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Temporal progression of common root rot [*Cochliobolus sativus*] lesions on subcrown internodes of wheat and barley cultivars

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The temporal progression of common root rot [*Cochliobolus sativus*] lesions on individual subcrown internodes of three wheat (Cypress, Neepawa and 680-1) and two barley (Galt and Bonanza) cultivars was measured in growth chamber tests. The vertical spread of lesions was much faster than the lateral spread, and generally lateral spread began after maximum vertical extension. Lesion development progressed faster in barley than in wheat. Comparisons of cultivars according to mean number of days required to attain maximum vertical lesion length, mean daily rates of linear development, percentage disease ratings, and probabilities of plants becoming infected and of infected plants being progressively transferred from less to more severe disease categories indicated that Cypress was the most susceptible of three wheats and 680-1 the least. Of the two barleys tested, Galt was more susceptible than Bonanza. The possible application of this technique to screening lines for resistance is discussed.

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Au cour d'expériences conduites en chambre de croissance, l'auteur a observé le développement des lésions du piétin commun, causées par *Cochliobolus sativus*, sur les entrenoeuds situés sous la couronne chez les variétés de blé Cypress, Neepawa et 680-1, et d'orge Galt et Bonanza. L'invasion verticale des lésions sur les entrenoeuds situés sous la couronne est plus rapide que l'invasion horizontale; normalement, l'invasion dans le sens horizontal ne commence pas avant que l'infection n'ait atteint sa pleine extension dans le sens vertical. La diffusion des lésions chez l'orge fut plus rapide que chez le blé. Les variétés ont été comparées par cinq méthodes: le nombre de jours moyen pour atteindre la pleine extension des lésions verticales, la moyenne quotidienne du taux d'expansion verticale de la lésion; l'intensité de l'infection exprimée en pourcentage, la probabilité que les plantes deviennent infectées, ainsi que la probabilité que les plantes passent d'une catégorie d'infection moins forte à plus forte entre les périodes d'observation. Ces comparaisons ont indiqué que la variété de blé Cypress fut la plus susceptible et que 680-1 fut la moins susceptible. Egalement, la variété d'orge Galt s'est révélée plus susceptible que Bonanza. L'application potentielle de ces méthodes pour évaluer la résistance à cette maladie chez des lignées de blé et d'orge est discutée.

Common root rot is a widespread and important disease of wheat and barley in western Canada (2, 4). Canadian spring wheat and spring barley cultivars differ considerably in their resistance to *Cochliobolus sativus* (Ito & Kurib.) Drechsl. ex Dastur [imperfect state: *Bipolaris sorokiniana* (Sacc. in Sorok.) Shoem. (Syn. *Helminthosporium sativum* P.K. and B.)], the main causal organism of the disease (1, 3, 5). The incidence and severity of lesions on subcrown internodes has been used to measure disease intensity and the relative resistance of cultivars (1, 3, 5).

The resistance of various cultivars is commonly based on disease intensity data collected only at the end of the season. Generally disease intensity is based on the percentages of plants in four qualitative disease categories, namely, clean (CL), slight (SL), moderate (MO), and severe (SE) (2, 3, 5, 6). Such data, however, fail to provide any information regarding the length and rate of development of subcrown internode lesions, and relative frequencies of plants changing from less to more severe disease categories during the season. All of these processes are important in comparative epidemiology. In the present study the temporal progression of subcrown internode lesions on individual plants of some wheat and barley cultivars was followed to compare various epidemiological aspects of disease development.

Materials and methods

General. The procedures for growing plants, preparing inoculum, inoculating plants, and recording observations were generally the same as reported previously (7). Seeds of Cypress, Neepawa, and 680-1 wheat (*Triticum aestivum* L.), and Galt and Bonanza barley (*Hordeum vulgare* L.) were surface sterilized in 10% Javex (0.6% sodium hypochlorite) and sown on autoclaved Sutherland clay loam soil in 18 cm pots. The seeds were covered with autoclaved vermiculite to a depth of 5 cm to promote formation of long subcrown internodes. Experiments were conducted in growth chambers maintained under 16 h day (40 000 lux) with day-night temperatures of 19 and 15°C, respectively. There were 50 plants of each cultivar in the first trial and at least 25 plants in each of two subsequent trials. There were 5 plants per pot in all trials.

Fourteen days after seeding the vermiculite was removed, the coleoptile severed, and the plants

inoculated by placing a 5 mm long infested split straw, from a 30 days old culture, around the base of the subcrown internode. The straws were removed after 4 days and subcrown internodes remained exposed for the duration of the experiment. Each plant was staked, numbered and the length of developing subcrown internode lesions measured every 4th day until plant maturity. In addition, on each observation date, the plants were classified into CL, SL, MO and SE disease categories according to the procedure of Verma et al. (6). When the maximum possible vertical lesion length (i.e. lesion covering entire length of subcrown internode) was attained, only the disease category was recorded until termination of the experiment.

Daily rates of linear extension. Since all inoculated plants of a cultivar did not show symptoms at the same time, lesion measurements for an individual plant were adjusted to a common starting time (day zero) calculated as 4 days prior to the first appearance of symptoms. From this common starting time, mean daily rates of vertical lesion length per plant (= [total subcrown internode length infected/number infected plants]/4 [days between observations]) were calculated for each subsequent observation date. Plants that had developed the maximum possible lesion length were not included in the calculations for the subsequent dates. Values for only 12 of 16 observation dates (i.e. 48 days from first date of symptom expression) are presented here, because the values for later dates were based on progressively fewer plants. A detailed description of the entire procedure was reported previously (7).

Percent disease ratings. The overall disease intensity expressed as percent disease ratings refers to the product of the disease severity and the percentage of plants infected. Using numerical values of 0, 1, 2, and 4, respectively, for CL, SL, MO, and SE categories, percent disease ratings (% DR) for each observation date were calculated using the following formula: $\%DR = ([\%SL \times 1] + [\%MO \times 2] + [\%SE \times 4])/4$.

Relative frequencies and probabilities of changes in disease category. Probabilities of plants both becoming infected and being transferred into progressively more severe disease categories (i.e. CL to SL to MO to SE) during the intervals between observations were calculated using a transfer matrix method described previously (7). In this method, change in the disease severity category for each individual plant between observation dates was recorded in a matrix. The number of frequency matrices for each cultivar in the three separate tests were 16, 15, and 16, respectively, which correspond to the number of observation dates. An overall frequency transfer matrix (OFTM) for a cultivar in a test was then obtained by totalling the values of all individual frequency matrices. The values in an OFTM indicated the relative frequency of changes to more severe disease categories during the entire test period. Probabilities of each type of interval change in an OFTM were then calculated by dividing the total of any matrix cell by the row total in the matrix. The overall probability values for disease category changes in single time intervals were calculated from an OFTM derived by combining the appropriate values of the OFTM of all three tests.

Results

Maximum lesion length. The spread of the lesion was much faster in the vertical than in the lateral axis of the subcrown internode in both wheat and barley cultivars, and generally the lesions extended the entire length of the subcrown internode on one side before progressing laterally. The maximum possible lesion length was attained in 78 to 85% of the infected plants, and these were the only plants included in the calculation of this variable (Table 1). For wheat the mean number of days required for lesions to cover the entire length of the subcrown internode was 27 for Cypress as compared to 23 for both Neepawa and 680-1; the subcrown internode length of Cypress is considerably greater than that of Neepawa and 680-1. Both barley cultivars required the same amount of time to attain maximum lesion length.

Daily rates of linear extension. The mean daily rates of linear growth of subcrown internode lesions for all adjusted interval observations were considerably higher in Cypress wheat than in Neepawa and 680-1; rates did not differ considerably between Neepawa and 680-1 (Table 2). In the two barley cultivars, the rates generally were slightly higher in Galt than in Bonanza, especially for the first four observation periods. The overall mean daily rates showed that internode lesions in Cypress grew linearly at the rate of 1.16 mm a day compared

Table 1. Percent infected plants attaining maximum lesion length, mean subcrown internode length, and mean number of days required for subcrown internode lesions to reach maximum length in five cereal cultivars (means of three tests)

Cultivar	% infected plants attaining maximum lesion length	Mean subcrown internode length (mm)	Mean number days for maximum lesion length
Cypress	78	37	27
Neepawa	85	20	23
680-1	78	21	23
Galt	81	31	21
Bonanza	82	28	21

Table 2. Mean daily rates (mm) of linear growth of subcrown internode lesions (means of three tests)

Adjusted interval observations	Cypress	Neepawa	680-1	Galt	Bonanza
1*	0.72	0.56	0.65	1.06	0.87
2	1.25	0.71	0.77	1.73	1.51
3	1.29	0.95	0.90	1.65	1.20
4	1.35	0.87	0.80	1.30	1.21
5	1.31	0.42	0.70	0.81	1.02
6	1.09	0.80	0.50	0.73	1.01
7	1.28	0.90	0.71	0.70	0.83
8	1.14	0.55	0.49	0.60	0.57
9	1.12	0.28	0.95	0.82	0.76
10	0.74	0.56	0.14	0.79	1.03
11	1.15	0.41	0.21	1.00	0.57
12	1.50	0.17	0.60	0.81	0.92
Overall mean	1.16	0.60	0.62	1.00	0.96

*Measurements were taken every 4th day. Therefore adjusted interval observation nos. 1, 2, 3, 4, and so on represent 4, 8, 12, and 16 days respectively after first day of symptom expression.

to only 0.60 and 0.62 mm a day, respectively in Neepawa and 680-1. The overall mean daily rate was slightly higher in Galt (1.00 mm) than in Bonanza (0.96 mm).

Percent disease ratings. Amongst the wheat cultivars, the overall percent disease ratings for all observation dates were in the following descending order: Cypress, Neepawa, and 680-1; percent ratings at the end of the experiment were 67, 46, and 38, respectively (Fig. 1). The results also show that percent disease ratings were consistently higher in Galt than in Bonanza.

Relative frequencies and probabilities of changes in disease category. Results of overall probabilities of disease category changes showed that amongst wheat cultivars the probability of plants staying CL during a single time interval was lower in Cypress (0.842) than in Neepawa (0.905) and 680-1 (0.947) (Fig. 2). Similarly the probabilities of SL and MO plants staying SL and MO were lower in Cypress than in the other two wheats; they were 0.464 and 0.949 for Cypress compared to 0.675 and 0.983 for Neepawa and 0.650 and 0.994 for 680-1. However the probabilities of CL plants becoming infected (i.e. CL to SL or MO), and also of infected plants moving from less to more severe disease categories were invariably higher in Cypress, followed in descending order by Neepawa and 680-1. The most obvious differences among the three wheat cultivars were in the movement of plants from SL to MO, and MO to SE. The probability of SL plants becoming MO was 0.536 in Cypress compared to only 0.325 and 0.350, respectively, in Neepawa and 680-1. Similarly the probability of MO plants becoming SE was 0.051 in Cypress compared to only 0.017 and 0.006 in Neepawa and 680-1, respectively.

Examination of probabilities of disease category changes in barley indicated that the cultivar Galt was more susceptible than Bonanza (Fig. 2).

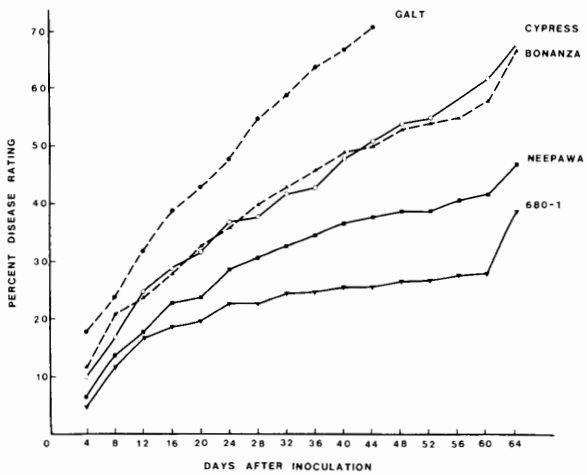

Figure 1. Percent disease ratings for each date of observation on plants of three wheat and two barley cultivars.

CYPRESS

WAS \ IS	CL	SL	MO	SE
CL	0.842	0.120	0.038	
SL		0.464	0.536	
MO			0.949	0.051
SE				1.00

GALT

WAS \ IS	CL	SL	MO	SE
CL	0.770	0.144	0.086	
SL		0.640	0.360	
MO			0.897	0.103
SE				1.00

NEEPAWA

WAS \ IS	CL	SL	MO	SE
CL	0.905	0.090	0.005	
SL		0.675	0.325	
MO			0.983	0.017
SE				1.00

BONANZA

WAS \ IS	CL	SL	MO	SE
CL	0.835	0.128	0.037	
SL		0.599	0.401	
MO			0.964	0.036
SE				1.00

680-1

WAS \ IS	CL	SL	MO	SE
CL	0.947	0.046	0.007	
SL		0.650	0.350	
MO			0.994	0.006
SE				1.00

Figure 2. Overall probabilities of disease category changes. Values in the cells are the mean probabilities of different category changes in single time intervals for the entire experiment over three tests. The type of change during an interval is indicated by the category before (was) and after (is) the interval.

Discussion

The relative lengths of common root rot lesions on exposed subcrown internodes have proved useful in comparing temporal progression of the disease in wheat and barley cultivars known to differ in disease reaction on the basis of end-of-season ratings. Results of the growth chamber experiments for mean number of days required to attain maximum possible lesion length, mean daily rates of lesion extension, percentage disease ratings, probabilities of plants becoming infected and of infected plants being transferred to more severe disease categories showed that amongst the three wheats, Cypress was the most susceptible and 680-1 the least, and that in barley Galt was more susceptible than Bonanza. A similar ranking of these cultivars has been reported from single-end-of-season disease intensity observations in the field (3, 5).

The cumbersome nature of the lesion development technique may not warrant its use in initial large-scale screening trials of cereal cultivars for resistance to *C. sativus*. However the technique could be useful in discriminating differences in reaction among selected cultivars whose disease intensities at the end of the season appear similar.

In general the temporal lesion development studies support the conventional method of assessing cereal root rot whereby plants are categorized into disease severity categories based on the extent of lesions on the subcrown internodes (2, 5, 8). However the percentages of plants in the various qualitative disease categories, or the percentage disease ratings derived from them, may sometimes be misleading, because a single-end-of-season observation provides no information on the duration of time individual plants have spent in different qualitative disease categories. Such information is important because the overall effect of the disease may depend not only upon the extent and severity of subcrown internode lesions, but also on the duration of infection. Conceivably the relative susceptibility of cultivars may vary differentially during their development. One cultivar may incur little disease until near maturity when infection might progress rapidly, whereas infection in another cultivar may increase steadily from an early inception. The two cultivars may display equally severe symptoms at the end of the season and, therefore, be considered comparable in resistance. However the rapid late disease progression in the former cultivar may cause negligible reduction in grain yield as compared to that suffered by the cultivar in which disease advanced steadily. Furthermore, the effect of a given level of disease on yield may also differ with the stage of plant development. Information on all of these processes is important in understanding the comparative epidemiology of common root rot.

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