Virulence of *Puccinia triticina* on Wheat in the United States from 1996 to 1998

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ABSTRACT

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Isolates of *Puccinia triticina* were obtained from wheat leaf collections made by cooperators throughout the United States and from surveys of wheat fields and nurseries in the Great Plains, Ohio Valley, and Gulf Coast states in 1996, 1997, and 1998. Virulence-avirulence phenotypes were determined on 14 host lines that are near-isogenic for leaf rust resistance. We found 31 phenotypes among 277 single uredinial isolates in 1996, 56 phenotypes among 989 isolates in 1997, and 43 phenotypes among 989 isolates in 1998. As in previous surveys, regional race distribution patterns showed that the central United States is a single epidemiological unit distinct from the eastern United States. The distinctive racial composition of collections from the southeast, northeast, and Ohio Valley indicate that populations of *P. triticina* in those areas are not closely connected, suggesting that epidemics originate from localized overwintering sources.

Additional keywords: plant disease monitoring, *Puccinia recondita*, rust epidemiology, wheat leaf rust

Wheat leaf rust, caused by *Puccinia triticina* Eriks. (1) (= *P. recondita* Roberge ex Desmaz. f. sp. *tritici*), occurs annually throughout most wheat (*Triticum aestivum*) growing areas of the United States. In recent years, estimates of yield losses to leaf rust have ranged from trace levels (<1%) in many states to 12% in California in 1996, 10% in Oklahoma in 1997, and 2.5% in Kansas in 1998 (9). Losses to leaf rust in winter wheat in the United States were estimated at 4.8, 4.8, 0.7, 2.4, 0.8, 2.9, and 1.6% in 1992, 1993, 1994, 1995, 1996, 1997, and 1998, respectively (9). During these years, spring wheat has not suffered significant losses to leaf rust in the United States, mainly because of more effective resistance in spring wheat cultivars and because *P. triticina* rarely overwinters in the northern Great Plains where most spring wheat is grown.

Virulence surveys of wheat leaf rust have been conducted by the USDA, ARS Cereal Disease Laboratory, formerly known as the Cereal Rust Laboratory, since 1978 to detect new pathogenic races and to monitor shifts of race frequencies in major wheat growing regions of the United States (14). Similar surveys have been done in Canada since 1931 (5) and in Mexico (24). In the United States (8) and Canada (4-7), leaf rust survey data have been used to characterize virulence and race dynamics and phenotypic diversity within and between wheat growing regions.

The objectives of this study were to characterize the virulence of *P. triticina* populations in the United States from 1996 through 1998 to the North American set of wheat leaf rust differentials (10) and other selected lines of wheat, and to compare these results with those of previous surveys.

MATERIALS AND METHODS

Collections and race identification.

Uredinial collections of leaf rust were made from wheat in annual surveys (over routes totaling approximately 22,000 km) of the Great Plains, Ohio Valley, and Gulf Coast and by cooperators throughout the United States. From 1996 to 1998, field surveys of wheat were made in southern and central Georgia (late March through May); eastern and southern Texas (early April); northern Texas and south-central

Oklahoma (late April); southeastern Gulf Coast (mid-April to early May); southeastern states (late April); Oklahoma and Kansas (mid-May); the Ohio River Valley (early June); northern Kansas, Nebraska, western Iowa, South Dakota, and southern Minnesota (mid-June); and northern Plains states (early July and again in late July). Visual inspections for the presence of rust were made in commercial fields (4 to 50 ha) every 32 km or in the first field thereafter. Additional collections were made in wheat breeding nurseries, trap plots, and demonstration plots (collectively referred to as nurseries in data analysis) along the route. Nurseries typically contain a wide array of leaf rust resistance phenotypes, including breeding lines with leaf rust resistance genes not yet in commercial cultivars. Trap plots usually contain older cultivars of wheat no longer prominent in commercial production. Leaf rust was also collected from goat grass, *Triticum cylindricum* (= *Aegilops cylindrica*), growing near wheat fields in Oklahoma. A collection consisted of one to several leaves bearing uredinia from a single plant or cultivar. The leaves were air-dried and stored at 4°C until spores were collected for inoculations. No collections from inoculated nurseries were included in the study.

Urediniospores were harvested twice from each collection with a cyclone spore collector. Urediniospores from the first harvest were used to inoculate 7-day-old seedlings of the wheat cultivar Thatcher (CI 100030) treated with maleic hydrazide at approximately 0.01 g (dissolved in 30 ml of H₂O) per pot to enhance spore production (20). Plants were sprayed at a rate of approximately 0.5 ml per pot of 10 to 20 seedlings with a suspension of spores in lightweight mineral oil (Soltrol 170). Inoculated plants were placed in a dew chamber overnight at 18°C. The plants were then transferred to a greenhouse where temperatures varied between 18 and 28°C daily. After 12 to 15 days, three seedlings were saved per collection, each with the primary leaf trimmed to bear a single uredinium. Six to 9 days later, a cyclone spore collector was used to collect urediniospores separately from one or two single uredinia per collection. If the single uredinium was small and few spores were

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collected, the isolates were increased through one uredinial generation on Thatcher seedlings before inoculating differential lines. Otherwise, spores from the single uredinium were directly inoculated onto 7- to 8-day-old plants of the differential host series (five to seven plants per line) of near-isogenic lines of Thatcher with single resistance genes *Lr1*, *2a*, *2c*, *3a*, *3ka*, *9*, *10*, *11*, *16*, *17*, *18*, *24*, *26*, and *30*. Lines included in this standard set of differentials were chosen by the North American Leaf Rust Workers Committee (10) because they account for a large part of the detectable diversity in virulence of *P. triticina* in North America and because they react with distinct low or high infection types. Sets of differential lines growing during June through September received no supplemental light. From October through May, natural daylight was supplemented with high-pressure sodium lamps from 0200 to 1400 (100 $\mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ over natural daylight at bench level). After 10 to 14 days, infection types were recorded as either high (IT 3–4) or low (IT 0–2+) as in previous surveys (11,13–17).

Race and virulence frequencies were determined for collections from each of eight agroecological geographic areas (Fig. 1): area 1, mainly southern-adapted soft red winter wheats; areas 2 and 3, mainly northern-adapted soft red and white winter wheat; area 4, mixed wheat types but primarily hard red winter; area 5, hard red winter wheat; area 6, mixed wheat types but primarily hard red spring and durum; area 7, spring wheats planted in late fall; and area 8, mixed wheat types but primarily soft white winter. Race designations were assigned as described by Long and Kolmer (10).

Resistant series. The second harvests of urediniospores from the infected leaf collections that had been stored at 4°C were combined in bulks of spores from up to 10 collections from the same geographical

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

area. Bulk collections were tested on a series of wheat lines resistant to common leaf rust races. This series in 1996 consisted of Thatcher near isolines RL6040 (*Lr19*), RL6043 (*Lr21*), and RL6080 (*Lr29*) (21); Aepoglom (*Lr26+*) (19); Arapahoe (*Lr16*, *24*) (19); AZ-FH 50-4-1-1-1 (17); AZ-FH 50-1-1-1-1 (16); BM/Polk/On/1592; Buck Manantial (*Lr3a*, *13*, *16*, *17*, *34*) (3); Ceruga 3 (12); CI 17906 (*Lr9*, *24*) (19); CK 9877 (*Lr9*, *24*) (19); Era/*Lr19*; Fla 304; Jagger; KS86WGRC02 (*Lr21* = *Lr39*) (2); KS86WGRC11 (*Lr42*) (2); KS86WGRC16 (*Lr43*) (2); Norm; RL 6059 (*Lr33*, *34*) (22); TcLr26/TcLr29//TcLr19/3/TcLr26/TcLr21; TcLr29/TcLr21//TcLr25/3/Stoa; Transec (*Lr25*) (21); and Thatcher, a susceptible check. In 1997, three of the entries that showed some susceptibility to bulk collections in 1996, CK 9877, KS86WGRC11 (*Lr42*), and RL 6059 (*Lr33*, *34*), were discontinued and replaced with CK 9835 (*Lr2a*, *9*, *11*) (19), Pioneer 2684, and Mason. Each entry in the series consisted of five to seven plants. This series was inoculated separately with 15 and 38 bulked collections in 1996 and 1997, respectively. Due to refrigerator failure, the bulked collections from 1998

were lost before they could be tested on the resistant series.

RESULTS AND DISCUSSION

Races identified. In 1996, 1997, and 1998, totals of 277, 989, and 989 single uredinial isolates, respectively, were characterized. Leaf rust infection was much lighter than normal in the Great Plains in 1996. Thirty-one races were identified in 1996, 56 in 1997, and 43 in 1998 (Tables 1 to 4), based on high-low infection types on the 12 differential host lines plus a Thatcher line with *Lr10* and one with *Lr18* (10). Races found in areas 1 to 8 are arranged by North American wheat leaf rust code (Pt) (10) in Tables 2 to 4. Results are presented as percentages of isolates within areas separated into collections made from nurseries and fields.

The M-- race group (virulent to *Lr1* and *3a*) comprised 82.4% of the total number of leaf rust isolates identified in 1996, 74.4% in 1997, and 76.2% in 1998. M-- races were common in all areas, although somewhat less so in area 2 (Northeast) in 1996 and area 3 (Ohio Valley) in 1997 than in areas 1, 4, 5, 6, and 7 in 1996 to 1998 (Table 5). The most frequently identified

Table 1. North American wheat leaf rust nomenclature (Pt) code and corresponding virulence formula for races identified in 1996 to 1998

Pt code ^a	Virulence formula ^b	Pt code	Virulence formula
CBG	3a,11	MJB-10	1,3a,10,16,24
CBR-18	3a,3ka,11,18,30	PBD-10	1,2c,3a,10,17
CCM-10,18	3a,3ka,10,18,26,30	PBG-10,18	1,2c,3a,10,11,18
FBR-18	2c,3a,3ka,11,18,30	PBM-10,18	1,2c,3a,3ka,10,18,30
FBR-10,18	2c,3a,3ka,10,11,18,30	PBR-18	1,2c,3a,3ka,11,18,30
LBB-10,18	1,10,18	PBR-10,18	1,2c,3a,3ka,10,11,18,30
LBL-10	1,3ka,10	PCG-10	1,2c,3a,10,11,26
LCB-10,18	1,10,18,26	PCM-18	1,2c,3a,3ka,18,26,30
LGB-10	1,10,16	PCR-10,18	1,2c,3a,3ka,10,11,18,26,30
MBB	1,3a	PLM-10,18	1,2c,3a,3ka,9,10,18,30
MBB-10	1,3a,10	PLR-10,18	1,2c,3a,3ka,9,10,11,18,30
MBB-10,18	1,3a,10,18	PMR-10,18	1,2c,3a,3ka,9,10,11,18,26,30
MBD-10	1,3a,10,17	PNM-10,18	1,2c,3a,3ka,9,10,18,24,30
MBG-10	1,3a,10,11	SBD-18	1,2a,2c,17,18
MBG-10,18	1,3a,10,11,18	SCD-18	1,2a,2c,17,18,26
MBJ-10	1,3a,10,11,17	TBB-10	1,2a,2c,3a,10
MBR	1,3a,3ka,11,30	TBD-10	1,2a,2c,3a,10,17
MBR-10	1,3a,3ka,10,11,30	TBG-10	1,2a,2c,3a,10,11
MBR-10,18	1,3a,3ka,10,11,18,30	TBR-10	1,2a,2c,3a,3ka,10,11,30
MBT	1,3a,3ka,11,17,30	TBR-10,18	1,2a,2c,3a,3ka,10,11,18,30
MBT-10	1,3a,3ka,10,11,17,30	TCB-18	1,2a,2c,3a,18,26
MCB-10	1,3a,10,26	TCB-10	1,2a,2c,3a,10,26
MCD-10	1,3a,10,17,26	TCG-10	1,2a,2c,3a,10,11,26
MCG-10	1,3a,10,11,26	TCG-10,18	1,2a,2c,3a,10,11,18,26
MCR-10	1,3a,3ka,10,11,26,30	TCM-10	1,2a,2c,3a,3ka,10,26,30
MCR-10,18	1,3a,3ka,10,11,18,26,30	TCR-10	1,2a,2c,3a,3ka,10,11,26,30
MCT-10	1,3a,3ka,10,11,17,26,30	TDB-10	1,2a,2c,3a,10,24
MDB-10	1,3a,10,24	TDD-10	1,2a,2c,3a,10,17,24
MDG-10	1,3a,10,11,24	TDG-10	1,2a,2c,3a,10,11,24
MDJ	1,3a,11,17,24	TDR-10	1,2a,2c,3a,3ka,10,11,24,30
MDR	1,3a,3ka,11,24,30	TDS-10	1,2a,2c,3a,3ka,10,11,17,24
MDR-10	1,3a,3ka,10,11,24,30	TFB-10	1,2a,2c,3a,10,24,26
MDR-10,18	1,3a,3ka,10,11,18,24,30	TFC-10	1,2a,2c,3a,10,24,26,30
MFB-10	1,3a,10,24,26	TFG-10	1,2a,2c,3a,10,11,24,26
MFR-10	1,3a,3ka,10,11,24,26,30	TFR-10	1,2a,2c,3a,3ka,10,11,24,26,30
MGB-10	1,3a,10,16	TGB-10	1,2a,2c,3a,10,16
MGD-10	1,3a,10,16,17	THB-10	1,2a,2c,3a,10,16,26
MGR-10	1,3a,3ka,10,11,16,30	TLG-18	1,2a,2c,3,9,11,18

^a Race code plus *Lr10* and *Lr18* near-isogenic supplements.

^b Resistances evaluated: *Lr1*, *2a*, *2c*, *3a*, *3ka*, *9*, *10*, *11*, *16*, *17*, *18*, *24*, *26*, and *30*.

Table 2. Races of *Puccinia triticina* collected from fields (F) and nurseries (N) in agroecological areas 1 (Southeast), 2 (Northeast), and 3 (Ohio Valley) of the United States in 1996, 1997, and 1998

Code ^a	Isolates from indicated source (%)																	
	Area 1						Area 2						Area 3					
	1996		1997		1998		1996		1997		1998		1996		1997		1998	
	F	N	F	N	F	N	F	N	F	N	F	N	F	N	F	N	F	N
CBG	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CBR-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0
CCM-10,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0
FBR-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
FBR-10,18	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
LBB-10,18	0	0	0	0	0	3	0	36	0	0	0	0	0	0	0	0	0	0
LBL-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LCB-10,18	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0
LGB-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MBB	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MBB-10	0	0	0	0	6	0	0	0	0	0	0	0	0	0	4	0	0	6
MBB-10,18	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0
MBD-10	0	0	0	0	0	1	0	0	0	0	0	0	6	0	8	0	3	6
MBG-10	33	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	4	0
MBG-10,18	0	3	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
MBJ-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MBR	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	12
MBR-10	67	37	27	24	17	21	0	0	0	0	0	6	25	60	13	0	24	24
MBR-10,18	0	2	32	16	22	18	0	0	29	0	18	44	20	4	0	17	18	0
MBT	0	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0
MBT-10	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0
MCB-10	0	3	0	1	0	0	0	0	0	0	0	6	0	0	0	0	3	0
MCD-10	0	8	0	0	0	3	0	0	0	0	0	0	7	4	21	6	18	0
MCG-10	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MCR-10	0	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0	10	0
MCR-10,18	0	0	3	12	28	23	0	0	0	14	0	24	0	0	8	0	8	0
MCT-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MDB-10	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MDG-10	0	7	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MDJ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MDR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MDR-10	0	5	11	6	0	4	0	0	0	0	12	0	0	4	14	1	0	0
MDR-10,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0
MFB-10	0	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0
MFR-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MGB-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MGD-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MGR-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MJB-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PBD-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PBG-10,18	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PBM-10,18	0	0	0	0	0	0	0	45	0	0	0	0	0	0	0	0	0	0
PBR-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0
PBR-10,18	0	0	0	1	0	0	0	0	0	0	0	0	0	0	17	14	3	0
PCG-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PCM-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0
PCR-10,18	0	0	0	0	0	1	0	0	0	14	0	0	0	0	0	0	3	0
PLM-10,18	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	14	0	0
PLR-10,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PMR-10,18	0	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0
PNM-10,18	0	2	0	1	0	0	0	0	100	0	0	0	0	0	0	0	0	0
SBD-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCD-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TBB-10	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TBD-10	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
TBG-10	0	3	0	2	0	1	0	0	0	0	0	0	0	0	4	0	0	0
TBR-10	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
TBR-10,18	0	0	5	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
TCB-18	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TCB-10	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	3	9
TCG-10	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4	0	0	0
TCG-10,18	0	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0
TCM-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TCR-10	0	3	0	0	6	0	0	0	0	0	0	0	0	0	0	0	10	0
TDB-10	0	5	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TDD-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TDG-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TDR-10	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TDS-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TFB-10	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	7	1	0
TFC-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TFG-10	0	2	0	0	0	4	0	0	0	0	0	0	7	0	0	0	0	0
TFR-10	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
TGB-10	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0
THB-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TLG-18	0	10	8	11	11	10	0	0	0	14	0	24	0	7	0	14	0	0
Isolates (no.)	3	59	37	215	18	165	0	11	1	14	0	17	16	15	24	14	71	33

^a Races based on 12 North American leaf rust differential lines (10) plus supplemental lines with *Lr10* and *Lr18*.

Table 3. Races of *Puccinia triticina* collected from fields (F) and nurseries (N) in agroecological areas 4 (Southern Plains), 5 (Central Plains), and 6 (Northern Plains) of the United States in 1996, 1997, and 1998

Code ^a	Isolates from indicated source (%)																	
	Area 4						Area 5						Area 6					
	1996		1997		1998		1996		1997		1998		1996		1997		1998	
	F	N	F	N	F	N	F	N	F	N	F	N	F	N	F	N	F	N
CBG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CBR-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CCM-10,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FBR-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FBR-10,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LBB-10,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LBL-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
LCB-10,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LGB-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
MBB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MBB-10	0	0	0	0	0	0	0	5	0	0	0	0	0	0	2	0	0	0
MBB-10,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MBD-10	0	0	2	1	11	11	0	0	4	1	0	10	0	5	13	12	16	13
MBG-10	0	9	0	0	0	1	0	14	0	1	0	0	0	3	2	1	0	0
MBG-10,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MBJ-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
MBR	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0
MBR-10	100	16	7	8	10	6	0	52	6	9	8	12	92	63	27	26	5	10
MBR-10,18	0	3	3	4	0	0	0	7	4	2	0	0	0	0	0	0	0	0
MBT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MBT-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MCB-10	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0
MCD-10	0	19	10	13	31	19	0	0	13	16	20	15	0	0	13	7	9	14
MCG-10	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MCR-10	0	0	2	0	0	0	0	5	0	1	0	1	0	0	3	0	0	0
MCR-10,18	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	2	1
MCT-10	0	0	0	4	0	0	0	0	0	1	0	0	0	0	0	0	0	0
MDB-10	0	0	4	1	2	1	0	7	6	2	0	0	0	0	0	1	5	1
MDG-10	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	2	0
MDJ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MDR	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MDR-10	0	0	24	21	15	28	0	5	43	50	50	53	0	8	17	35	24	30
MDR-10,18	0	0	3	0	2	3	0	0	11	2	0	0	0	0	0	0	0	0
MFB-10	0	0	5	1	0	3	0	2	2	0	0	0	0	5	0	2	0	1
MFR-10	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
MGB-10	0	6	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
MGD-10	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MGR-10	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MJB-10	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	2	1
PBD-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PBG-10,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PBM-10,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PBR-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PBR-10,18	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PCG-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PCM-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PCR-10,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLM-10,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLR-10,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
PMR-10,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PNM-10,18	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SBD-18	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCD-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
TBB-10	0	6	0	1	0	0	0	0	0	0	0	0	0	0	4	1	0	0
TBD-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
TBG-10	0	3	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
TBR-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
TBR-10,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TCB-18	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TCB-10	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	4	10	7
TCG-10	0	0	0	1	0	0	0	0	2	0	0	0	0	0	7	0	0	0
TCG-10,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TCM-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
TCR-10	0	0	0	0	0	0	0	0	0	0	3	0	0	0	2	1	0	2
TDB-10	0	16	6	10	0	1	0	2	4	2	0	1	8	5	2	1	1	1
TDD-10	0	0	0	0	7	1	0	0	0	1	0	0	0	0	1	1	0	0
TDG-10	0	16	0	0	0	0	0	0	0	0	3	1	0	5	0	0	0	0
TDR-10	0	0	14	11	5	11	0	0	0	11	13	5	0	0	0	2	3	2
TDS-10	0	0	0	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0
TFB-10	0	0	2	7	5	4	0	0	4	0	5	2	0	0	0	0	9	6
TFC-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TFG-10	0	0	0	1	8	2	0	0	0	1	0	0	0	5	0	1	0	0
TFR-10	0	0	3	1	0	4	0	0	0	0	0	0	0	0	0	0	0	2
TGB-10	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	5	0
THB-10	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3	5
TLG-18	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2	0	2	1
Isolates (no.)	1	32	102	140	61	142	0	44	47	127	40	117	12	40	110	137	128	173

^a Races based on 12 North American leaf rust differential lines (10) plus supplemental lines with Lr10 and Lr18.

Table 4. Races of *Puccinia triticina* collected from fields (F) and nurseries (N) in agroecological areas 7 (Southwest) and 8 (Northwest) of the United States in 1996, 1997, and 1998

Code ^a	Isolates from indicated source (%)											
	Area 7						Area 8					
	1996		1997		1998		1996		1997		1998	
	F	N	F	N	F	N	F	N	F	N	F	N
CBG	0	0	0	0	0	0	0	0	0	0	0	0
CBR-18	0	0	0	0	0	0	0	0	0	0	0	0
CCM-10,18	0	0	0	0	0	0	0	0	0	0	0	0
FBR-18	0	0	0	0	0	0	0	0	0	0	0	0
FBR-10,18	0	0	0	0	0	0	0	0	0	0	0	0
LBB-10,18	0	0	0	0	0	0	0	0	0	0	0	0
LBL-10	0	0	0	0	0	0	0	0	0	0	0	0
LCB-10,18	0	0	0	0	0	0	0	0	0	0	0	0
LGB-10	0	0	0	0	0	0	0	0	0	0	0	0
MBB	0	0	0	0	0	0	0	0	0	0	0	0
MBB-10	24	40	67	14	0	0	13	0	0	0	0	0
MBB-10,18	0	0	0	29	0	0	0	0	0	0	0	0
MBD-10	0	0	0	0	0	0	0	0	0	0	0	0
MBG-10	14	0	33	24	100	89	7	0	0	0	0	0
MBG-10,18	0	0	0	0	0	0	0	0	0	0	0	0
MBJ-10	0	0	0	0	0	0	0	0	50	0	0	0
MBR	0	0	0	0	0	0	0	0	0	0	0	0
MBR-10	5	40	0	5	0	0	13	0	0	0	0	0
MBR-10,18	0	0	0	0	0	11	0	0	0	0	0	0
MBT	0	0	0	0	0	0	0	0	0	0	0	0
MBT-10	0	0	0	0	0	0	0	0	0	0	0	0
MCD-10	43	20	0	19	0	0	7	0	25	100	0	0
MCD-10	0	0	0	0	0	0	0	0	0	0	0	0
MCG-10	14	0	0	0	0	0	0	0	0	0	0	0
MCR-10	0	0	0	5	0	0	0	0	0	0	0	0
MCR-10,18	0	0	0	0	0	0	0	0	0	0	0	0
MCT-10	0	0	0	0	0	0	0	0	0	0	0	0
MDB-10	0	0	0	0	0	0	13	0	0	0	0	0
MDG-10	0	0	0	0	0	0	0	0	0	0	0	0
MDJ	0	0	0	0	0	0	13	0	0	0	0	0
MDR	0	0	0	0	0	0	0	0	0	0	0	0
MDR-10	0	0	0	0	0	0	0	0	25	0	0	0
MDR-10,18	0	0	0	0	0	0	0	0	0	0	0	0
MFB-10	0	0	0	0	0	0	20	0	0	0	0	0
MFR-10	0	0	0	0	0	0	0	0	0	0	0	0
MGB-10	0	0	0	0	0	0	0	0	0	0	0	0
MGD-10	0	0	0	0	0	0	0	0	0	0	0	0
MGR-10	0	0	0	0	0	0	0	0	0	0	0	0
MJB-10	0	0	0	0	0	0	0	0	0	0	0	0
PBD-10	0	0	0	0	0	0	13	0	0	0	0	0
PBG-10,18	0	0	0	0	0	0	0	0	0	0	0	0
PBM-10,18	0	0	0	0	0	0	0	0	0	0	0	0
PBR-18	0	0	0	0	0	0	0	0	0	0	0	0
PBR-10,18	0	0	0	0	0	0	0	0	0	0	0	0
PCG-10	0	0	0	5	0	0	0	0	0	0	0	0
PCM-18	0	0	0	0	0	0	0	0	0	0	0	0
PCR-10,18	0	0	0	0	0	0	0	0	0	0	0	0
PLM-10,18	0	0	0	0	0	0	0	0	0	0	0	0
PLR-10,18	0	0	0	0	0	0	0	0	0	0	0	0
PMR-10,18	0	0	0	0	0	0	0	0	0	0	0	0
PNM-10,18	0	0	0	0	0	0	0	0	0	0	0	0
SBD-18	0	0	0	0	0	0	0	0	0	0	0	0
SCD-18	0	0	0	0	0	0	0	0	0	0	0	0
TBB-10	0	0	0	0	0	0	0	0	0	0	0	0
TBD-10	0	0	0	0	0	0	0	0	0	0	0	0
TBG-10	0	0	0	0	0	0	0	0	0	0	0	0
TBR-10	0	0	0	0	0	0	0	0	0	0	0	0
TBR-10,18	0	0	0	0	0	0	0	0	0	0	0	0
TCB-18	0	0	0	0	0	0	0	0	0	0	0	0
TCB-10	0	0	0	0	0	0	0	0	0	0	0	0
TCG-10	0	0	0	0	0	0	0	0	0	0	0	0
TCG-10,18	0	0	0	0	0	0	0	0	0	0	0	0
TCM-10	0	0	0	0	0	0	0	0	0	0	0	0
TCR-10	0	0	0	0	0	0	0	0	0	0	0	0
TDB-10	0	0	0	0	0	0	0	0	0	0	0	0
TDD-10	0	0	0	0	0	0	0	0	0	0	0	0
TDG-10	0	0	0	0	0	0	0	0	0	0	0	0
TDR-10	0	0	0	0	0	0	0	0	0	0	0	0
TDS-10	0	0	0	0	0	0	0	0	0	0	0	0
TFB-10	0	0	0	0	0	0	0	0	0	0	0	0
TFC-10	0	0	0	0	0	0	0	0	0	0	0	0
TFG-10	0	0	0	0	0	0	0	0	0	0	0	0
TFR-10	0	0	0	0	0	0	0	0	0	0	0	0
TGB-10	0	0	0	0	0	0	0	0	0	0	0	0
THB-10	0	0	0	0	0	0	0	0	0	0	0	0
TLG-18	0	0	0	0	0	0	0	0	0	0	0	0
Isolates (no.)	21	5	3	21	2	18	0	15	0	4	6	0

^a Races based on 12 North American leaf rust differential lines (10) plus supplemental lines with *Lr10* and *Lr18*.

race in 1996 was MBR-10 (virulent to *Lr1*, *3a*, *3ka*, *10*, *11*, and *30*), which comprised 38.3% of the nationwide sample. MBR-10 was common in areas 1, 3, 4, 5, 6, and 7 of the United States in all 3 years from 1996 to 1998 (Tables 2 to 5). In 1997 and 1998, MBR-10 declined in frequency and comprised 16.6 and 12%, respectively, of the nationwide sample. It was the second most frequently identified race in these years, being replaced by MDR-10 as the most frequent race in areas 4, 5, and 6 (Table 5). Race MBR-10 was not identified in the 1992 survey (13), but in 1993 (11), MBR-10 comprised 6% of the nationwide sample. In 1994 and 1995 (11), MBR-10 was the most frequently found race and comprised 36 and 28% of the nationwide samples, respectively. MBR-10 has been common, especially in the Great Plains, where it was the most common race in 1996, particularly in areas 5 and 6. In 1996, MBR-10 also was the most common race in areas 1 and 3 (Table 5).

In 1997 and 1998, the most frequently found race was MDR-10 (virulent to *Lr1*, *3a*, *3ka*, *10*, *11*, *24*, and *30*), which comprised 22.6% of the nationwide population in both years. Race MDR-10 was found in all areas of the United States except in area 7, and was most common in areas 4, 5, and 6 (Tables 2 to 5). In 1996, MDR-10 comprised 2.9% and in 1995, 0.3% of the population (11).

Race MBR-10,18 (virulent to *Lr1*, *3a*, *3ka*, *10*, *11*, *18*, and *30*) comprised 5.4, 6.4, and 5.7% of the nationwide sample in 1996, 1997, and 1998, respectively, and was common in areas 1 and 3, as was race MCR-10,18 (Table 5).

Race group M-D (virulent to *Lr1*, *3a*, *10*, and *17*) comprised 5.4% of the isolates in the United States in 1996, 12.1% in 1997, and 20.8% in 1998. The M-D race group was common in areas 4, 5, and 6 in 1997 and 1998 (Tables 3 and 5). Increase of the M-D race group may be attributed to the popularity of the hard red winter wheat cultivar Jagger in the central and southern Great Plains in recent years. M-D races are virulent on *Lr 17*, which occurs in Jagger.

Fifteen, 16, and 14 of the other M-- phenotypes (virulent to *Lr1*, *3a*) comprised 23.5, 14.1, and 15.8% of the nationwide sample in 1996, 1997, and 1998, respectively (Tables 2 to 4).

Eight, 18, and 16 T-- races (virulent to *Lr1*, *2a*, *2c*, and *3a*) formed the second largest group of races, which comprised 15.1, 20.7, and 22.6% of the nationwide sample in 1996, 1997, and 1998, respectively (Tables 2 to 4). Race group TD- (virulent to *Lr1*, *2a*, *2c*, *3a*, *10*, and *24*) comprised 6.8% in 1996, 9.4% in 1997, and 4.8% in 1998. The TD- race group was common in areas 4 and 5, in both 1997 and 1998 (Tables 3 and 5).

Race TLG-18 comprised 2.9, 3.5, and 6.3% of the nationwide sample in 1996, 1997, and 1998, respectively, occurring

mainly in areas 1 and 2 (Tables 2 to 5). In 1993, 1994, and 1995 (11), TLG-18 comprised 9, 6, and 1%, respectively, of the nationwide sample. In the years from 1993 through 1998, this race was almost exclusively identified from soft red winter wheat collections (i.e., CK 9835) from areas 1 and 2 (Tables 2 to 5). CK 9835 has resistance genes *Lr2a*, 9, and 11, which would account for the virulence to *Lr9* and 11 in TLG-18, but not for the virulence to *Lr1*, 3a, and 18. Several other Coker cultivars also have *Lr9* and *Lr11* (19).

Isolates of the M-- and T-- race groups were widely distributed throughout areas 4, 5, and 6 in 1996, 1997, and 1998 (Tables 3 and 5, Fig. 1), which is consistent with our earlier conclusion that these areas represent a continuous south-north epidemiological unit (8). In particular, races MBR-10, MCD-10, and MDR-10 were common in each of these three areas. In all three areas, MBR-10 declined from greater frequency in 1996 to lower frequencies in 1997 and 1998, while MDR-10 increased from lower frequency in 1996 to greater frequencies in 1997 and 1998.

From 1981 through 1986 (15–17), the K-- races (virulent to *Lr2a*, 2c, and 3a) were the most frequently identified races nationwide. The frequency of this group has decreased from 39% in 1985 (15) to 3% in 1993 (14), 0.1% in 1994 (14), and none from 1995 (14) to 1998.

Most of the P-- races (virulent to *Lr1*, 2c, and 3a) from 1996 to 1998 were found in the eastern soft winter wheat region (areas 1, 2, and 3) (Tables 2 and 4). The P-- races comprised 3.2, 3.6, and 0.5% of the

nationwide sample in 1996, 1997, and 1998, respectively (Tables 2 to 5).

In the nationwide surveys from 1996 to 1998, the race groups C-- (virulent to *Lr3a*), F-- (virulent to *Lr2c*, 3a), and L-- (virulent to *Lr1*) represented less than 2% of all isolates identified (Tables 2 to 4) and were found scattered from Florida to New York in the eastern soft red winter wheat region.

In 1997, the S-- race group (virulent to *Lr1*, 2a, 2c) was identified from *T. cylindricum* (*Aegilops cylindricum*) collections made in southwestern Oklahoma and comprised <1% of the total isolates nationwide.

Virulence frequencies. Frequencies of virulence to each of the 14 differential lines differed among collections from the eight agroecological areas (Table 6). Due to variation in greenhouse environment, temperature-sensitive genes *Lr3ka*, 11, 17, and 18 may have been misclassified occasionally. Incidence of virulence to lines with *Lr26* increased from 17% of the total U.S. isolates in 1996 to 34% in 1998 (Table 6). In 1986 (15), less than 1% of isolates were virulent to *Lr26* (16). Virulence to *Lr24* has ranged from 2% in 1986 (16) to 41% in 1997 (Table 6). Virulences to *Lr24* and *Lr26* were most common in areas 4, 5, and 6 (Table 6). Cultivars with *Lr24*, such as Siouxland and Collin, were widely grown in the southern Great Plains (18). Combined virulence to *Lr24* and *Lr26* was found in KF-, MF-, and TF- race groups in 1996 to 1998.

Virulence to *Lr11* was common throughout the United States and was identified in 16, 34, and 22 virulence combinations in 1996, 1997, and 1998, respectively. This

reflects a selective advantage of this virulence combination that may be due to an increase in the acreage of cultivars with *Lr11* (23). *Lr11* is found in many soft red winter wheats grown in areas 1, 2, and 3, but in only a few hard red winter and spring wheats (19). The number of races found with virulence to *Lr11* also suggests an accumulation of independent mutations to *Lr11* virulence in a variety of genetic lineages in the *P. triticina* population. Virulence to *Lr11* was most frequent in M-- and T-- races, the two most common race groups.

Virulence to *Lr17* was identified in 9, 15, and 21% (Table 6) of the nationwide sample of *P. triticina* in 1996, 1997, and 1998, respectively. In 1994 and 1995 (11), *Lr17* virulence was identified in only 2% of the nationwide population. This increase in virulence from 2% in 1995 to 21% in 1998 corresponds with a significant increase in the acreage of Jagger, a hard red winter cultivar with *Lr17* (19) resistance, in areas 4 and 5. Verde, a hard red spring cultivar, also has *Lr17*.

Virulence to *Lr9* was identified in 4, 5, and 3% (Table 6) of the nationwide sample of *P. triticina* in 1996, 1997, and 1998, respectively. During 1996 to 1998, *Lr9* virulence was found only in the PL-, PM-, PN-, and TL- races and mainly in the eastern soft red winter wheat region (areas 1, 2, and 3). *Lr9* is found almost exclusively in soft red winter wheats, including those from the Coker and Purdue breeding programs (19).

Virulence to *Lr16* decreased from a high of 17% in 1986 (15) in the U.S. population to less than 1 and 3% in 1997 and 1998,

Table 5. Distribution and frequency (%) of common wheat leaf rust races^a in the United States, 1996 to 1998

Code	Area 1			Area 2			Area 3			Area 4			Area 5			Area 6			Area 7		
	96	97	98	96	97	98	96	97	98	96	97	98	96	97	98	96	97	98	96	97	98
LBB-10,18	0	0	3	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LCB-10,18	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MBB-10	0	0	1	0	0	0	0	3	2	0	0	0	5	0	0	0	1	0	27	21	0
MBB-10,18	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0
MBD-10	0	0	1	0	0	0	3	5	4	0	2	11	0	2	8	4	12	15	0	0	0
MBG-10	3	3	0	0	0	0	0	0	3	9	0	0	14	1	0	2	2	0	12	25	90
MBR-10	39	25	21	0	0	6	42	8	18	18	7	7	52	9	11	69	26	8	12	4	0
MBR-10,18	2	18	18	0	27	18	32	3	17	3	4	0	7	2	0	0	0	0	0	0	10
MBT	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MBT-10	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MCB-10	3	1	0	0	0	0	3	0	2	0	1	0	0	0	0	0	1	0	38	17	0
MCD-10	8	0	3	0	0	0	3	11	10	18	12	23	0	15	16	0	9	12	0	0	0
MCG-10	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0
MCR-10,18	0	11	23	0	13	24	0	5	6	0	2	0	0	0	0	0	0	1	0	0	0
MDR-10	5	7	4	0	0	12	0	8	1	0	22	24	5	48	52	6	27	28	0	0	0
PBM-10,18	0	0	0	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PBR-10,18	0	1	0	0	0	0	0	16	2	0	0	0	0	0	0	0	0	0	0	0	0
PCR-10,18	0	0	1	0	13	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
PMR-10,18	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TCG-10,18	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TDB-10	5	2	0	0	0	0	0	0	0	15	8	0	2	3	1	6	2	1	0	0	0
TDG-10	0	0	0	0	0	0	0	0	0	15	0	0	0	0	1	4	0	0	0	0	0
TDR-10	0	1	0	0	0	0	0	0	0	0	12	9	0	8	7	0	1	3	0	0	0
TLG-18	10	11	10	0	13	24	3	5	0	0	0	0	2	0	0	0	1	1	0	0	0
Total isolates	62	252	183	11	15	17	31	38	104	33	242	203	44	174	157	52	247	301	26	24	20

^a Only races that occurred at >10% frequency in at least one area are included. Area 8 is excluded because fewer than 10 isolates were obtained from area 8 in 1997 and 1998.

respectively (Table 6). In 1998, five phenotypes (LGB, MGB, MJB, TGB, and THB) were identified with virulence to *Lr16*. In Canada, virulence to *Lr16* occurred in 6% of the isolates in 1987 (5) and 11.6% in 1997 (7), but it was not found from 1989 to 1994.

Virulence to *Lr30*, which is associated with virulence to *Lr3ka*, increased from

16% in 1993 (13) to 56% in 1998 (Table 6). *Lr30* virulence was common in most areas of the United States except the Southwest (area 7) and the Pacific Northwest (area 8) from 1996 to 1998. The increase in virulence to *Lr30* is apparently due to selection for virulence to *Lr3ka*, which has been used in Kansas wheat cultivars. *Lr30* does not occur in

common wheat cultivars in the United States.

From the 1996 and 1997 bulked collections, no virulence was found to 14 resistant series entries: Arapahoe (*Lr16*, 24), AZ-FH 50-4-1-1-1, AZ-FH 50-1-1-1-1, BM/Polk/On/1592, Buck Manantial (*Lr3a*, 13, 16, 17, 34), Ceruga 3, Era/*Lr19*, KS86WGRC16 (*Lr43*), Mason, Norm,

Table 6. Percentage of isolates of *Puccinia triticina* virulent on the single-gene differential lines used in the 1996 to 1998 surveys

Area	Source	Year	No. of isolates	Isolates virulent on <i>Lr</i> gene (%)													
				<i>1</i>	<i>2a</i>	<i>2c</i>	<i>3a</i>	<i>3ka</i>	<i>9</i>	<i>10</i>	<i>11</i>	<i>16</i>	<i>17</i>	<i>18</i>	<i>24</i>	<i>26</i>	<i>30</i>
1	Field	1996	3	100	0	0	100	67	0	100	100	0	0	0	0	0	67
1	Field	1997	37	100	14	22	100	78	8	92	95	0	0	57	16	8	78
1	Field	1998	18	100	17	17	100	72	11	89	83	0	0	72	0	33	72
1	Nursery	1996	59	100	27	29	100	49	12	83	75	0	8	20	20	20	49
1	Nursery	1997	215	99	23	27	100	67	14	88	85	0	0	43	19	23	68
1	Nursery	1998	165	99	21	23	97	72	10	90	89	0	5	58	10	35	72
2	Field	1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Field	1997	1	100	0	100	100	100	100	100	0	0	0	100	100	0	100
2	Field	1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Nursery	1996	11	100	0	45	64	64	0	82	18	0	18	82	0	0	64
2	Nursery	1997	14	100	29	57	100	71	29	86	100	0	0	100	0	57	71
2	Nursery	1998	17	100	29	29	88	59	24	76	82	0	0	76	18	41	59
3	Field	1996	16	100	0	0	100	88	0	100	88	0	25	44	0	6	88
3	Field	1997	24	92	13	46	100	75	0	75	75	0	13	58	4	25	75
3	Field	1998	71	99	14	21	100	77	0	99	82	0	8	32	6	46	77
3	Nursery	1996	15	100	13	13	100	80	7	93	93	0	7	27	7	13	80
3	Nursery	1997	14	86	21	50	100	57	29	86	43	0	21	57	21	43	57
3	Nursery	1998	33	100	9	9	100	61	0	88	61	0	24	24	6	27	61
4	Field	1996	1	100	0	0	100	100	0	100	100	0	0	0	0	0	100
4	Field	1997	102	100	35	36	89	61	0	89	61	0	23	21	62	26	61
4	Field	1998	61	100	28	28	100	31	0	100	39	2	49	2	44	48	31
4	Nursery	1996	32	100	44	47	100	22	3	97	47	6	19	9	34	22	22
4	Nursery	1997	140	100	39	40	100	56	1	99	59	4	22	6	60	34	53
4	Nursery	1998	142	100	23	23	100	53	0	99	56	3	31	3	58	32	53
5	Field	1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Field	1997	47	100	11	11	100	64	0	100	66	0	17	15	70	21	64
5	Field	1998	40	100	23	23	100	73	0	100	75	0	20	0	70	28	73
5	Nursery	1996	44	100	5	5	100	68	2	98	84	0	0	9	16	7	68
5	Nursery	1997	127	100	15	15	100	76	0	100	78	0	18	4	70	18	76
5	Nursery	1998	117	100	9	9	100	71	0	100	73	0	25	0	62	17	71
6	Field	1996	12	100	8	8	100	92	0	100	92	0	0	0	8	0	92
6	Field	1997	110	100	19	19	99	52	2	96	64	0	29	3	22	28	51
6	Field	1998	128	100	37	37	100	37	2	98	39	9	25	4	45	34	37
6	Nursery	1996	40	100	18	18	100	70	0	100	85	0	5	0	28	10	70
6	Nursery	1997	137	100	11	14	100	68	3	99	72	0	20	3	43	15	68
6	Nursery	1998	173	100	25	25	98	49	1	99	49	7	28	2	45	38	48
7	Field	1996	21	100	0	0	100	5	0	100	33	0	0	0	0	57	5
7	Field	1997	3	100	0	0	100	0	0	100	33	0	0	0	0	0	0
7	Field	1998	2	100	0	0	100	0	0	100	100	0	0	0	0	0	0
7	Nursery	1996	5	100	0	0	100	40	0	100	40	0	0	0	0	20	40
7	Nursery	1997	21	100	0	5	100	10	0	100	38	0	0	29	0	29	10
7	Nursery	1998	18	100	0	0	100	11	0	100	100	0	0	11	0	0	11
8	Field	1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	Field	1997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	Field	1998	6	100	0	0	100	0	0	100	0	0	0	0	0	100	0
8	Nursery	1996	15	100	0	13	100	13	0	87	33	0	27	0	47	27	13
8	Nursery	1997	4	100	0	0	100	25	0	100	75	0	50	0	25	25	25
8	Nursery	1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals																	
U.S.	Field	1996	53	100	2	2	100	55	0	100	68	0	8	13	2	25	55
U.S.	Field	1997	324	99	22	26	96	61	2	93	67	0	20	21	40	24	60
U.S.	Field	1998	326	100	26	28	100	50	2	98	55	4	23	13	36	40	50
U.S.	Nursery	1996	221	100	19	23	98	53	5	92	69	1	9	14	22	15	53
U.S.	Nursery	1997	672	99	22	25	100	65	6	95	74	1	13	20	41	24	64
U.S.	Nursery	1998	665	100	19	20	98	59	3	96	67	2	21	19	38	31	59
Totals - field and nursery																	
U.S.		1996	274	100	15	19	99	53	4	94	69	1	9	14	18	17	53
U.S.		1997	996	99	22	25	99	63	5	94	71	1	15	20	41	24	63
U.S.		1998	991	100	22	23	99	56	3	97	63	3	21	17	37	34	56
Total																	
U.S.		1996-1998	2261	100	21	23	99	59	4	95	68	2	17	18	37	27	59

RL6040 (*Lr19*), RL6080 (*Lr29*), *TcLr26/TcLr29/TcLr19/3/TcLr26/TcLr21*, and *TcLr29/TcLr21/3/TcLr25/3/Stoa*. There was no attempt to reisolate races from the bulked inoculum to determine which races infected the other 12 entries in the resistant series. It is apparent, however, that the virulent isolates must have had virulence to one or more of the following resistance genes: *Lr2a*, 9, 11, 17, 21, 24, 25, 26, 33, 34, 39, and 42.

Leaf rust resistance genes *Lr1*, 2a, 2c, 3a, and 10 have been used in wheat cultivars in the Great Plains for many years, during which virulence to these genes became common. Most races found in recent years are virulent to *Lr1*, 3a, and 10. Both the K-- races, which were common before 1985, and the S-- races, which were found on wheat in the 1960s, are virulent to both *Lr2a* and *Lr2c*. By 1986, the M-- races replaced K-- races as the most prevalent races in the Great Plains. M-- races are virulent to *Lr1* and 3a but avirulent to *Lr2a* and 2c. The recent increase of T-- races may indicate another shift in the race pattern of the Great Plains and a return to increased virulence to *Lr2a* and 2c as well as *Lr1* and 3a. The genes *Lr9*, 16, 24, and 26 are currently being used in many of the U.S. wheat breeding programs in combination with other leaf rust resistances. During the past 20 years, these genes have lost effectiveness, especially when they were added one gene at a time to new wheat cultivars. *Lr24* and 26 were highly effective as late as 1985, but now provide little protection in the Great Plains. Nearly half of the leaf rust isolates collected in recent years were virulent to *Lr24* and 26. In the past 10 years, virulence to *Lr9* and 16 has increased whenever cultivars with these genes have been planted in significant acreage. In the past, virulence to *Lr16* has declined when cultivars with *Lr16* lost favor and were removed from production, which has allowed *Lr16* to be recycled in some breeding programs. Since 1995, cultivars with *Lr17* (e.g., Jagger) have gained popularity, and there has been a corresponding increase in virulence to *Lr17*. By

1998, more than 20% of the U.S. leaf rust isolates could attack cultivars with *Lr17*. The history of breeding for leaf rust resistance, especially in winter wheats, has shown that it is a never ending battle. Whenever new resistant genes have been used alone over significant areas, the corresponding virulence has appeared and increased in the *P. triticina* population within a few years. Therefore, it is important to combine new genes for race-specific resistance with other effective genes for resistance.

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