Sources of Resistance to Pathotype QCC of *Puccinia graminis* f. sp. *tritici* in Barley

Yue Jin,* Brian J. Steffenson, and Thomas G. Fetch, Jr.

**ABSTRACT**

The occurrence of a wheat stem rust (*Puccinia graminis* Pers.:Pers. *f. sp. tritici* Eriks. & E. Henn.) pathotype (Pgt-QCC) with virulence for the *Rpg* gene in barley (*Hordeum vulgare* L.) necessitated the search for resistant barley germplasm. From preliminary screenings of over 18,000 barley accessions, 13 lines were identified as possessing resistance to pathotype QCC: ‘Diamond’, ‘Hietpas 5’, Q21861, PC 11, PC 84, PC 249, PC 250, CI 5541, PI 452,406, PI 452,421, PI 477,845, PI 477,854, and PI 477,860. This study was conducted to further characterize the reaction of the selected lines to pathotype QCC. The reaction was assessed by evaluating infection types at the seedling stage and infection responses at the adult plant stage in the greenhouse, and by evaluating disease severity and infection responses at the adult plant stage in the field compared to susceptible cultivars. Most lines exhibited low to intermediate infection types at the seedlings stage and moderately resistant to moderately susceptible infection responses at the adult plant stage in the greenhouse experiments. Among the selected lines, Q21861 exhibited the highest level of resistance at both the seedling and adult plant stages. These lines may provide an adequate level of resistance to pathotype QCC for cultivar development.

In cultivated barley, three genes are known to confer resistance to *P. graminis* f. sp. *tritici*, the wheat stem rust pathogen: *Rpg* derived from cultivars Chevron (CI 1111) (Shands, 1939), Peatland (CI 5267) (Powers and Hines, 1933), and Kindred (CI 6969) (Steffenson, 1992); *Rpg* from line ‘Hietpas 5’ (CI 7124) (Patterson et al., 1957); and *Rpg* from line PI 382,313 (Jedel, 1990). Of the three described stem rust resistance genes, only *Rpg* has been used to any extent in breeding programs. This gene confers resistance to a number of stem rust pathotypes (Immer et al., 1943) and has been incorporated into most commercial barley cultivars of the northern Great Plains (Steffenson, 1992). The widespread use of *Rpg* in breeding programs has resulted in a high level of genetic uniformity for stem rust resistance in barley. In 1989, the vulnerability of this gene deploy-


Field Evaluations

Field nurseries were established at Fargo and Langdon, ND, in 1991 and 1992. Barley accessions were planted in hill plots (10–20 seeds per hill) in 1991 and in 1.3-m rows in 1992. Experiments were arranged in a randomized complete block design with four replications. Robust was used as a spreader row for pathotype QCC in the nurseries and was planted 10 to 14 d prior to the seeding date of the test entries. The nurseries were planted with a four-row center planter, with test entries in the middle two rows and spreader plants in the outer rows. At each location, test entries were planted 15 to 20 d later than the recommended commercial planting date for barley to increase the chance for a natural stem rust epidemic. To augment the level of rust infection in the nurseries, test entries were inoculated withuredinisporas from Robust spreader plants in the same nurseries when most of the test entries were between the late boot and early heading stages of development. Uredinisporas were suspended in a light weight mineral oil (Soltron 170, Phillips Petroleum, Borger, TX) at a concentration of 200 mg uredinisporas per 500 mL oil and inoculated with a Microprayer (Micron Sprayers, Bromyard, UK) onto plants at a rate of approximately 1 mL per hill or 4 mL per short row. The stem rust on Robust spreader plants was identified to be pathotype QCC based on the reaction of the winter wheat cultivar McNair 701 (Cl 15208). This cultivar is resistant to pathotype QCC (exhibits low infection types) and susceptible to other common pathotypes in the Great Plains.

Infection response and disease severity (percentage of leaf sheath and stem area infected by rust) were assessed on each line between the soft and hard dough stages of development by the scales of Stubbs et al. (1986). The lowest, highest, and most common types of infection responses and estimated average rust severity were recorded on 20 to 30 randomly selected tillers in each hill or row plot. Tests for homogeneity of variance were nonsignificant between experiments; thus, rust severity data were pooled over locations and years for the analysis of variance and mean separation tests. Pathotypes of *P. graminis* f. sp. *tritici* present in each nursery were determined based on the seedling reaction of McNair 701. In the second year of the study, McNair 701 was planted in each nursery to monitor the presence of other pathotypes.

Greenhouse Evaluations

For seedling evaluations, four seeds of each line were sown in a plastic cone filled with a 3:1 peat moss:perlite mixture. Each cone represented an experimental unit and treatments were replicated three times in a completely randomized design. Plants were grown in a greenhouse at 22 ± 3 °C with 12-h photoperiod. Seedlings were inoculated with pathotype QCC when the primary leaves were fully expanded (about 1 wk after planting). These inoculations were made using a concentration of 6.0 mg uredinisporas per mL oil applied at an approximate rate of 2 μL oil per plant. For adult plant evaluations, three to four seeds were sown in a clay pot (15-cm diam.) filled with the peat moss:perlite mixture and were grown at 22 ± 3 °C in a greenhouse. Each pot represented an experimental unit and treatments were replicated four times in a randomized complete block design. Plants were inoculated when the main tiller was between the flowering to water rip stages of development. A rate of approximately 2 mg uredinisporas per 80 μL oil was applied to the upper three internodes of each plant. After inoculation, plants (both seedling and adult) were incubated in an enclosed chamber where the humidity was maintained near saturation for 16 h at 21 °C in the dark. Then, the plants were exposed to light (160–230 μmol photon m⁻² s⁻¹) and allowed to dry for 4 h before being placed in a greenhouse.

Seeding plants were incubated in greenhouses at two temperature regimes (23 ± 5 °C and 20 ± 3 °C) with a 12-h photoperiod supplied by sodium vapor bulbs (430 W bulbs emitting 230–270 μmol photon m⁻² s⁻¹). Infection types were assessed on seedlings 12 d after inoculation using a rating scale based on the system of Stakman et al. (1962) as modified by Steffenson et al. (1993) for barley. Low infection types (0, 0-, 1, 2, or combinations thereof) were considered indicative of host resistance, whereas high infection types (3 and 4) were considered indicative of host susceptibility (Jin et al., 1993; Steffenson et al., 1993). Symbols + and − were used to denote more or less sporulation, respectively. Adult plants were incubated in greenhouses at 23 ± 5 °C under the same lighting conditions as described for the seedling tests. Infection responses (size and type of uredinia) were assessed on the leaf sheaths, stems, and peduncles of adult plants 18 to 20 d after inoculation by the scale of Stubbs et al. (1986).

RESULTS

The level of stem rust infection in the field varied among locations and years. Infection was low in the Langdon nursery (10–20% on Robust checks), moderately high in the Fargo nursery in 1991 (40–70% on...
### Table 2. Adult plant infection response (IR), seeding infection type (IT), and terminal stem rust severity of barley lines to pathotype QCC of *Puccinia graminis* f. sp. *tritici* evaluated in the field and greenhouse in 1991 and 1992.

<table>
<thead>
<tr>
<th>Line</th>
<th>Adult IR†</th>
<th>Disease severity(%)‡</th>
<th>Seeding IT§</th>
<th>Greenhouse evaluations</th>
<th>Adult IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robust</td>
<td>S (MS/S)</td>
<td>40.0 a†</td>
<td>2.1(1,2,2,3-)</td>
<td>S (MS/S)</td>
<td></td>
</tr>
<tr>
<td>Steptoe</td>
<td>S (MS/S)</td>
<td>40.0 a</td>
<td>3.3(2,3,3-)</td>
<td>S-MS (MS/S)</td>
<td></td>
</tr>
<tr>
<td>Q21861</td>
<td>MR (R/S)</td>
<td>3.6 b</td>
<td>1.0(2,2,3-)</td>
<td>R-MR (R/S)</td>
<td></td>
</tr>
<tr>
<td>Diamond</td>
<td>MR-MS (MR/S)</td>
<td>5.9 b</td>
<td>2.1(1,2,2,3-)</td>
<td>MR-MS (R/S)</td>
<td></td>
</tr>
<tr>
<td>Hietpas 5</td>
<td>MS-S (MR/S)</td>
<td>5.8 b</td>
<td>2.3(2,3,3-,-2)</td>
<td>0-MS (0/S)</td>
<td></td>
</tr>
<tr>
<td>PC 11</td>
<td>MR-MS (R/S)</td>
<td>4.2 b</td>
<td>1.2(1,2,3,3-)</td>
<td>R-MR (R/S)</td>
<td></td>
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<tr>
<td>PC 84</td>
<td>MR-MS (R/S)</td>
<td>7.3 b</td>
<td>2.3(1,2,2,3-)</td>
<td>R-MR (R/S)</td>
<td></td>
</tr>
<tr>
<td>PC 249</td>
<td>MR-MS (R/S)</td>
<td>3.6 b</td>
<td>2.1(1,2,2,3-)</td>
<td>MR-MS (MR/S)</td>
<td></td>
</tr>
<tr>
<td>PC 250</td>
<td>MR-MS (R/S)</td>
<td>3.4 b</td>
<td>2.1(1,2,2,3-)</td>
<td>MR-MS (MR/S)</td>
<td></td>
</tr>
<tr>
<td>CI 5541</td>
<td>MS-S (MR/S)</td>
<td>4.5 b</td>
<td>1.2(1,2,-2,3)</td>
<td>MR-MS (MR/S)</td>
<td></td>
</tr>
<tr>
<td>PI 452406</td>
<td>MS-MR (R/S)</td>
<td>7.4 b</td>
<td>2.3(1,2,-2,3)</td>
<td>MS (MR/S)</td>
<td></td>
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<tr>
<td>PI 452421</td>
<td>MS-MR (R/S)</td>
<td>9.0 b</td>
<td>2.3(1,-2,3,-2)</td>
<td>MR-MS (R/S)</td>
<td></td>
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<tr>
<td>PI 477843</td>
<td>MR-MS (R/S)</td>
<td>5.9 b</td>
<td>2.3(2,3,-2)</td>
<td>MR-MS (MR/S)</td>
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<tr>
<td>PI 477854</td>
<td>MR-MS (R/S)</td>
<td>6.9 b</td>
<td>2.3(2,3,-2)</td>
<td>MR-MS (MR/S)</td>
<td></td>
</tr>
<tr>
<td>PI 477860</td>
<td>MR-MS (R/S)</td>
<td>6.9 b</td>
<td>2.3(2,3,-2)</td>
<td>MR-MS (MR/S)</td>
<td></td>
</tr>
</tbody>
</table>

† Infection responses (IRs) (size and type of uredinia) were used to characterize the reaction of barley lines to the stem rust pathogen at the adult plant stage where, 0 = immune, R = resistant, MR = moderately resistant, MS = moderately susceptible, and S = susceptible following the rating scale of Stubbs et al. (1986). The one or two most common IRs observed on a line were listed first in order of prevalence followed by the lowest and highest IRs in parentheses.

‡ The mean disease severity was based on 16 observations, and each observation was obtained as an average of estimates from 20 to 30 tillers in a plot from the Fargo and Langdon nurseries in 1991 and 1992.

§ Infection types (ITs) (size and type of uredinia) were used to characterize the reaction of barley lines to the stem rust pathogen at the seedling stage. Low ITs (0, 0, 1, and 2) were considered indicative of resistance and high ITs (3, 4) of susceptibility following a system modified from Stakman et al. (1962). Symbols + and – denoted more or less sporulation of uredinia, respectively. The two most common ITs observed on a line were listed first in order of prevalence followed by the lowest and highest in parentheses.

Means followed by the same letter were not significantly different at P = 0.05 using Duncan’s new multiple range test.

Robust), and moderate in both nurseries in 1992 (20–40% on Robust). Pathotype determinations of 20 stem rust collections from Steptoe and Robust at each location in 1991 indicated that QCC was the only pathotype present in the nurseries. In 1992, no susceptible infection types were observed on McNair 701 in either of the two nurseries, indicating that QCC was the primary pathotype present.

The reactions of 15 barley lines (including checks) to pathotype QCC in the field are given in Table 2 (columns 2 and 3). Robust and Steptoe exhibited mostly susceptible infection responses, whereas most of the other lines exhibited moderately resistant to moderately susceptible infection responses. Moderately susceptible to susceptible infection responses were observed on Hietpas 5 and CI 5541. Q21861 exhibited the lowest infection response (moderately resistant), but the range was within that of most other lines. The range of infection responses overlapped among the lines because compatible uredinia occurred frequently on the peduncle and near the uppermost node on most lines, including Q21861. Mean disease severity on each of the 13 selected lines was significantly lower than on Robust and Steptoe. No significant difference for mean disease severity was detected among the 13 lines.

A wide range of infection types was observed on lines at the seedling stage (Table 2 columns 4 and 5). Intermediate infection types (2 to 3-) predominated on lines Hietpas 5, PC 84, PI 452406, PI 452421, PI 477843, PI 477854, and PI 477860, whereas low infection types (1 to 2) predominated on lines Diamond, PC 11, PC 249, PC 250, and CI 5541. The infection types on Q21861 were distinctly lower (0; to 1) than on all other lines. Robust also exhibited low infection types at the seedling stage even though it is considered susceptible to pathotype QCC at the adult stage of development. Infection responses on adult plants in the greenhouse experiments generally corresponded to those observed in the field. A few lines, Q21861, PC 11, PC 84, and CI 5541, exhibited lower infection responses (resistant to moderately resistant) in the greenhouse than in the field.

**DISCUSSION**

Evaluations of more than 18,000 accessions of cultivated barley and several wild barley species indicated that the frequency of resistance in *Hordeum* to pathotype QCC is very low. Of the 13 lines selected from preliminary germplasm evaluations, none possessed complete resistance to pathotype QCC (Table 2). A high degree of variation for disease reaction was observed in *H. vulgare*, but only a few lines exhibited levels of resistance that were considered sufficient for use in breeding programs. Q21861 exhibited the highest level of resistance to pathotype QCC among the 13 selected lines. This line also possesses resistance to several pathotypes of the wheat stem rust pathogen in Australia (Dill-Macky et al., 1992). Although Q21861 consistently exhibited a relatively high level of resistance in our experiments, severe stem rust infection was observed on this line in Brandon, Manitoba, in 1992 (W.G. Legge and D.E. Harder, 1992, personal communication). The reason for this discrepancy is unclear.

The ontogenetic expression of stem rust resistance can vary in different barley accessions. This was not thought to be a major factor in this study since most of the lines were similar in growth stage at the time of evaluation for terminal disease severity in the field. Environmental conditions, especially incubation temperature, can also affect the expression of resistance in barley to stem rust (Steffenson, 1992; Steffenson et al., 1993). Line Q21861 exhibited mostly susceptible infection types to pathotype
QCC at the seedling stage when incubated at a temperature greater than 27 °C (J.D. Miller, 1992, personal communication). Similar results were observed on all other selected lines in this study. The temperature sensitivity of resistance gene(s) in these lines may have contributed to the variable stem rust reactions observed in the field and greenhouse experiments.

Our preliminary data (Y. Jin and B.J. Steffenson, 1992, unpublished) indicate that resistance to pathotype QCC in Q21861, Diamond, Hietpas 5, PC 11, PC 84, and CI 5541 is simply inherited. Further studies are needed to genetically characterize these sources of resistance and their reaction to other pathotypes of *P. graminis* f. sp. *tritici*. If one or more genes for resistance to pathotype QCC is incorporated into cultivars already possessing *Rpg1*, possible losses in barley to stem rust should be averted.

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