

Virulence Phenotypes of *Puccinia triticina* in the South Atlantic States in 1999

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ABSTRACT

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Collections of *Puccinia triticina* were made from rust-infected wheat leaves in Georgia, South Carolina, North Carolina, and Virginia in 1999 to examine if these states can be considered as a single epidemiological unit for virulence phenotypes of the wheat leaf rust pathogen. Single-uredinial isolates derived from the leaf rust collections were processed for identification of virulence phenotypes on seedling plants in greenhouse tests. Twenty-one virulence phenotypes from 253 isolates were described based on infection type to 16 Thatcher wheat lines near-isogenic for leaf rust resistance genes. Virulence phenotype MBRK (virulent to leaf rust resistance genes *Lr1*, *Lr3*, *Lr3ka*, *Lr11*, *Lr30*, *Lr10*, *Lr14a*, and *Lr18*) was the most common phenotype in the region, at 38.7% of all isolates. Phenotype TLGF (virulent to *Lr1*, *Lr2a*, *Lr2c*, *Lr3*, *Lr9*, *Lr11*, *Lr14a*, and *Lr18*) was the second most common phenotype overall, at 33.8% of isolates. Twenty-nine isolates selected on the basis of seedling virulence phenotypes also were tested for virulence to adult wheat plants with the resistance genes *Lr12*, *Lr13*, *Lr22b*, and *Lr34*. In all, 23 isolates were avirulent to *Lr12* and 26 isolates were virulent to *Lr13*. All isolates had fewer and smaller uredinia on the Thatcher line with *Lr34* compared with Thatcher. The widespread occurrence of the predominant *P. triticina* virulence phenotypes throughout the region indicated that the South Atlantic states should be considered as a single epidemiological area for wheat leaf rust. Some virulence phenotypes which occurred at lower frequencies were found primarily in the Coastal Plain and mountains of North Carolina or in breeding plots in southern Georgia. Localized populations of *P. triticina* may develop in the South Atlantic region due to overwintering of leaf rust infections or specific selection by leaf rust resistance genes in wheat cultivars.

Additional keywords: epidemiology, *Puccinia recondita* f. sp. *tritici*, specific resistance genes

Leaf rust of wheat, caused by *Puccinia triticina* Eriks., occurs nearly wherever wheat is grown in the United States and worldwide (7). In the southeastern United States, southern soft red winter wheat is grown from Virginia to eastern Texas and Arkansas. In eastern Virginia, wheat is planted from late October to the first week of November, and harvested in the last 2 weeks of June. In North Carolina, wheat is planted from late October through the middle of November, and the harvest is completed by mid-June. Most of the wheat production fields in North Carolina are in the Coastal Plain region along the Atlantic coast that runs from Wilmington in the south to the northern border with Virginia. In South Carolina, wheat is seeded in the first 2 weeks of November, and harvested in the first 2 weeks of June. In Georgia, wheat is planted from the second week to

the end of November, and harvest is usually completed by the end of May.

Leaf rust infections have been observed as early as February in breeding plots at Plymouth, NC. The wheat crop at this time of year has not yet developed stems and is primarily leaves that are prostrate on the ground. Rust observations at this early date generally indicate that weather conditions have been favorable for the establishment of leaf rust infections on wheat during the preceding fall. The rust infections that overwinter are initially observed in scattered and isolated foci. In years in which leaf rust does not become established in the fall, or survive the winter, the initial leaf rust infections may not be observed until the middle of March. In those years, the initial inoculum must arrive on the southerly winds from Georgia and South Carolina. Weather conditions along with host resistance directly influence the establishment of leaf rust in the fall and survival through the winter. Extremely hot and dry weather in the preceding summer can reduce the amount of leaf rust inoculum present on volunteer wheat. Dry conditions in the fall following wheat planting also can limit leaf rust infection. Widespread overwintering of leaf rust does not occur every year in North Carolina, because the weather conditions are not always suitable.

In years in which overwintering does occur, the early development of rust infections can lead to higher levels of localized rust infections in April and early May.

Severity of leaf rust infections are usually low through the first weeks of April on susceptible wheat cultivars in the Coastal Plain region of North Carolina. The severity of leaf rust infections increases in late April and reaches maximum levels in the first 2 weeks of May. Leaf rust development in the Piedmont region of North Carolina occurs later, often shortly before the wheat reaches maturity in late May and early June.

The *P. triticina* population in the southeastern United States generally is considered to be distinct when compared with other regional populations in North America (2,4,5). The predominant virulence phenotypes of *P. triticina* in the Southeast have been different from those in the southern and northern Great Plains, Ohio Valley, and the Pacific Northwest. The objective of this study was to identify virulence phenotypes of *P. triticina* sampled from different geographic regions of North Carolina, and also from locations in Georgia and South Carolina, to determine if the South Atlantic region could be considered as a homogeneous epidemiological unit for *P. triticina*.

MATERIALS AND METHODS

Wheat leaves with leaf rust infections were collected from three regions in North Carolina in early May and June of 1999. Samples from the Coastal Plain of North Carolina were collected from breeding plots at Kinston and Plymouth and from farm fields. Leaf rust collections for the Piedmont region were made from wheat plots at Clayton. Plots of susceptible wheat at Laurel Springs in the mountains of western North Carolina were sampled for leaf rust in the first week of June. Collections also were obtained from wheat breeding plots at Plains and Griffin in southern and central Georgia, respectively. Collections were obtained from plots at Blackwell and Barnwell in southwest South Carolina, and from Clemson in western South Carolina. Collections were obtained from plots at Blacksburg in western Virginia, and from and Holland and Painter in southeast Virginia.

Urediniospores from the leaf rust collections were inoculated onto 7-day-old seedlings of the wheat cultivar Thatcher that had been treated with 20 ml of a maleic hydrazide (MH) solution (5 g MH per 15

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liters H₂O) to prevent emergence of secondary leaves and to increase the size of uredinia. One week after inoculation, the leaves were trimmed so that only one uredinium remained on each plant. Two weeks after inoculation, when secondary rings had formed, spores from a single uredinium were collected with a cyclone spore collector into a 00 gelatin capsule. Soltrol 170 light industrial oil (330 µl) was added to each capsule, and the spore suspensions were atomized onto 1-week-old seedling differential sets composed of 16 Thatcher near-isogenic lines of wheat, each with a different gene for leaf rust resistance. The differential sets were planted in fiber flats (20 by 25 cm) that were filled with a sand-peat-soil mixture. The 12 Thatcher differentials (*Lr1*, *Lr2a*, *Lr2c*, *Lr3*, *Lr9*, *Lr16*, *Lr24*, *Lr26*, *Lr3ka*, *Lr11*, *Lr17*, and *Lr30*) used to describe virulence phenotypes of *P. triticina* (3) were used along with the isogenic lines that have *LrB*, *Lr10*, *Lr14a*, and *Lr18*. After the oil evaporated (approximately 1 h), the seedling flats were placed in a 100% humidity chamber for 16 h. All plants were then maintained on a greenhouse bench between 18 and 25°C with supplemental metal halide lighting. Three single uredinial isolates from each collection were evaluated for virulence phenotype. Infection types on the differentials were read 12 days after inoculation. Each single-uredinial isolate was assigned a four-letter virulence phenotype description based on high or low infection type to the differentials and supplemental lines, according to the established nomenclature (3).

Twenty isolates of *P. triticina* that were selected based on their virulence pheno-

types to the 16 differential lines also were tested for virulence to Thatcher lines with genes *Lr3bg*, *Lr14b*, *Lr15*, *Lr19*, *Lr20*, *Lr21*, *Lr23*, *Lr25*, *Lr28*, *Lr29*, *Lr32*, *Lr33*, and *Lr45*. The same procedures that were used for the standard set of 16 differentials were used to inoculate the additional differentials and evaluate the *P. triticina* isolates for infection type. Twenty-nine isolates also were tested for virulence to adult plants of Thatcher lines with the adult plant genes *Lr12*, *Lr13*, and *Lr34*. Four plants (one each of Thatcher lines with *Lr12*, *Lr13*, *Lr34*, and Thatcher) were grown together to heading stage in 15-cm-diameter pots in a greenhouse at 18 to 25°C with supplemental metal halide lighting. Plants were trimmed such that two tillers remained on each plant. The flag leaves of each pot of plants were inoculated at anthesis with a single isolate by atomizing 2 to 3 mg of urediniospores mixed with oil. Incubation and growth conditions were the same as for the seedling tests. Infection types were read in the same manner as for the seedling tests on the flag leaves of each plant 14 days after inoculation.

RESULTS

Virulence phenotype distribution. In all, 253 isolates of *P. triticina* collected from the South Atlantic region in 1999 were tested for virulence phenotype. Twenty-one virulence phenotypes were described based on infection types to the Thatcher near-isogenic lines (Table 1). A total of 6 phenotypes were found in collections from Georgia, 13 from South Carolina, 15 from North Carolina, and 4 from Virginia. Virulence phenotype MBRK

(virulence to genes *Lr1*, *Lr3*, *Lr3ka*, *Lr11*, *Lr30*, *Lr10*, *Lr14a*, and *Lr18*) was the most common phenotype in Georgia, South Carolina, and North Carolina, and was the second most common isolate from Virginia. MBRK was the most common phenotype across all locations, occurring at 38.7% of all isolates. Phenotype TLGF (virulent to *Lr1*, *Lr2a*, *Lr2c*, *Lr3*, *Lr9*, *Lr11*, *Lr14a*, and *Lr18*) was the second most common phenotype in Georgia, South Carolina, and North Carolina, and was the most common phenotype in Virginia. TLGF was the second most common phenotype across all locations at 33.8% of all isolates.

Some virulence phenotypes that occurred at lower frequencies were found in isolated locations in the South Atlantic region. Phenotype KCGD was found only at Plains, GA. Five isolates of phenotype TFGJ and nine isolates of TNRJ also were found in Plains, GA. Phenotypes MBGK and MCGS were found only at Blackville, SC and phenotype MBRJ was found only once at Barnwell, SC. No phenotypes were unique to the *P. triticina* collections from Virginia.

In North Carolina, phenotype MBRK was the most common virulence phenotype in the Coastal Plain, Piedmont, and Mountain regions. TLGF was the second most common phenotype in the Coastal Plain, MCRK was the second most common in the Piedmont, and LBBK was the second most common in the Mountain region. Fourteen, five, and six virulence phenotypes were found in the Coastal Plain, Piedmont, and Mountain regions, respectively. Eight isolates of LBBK, five isolates of FBMT, and four isolates of

Table 1. Number and frequency (%) of isolates of *Puccinia triticina* identified for virulence phenotype on 16 lines of Thatcher wheat near-isogenic for leaf rust resistance genes in the South Atlantic states in 1999

Virulence phenotype	Virulences (<i>Lr</i> genes)	Isolates of <i>Puccinia triticina</i>									
		Georgia		South Carolina		North Carolina		Virginia		Total	
		No.	%	No.	%	No.	%	No.	%	No.	%
FBMT	<i>2c, 3, 3ka, 30, B, 10, 14a, 18</i>	0	0.0	0	0.0	8	5.6	0	0.0	8	3.2
FBRT	<i>2c, 3, 3ka, 11, 30, B, 10, 14a, 18</i>	0	0.0	0	0.0	5	3.5	0	0.0	5	2.0
KCGD	<i>2a, 2c, 3, 26, 11, 14a</i>	6	13.6	0	0.0	0	0.0	0	0.0	6	2.4
LBBK	<i>1, 10, 14a, 18</i>	1	2.3	2	3.6	9	6.3	0	0.0	12	4.7
MBGD	<i>1, 3, 11, 14a</i>	0	0.0	3	5.4	8	5.6	0	0.0	10	4.0
MBGJ	<i>1, 3, 11, 10, 14a</i>	0	0.0	1	1.8	2	1.4	0	0.0	3	1.2
MBGK	<i>1, 3, 11, 10, 14a, 18</i>	0	0.0	5	8.9	0	0.0	0	0.0	5	2.0
MBRD	<i>1, 3, 3ka, 11, 30, 14a</i>	0	0.0	2	3.6	2	1.4	0	0.0	4	1.6
MBRJ	<i>1, 3, 3ka, 11, 30, 10, 14a</i>	0	0.0	1	1.8	0	0.0	0	0.0	1	0.4
MBRK	<i>1, 3, 3ka, 11, 30, 10, 14a, 18</i>	12	27.3	19	33.9	64	45.0	3	27.3	98	38.7
MCGJ	<i>1, 3, 26, 11, 10, 14a</i>	0	0.0	5	8.9	8	5.6	0	0.0	13	5.1
MCGS	<i>1, 3, 26, 11, B, 10, 14a</i>	0	0.0	1	1.8	0	0.0	0	0.0	1	0.4
MCRJ	<i>1, 3, 26, 3ka, 11, 30, 10, 14a</i>	0	0.0	0	0.0	1	1.0	0	0.0	1	0.4
MCRK	<i>1, 3, 26, 3ka, 11, 30, 10, 14a, 18</i>	0	0.0	4	7.1	5	3.5	1	9.1	10	4.0
MFRJ	<i>1, 3, 24, 26, 3ka, 11, 30, 10, 14a</i>	0	0.0	0	0.0	1	1.0	0	0.0	1	0.4
TBRJ	<i>1, 2a, 2c, 3, 3ka, 11, 30, 10, 14a</i>	0	0.0	0	0.0	6	4.2	0	0.0	6	2.4
TCRJ	<i>1, 2a, 2c, 3, 26, 3ka, 11, 30, 10, 14a</i>	0	0.0	1	1.8	2	1.4	0	0.0	3	1.2
TDRJ	<i>1, 2a, 2c, 3, 24, 3ka, 11, 17, 30, 10, 14a</i>	0	0.0	0	0.0	1	1.0	0	0.0	1	0.4
TFGJ	<i>1, 2a, 2c, 3, 24, 26, 11, 10, 14a</i>	5	11.4	1	1.8	0	0.0	0	0.0	6	2.4
TLGF	<i>1, 2a, 2c, 3, 9, 11, 14a, 18</i>	11	25.0	11	19.6	20	14.0	6	54.5	48	33.8
TNRJ	<i>1, 2a, 2c, 3, 9, 24, 3ka, 11, 30, 10, 14a</i>	9	20.5	0	0.0	0	0.0	1	9.1	10	4.0
Total isolates		...	44	...	56	...	142	...	11	...	253

FBRT were found in the collections from Laurel Springs. These three virulence phenotypes were found in lower numbers or not all in the Coastal Plain and Piedmont locations. Phenotypes MBGD, MBRD, MCGJ, MFRJ, TBRJ, TCRJ, and TDRJ were only found in breeding plots in the Coastal Plain region. In collections from farm fields in the Coastal Plain of North Carolina, there were 14 isolates of phenotype MBRK, 7 isolates of TLGF, and 1 isolate each of FBMT and MCRK.

Virulence frequencies. Virulence to *Lr16* and *Lr17* was not found in any isolates from the South Atlantic region (Table 2). Virulence to *Lr14a* was found in all of the isolates. Over 90% of isolates across the region had virulence to *Lr1*, *Lr3*, and *Lr11*. Among isolates across the region, 40 to 74% had virulence to *Lr2a*, *Lr2c*, *Lr3ka*, *Lr30*, *Lr10*, and *Lr18*. Virulence frequencies to genes *Lr9*, *Lr24*, *Lr26*, and *LrB*, were between 23 and 3.6% of isolates across the region.

Twenty-nine isolates of 16 different virulence phenotypes were tested for virulence to lines with adult plant resistance genes (Table 3). All isolates had high infection types on Thatcher (*Lr22b*). Six isolates (virulence phenotypes FBMT, FBRT, MBRD, TFGJ, and TNRJ) had high infection types on *TcLr12*, and the remaining isolates had low infection type. Only three isolates (FBMT, FBRT, and LBBK) had low infection type to *TcLr13*; the other isolates had high infection type. All isolates had lower infection type with fewer pustules on *TcLr34* compared with Thatcher.

Twenty isolates, each with a different virulence phenotype, also were tested for virulence to the supplemental near-isogenic Thatcher lines. Every isolate had low infection types to lines with genes *Lr3bg*, *Lr19*, *Lr21*, *Lr25*, *Lr29*, *Lr32*, *Lr33*, and *Lr45*. All isolates had high infection types

to lines with *Lr14b*, *Lr15*, *Lr20*, *Lr23*, and *Lr28*.

DISCUSSION

The widespread occurrence of virulence phenotypes MBRK and TLGF in the South Atlantic region indicates that these states generally should be considered as a single epidemiological unit for the wheat leaf rust

pathogen. Much of the leaf rust inoculum in North Carolina and Virginia originates from urediniospores that arrive on the southerly winds from north Florida, Georgia, and South Carolina. Soft red winter wheats with combinations of leaf rust resistance genes *Lr2a*, *Lr9*, *Lr10*, and *Lr11* are grown throughout the region, which imposes a similar selection pressure in the

Table 3. Infection types on adult plants of near-isogenic Thatcher lines with resistance genes *Lr12*, *Lr13*, *Lr34*, and *Lr22b* (Thatcher) of representative *Puccinia triticina* isolates collected from the South Atlantic states in 1999

Isolate	Phenotype ^b	State	Thatcher line ^a			
			<i>TcLr22b</i>	<i>TcLr12</i>	<i>TcLr13</i>	<i>TcLr34</i>
31-3	FBMT	NC	4	4	;	23
49-2	FBRT	NC	4	4	;	23
87-3	KCGD	GA	4	12	4	23
66-1	LBBK	NC	4	:2	:2	23
21-4	MBGD	NC	4	12	4	23
23-1	MBGJ	NC	4	12	4	23
26-2	MBRD	NC	4	4	4	23
28-1	MBRK	NC	4	12	4	23
18-2	MBRK	NC	4	12	4	23
31-2	MBRK	NC	4	12	4	23
22-1	MBRK	NC	4	12	4	23
4-2	MBRK	NC	4	12	4	23
24-3	MCGJ	NC	4	12	4	23
102-1	MCGJ	SC	4	12	4	23
6-1	MCRJ	NC	4	12	4	23
58-5	MCRK	NC	4	12	4	23
32-2	MCRK	NC	4	12	4	23
24-2	TBRJ	NC	4	12	4	23
9-1	TBRJ	NC	4	12	4	23
7-2	TCRJ	NC	4	12	4	23
3-3	TCRJ	NC	4	12	4	23
96-3	TFGJ	GA	4	4	4	23
30-1	TLGF	GA	4	12	4	23
44-1	TLGF	NC	4	12	4	23
1-1	TLGF	NC	4	12	4	23
1-2	TLGF	NC	4	12	4	23
69-3	TLGF	VA	4	12	4	23
86-3	TNRJ	GA	4	4	4	23
67-2	TNRJ	VA	4	4	4	23

^a Infection types are identified as ; = hypersensitive flecks, 1 = small uredinia with necrosis, 2 = small uredinia with chlorosis, 3 = moderate size uredinia, and 4 = large uredinia.

^b Virulence phenotype.

Table 2. Number and frequency (%) of *Puccinia triticina* isolates virulent to Thatcher lines near-isogenic for leaf rust resistance genes in the South Atlantic States in 1999

Genes	Isolates of <i>Puccinia triticina</i>									
	Georgia		South Carolina		North Carolina		Virginia		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
<i>Lr1</i>	39	88.6	56	100.0	129	90.8	11	100.0	235	92.9
<i>Lr2a</i>	31	70.5	42	75.0	29	20.4	7	63.6	108	42.7
<i>Lr2c</i>	31	70.5	42	75.0	42	29.5	7	63.6	121	47.8
<i>Lr3</i>	43	97.7	54	96.4	133	93.6	11	100.0	241	95.3
<i>Lr9</i>	20	45.5	11	19.6	20	14.0	7	63.6	58	22.9
<i>Lr16</i>	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
<i>Lr24</i>	14	31.8	1	1.8	2	1.4	1	9.1	18	7.1
<i>Lr26</i>	11	25.0	12	21.4	17	11.9	1	9.1	41	16.2
<i>Lr3ka</i>	21	47.7	27	48.2	95	66.9	4	36.4	147	58.1
<i>Lr11</i>	43	97.7	54	96.4	125	88.0	11	100.0	233	92.1
<i>Lr17</i>	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
<i>Lr30</i>	21	47.7	27	48.2	95	66.9	4	36.4	147	58.1
<i>LrB</i>	0	0.0	1	1.8	13	9.2	0	0.0	9	3.6
<i>Lr10</i>	27	61.4	44	78.6	40	64.7	5	45.5	168	66.4
<i>Lr14a</i>	44	100.0	56	100.0	142	100.0	11	100.0	253	100.0
<i>Lr18</i>	24	54.5	41	73.2	111	78.1	10	90.9	186	73.5
Total isolates	44	...	56	...	142	...	11	...	253	...

different states. Wheat cvs. FFR 555W (*Lr10*), Saluda (*Lr11*), Pocahontas (*Lr11*), Jackson (*Lr1*, *Lr11*), and Pioneer 2580 (*Lr11*) (J. A. Kolmer, unpublished data), which have been grown from Georgia to Virginia, have been selected for phenotype MBRK (virulences *Lr1*, *Lr3*, *Lr3ka*, *Lr11*, *Lr30*, *Lr10*, *Lr14a*, and *Lr18*) throughout the South Atlantic states. Most *P. triticina* phenotypes have virulence to genes *Lr10* and *Lr11* and cultivars with these genes have been widely grown in the South Atlantic region for several years.

Other current cultivars, such as FFR 518 (*Lr9*), FFR 522 (*Lr9*, *Lr18*), Coker 9474 (*Lr2a*, *Lr9*), Coker 9766 (*Lr2a*, *Lr9*), and especially Coker 9835 (*Lr2a*, *Lr9*), also widely grown in the South Atlantic States in the late 1990s, have been selected for phenotype TLGF (virulences *Lr1*, *Lr2a*, *Lr2c*, *Lr3*, *Lr9*, *Lr11*, *Lr14a*, and *Lr18*). Virulence to *Lr9*, which is present in many soft red winter wheats, was found in 1999 in only two phenotypes, TLGF and TNRJ, in the South Atlantic region.

Coker 9663 (*Lr2a*, *Lr9*, and *Lr10*) has been the most commonly grown wheat in the southeastern states in recent years. Among the isolates in this study, only phenotype TNRJ (virulences *Lr1*, *Lr2a*, *Lr2c*, *Lr3*, *Lr9*, *Lr3ka*, *Lr11*, *Lr30*, *Lr10*, and *Lr14a*) has virulence to this cultivar. If Coker 9663 remains popular, then TNRJ may increase in frequency throughout the region, because it has virulence to *Lr2a*, *Lr9*, and *Lr10*. Some advanced breeding lines and cultivars, such as Patton and Foster, have gene *Lr26*. Phenotypes with virulence to *Lr26* (KCGD, MCGJ, MCGS, MCRJ, MFRJ, TCRJ, and TFGJ) occurred at lower frequencies. Although *Lr26* conditions resistance to the current predominant isolates, the resistance of lines with *Lr26* will inevitably be eroded as the frequency of phenotypes with virulence to this gene increase. Virulence to *Lr26* in the Great Plains population of *P. triticina* increased shortly after the introduction of Siouxland wheat (*Lr24*, *Lr26*) in the late 1980s (2).

Some less frequent virulence phenotypes of *P. triticina* were found mostly in localized areas, and were not generally distributed throughout the entire South Atlantic region. This could be attributed to populations of *P. triticina* that overwinter in localized areas or the effects of host selection within a localized area. Phenotype KCGD was found only in Plains, GA. This phenotype is unique in that it is avirulent to both *Lr1* and *Lr10*, yet virulent to *Lr26*. A *P. triticina* population with this

phenotype may have overwintered in the nurseries at Plains, or a breeding line may have specifically selected this phenotype. The higher number of virulence phenotypes obtained from the breeding nurseries in the Coastal Plain of North Carolina compared with phenotypes from farm fields can be attributed to the selective effects of additional leaf rust resistance genes such as *Lr18*, *Lr24*, and *Lr26* in the breeding lines that were not present in the commonly grown commercial wheat cultivars.

Virulence surveys of the southeastern United States (from North Carolina and Florida to Arkansas and Louisiana) conducted by the United States Department of Agriculture-Agricultural Research Service Cereal Disease Laboratory (5), showed that MCRK, MBRJ, MBRK, and TLGF were the most common phenotypes in 1997 and 1998 in collections from breeding plots and farm fields. In 1996, MBRJ (with 37% of isolates) was the most common phenotype in the region, while the other phenotypes that also were common in 1997 and 1998 occurred at less than 10%. Since 1996, there has been an increase in *P. triticina* phenotypes with virulence to *Lr18* in the southeastern region. This may have been caused by the use of cultivars with *Lr18* in this region, such as cvs. FFR 522 (*Lr9*, *Lr18*), Pioneer 2684 (*Lr10*, *Lr18*), and Coker 9803 (*Lr10*, *Lr18*).

In North Carolina, there was a distinct difference in distribution of virulence phenotypes from the Coastal Plain to the Mountain region. The collections from Laurel Springs in the Mountain region were distinct due to the higher frequency of phenotypes FBMT, FBRT, and LBBK. These phenotypes occurred at lower frequencies or not at all in the other two regions. The collections from Laurel Springs were made from susceptible wheat in early June, a month later than collections from the Coastal Plain and Piedmont regions. Phenotype LBBK is relatively avirulent and is probably restricted to wheat with *Lr10*, *Lr18*, or no resistance genes. The *P. triticina* population in the Mountain region of the South Atlantic states may be somewhat isolated from the major wheat-growing areas of the region, although phenotype MBRK also was collected at Laurel Springs.

Most of the *P. triticina* isolates tested to adult plant resistance genes were avirulent to lines with *Lr12*. This gene has most likely been present in the soft red winter wheat germ plasm ever since cv. Knox was released. Knox has Chinese Spring (*Lr12*,

Lr31, and *Lr34*) (1) in its pedigree and it likely has *Lr12* and *Lr34*. All of the isolates that were tested had smaller and fewer pustules on the Thatcher line with *Lr34*, compared with Thatcher. Lines and cultivars that have been genetically shown or postulated to have *Lr12*, *Lr34*, or both (Sturdy, *Lr10*, *Lr12*, *Lr34*; Monon, *Lr12*; Knox, *Lr12*, *Lr34*; and Bezostaya 1, *Lr13*, *Lr34*) had good leaf rust resistance in plots at Kinston, NC in 2000 (J. A. Kolmer, unpublished data). Genes *Lr12* and *Lr34* may condition the adult plant resistance in many current soft red winter wheats. Almost all isolates tested were virulent to *Lr13*. Wheat cvs. Coastal, Hadden, and Atlas 66, which have been postulated to have *Lr13* (6), had severe leaf rust in plots at Kinston NC in 2000.

Leaf rust-resistant wheat cultivars that are grown in northern Florida and Georgia will select for *P. triticina* isolates, which then spread into South Carolina, North Carolina, and Virginia. The movement of *P. triticina* virulence phenotypes in the South Atlantic states is similar to the yearly northward spread of rust that occurs in the Great Plains region (4,5). If cultivars are widely grown throughout the South Atlantic region, then selection of *P. triticina* isolates with virulence to resistance genes in wheat cultivars will occur at a faster rate. Effective leaf rust resistance may be prolonged by diversification of resistance genes in wheat cultivars that are commonly grown in this region.

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