Distribution of Pathotypes of *Rhynchosporium secalis* and Cultivar Reaction on Barley in Alberta

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ABSTRACT

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Forty-four barley accessions and commercial cultivars with different levels of resistance to scald caused by *Rhynchosporium secalis* were evaluated for scald reaction from 1997 to 1999 at various sites in Alberta. The accessions Hudson, Atlas, Atlas 46, Atlas 68, Abyssinian, and Kitchen that have the major resistance genes were resistant to pathotypes of *R. secalis* at all sites. Although scald levels were low for these accessions, they were significantly different among years. Pathotypes of *R. secalis* and environmental conditions affected diseases levels on 32 commercial cultivars, resulting in significantly different scald reactions among sites and seasons. Resistance in commercial cultivars, AC Stacy, Kasota, and Seebe, held up at most sites with the majority of cultivars being intermediate to moderately susceptible. Cultivars that were previously considered resistant were intermediate in reaction and became increasingly susceptible at some sites from 1997 to 1999. Pathogen virulence was more diverse at the sites where the cultivars became increasingly susceptible compared with sites where the same cultivars were resistant. Scald reactions of the commercial cultivars depended on location, which reflected the presence of different pathotypes, as well as variation in environmental conditions. Consequently, scald management via cultivar choice will be dependent on location.

Barley (*Hordeum vulgare* L.) production in Alberta averaged around 6 million metric tons from 2 million hectares annually from 1995 to 1999, and accounted for nearly 50% of the total barley production in western Canada (2). Scald, caused by *Rhynchosporium secalis* J.J. Davis, is one of the major foliar diseases of barley in Alberta as a result of intensive production, and cool and wet environmental conditions that favor disease development (11). Yield losses due to scald are estimated to be 1 to 19% in field trials (17,23), and losses as high as 20 to 36% have been reported (4). Average barley yield reductions can result in annual estimated monetary losses of approximately \$7 million in Alberta (21).

In Alberta, a shift in virulence of *R. secalis* populations has been evidenced by changes in cultivar reaction (21,23). The

scald-resistant cultivars, CDC Guardian, CDC Richard, and TR129, showed less than 30% of the scald severity of the average of three susceptible cultivars, Argyle, Harrington, and Jackson, in a 1993 survey in Alberta (24). In later studies, these resistance cultivars frequently had 70 to 100% of the scald severity of the susceptible cultivars (23). The scald-resistant cultivar, CDC Guardian, showed 1, 26, and 70% of the disease severity relative to the susceptible cultivar, Harrington, in field trials during 1993, 1995, and 1996, respectively. Yield losses of 1.6, 4.8, and 15.7% were observed in CDC Guardian in the same trials during 1993, 1995, and 1996, respectively (23). These observations indicate that shifts in the virulence of *R. secalis* and the potential for high variability in the virulence of the scald pathogen were responsible for the observed breakdown of barley cultivar resistance in Alberta.

Planting resistant cultivars is one of the major methods for control of scald of barley, but successful control using resistance depends on a clear understanding of the interaction between host and pathogen. Knowledge about variation in the virulence of pathotypes of *R. secalis* is important for breeding programs that are attempting to incorporate scald resistance, so breeders

can deploy sources of resistance that are likely to be effective against the range of pathotypes in a given area. Variation in the virulence of *R. secalis* among locations may be exploited by the deployment of cultivars with diverse sources of scald resistance.

The current status of scald resistance in commercial barley cultivars in relation to the distribution of pathotypes of *R. secalis* needs to be clarified. The objectives of this study were to evaluate the scald reaction of commercially available cultivars in relation to spatial and temporal patterns of scald distribution across the major barley production areas of Alberta, and to provide information on potential sources of resistance that are effective against the most prevalent pathotypes in Alberta.

MATERIALS AND METHODS

Hill plots were established at Edmonton (53°34' N, 113°31' W), Beaverlodge (55°13' N, 119°26' W), Calmar (53°16' N, 113°49' W), Carstairs (51°34' N, 114°06' W), Lacombe (52°28' N, 113°44' W), Stettler (52°19' N, 112°43' W), Trochu (51°50' N, 113°13' W), Vegreville (53°30' N, 112°03' W), and Westlock (54°09' N, 113°52' W). Each of these trials included nine accessions and 35 commercial cultivars with different levels of scald resistance (Tables 1 and 2). The set of acces-

Table 1. Relative mean percentage of scald severity for barley accessions in 18 field trials in Alberta from 1997 to 1999

Accession	CI no ^x	Disease severity (%) ^y
Abyssinian	668	32
Atlas	4118	37
Atlas46	7323	29
Atlas68	13824	38
Hudson	8067	4
Kitchen	1296	38
Modoc	7566	67
Trebi	936	68
Turk	14400	29

^x Accession number of Cereal Crops Research Branch, ARS, USDA, Beltsville, Maryland.

^y Percent disease severity relative to the mean of three susceptible cultivars: Argyle, Harrington, and Jackson. The mean disease severity for the three susceptible cultivars, 6.0 on a scale of 0 to 9, was considered 100%.

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sions used (Table 1) have the major scald resistance genes (19,20), and these genes have been used for pathotype differentiation in numerous studies (9,19,22,26). Cultivar Atlas 68, an isogenic line of Atlas 46 (15), was used because it displayed differential scald reactions compared with Atlas 46 in previous tests. The commercial cultivars (Table 2) included two- and six-row malt and feed barley types grown in western Canada. All accessions and cultivars were spring types except for Hudson, which is a winter barley. All trials, except for Edmonton in 1998, were established on land where scald of barley occurred in previous seasons to provide a natural source of inoculum. Each test was a randomized complete block design with four replicates for 1997 and 1998 and five replicates for 1999. Seeding was done by planting about 10 seeds to a hill plot with 0.5-m spacing between hills and 1 m between replicates. At growth stage (GS) 40-50 and GS 80-90 (27), disease severity was

assessed visually using a 0 to 9 scale described by Couture (5) and Saari and Prescott (14). This scale assesses diseased leaf area at the bottom, middle, and upper levels of the canopy, where 0 is no disease and 9 represents a plant with greater than 50% of all three levels of the canopy diseased.

For each site and season, disease severity data using the 0 to 9 scale for the nine accessions and 32 commercial cultivars were converted to percentage of disease severity relative to the average of the three susceptible cultivars, Argyle, Harrington, and Jackson. An arcsine transformation was applied to equalize the variance of the percent data for relative disease severity. The transformed data of relative severity for the accessions and for the cultivars were analyzed separately, and analysis of variance was used to determine interactions between accession or cultivar, location, and year. The error variances from the individual experiments were examined for heterogeneity by comparing the ratio of the

largest error variance to the smallest (13). This resulted in four homogeneous groups, accession group 1 and cultivar group 1 (Table 3), and accession group 2 and cultivar group 2 (Table 4), for analysis of variance. Analysis of the group 1 accessions or cultivars included year, location, cultivar or accession, and their interactions, while analysis of the group 2 accessions or cultivars included all effects except for year and its interaction effects. The year factor was not included in accession group 2 and cultivar group 2 because of the lack of replication within year. Accession or cultivar and location were considered fixed effects, while all other factors were considered to be random effects. Because of the mixed model for analysis and imbalanced data sets caused by excluding tests with heterogeneous variances, SAS GLM Type IV sums of squares were used for the analyses (1989, SAS Institute, Cary, NC). The TEST option in the RANDOM statement of the SAS GLM procedure was used

Table 2. Mean percentage of scald severity for 32 commercial barley cultivars relative to the mean of three susceptible cultivars, Argyle, Harrington, and Jackson, in 18 field trials, Alberta, 1997 to 1999

Cluster ^x Cultivar	Field trial site and year																	
	Beav ^y 97	Cal 97	Car 97	Laco 97	Ste 97	Tro 97	Ed 97	West 97	Laco 98	Ste 98	Tro 98	Ed 98	Veg 98	West 98	Car 99	Cal 99	Laco 99	Ste 99
MS																		
ACLacombe	63	89	63	87	69	75	82	80	90	48	66	18	69	80	72	72	73	76
Vantage	68	91	91	85	77	80	80	76	77	73	79	6	69	64	79	79	82	76
Falcon	73	85	93	71	63	77	87	85	65	63	74	6	73	66	60	75	64	44
Stetson	52	87	69	71	79	89	83	98	52	52	82	30	70	73	57	68	77	44
Brier	63	85	71	92	81	84	79	94	81	79	79	36	88	78	79	75	59	69
Tukwa	52	71	84	100	81	86	91	98	73	75	79	30	76	82	64	72	73	62
Steptoe	52	76	97	91	97	89	74	94	77	67	82	12	72	64	83	75	82	69
Bronco	78	98	106	83	81	95	83	85	87	79	84	24	88	89	79	87	77	80
Condor	89	89	88	87	87	93	83	71	92	93	84	36	96	82	64	83	68	80
Husky	73	92	84	87	87	93	88	98	98	83	99	36	82	83	79	79	77	73
Phoenix	73	91	93	80	81	98	91	80	81	75	82	30	88	52	79	61	74	76
Klondike	104	98	86	87	85	95	88	103	65	77	89	36	84	73	83	91	86	84
Melvin	109	91	101	100	99	98	90	107	94	83	89	6	79	82	87	87	73	73
Otal	94	105	75	98	87	91	95	80	90	65	71	12	99	54	83	87	95	80
Mean	82																	
INT																		
CDCEarl	21	89	78	83	54	100	82	40	77	48	105	91	66	31	79	75	91	58
CDCGuardian	0	80	93	80	44	84	75	58	104	62	94	0	93	52	98	87	95	58
CDCRichard	0	74	69	65	58	77	74	31	92	44	87	0	75	49	75	75	86	47
TR239	26	76	47	82	67	84	83	54	87	52	84	0	75	52	72	68	95	58
TR129	0	101	93	92	71	102	87	45	92	73	117	12	84	17	83	106	105	73
Winchester	63	94	75	96	73	100	79	49	90	65	105	24	87	33	94	83	91	51
Mean	69																	
MR																		
CDCDawn	16	71	75	67	67	80	80	27	85	42	84	24	78	45	45	52	55	36
Keystone	10	69	47	78	67	73	58	45	52	42	69	18	66	54	60	64	55	47
Leduc	42	74	45	78	69	68	59	71	71	62	77	30	82	69	72	57	59	55
Vantmore	42	80	47	80	77	91	72	40	40	67	79	24	66	42	60	72	59	51
Johnston	73	83	41	71	77	82	66	54	67	62	69	30	81	71	42	68	55	55
Windsor	120	82	65	62	82	80	66	63	71	63	66	24	70	61	68	64	50	55
CDCDolly	16	72	58	63	75	82	67	49	21	28	64	0	55	52	15	64	41	22
CDCSilky	63	72	86	43	63	91	64	27	65	12	89	18	58	3	60	60	86	51
Duke	47	69	43	71	67	93	53	4	69	32	87	36	64	7	75	72	91	40
Mean	58																	
R																		
ACStacey	10	53	17	34	38	64	45	13	0	24	51	0	12	3	8	8	23	7
Kasota	16	65	43	54	60	70	58	9	8	16	64	24	30	7	11	4	14	7
Seebe	0	62	13	60	48	61	45	0	42	8	46	12	40	40	4	26	14	11
Mean	31																	

^x MS = moderately susceptible; INT = intermediate; MR = moderately resistant; R = resistant.

^y Beav = Beaverlodge; Cal = Calmar; Car = Carstairs; Laco = Lacombe; Ste = Stettler; Tro = Trochu; Ed = Edmonton; Veg = Vegreville; West = Westlock.

to calculate *F* tests for each effect based on an appropriate error term. A complete linkage method of cluster analysis using the Statistical Analysis System (SAS Institute) was carried out to classify the different responses of the 32 commercial cultivars to the scald pathogen as measured by Euclidean distance between the responses (7). This classification of cultivar reactions was used to determine if resistance had been overcome as a result of new virulent pathotypes on resistant cultivars, as evidenced by an increase in disease severity at particular sites or seasons.

The phenotypic diversity of the scald pathogen based on the reactions of 32 commercial cultivars was estimated by Shannon's information statistic (28) as

$$H_o = -\sum_j (f_{ij} / \sum_j f_{ij}) \ln(f_{ij} / \sum_j f_{ij})$$

for all $j = 0, 1 \dots 9$

where f_{ij} is the score of disease severity in the j th category from 0 to 9 for i th cultivar. H_{sy} was the mean of the phenotypic diversity (H_o) over all cultivars at each site and season.

RESULTS

The first assessment at GS 40-50 had low disease severity (1 to 3 based on the 0 to 9 scale); however, significant levels of disease were observed by the second assessment date at GS 80-90. In the second assessment, the average severity level was greater than 4.4 for the mean rating for the three susceptible cultivars, which was adequate to differentiate accession and cultivar reactions and indicated sites where environmental conditions were conducive for scald development. A rating of 4.4 was the minimum level set (Table 5) to arbitrarily select tests for analyses. As a result, analyses were based on the second assessment date from eight sites in 1997, six sites in 1998, and four sites in 1999, with average disease severity for the susceptible cultivars ranging from 4.4 at Lacombe in 1999 to 8.2 at Vegreville in 1998 (Table 5).

The results of the analysis of variance for groups 1 and 2 are presented in Tables 2 and 3, respectively. Since the interaction between location and accessions in group 1 was not significant, but the interaction between year and accession was significant, the three-way interaction between year, location, and the accessions was mainly attributed to the interaction between accession and year. No consistent trends were observed for the three-way interaction (data not presented). This indicated that pathotypes differentiated by the accessions were similar among sites, but the accessions responded differently over years due to variation in environmental conditions. Mean disease levels were highest in 1997 and lowest in 1999. Hudson had the lowest scald rating and was resistant at all locations and in all years (Table 1). Atlas, Atlas 46, Atlas 68, Abyssinian,

Kitchin, and Turk had relative severity values of 40% or less, indicating that the major genes in these accessions were effective against the predominant pathotypes in Alberta. Modoc and Trebi had intermediate disease severity levels (>60%).

For the commercial cultivars, all interactions among year (group 1 only), site, and

cultivar were significant (Tables 3 and 4), indicating that cultivar reactions to scald were dependent on the presence of different pathotypes and environmental conditions among the test sites. Greenhouse inoculations reported in another study (22) confirmed that the scald reactions of commercial cultivars were different from those

Table 3. Results of analysis of variance for relative scald severity for homogeneous group 1 of barley accessions and cultivars in field trials, Alberta, 1997 to 1999

Accession group 1 ^x				Cultivar group 1 ^y			
Source	df	MS	F ^z	Source	df	MS	F ^z
Year (Y)	2	2,784	2.28	Year (Y)	2	969	3.10*
Location (L)	7	6,250	2.98	Location (L)	7	2,945	9.60**
Y × L	4	3,235	7.31**	Y × L	2	153	<1
Rep in Y, L	45	276	1.72**	Rep in Y, L	39	561	4.56**
Accession (A)	7	15,610	3.58*	Cultivar (C)	32	6,274	6.30**
Y × A	14	1,559	4.42**	Y × C	64	470	2.30**
L × A	49	481	1.40	L × C	224	353	1.75**
Y × A × L	28	339	2.11**	Y × C × L	64	202	1.65**

^x Includes 14 trials: Calmar 1997, Lacombe 1997, Stettler 1997, Trochu 1997, Edmonton 1997, Westlock 1997, Lacombe 1998, Stettler 1998, Trochu 1998, Vegreville 1998, Westlock 1998, Carstairs 1999, Calmar 1999, and Stettler 1999.

^y Includes 12 trials: Calmar 1997, Lacombe 1997, Stettler 1997, Trochu 1997, Edmonton 1997, Westlock 1997, Lacombe 1998, Trochu 1998, Vegreville 1998, Calmar 1999, Carstairs 1999, and Stettler 1999.

^z *, ** significant at $P \leq 0.05$ or 0.01 , respectively.

Table 4. Results of analysis of variance for relative scald severity for homogeneous group 2 of barley accessions and cultivars in field trials, Alberta, 1997 to 1999

Accession group 2 ^x				Cultivar group 2 ^y			
Source	df	MS	F ^z	Source	df	MS	F ^z
Location (L)	3	4,945	8.29**	Location (L)	5	24,286	32.44**
Rep in L	12	628	1.67	Rep in L	18	748	1.96**
Accession (A)	8	1,582	4.22**	Cultivar (A)	32	4,066	10.68**
L × A	20	344	<1	L × C	160	850	2.23**

^x Includes four trials: Beaverlodge 1997, Carstairs 1997, Edmonton 1998, and Lacombe 1999.

^y Includes six trials: Beaverlodge 1997, Carstairs 1997, Stettler 1998, Edmonton 1998, Westlock 1998, and Lacombe 1999.

^z *, ** significant at $P \leq 0.05$ or 0.01 , respectively.

Table 5. Mean scald severity for the three susceptible cultivars and Shannon's information statistic for each test site and year

Year	Site	Mean severity of three susceptible cultivars ^x	Resistance status ^y	Shannon's statistic ^z
1997	Beaverlodge	4.8	—	0.074
1997	Calmar	6.8	+	1.340
1999	Calmar	5.3	+	1.104
1997	Carstairs	5.8	—	1.247
1999	Carstairs	5.3	+	1.064
1997	Edmonton	7.8	+	1.339
1998	Edmonton	5.5	—	0.095
1997	Lacombe	6.9	+	1.305
1998	Lacombe	6.5	+	1.169
1999	Lacombe	4.4	+	1.150
1997	Trochu	5.5	+	1.322
1998	Trochu	4.9	+	1.354
1997	Stettler	6.3	—	1.276
1998	Stettler	6.3	—	1.105
1999	Stettler	5.5	—	1.060
1997	Westlock	5.6	—	1.079
1998	Westlock	7.2	—	0.098
1998	Vegreville	8.2	+	1.261

^x Mean disease severity of three susceptible cultivars, Argyle, Harrington, and Jackson, measured using a 0 to 9 scale.

^y — resistance held up; + resistance overcome in cultivars classified in the intermediate reaction group as determined by cluster analysis.

^z Shannon's information statistic for phenotypic diversity.

of the accessions used as differentials and that there were significant differences in pathotype frequency among locations.

At a distance of 1.4 for relative disease severity based on cluster analysis, the scald reaction of commercial cultivars can be classified into four major groups consisting of three resistant (R), nine moderately resistant (MR), six intermediate (I), and 14 moderately susceptible cultivars (MS) (Fig. 1, Table 2). The cultivars in each group were similar in scald reaction. Cultivars

AC Stacey, Kasota, and Seebe were grouped together with a mean of relative disease severity of 31% (Table 2). The MR, I, and MS groups joined each other at a distance level of 1.5, and these three groups joined the R group at 2.5 (Fig. 1). This indicated that there was a greater difference in scald reaction between the resistant group and the remaining three groups, compared with differences among the MR, I, and MS groups. Cultivars in the MR group had a relative mean disease

severity of 58%. The majority of the commercial cultivars evaluated had intermediate to moderately susceptible reactions with relative mean disease severity values ranging from 69 to 82%. In the intermediate group, a few cultivars, including CDC Earl at Trochu in 1997 and 1998, CDC Guardian at Lacombe in 1998, TR129 at Calmar in 1997 and 1999, at Trochu in 1997 and 1998, and at Lacombe in 1999, were as susceptible as the three susceptible cultivars, Argyle, Harrington, and Jackson (Table 2).

Fig. 1. Hierarchical classification of 32 commercial barley cultivars based on relative scald severity in relation to the mean of three susceptible cultivars using the complete linkage method of cluster analysis.

Cultivars in the intermediate group were first classified as resistant (1) when registered for commercial production and were similar in scald reaction to resistant cultivars, including AC Stacey, Kasota, and Seebe. However, cultivars in the intermediate group in the current study were subsequently found to have intermediate or susceptible reactions in commercial fields and small plot trials (21,23). The reactions of the intermediate group were chosen to determine if the breakdown of resistance had occurred at a particular site. For each site and year, if the value for relative mean disease severity in the intermediate group was equal to or higher than the relative mean severity in the moderately susceptible group, cultivar resistance was considered to have been overcome as a result of the occurrence of new virulent pathotypes at that site and season. Based on this criterion, virulent pathotypes that attacked cultivars in the intermediate group occurred at Calmar in 1997 and 1999, Carstairs in 1998, Lacombe in 1997 to 1999, Trochu in 1997 and 1998, Vegreville in 1998, and Edmonton in 1997. Virulent pathotypes did not occur at Beaverlodge in 1997, Carstairs in 1997, Edmonton in 1998, Stettler in 1997 to 1999, or Westlock in 1997 and 1998 (Tables 2 and 5). Cultivars at Beaverlodge, Stettler, and Westlock showed no sign of resistance breakdown during the study period.

Based on disease reaction data, Shannon's information statistic indicated that on average from 1997 to 1999, populations of *R. secalis* at Beaverlodge, Stettler, and Westlock were less diverse than those at the other locations (Table 5). Phenotypic diversity of populations of *R. secalis* was greater at Edmonton and Westlock in 1997 compared with 1998, reflecting the difference in frequency and composition of *R. secalis* populations and the influence of environmental conditions.

DISCUSSION

The majority of test sites were established on land with scald-infested barley stubble and without artificial inoculation, which resembled conditions in commercial barley fields in Alberta. The host/pathogen system for barley/*R. secalis* was evaluated under conditions where the cultivars were likely exposed to multiple pathotypes, and where both qualitative and quantitative resistance genes, if present, were fully tested and expressed and adult plant resistance was able to be determined. The tests at multiple sites and seasons allowed comparison and determination of spatial and temporal variation in pathogen virulence under natural conditions that were similar to those for commercial barley production. Multi-season and -site tests can confound the effects of environment, as well as host, on the shifts in pathotypes of *R. secalis*. In the present study, only those sites with an average severity level greater than 4.4 for

the mean rating for the three susceptible cultivars from the second assessment date were used for the analyses, which reduced the impact of environmental variation among sites by assuring that environmental conditions were conducive for scald development. In addition, the effects of environment and cultivars on pathotypes were estimated using the analysis of variance. The potential impact of the environment can also be removed by the use of artificial inoculation under controlled environmental conditions. A previous greenhouse study in which 256 isolates of *R. secalis* from the same sites and years used for the current study were inoculated on a set of differentials demonstrated that there were significant differences in pathotype diversity and complexity among locations in Alberta (22). Isolate virulence was most diverse at the Calmar site compared with the other sites. Edmonton and Lacombe were similar in pathogen variability, and these two sites were significantly more diverse compared with Beaverlodge, Carstairs, Stettler, and Westlock, which had the lowest diversity of pathotypes of *R. secalis*. Isolates at the Trochu and Vegreville sites had intermediate levels of diversity in virulence.

Based on restriction fragment length polymorphism (RFLP) markers, a population of 265 isolates of *R. secalis* from different locations in Australia differed significantly in allele frequency and genotype diversity (10). Similarly, gene flow among the populations of *R. secalis* sampled from Idaho and Oregon was considered to be limited because there was strong geographic differentiation among the pathotypes and in the virulence frequencies in different locations (8). No obvious relationship was observed between virulence pattern and geographic origin among 38 isolates from various areas of Denmark (9). It appears that the number of isolates used and the size of the geographic areas studied contributed to different results when determining the relationship between pathotype composition and geographic locations. Multiple infection cycles by *R. secalis* during a growing season are primarily through the production of splash-dispersed conidia (16). Scald develops mainly between adjacent plants, and infection loci occur several meters away from the source of inoculum (3). Splash-dispersed transmission tends to localize pathotype development compared with diseases with windborne inoculum, such as powdery mildew and rust (8).

Differences in scald reactions for commercial cultivars among locations, as indicated by significant interactions and the localization of pathotypes demonstrated in a previous greenhouse study (22), indicate an uneven distribution of pathotypes of *R. secalis* in Alberta. Consequently, the selection of cultivars grown by producers in a particular area may be important when trying to use disease resistance for scald

management. For example, cultivars in the intermediate group should not be grown at Edmonton, Calmar, Carstairs, Lacombe, Trochu, or Vegreville, where virulent pathotypes that are able to overcome the resistance in these cultivars are present. Cultivars in the moderately resistant group also showed relatively high levels of scald at these sites, so crop rotation, where appropriate, also should be used to slow the appearance and increase of virulent pathotypes. These recommendations serve only as a general guide for scald management in Alberta. Monitoring of individual fields by producers will be important for determining which resistant cultivars are still effective against the pathotypes of *R. secalis* in their local area. Producers will need to consider using different sources of resistance where higher than expected disease levels are encountered in previously resistant cultivars.

The present study classified several western Canadian cultivars, including CDC Earl, CDC Guardian, TR123, and Winchester, into one cluster, indicating that the genetic basis for scald resistance in these western Canadian cultivars may be similar. These results are in agreement with those obtained by Penner et al. (12). In contrast, in the present study, Hudson and Atlas were resistant, but the four western Canadian cultivars, which were considered by Penner et al. (12) to be similar in scald reactions to Hudson, were intermediate to moderately susceptible. The discrepancy between the two studies may reflect the development of new pathotypes that caused differences in scald reactions. While there was similarity in scald reactions among barley cultivars between the present study and a study in 1993 (25), the cultivars CDC Earl, CDC Guardian, AC Lacombe, Brier, Falcon, and Tukwa were more susceptible in the present study. Most of these cultivars were registered for commercial production between 1991 and 1993, except for Brier, which was registered in 1988 (6). With the time needed to increase seed stocks, these cultivars were not widely available for commercial production for 2 to 3 years after registration. Thus, the resistance in most of these cultivars only remained effective for 1 to 4 years after being widely available for commercial production by farmers. Breakdown of resistance in newly released cultivars has also been observed in eastern Canada (26). Consequently, because of the rapid appearance of virulent pathotypes, it is necessary to monitor changes in the composition and frequency of pathotypes of *R. secalis* for breeders, pathologists, and farmers to effectively utilize the most resistant cultivars. The scald resistance in some accessions and cultivars has remained stable. For example, the resistance in Abyssinian, Hudson, Atlas 46, Atlas 68, Kitchin, Turk, AC Stacey, Kasota, and Seebe remained effective over all test sites

and years. Other cultivars in the resistant and moderately resistant groups may also be useful for breeding durable resistance. For example, cv. Leduc has been shown to be tolerant to scald with minimum yield reductions over a 3-year field test (23), and CDC Dolly has been considered to possess a slow-scalding characteristic (18).

The diversity of pathogen virulence was determined using commercial cultivars instead of accessions. This was based on the consideration that the diversity of pathogen virulence is likely a function of the commercial cultivars that have been grown at a particular site. Calmar and Lacombe have been used at a barley breeding location and a scald nursery, respectively, where numerous barley genotypes have been planted and screened for resistance. Selection toward more pathotypes with complex virulence may have arisen at Calmar and Lacombe from unidentified resistance genes in the local cultivars and breeding lines. Trochu and Stettler have also been used as barley breeding sites, but received a half to two-thirds less rainfall compared with Calmar and Lacombe during the growing seasons of 1997 to 1999 (Environment Canada, data not presented). Virulent pathotypes occurred at Trochu that overcame cultivar resistance at this site, but not at Stettler during the course of this study. A preliminary study in 2000 and 2001 at Stettler showed that resistant cultivars, such as CDC Guardian and CDC Earl, tended to increase their level of susceptibility (K. Xi, unpublished data).

The population of *R. secalis* was more diverse at Edmonton in 1997 than in 1998, but the tests were conducted at different sites each season. The plots in 1997 were established on land where scald-infested barley stubble was retained, whereas those in 1998 were on the land without scald-infested stubble. Thus, the substantial change in diversity at Edmonton likely reflected the difference in the potential number of pathotypes available for these two sites. Lower disease ratings on the resistant cultivars at Beaverlodge, Stettler, and Westlock likely indicated that these sites lacked many of the virulent pathotypes that were commonly found at other sites. These results were supported by a greenhouse study (22) in which four to eight pathotypes were identified at Beaverlodge, Stettler, and Westlock, but one pathotype that was only virulent on the susceptible cultivar Harrington predominated. Breakdown of cultivar resistance, as indicated by higher disease ratings, occurred at Calmar, Edmonton, Lacombe, Trochu, and Vegreville, where 9 to 16 pathotypes were identified that were virulent on up to 7 of 12 differentials (22). At

the Carstairs site, where resistance appeared to be overcome based on scald reactions from the present study, only five pathotypes were identified in the previous study (22). Overall, the cultivar resistance that was evaluated tended to break down more readily at those sites where a greater diversity of pathotypes occurred. Shannon's information statistic was significantly correlated with mean percent relative disease severity for the 32 commercial cultivars ($r = 0.83$, $P = 0.01$), suggesting that under the current test conditions, disease severity was a measure of the diversity of the populations of *R. secalis*.

The considerable variability of *R. secalis* in response to cultivar resistance in Alberta requires ongoing monitoring of the development and changes of pathotypes in commercial fields. Furthermore, as new cultivars are registered each year, the commercial cultivars evaluated in the present study may not represent the newer genotypes grown in Alberta. As a consequence, newly registered cultivars should be evaluated to update information on their scald reactions over a range of sites and years. Further studies using more accessions with additional genes may also be needed to facilitate ongoing assessment of pathotype variation and identification of novel sources of resistance.

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