Comparison of Durum and Common Wheat Cultivars for Reaction to Leaf Spotting Fungi in the Field

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ABSTRACT

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Durum (*Triticum turgidum* var. *durum*) and common (*T. aestivum*) wheat cultivars (Canada Western Red Spring, Canada Prairie Spring, and Canada Western Soft White Spring), grown at two locations for 3 years, were assessed for severity of the leaf spot complex and relative proportion of leaf spotting fungi. The most prevalent fungi isolated were *Pyrenophora tritici-repentis* and *Phaeosphaeria nodorum*. Their percent isolation and leaf spot severity varied among years and between locations. The relative prevalence of the leaf spotting fungi in the individual cultivars, or cultivars grouped by species, varied with year, whereas the leaf spot score varied with location. Cultivars and species differed in susceptibility to the leaf spotting fungi. The common wheat classes were mostly colonized by *P. nodorum* and the durum wheat by *P. tritici-repentis*. Cultivars, but not cultivars grouped by species, also differed in the severity of the leaf spot complex. Within both durum and common wheat there were cultivars with low and high leaf spot scores.

All wheat (*Triticum* spp.) cultivars currently grown in western Canada are susceptible to leaf spotting fungi. Surveys conducted over several years in Saskatchewan and Manitoba have determined that the main fungi involved in this disease complex are *Pyrenophora tritici-repentis* (Died.) Drechs. (anamorph *Drechslera tritici-repentis* (Died.) Shoemaker) (tan spot), *Phaeosphaeria nodorum* (E. Müller) Hedjaroude (anamorph *Stagonospora nodorum* (Berk.) Castellani & E. G. Germano (Stagonospora blotch), and *Mycosphaerella graminicola* (Fuckel) J. Schröt. in Cohn (anamorph *Septoria tritici* Roberge in Desmaz.) (Septoria blotch), and *Cochliobolus sativus* (Ito & Kuribayashi) Drechs. ex Dastur (anamorph *Bipolaris sorokiniana* (Sacc.) Shoemaker (spot blotch) (3,4,8,10). These surveys of commercial fields also revealed differences among years, and between durum (*T. turgidum* L. var. *durum* Desf.) and common wheat (*T. aestivum* L.), in leaf spot ratings and percent isolation of leaf spotting fungi from diseased leaf tissue (3,4).

No detailed comparisons have been made of wheat cultivars of different quality classes and species for field reaction to leaf spotting fungi. Information on the reaction of the most commonly grown wheat cultivars to the various leaf spotting fungi would help to identify appropriate benchmarks for selecting for disease resistance in different quality classes or species under different environments. It would also help breeders to set priorities in the incorporation of disease resistance to the leaf spotting complex into adapted wheat cultivars. The objective of this study was to examine durum and common wheat cultivars currently registered for use in western Canada for leaf spot severity and relative prevalence of the leaf spotting fungi, under different environments.

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MATERIALS AND METHODS

The trials were grown in 1991, 1992, and 1993, at Swift Current and Outlook, about 200 km apart, in southern Saskatchewan, in a two-replicate, randomized complete block design. The soil type was Swinton loam (2), characterized as brown at Swift Current and dark brown at Outlook (5). Plots consisted of four rows 3 m long with a row spacing of 0.23 m (Swift Current) or 0.20 m (Outlook). Six Canada Western Amber Durum (CWAD) cultivars (Medora, Wakooma, Kyle, Sceptre, Arcola, and Plenty), and six common wheat cultivars, including two Canada Western Red Spring (CWRS) (Katepwa and Laura), three Canada Prairie Spring (CPS) (Biggar, Genesis, and AC Taber), and one Canada Western Soft White Spring (CWSWS) (Fielder), were examined. These cultivars were part of trials that included 150 cultivars and lines in 1991 and 200 in 1992. Plots were seeded on 23 May 1991, 11 May 1992, and 13 May 1993 at Swift Current, and 22 May 1991, 18 May 1992, and 14 May 1993 at Outlook. Harvest was on 7 September 1991, 10 October 1992, and 4 October 1993 at Swift Current, and on 12 September 1991, 10 October 1992, and 13 September 1993 at Outlook.

Plots were planted on fallow at Swift Current and on land continuously cropped to wheat at Outlook. Fertilizer was applied in accordance with soil test recommendations (17). Irrigation water was applied by overhead sprinklers as required to maximize yield.

Leaf spots were rated at Zadoks's growth stage (GS) 77-84 (24), using a 0 to 9 scale (6) based on percent leaf area covered with leaf spots (Table 1). Leaf spot scores were recorded as the average of the scores of approximately 20 plants from the center rows of each plot (7). To identify the fungi responsible for leaf spots, 1-cm^2 sections were collected from lesioned areas of 15 to 20 randomly sampled upper leaves. The diseased leaf material was surface disinfested in 0.06% sodium hypochlorite for 1 min, rinsed three times in sterile distilled water, plated on water agar and incubated for 7 days under near-UV lights (12 h light at 22°C, 12 h dark at 15°C). The percent leaf area covered by each fungus was calculated relative to its frequency of isolation.

Meteorological data were collected on site at both locations. Total rainfall during the growing season (22 May to 13 August) was 270 mm for 1991, 182 mm for 1992, and 189 mm for 1993 at Swift Current, and 238 mm for 1991, 122 mm for 1992, and 190 mm for 1993 at Outlook. Although

Table 1. A leaf spotting score for disease severity on upper, middle and lower wheat leaves[a]

Leaf spotting score	Diseased leaf area (%) Upper	Middle	Lower
0	0	0	0
1	0	0	Trace
2	0	0	5
3	0	0	10
4	0	5 to 10	25 to 50
5	Trace	11 to 25	>50
6	5 to 10	26 to 50	>50
7	11 to 25	>50	>50
8	26 to 50	>50	>50
9	>50	>50	>50

[a] Scale based on Couture (6).

there was more rainfall during the growing season in 1991 than in the two subsequent years, precipitation was not evenly distributed and fell mostly during the early part of the season (Table 2). In 1991, the first part of the growing season (29 May to 2 July) received high rainfall, but it was drier during the same period at both sites in 1992 and 1993. Days of rain/irrigation were 23 in 1991, 21 in 1992, and 18 in 1993 at Swift Current, and 17 in 1991, 10 in 1992, and 19 in 1993 at Outlook. Average maximum temperatures were the same in 1992 and 1991, but slightly lower in 1993.

The latter part of the 1991 growing season (3 July to 6 August) was drier at both sites than in 1992 or 1993 (Table 2). In addition, there were 9 more days of rain/irrigation at Swift Current in 1992 and 8 in 1993, and 5 at Outlook in 1992 and 1993, than in 1991. Average temperatures in the latter part of the season were lower in 1992 and 1993 than in 1991, with 1993 having the lowest mean maximum temperatures.

Statistical procedures. For the responses measured in this study the assumption of analysis of variance that the variances are independent of the mean and homogeneous was not true. Failure to meet these assumptions is often expressed by seemingly significant interaction terms in the analysis that appear to have no biological foundation. In the past, departures from the assumptions were met by transforming the observed responses, but such transformations introduce bias that has to be removed when returning to estimates of the effects in terms of the original units (16). Since the early 1970s, when the concept of generalized linear models was introduced, many of these difficulties were removed by the simple expedient of replacing the standard model for analysis of variance, which for a two-factor analysis can be written as $y(i,j,k) = a + b(i) + c(j) + d(i,j) + \mathrm{error}(i,j,k)$, where the error term is assumed to be homogeneous, with $y(i,j,k) = h[a + b(i) + c(j) + d(i,j)] + \mathrm{error}(i,j,k)$.

The term in [ ] is called the linear predictor; $h[\ ]$ is the so-called link function, which transforms the linear predictor to give the expected values in the original units. The error term (the random component) is an appropriate member of a class of well-known forms (16). If $h[\ ]$ is the identity, and the random component is homogeneous, the standard analysis of variance is recovered, i.e., the analysis of variance is included among generalized linear models. The block and treatment structure of the design are the framework determining the analysis, but the response determines $h[\ ]$ and also the error distribution for the random component. The estimation procedure for fitting this class of models is by maximizing likelihood or quasi-likelihood, as appropriate.

Analysis of the percent leaf area colonized by the fungi is based on a generalized linear model in which the random component is assumed to follow a "pseudo-binomial" distribution; the estimates obtained maximize the quasi-likelihood of the data (16). Significance was tested by comparing the ratio of mean deviances (the deviance is twice the negative of the logarithm of the likelihood ratio) with the *F*-distribution. The leaf spot scores (0 to 9) were analyzed by using the ordinal logistic model approximated by a true binomial by forming two groups (13) as follows: scores of 0 versus the rest, scores less than or equal to *i*, for $i = 1 \ldots 8$, versus the rest (6). Significance was tested by comparing the change in deviance with a chi-square distribution.

For both responses (leaf spot scores and percent leaf area colonized by the fungi), the values predicted by the fitted model are to be interpreted as expected values; they need not coincide with the means calculated directly, which refer just to the experiment itself. All computations were performed with Genstat 5, release 2.2 (NAG Ltd., Wilkinson House, Jordan Hill Rd., Oxford UK, 0X2 8DR). Probabilities less than 0.05 are deemed significant.

RESULTS

Scores of the leaf spot complex ranged from 5 to 8 (see Table 1). The most commonly isolated fungi from leaves of all cultivars in all years were *P. tritici-repentis* and *P. nodorum. Cochliobolus sativus, M. graminicola* and *Leptosphaeria avenaria* G. F. Webber f. sp. *triticea* T. Johnson (anamorph *Stagonospora avenae* (A. B. Frank) Bissett f. sp. *triticea* T. Johnson) were less prevalent. *Mycosphaerella graminicola*, isolated mainly from the CWRS cultivars and only in 1992 and 1993, and *L. avenaria* f. sp. *triticea*, isolated less than 3% in all years and locations, were not included in the analyses.

Based on analyses of deviance of the observed leaf spot scores, the clearest dis-

Table 2. Rain (mm), irrigation (mm) and average maximum temperature (C), in the early (29 May to 2 July) and late (3 July to 6 August) part of the growing season, at Swift Current and Outlook, from 1991 to 1993

		29 May to 2 July			3 July to 6 August		
Year	Location	Rain (mm)	Irrigat. (mm)	Temp. (C)	Rain (mm)	Irrigat. (mm)	Temp. (C)
1991	Swift Current	177	. . .	20.9	56	98	25.4
	Outlook	205	. . .	21.4	46	67	26.1
1992	Swift Current	80	50	20.9	96	72	22.1
	Outlook	39	61	21.4	69	85	23.1
1993	Swift Current	61	20	20.2	118	45	20.7
	Outlook	72	55	20.1	98	25	21.5

Table 3. Analysis of deviance of the probability of leaf spot scores not exceeding 6, and of percent leaf area colonized by three leaf spotting pathogens

		Deviance	Deviance ratio		
Source of variation	df[a]	Leaf spot score	*Pyrenophora tritici-repentis*	*Leptosphaeria nodorum*	*Cochliobolus sativus*
Year (Y)	2	11.16**[b]	67.99**	219.52**	142.73**
Location (L)	1	29.64**	89.02**	63.26**	32.93**
Y × L	2	39.50**	4.43**	10.42**	0.22
Cultivar (C)	12	54.49**	34.13**	132.78**	3.70**
C × Y	22	8.40	2.59**	3.57**	0.81
C × L	12	41.24**	1.57	1.40	1.13
C × Y × L	22	0.00	1.58	2.58**	0.37
Residual	22	0.00	NA[c]	NA	NA
Species (S)	1	0.56	181.27**	1,149.07**	20.71**
S × Y	2	1.88	3.81*	1.31	2.03
S × L	1	12.45**	1.09	0.14	0.34
S × Y × L	2	10.66*	1.47	2.95	0.91
Residual	62	78.59	NA	NA	NA

[a] Degrees of freedom.
[b] * and **, significant at $P < 0.05$ and $P < 0.01$, respectively.
[c] Not applicable.

tinction between the species and cultivars proved to be for a score of 6, i.e., scores of 5 to 6 grouped together (data for all leaf spot scores not presented). The effects of year and location on the leaf spotting complex were highly significant (Table 3). For all cultivars combined, the probability of a leaf spot score greater than 6 was almost three times higher at Outlook than at Swift Current (Table 4), indicating that the disease pressure at Outlook was much higher than at Swift Current. The probability of a leaf spot score higher than 6 was also somewhat higher in 1993 than in 1991, with 1992 having the lowest probability. The low disease severity in 1992 was probably due to a slow development of leaf spots early in the season attributed to dry and cool conditions.

The significant year × location interaction (Table 3) indicates that overall differences in the severity of the leaf spot complex were not consistent for the two locations during the 3 years of the study. The probability of a leaf spot score greater than 6 was higher at Outlook than at Swift Current in 1991 and 1993, but lower in 1992, and it was lower in 1992 than in the other 2 years at Outlook, but increased from 1991 to 1993 at Swift Current (0 and 96% for 1991, 33 and 21% for 1992, and 39 and 80% for 1993, at Swift Current and Outlook, respectively).

Analysis of the proportion of leaf spotted area colonized by each of the fungi in the 3 years and two locations of testing showed that year and location differences were also highly significant for all three fungi (Table 3). *Pyrenophora tritici-repentis* was more commonly isolated in 1991 than in 1992 (Table 4), the lowest levels being observed in 1993, and it was more common at Swift Current than Outlook. In contrast, *P. nodorum* was more commonly isolated in 1993 and 1992 than in 1991, while *C. sativus* was more common in 1991 than in the following years. The latter two fungi were more prevalent at Outlook than Swift Current. There was also an interaction of year with location for *P. tritici-repentis* and *P. nodorum*, indicating that the relative proportion of each of these fungi, as for the leaf spot scores, differed between locations from year to year. For example, both fungi were equally common in 1992 and 1993 at Swift Current (mean of 61% for *P. tritici-repentis*, 36% for *P. nodorum*), but *P. tritici-repentis* was less, and *P. nodorum* was more, common in 1993 than in 1992 at Outlook (for *P. tritici-repentis* 44 and 30%, for *P. nodorum* 54 and 61%, in 1992 and 1993, respectively).

For the leaf spot score, the effect of cultivar, but not of cultivars grouped by species, was significant (Table 3). Within both the common and the durum wheat, there were cultivars with low and high severity of the leaf spot complex. Overall, the common wheat Katepwa (Canada Western Red Spring) was the most susceptible cultivar (average score of 7.0). Within durum wheat, Medora had the highest leaf spot score (average score of 6.7). The durum wheat cultivar Plenty and the common wheat cultivar Genesis (Canada Prairie Spring) had the lowest severity of leaf spots (average score of 5.7 for both). The interactions of cultivar or species with location, but not with year, were also highly significant (Table 3), indicating that the relative leaf spot reaction of the cultivars, individually or grouped by species, was consistent across years but not locations. For example, there was a much higher probability of a leaf spot score greater than 6 at Outlook than at Swift Current for common wheat (73 and 13%, respectively) than for durum wheat (60 and 36%, respectively).

Differences among individual cultivars, and of cultivars grouped by species, were also highly significant for the proportion of diseased leaf tissue occupied by each of the three fungi. *Pyrenophora tritici-repentis* was more commonly isolated from durum than from common wheat, whereas *P. nodorum* and *C. sativus* were isolated more from common than from durum wheat (Table 4). For *P. tritici-repentis* and *P. nodorum*, the deviance of the interaction between the proportion of leaf area colonized by the fungi and year was significant for the individual cultivars and for cultivars grouped by species (*P. tritici-repentis* only for the latter), indicating that, in contrast to the leaf spotting score, factors associated with years had influenced the relative colonization of the cultivars by each of these fungi. The proportion of leaf area occupied by *P. nodorum* increased, and that of *P. tritici-repentis* decreased, in common wheats, from 1991 to 1993 (Table 5). The proportion of leaf area occupied by *P. tritici-repentis* decreased and that of *P. nodorum* increased also in the durum

Table 4. Estimated percent diseased leaf area colonized by *Pyrenophora tritici-repentis*, *Phaeosphaeria nodorum*, and *Cochliobolus sativus*, and probability of a leaf spot score greater than 6, in two locations and 3 years[a]

	Diseased leaf area colonized (%)			Leaf spot score
	Pyrenophora tritici-repentis	*Phaeosphaeria nodorum*	*Cochliobolus sativus*	Probabilityof score >6
Location				
Swift Current	67 (1)[b]	28 (1)	4 (1)	24 (2)
Outlook	47 (1)	42 (1)	9 (1)	66 (2)
Year				
1991	74 (2)	8 (1)	18 (1)	48 (2)
1992	53 (2)	45 (1)	1 (<1)	27 (2)
1993	44 (2)	49 (2)	1 (<1)	59 (3)
Species				
Durum wheat	76 (2)	19 (2)	4 (1)	48 (4)
Common wheat	39 (2)	49 (2)	8 (1)	43 (4)

[a] Values based on 12 wheat cultivars.
[b] Standard errors in parentheses.

Table 5. Estimated percent diseased leaf area colonized by *Pyrenophora tritici-repentis*, *Phaeosphaeria nodorum*, and *Cochliobolus sativus*, and probability of a leaf spot score greater than 6 for durum and common wheat, at two locations from 1991 to 1993

		Percent leaf area			
Species/year	Location	*Pyrenophora tritici-repentis*	*Phaeosphaeria nodorum*	*Cochliobolus sativus*	Probability of score >6
Durum wheat					
1991	Swift Current	89 (3)[a]	4 (2)	7 (2)	0 (<1)
	Outlook	81 (4)	3 (2)	16 (2)	100 (0)
1992	Swift Current	80 (4)	19 (4)	1 (<1)	67 (14)
	Outlook	73 (5)	26 (4)	1 (1)	0 (<1)
1993	Swift Current	84 (4)	15 (4)	1 (<1)	42 (14)
	Outlook	49 (5)	46 (5)	1 (1)	75 (13)
Mean	Swift Current	84 (2)	13 (2)	3 (1)	36 (7)
	Outlook	67 (3)	26 (2)	6 (1)	59 (4)
Common wheat					
1991	Swift Current	71 (5)	15 (4)	15 (2)	0 (<1)
	Outlook	56 (5)	11 (3)	33 (3)	92 (8)
1992	Swift Current	44 (5)	53 (5)	0 (<1)	0 (<1)
	Outlook	16 (4)	81 (4)	2 (1)	42 (14)
1993	Swift Current	37 (5)	55 (5)	0 (0)	36 (13)
	Outlook	11 (3)	76 (4)	1 (1)	86 (9)
Mean	Swift Current	50 (3)	42 (3)	5 (1)	13 (5)
	Outlook	27 (2)	57 (2)	11 (1)	73 (6)

[a] Standard errors in parentheses.

wheat cultivars, although to a lesser extent than in the common wheat cultivars, and only at Outlook. *Cochliobolus sativus* also seemed to follow a trend similar to that of *P. tritici-repentis*. In 1993, when *P. nodorum* was the most prevalent fungus, Wakooma and Kyle had higher levels of *P. tritici-repentis* than the rest of the durum wheat cultivars (average for both locations of 79% for Wakooma and 75% for Kyle).

For the common wheat at Outlook, the high probability of scores greater than 6 corresponded with a higher proportion of leaf area colonized by *P. nodorum* compared with the other leaf spotting fungi (Table 5). Common wheat also had a higher probability of scores greater than 6 than the durum wheat at Outlook, where the proportion of leaf area occupied by *P. nodorum* (the most prevalent fungus at this location) was higher in common than in durum wheat. Overall, common wheat had a lower probability of scores greater than 6 than durum wheat cultivars at Swift Current, where *P. tritici-repentis* was the most prevalent fungus isolated from spotted leaves, and was more prevalent in durum than in common wheat.

DISCUSSION

The different relative prevalence of the three leaf spotting fungi from 1991 to 1993, and severity of the leaf spot complex, can be attributed to environmental differences among years. Low temperatures and precipitation early in the 1992 season resulted in less foliar infection than in 1991 or 1993. Competition among the different pathogenic fungi and its effect on colonization of leaves were not determined. However, the relative higher level of *P. tritici-repentis* than of *P. nodorum* in 1991 than in the two subsequent years is largely explained by the high temperatures and dry conditions during the latter part of the season, and not by low inoculum levels and/or competition (1). The former conditions are known to be less favorable to the development of *P. nodorum* infections (20, 23). Higher rainfall and greater number of days of rain/irrigation, and lower temperatures in the latter part of the season in 1992 and 1993 (particularly 1993) than in 1991 were favorable for infection and development of *P. nodorum* (20,21) and *M. graminicola* (19,22), but less suitable for *C. sativus* (15) or *P. tritici-repentis* infections (12). A survey conducted in Manitoba (10) also revealed a lower incidence of *C. sativus* in 1992 than in 1989 to 1991, and *P. nodorum* and *M. graminicola* were isolated more frequently in 1992 than in previous years. Severities of the leaf spot complex lower or similar to what was found in this study in all years have resulted in yield losses of over 10%, and significant reductions in grain quality in durum and common wheat (11,18).

Even though the weather seemed to have played an important role, available inoculum, soil type, and management practices likely contributed to the differences in levels of the fungi between locations, and in particular, to the higher disease pressure at Outlook than at Swift Current.

There were differences in the severity of the leaf spot complex among cultivars. The common wheat Genesis (Canada Prairie Spring) and the durum wheat Plenty were consistently more resistant than the rest. However, when cultivars were grouped by species, durum and common wheat differed only in their relative susceptibility to each of the leaf spotting fungi, and not in the overall severity of the leaf spot complex. The common wheat cultivars examined here were colonized mostly by *P. nodorum* in those environments where this pathogen was favored, with leaf spot scores highest when the proportion of this fungus was the highest. The durum wheat cultivars apparently were more susceptible to *P. tritici-repentis* than to *P. nodorum*. These observations are consistent with other reports (3,4,8) of a greater incidence of *Septoria* spp. and lower incidence of *P. tritici-repentis* in common than in durum wheats in commercial fields in Saskatchewan and Manitoba. Gilbert and Tekauz (9) also reported that durum wheats were more resistant than common wheats to inoculations with *P. nodorum*.

The relative percent isolation of fungi from leaf spot lesions from each of the cultivars examined was consistent between locations, even though differences in the overall relative levels of the fungi from year to year varied with location. Cultivars differed among years in the relative colonization by leaf spotting fungi, but this was not reflected in significant differences in the relative leaf spotting scores; the latter differed only between locations, despite the fact that there were differences in the overall leaf spot severity among years. Together, these observations suggest that other factors, such as differences in disease pressure between locations, and possible interactions among the fungi (14), influenced the relative overall leaf spot score of the cultivars, and that weather factors appeared to have been important in determining the relative colonization of cultivars by each of the fungi.

To identify the most appropriate locations and most useful benchmarks for selecting for leaf spot disease resistance in a given type of wheat, it would therefore be necessary to assess the leaf spot reaction of diverse wheat cultivars under different environments, and to identify the leaf spotting fungus that appears to be consistently most prevalent. For example, selection of leaf spot–resistant durum wheat germ plasm in locations where *P. tritici-repentis* is consistently the most prevalent fungus (e.g., Swift Current) will require checks other than the currently registered durum wheats in order to effectively assess resistance against the other leaf spotting pathogens. The common wheat cultivars will be useful as checks at such a location. Given the greater susceptibility of the durum wheat cultivars currently registered in western Canada to *P. tritici-repentis* than to the other leaf spotting pathogens, such an environment would be best suited for selection of durum wheat germ plasm with better tan spot resistance.

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