3	5	3.7
TDG-10,18	1,2a,2c,3,24,11,10,18	3	5.8	0	0	0	0	2	10.5	5	3.7
TDG-10,18,21	1,2a,2c,3,24,11,10,18,21	2	3.8	1	4.2	0	0	0	0	3	2.2
TDH-10,18	1,2a,2c,3,24,11,30,10,18	4	7.7	0	0	3	7.7	1	5.3	8	6.0
TDH-10,18,21	1,2a,2c,3,24,11,30,10,18,21	3	5.8	1	4.2	1	2.6	0	0	5	3.7
TDR-10,18	1,2a,2c,3,24,3ka,11,30,10,18	3	5.8	1	4.2	0	0	0	0	4	3.0
TDR-10,18,21	1,2a,2c,24,3ka,11,30,10,18,21	0	0	1	4.2	0	0	1	5.3	2	1.5
TFB-10,18	1,2a,2c,3,24,26,10,18	2	3.8	0	0	0	0	1	5.3	3	2.2
TFC-10,18	1,2a,2c,3,24,26,30,10,18	1	1.9	0	0	2	5.1	1	5.3	4	3.0
TFG-10	1,2a,2c,3,24,26,11,10	1	1.9	0	0	0	0	0	0	1	0.7
TFG-10,18	1,2a,2c,3,24,26,11,10,18	0	0	0	0	2	5.1	1	5.3	3	2.2
TFH-10,18	1,2a,2c,3,24,26,11,30,10,18	4	7.7	2	8.3	1	2.6	2	10.5	9	6.7
TFH-10,18,21	1,2a,2c,3,24,26,11,30,10,18,21	1	1.9	1	4.2	1	2.6	1	5.3	4	3.0
TFS-10,18	1,2a,2c,3,24,26,3ka,11,17,10,18	0	0	0	0	3	7.7	0	0	3	2.2
Total		52		24		39		19		134	

[a] *Prt* code (5) plus *Lr10, Lr18,* and *Lr21* near-isogenic supplemental differentials.

[b] *Lr* genes on which that isolate is virulent

cultivars Rawhide and TAM 107 had leaf rust severities of 80–100% in cultivar trials in central Nebraska and 50–70% in a cultivar trial in west central Nebraska (19). Severity readings were made on five flag leaves per plot from six replicates at Growth Stage 10.5, Feekes scale.

During this 2-yr study, 298 single-pustule isolates were characterized for virulence phenotype: 164 in 1992 and 134 in 1993. Of the 1992 isolates, 32% came from the east, 26% from the central, 25% from the west central, and 17% from the Panhandle. The distribution of isolates in 1993 was 40% from the east, 18% from the central, 29% from the west central, and 13% from the Panhandle. Approximately 60% of the isolates in both years came from the east and central where higher rainfall favors leaf rust.

Table 1 summarizes the virulence frequencies to each of the 16 differential host lines among collections from the four wheat production regions for both years. Over 60% of the isolates collected during both years in all regions were virulent to *Lr1, Lr2a, Lr2c, Lr3, Lr10, Lr11*, and *Lr18*. All isolates were virulent to *Lr1* and *Lr10*, and over 90% were virulent to *Lr18*. A 1991 survey in Canada (4) also found a high incidence of virulence to *Lr1, Lr2a, Lr2c, Lr3*, and *Lr11* but not *Lr18*; *Lr10* was not included in this Canadian survey. Virulence to *Lr24* and *Lr26* declined in all regions between 1992 and 1993. This could be due to the decline in acreage in the Great Plains of the hard red winter wheat cultivar Siouxland, having both *Lr24* and *Lr26* (16). Previous surveys in the United States (8,9) reported an increase in virulence to *Lr24* and *Lr26* during 1988–1992, whereas in Canada (4,5) the frequency of virulence to these two genes declined between 1990 and 1991, but showed a slight increase between 1991 and 1992.

No virulence was found to *Lr3ka, Lr9*, and *Lr16* in 1992, but a low frequency of this virulence combination was observed in 1993. Virulence to *Lr17* remained low in all regions both years. No virulence was found to *Lr19* (Table 1). Long et al (8,9), Statler et al (18), and Marshall (13) also reported low virulence frequencies to *Lr3ka, Lr9*, and *Lr16* in the hard red winter wheat region in their surveys. The gene *Lr16* provides an intermediate level of protection; however, *Lr19* provides a high level of protection (8,14).

The isolates were classified into 37 and 46 virulence phenotypes in 1992 and 1993, respectively. Twenty-two new virulence phenotypes were identified in the 1993 rust population that were not identified in 1992. The virulence phenotypes are arranged in Tables 2 and 3 by *Prt* code (6), and results are presented as numbers and percentages of isolates within the four Nebraska wheat production regions. Phenotype TFH-10,18,21 was the most common virulence phenotype in 1992. It accounted for 17% of the total rust population and ranged from 14% of the east rust population to 20% of the central rust population (Table 2). In 1993, this physiologic race was present in only 3% of the total rust population (Table 3). However, the most common virulence phenotype in 1993 was TFH-10,18—present at a frequency of 6.7% of the total rust population (Table 3). The only difference in these two races is virulence to *Lr21*. TFH has a virulence formula of *Lr1, Lr2a, Lr2c, Lr3, Lr24*, and *Lr11*. Data from both years show a high frequency of virulence to these *Lr* genes plus *Lr10* and *Lr18*.

Forty-three percent of the 1992 isolates were virulent to 10 or more *Lr* genes, while in 1993 this decreased to 25%. Isolate TFK-10,18,21 in 1991 was virulent to 12 *Lr* genes and was present in 6% of the total rust population (Table 2). It was found in the east and west central populations. In 1993 isolate TFS-10,18 was virulent to 11 *Lr* genes and was present only in the west central at a frequency of approximately 8% (Table 3). Surveys in 1992 found a high frequency of the MBG-virulence phenotype (virulent on *Lr1, Lr3*, and *Lr11*) in Quebec and Ontario (5) but not in Alberta, Manitoba, or Saskatchewan. Long et al (8) reported MBG-10 to be the second most frequent race identified in a 1992 survey in the United States. The most frequent race was TBG-10 (virulent on *Lr1, Lr2a, Lr2c, Lr3, Lr10, Lr11*). They noted a wide distribution of M (virulent on *Lr1* and *Lr3*) and T (virulent on *Lr1, Lr2a, Lr2c*, and *Lr3*) phenotypes in the Great Plains in 1992. In our survey MBG and TBG races accounted for less than 5% of the total rust population in both 1992 and 1993. However, we also noted a wide distribution of the T phenotype in the Nebraska population. Eighty-three percent of the 1992 isolates and 74% of the 1993 isolates had the T phenotype.

Our survey has shown that the 1992 and 1993 wheat leaf rust populations had a wide range of virulence to the *Lr* differentials and supplementals we tested. *Lr* genes *3ka, 9, 16*, and *19* showed a high level of resistance to the rust populations both years. McVey (14) suggests pyramiding resistance genes to provide more stable resistance that would require multiple gene mutations for virulence in the pathogen to overcome the resistance. *Lr* genes *3ka, 9, 16*, and *19* would provide gene combinations for pyramiding resistance in Nebraska.

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LITERATURE CITED

1. Doupnik, B., Jr., and Watkins, J. E. 1994. Effect of foliar fungicides and Dividend seed treatment on leaf rust development in winter wheat, 1992. Fungic. Nematicide Tests 49:207.
2. Kolmer, J. A. 1989. Physiologic specialization of *Puccinia recondita* f. sp. *tritici* in Canada in 1988. Can. J. Plant Pathol. 11:431-434.
3. Kolmer, J. A. 1991. Physiologic specialization of *Puccinia recondita* f. sp. *tritici* in Canada in 1990. Can. J. Plant Pathol. 13:371-373.
4. Kolmer, J. A. 1993. Physiologic specialization of *Puccinia recondita* f. sp. *tritici* in Canada in 1991. Can. J. Plant Pathol. 15:34-36.
5. Kolmer, J. A. 1994. Physiologic specialization of *Puccinia recondita* f. sp. *tritici* in Canada in 1992. Can. J. Plant Pathol. 16:61-63.
6. Long, D. L., and Kolmer, J. A. 1989. A North American system of nomenclature for *Puccinia recondita* f. sp. *tritici*. Phytopathology 79:525-529.
7. Long, D. L., Roelfs, A. P., Leonard, K. J., and Roberts, J. J. 1993. Virulence and diversity of *Puccinia recondita* f. sp. *tritici* in the United States in 1991. Plant Dis. 77:786-791.
8. Long, D. L., Roelfs, A. P., Leonard, K. J., and Roberts, J. J. 1994. Virulence and diversity of *Puccinia recondita* f. sp. *tritici* in the United States in 1992. Plant Dis. 78:901-906.
9. Long, D. L., Roelfs, A. P., and Roberts, J. J. 1992. Virulence of *Puccinia recondita* f. sp. *tritici* in the United States during 1988-1990. Plant Dis. 76:495-499.
10. Long, D. L., Schafer, J. F., Roelfs, A. P., and Roberts, J. J. 1988. Virulence of *Puccinia recondita* f. sp. *tritici* in the United States in 1986. Plant Dis. 72:22-24.
11. Long, D. L., Schafer, J. F., Roelfs, A. P., and Roberts, J. J. 1989. Virulence of *Puccinia recondita* f. sp. *tritici* in the United States in 1987. Plant Dis. 73:294-297.
12. Mains, E. B., and Jackson, H. S. 1921. Two strains of *Puccinia triticina* on wheat in the United States. Phytopathology 11:40.
13. Marshall, D. 1992. Virulence of *Puccinia recondita* in Texas from 1988 to 1990. Plant Dis. 76:296-299.
14. McVey, D. V., and Hamilton, K. 1985. Occurrence and virulence of *Puccinia recondita* in Minnesota in 1982 and 1983. Plant Dis. 69: 404-405.
15. Rutledge, S. S., Watkins, J. E., and Baenziger, P. S. 1993. Virulence pattern and distribution of the 1992 leaf rust population in Nebraska. Phytopathology 83:1336.
16. Schmidt, J. W., Johnson, V. A., Mattern, P. J., Dreier, A. F., McVey, D. V., and Hatchett, J. H. 1985. Registration of 'Siouxland' Wheat. Crop Sci. 25:1130-1131.
17. Singh, R. P. 1991. Pathogenicity variations of *Puccinia recondita* f. sp. *tritici* and *P. graminis* f. sp. *tritici* in wheat-growing areas of Mexico during 1988 and 1989. Plant Dis. 75:790-794.
18. Statler, G. D., Miller, J. D., and Hirsch, D. C. 1985. Wheat leaf rust in North Dakota during 1982-1984. Plant Dis. 69:720-721.
19. Watkins, J. E., Doupnik, B., Jr., Elmore, R. W., and Klein, R. N. 1994. Leaf rust severity on winter wheat cultivars at three Nebraska locations, 1993. Biol. Cultural Tests 9:126.