Reaction of a Diverse Collection of Barley Lines to Fusarium Head Blight

B. D. McCallum, A. Tekauz, and J. Gilbert, Cereal Research Centre, Agriculture and Agri-Food Canada, Winnipeg, Manitoba, R3T 2M9, Canada

ABSTRACT

McCallum, B. D., Tekauz, A., and Gilbert, J. 2004. Reaction of a diverse collection of barley lines to Fusarium head blight. *Plant Dis.* 88:167-174.

Fusarium head blight (FHB) is currently the primary disease of concern in barley in Canada and sources of FHB resistance need to be identified. A diverse collection of 77 two-rowed and 81 six-rowed barley lines was screened for resistance to FHB in inoculated, irrigated nurseries from 1995 to 1998. Barley spikes were spray inoculated with conidia of *Fusarium graminearum* and visual symptoms of FHB were scored to determine an FHB index. Deoxynivalenol (DON) content was determined from harvested seed samples during 1997 and 1998. Although there was variation in the average FHB index and DON content among the different years of testing, the rankings of the lines generally were correlated among the years of testing and the two measures of FHB. Based on the FHB index from 1995 and 1996, a subset of 18 lines with low FHB and 12 lines with high FHB were compared with 20 FHB resistance sources and 7 Canadian lines or cultivars during 1997 and 1998 in both inoculated and noninoculated nurseries. Lines Nepolegajuscij, Krasnojarskij, Nordic, Murakaki-mochi, Golozernyj 1, Maris Mink, Symko, Ussurijskij 8, Suvenir, and Canadian cultivars AC Sterling and Morrison were similar to the best resistance sources (Zhedar 1, Seijo II, and Chevron) and had consistently low DON content.

Additional keywords: *Hordeum vulgare*, *Gibberella zeae*, scab

Fusarium head blight (FHB) rapidly has become the most serious disease in barley (*Hordeum vulgare* L.) in the eastern prairie region of western Canada (16). FHB on barley was moderate to severe in Manitoba in 1993, 1994, and from 1996 to 1998 (16) and also was more prevalent than in previous years in the southeastern portion of Saskatchewan in 2000 (1,14). The main causal organism, *Fusarium graminearum* Schwabe (teleomorph *Gibberella zeae* (Schwein.) Petch), produces the mycotoxin deoxynivalenol (DON) during infection. Yield losses attributed to FHB infection on barley in Manitoba were estimated at 3.7% in 1997 (4), 6.3% in 1998 (5), 3.3% in 1999 (3), 5.5% in 2000 (14), and 2.0% in 2001 (15). Losses in grain quality in barley, due particularly to the accumulation of DON may be more important than the associated yield losses. DON is toxic to animals and humans; therefore, serious FHB infestation makes barley unsuitable for malting, human food, and animal feed (16). Fungicides such as tebuconazole (Folicur) and propiconazole

(Tilt) have some effect on reducing FHB and DON content in cereal grains, but resistant cultivars represent the most economical and environmentally acceptable method of disease management (8).

Efforts are underway to develop barley cultivars with improved levels of resistance to FHB to help minimize the destructive effects of the disease. If barley lines with superior FHB resistance were identified, they could be used as parents to breed barley cultivars with improved FHB resistance, but genetic resistance to FHB in barley is not well characterized. Takeda and Heta (13) screened approximately 5,000 barley lines from diverse origins, both two- and six-rowed, for FHB resistance under controlled conditions and in field screening nurseries. From three successive rounds of screening, they identified 23 elite two-rowed lines with superior FHB resistance. Other reported sources of resistance were the cultivars Chevron (9), Shyri, Gobernadora, Atahualpa, Zhedar 1, and Zhedar 2 (2).

The objective of this study was to screen a diverse collection of barley germ plasm for resistance to FHB. The most promising lines from an initial screen then were compared for resistance with lines reported previously to have some level of resistance to FHB.

MATERIALS AND METHODS

A diverse collection of 158 barley lines, 77 two-rowed and 81 six-rowed, was chosen from the collection of the Plant Genetic Resources (PGR) unit of Agriculture

and Agri-Food Canada. Lines were chosen from geographically different sources of origin to sample a wide variety of barley germ plasm. The lines were screened for resistance to FHB in a nursery inoculated with *F. graminearum* in 1995, 1996, and 1998 at Glenlea, MB and in 1997 at Morden, MB. Single 1.5-m rows were planted every year for each entry. Barley spikes were spray inoculated at heading and again at 7 days after heading. For each inoculation, every row was sprayed with approximately 100 ml of a suspension containing 5.0×10^4 *F. graminearum* macroconidia per milliliter of H₂O. To prepare this suspension, four isolates of *F. graminearum*, previously isolated from FHB-infected barley spikes in Manitoba, were separately grown on petri plates containing potato dextrose agar. Colonized agar from one petri plate per isolate was cut into small pieces (approximately 2 by 2 cm) and transferred to a flask containing 1 liter of liquid medium (15.0 g of carboxymethyl cellulose, 1 g of NH₄NO₃, 1 g of KH₂PO₄, 0.5 g of MgSO₄·7H₂O, 1 g of yeast extract, and 1 liter of H₂O). The liquid cultures were grown with continuous aeration at room temperature for approximately 5 days, filtered through cheese cloth to remove the pieces of agar, and then diluted to a concentration of 5.0×10^4 macroconidia/ml with H₂O. One drop of the surfactant Tween 20 was added per liter of macroconidial suspension. Mist irrigation was provided after each inoculation and at regular intervals afterward.

Fourteen days after the final inoculation, all the spikes were harvested from a 60-cm section in the middle of each row and frozen at -20°C. The spikes subsequently were thawed and the immature spikes from late maturing tillers, which could have escaped inoculation, were discarded. The FHB index (incidence $\times$ average severity), was calculated for each line on approximately 30 spikes to determine the level of FHB infection based on visual symptoms. Incidence (infected spikes/total spikes) was determined by counting the number of spikes with discolored spikelets that are indicative of FHB from approximately 30 mature spikes. Discolored spikelets appeared typically as tan, brown, or sometimes dark brown or black compared with the healthy green spikelets. Average severity was determined by dividing the mean number of infected spikelets by the mean number of total spikelets. Discolored spikelets per spike were counted from all infected spikes and the number averaged to

Corresponding author: B. D. McCallum
E-mail: bmccallum@agr.gc.ca

Agriculture and Agri-Food Canada, Cereal Research Centre contribution #1846.

Accepted for publication 5 September 2003.

Publication no. D-2003-1124-03R
© 2004 Minister of Public Works and Government Services Canada

Table 1. Fusarium head blight (FHB) index and deoxynivalenol (DON) concentration for 158 barley lines inoculated with *Fusarium graminearum* in irrigated nurseries in 1995, 1996, 1997, and 1998^a

Cultivar	Designation	Row	FHB index (%)				Mean ^b	Transformed mean ^c	DON (ppm)	
			1995	1996	1997	1998			1997	1998
Nepolegajuscij	PGR0001240	2	1.2	10.3	10.2	5.7	6.1	2.5	2.6	0.2
Murasaki-mochi	PGR0016961	6	2.3	8.4	9.4	8.4	6.7	2.6	0.1	5.2
Nordic	PGR0012721	6	6.7	10.4	14.6	2.0	7.6	2.8	3.2	1.3
Symko	PGR0017142	2	0.4	9.3	32.9	2.9	7.7	2.8	3.7	0.4
Krasnojarskij 1	PGR0001594	2	8.0	8.4	10.7	5.5	8.0	2.8	4.4	1.3
Dziugiaj	PGR0001590	2	1.4	18.2	8.7	9.1	8.1	2.9	3.9	0.5
Golozernyj 1	PGR0008202	2	3.4	10.7	19.3	5.0	8.6	2.9	0.5	0.5
PI25744 Franconian	CIho000679	2	4.0	13.9	10.9	8.7	9.0	3.0	1.6	0.3
PI28596 Black Algerian	CIho000708	6	8.9	6.6	12.6	9.2	9.2	3.0	8.6	0.9
Nosovskij 6	PGR0001593	2	2.3	15.1	16.2	7.8	9.3	3.1	3.5	0.3
Duncan	PGR0002045	2	1.0	16.5	25.4	4.6	9.4	3.1	2.6	...
Hazen	PGR0026752	6	1.4	1.9	49.8	7.5	9.5	3.1	5.2	1.3
Tristan	PGR0002046	2	0.6	15.5	32.8	3.7	9.6	3.1	1.1	1.8
Suvenir	PGR0001243	2	4.8	7.6	10.9	19.3	10.0	3.2	2.3	...
Maris Mink	PGR0001804	2	4.5	12.2	17.1	8.5	10.0	3.2	2.8	...
Helong 2r	PGR0026739	6	3.6	16.0	26.4	3.1	10.2	3.2	2.6	1.6
Tellus	PGR0012731	2	5.7	19.5	15.2	4.8	10.4	3.2	6.6	...
Ussurijskij 8	PGR0000009	2	0.2	11.2	31.6	12.9	10.6	3.3	1.1	0.3
Andre	PGR0026736	2	8.9	12.7	17.8	5.3	10.7	3.3	0.3	2.4
Summit	PGR0005746	2	2.6	14.8	26.8	6.9	11.0	3.3	4.3	4.1
CIho 1340 Goldthorpe	CIho001340	2	4.3	17.2	23.2	5.3	11.1	3.3	9.0	2.0
CIho 1609 O.A.C. 38	CIho001609	2	3.0	19.1	33.1	2.4	11.2	3.4	2.9	0.9
Stepovyj	PGR0001001	2	1.0	18.6	22.6	11.2	11.2	3.4	3.2	0.4
ZAO-SU 3	PGR0026740	2	7.0	5.7	24.9	12.2	11.4	3.4	2.3	7.5
Freja	PGR0002804	2	2.8	27.9	10.2	11.5	11.5	3.4	3.1	0.3
Timiriazevskij 85	PGR0013306	6	11.2	20.2	3.9	17.4	12.2	3.5	2.8	5.3
Odesskij 36	PGR0013298	2	6.9	20.8	18.6	6.6	12.4	3.5	10.1	0.7
CIho 1243 Abyssinian	CIho001243	6	2.1	32.6	23.5	4.4	12.4	3.5	7.2	0.9
CIho 1554 Hanna	CIho001554	2	7.7	4.2	54.4	4.0	12.6	3.5	5.7	0.6
CIho 657 Chile Brewing	CIho000657	6	7.1	17.1	32.2	3.4	12.8	3.6	0.7	...
Mensury Ottawa 60	PGR0004995	6	16.2	22.8	12.2	4.3	12.9	3.6	5.1	0.7
Mari	PGR0001755	2	5.5	13.2	10.5	26.7	12.9	3.6	7.9	6.9
PI19894 Wakamatsu	CIho000579	6	4.5	11.6	27.5	13.4	13.0	3.6	0.2	5.9
CIho 1365 Bolivia	CIho001365	6	5.8	17.4	25.6	7.8	13.0	3.6	6.4	1.6
Moskovskij 121	PGR0013301	2	8.8	20.1	26.8	3.3	13.0	3.6	2.2	0.6
CIho 1970 Gartons 66	CIho001970	6	4.6	9.3	41.3	8.1	13.1	3.6	10.2	0.8
PI26179 Barbary	CIho000695	6	6.4	15.3	25.1	9.2	13.1	3.6	0.2	1.7
Manker	PGR0013125	6	3.7	10.7	18.8	25.4	13.3	3.6	6.5	2.7
Gazelle	PGR0019893	2	4.8	15.8	44.6	3.0	13.3	3.6	4.0	0.2
Doneckij 4	PGR0013299	2	5.1	16.4	35.2	5.8	13.4	3.7	6.4	0.7
CIho 1137 Oderbrucker	CIho001137	6	8.4	20.6	21.0	7.0	13.4	3.7	10.8	2.3
Gryf	PGR0017846	2	2.9	14.9	47.6	5.2	13.6	3.7	5.5	0.3
H. dis. nigrinudum No. 1	P3GR0016858	2	9.6	16.8	18.2	10.8	13.6	3.7	12.4	4.6
Arvo	PGR0002059	2	7.6	23.5	24.6	5.1	13.7	3.7	1.7	...
Early Russian/CI13839	PGR0002066	6	14.5	11.2	21.3	9.7	13.8	3.7	6.4	3.6
CIho 1131 Peruvian	CIho001131	6	3.7	20.2	28.7	10.1	14.0	3.7	14.3	2.5
Taplani	PGR0017879	2	0.6	25.4	54.8	3.2	14.1	3.8	2.3	11.3
Juznyj	PGR0001002	2	2.6	22.5	17.5	20.7	14.2	3.8	6.1	2.0
Mazurka	PGR0010077	2	1.1	42.2	31.5	4.0	14.4	3.8	5.1	...
LB.IRAN-3	PGR0022309	6	3.5	16.5	32.8	12.4	14.4	3.8	5.0	...
Vinnickij 7	PGR0012988	2	2.8	20.0	41.4	6.8	14.4	3.8	1.9	...
Karat	PGR0016076	2	8.8	17.3	19.3	13.6	14.5	3.8	1.7	...
Zhouma 12	PGR0026741	2	6.6	13.8	26.3	14.4	14.5	3.8	7.8	7.3
Moskovskij 121	PGR0001591	2	3.4	13.9	26.1	20.8	14.5	3.8	0.9	3.4
Morex	PGR0013126	6	28.0	19.3	4.8	11.9	14.7	3.8	6.7	2.9
Krasnodarskij 35	PGR0001242	2	3.8	14.6	32.1	15.2	14.7	3.8	5.4	3.4
Wing	PGR0002000	2	2.6	12.9	16.7	39.5	15.2	3.9	1.2	0.1
CIho 933 Bohemian	CIho000933	2	2.4	26.9	42.8	5.8	15.4	3.9	4.0	1.0
CIho1392 Sealand Prentice	CIho001392	2	13.9	17.8	27.4	6.5	15.5	3.9	4.2	...
Midas	PGR0002014	2	6.8	23.0	37.9	5.5	15.8	4.0	0.6	...
Karri	PGR0008758	2	2.0	40.0	25.2	9.9	15.8	4.0	1.4	...
Akka W6039	PGR0002138	2	2.9	10.0	39.4	22.7	15.8	4.0	3.4	5.2
LB.IRAN-1	PGR0022297	6	1.9	22.4	39.6	12.8	16.0	4.0	0.9	0.2
PI24159 Szechwan	CIho000664	6	7.7	18.3	30.4	12.0	16.1	4.0	12.4	2.3
Manchuria	PGR0004980	6	16.6	22.1	31.6	3.1	16.3	4.0	6.4	13.2
Sofia	PGR0015534	6	0.6	46.7	40.1	5.0	16.4	4.0	5.8	0.4
CIho 392 Moldavia	CIho000392	6	6.7	29.1	30.8	7.4	16.5	4.1	1.5	2.4
La Sa-bai	PGR0016595	6	5.7	25.4	20.3	18.8	16.5	4.1	10.7	7.4

(continued on next page)

^a ... Indicates missing data or not applicable.

^b Means were obtained by squaring the transformed mean.

^c Mean of the FHB index transformed by square root. The least significant difference ($P \leq 0.05$) between the transformed mean for any two lines is 1.8.

Table 1. (continued from preceding page)

Cultivar	Designation	Row	FHB index (%)				Mean ^b	Transformed mean ^c	DON (ppm)	
			1995	1996	1997	1998			1997	1998
Mx 37 Keystone	PGR0007162	6	3.1	26.2	42.4	8.5	16.6	4.1	6.1	0.5
Svalof 50-109	PGR0002818	2	2.8	28.6	21.6	22.2	16.8	4.1	4.9	0.5
CIho 935 Peruvian	CIho000935	6	8.2	27.2	30.4	8.0	16.9	4.1	4.6	3.1
Belogorskij	PGR0013310	6	3.6	32.8	40.9	6.3	17.1	4.1	4.9	0.7
PI22494 Manchuria	CIho000643	6	4.8	25.5	47.0	6.2	17.2	4.1	5.6	0.3
CIho 1892 Champion of Vermont	CIho001892	2	2.5	30.3	59.6	3.2	17.2	4.1	6.2	0.4
Zephyr	PGR0012740	2	5.4	48.2	23.3	7.1	17.6	4.2	3.8	...
Celinnij 5	PGR0001776	2	4.7	26.1	19.5	25.7	17.6	4.2	1.9	0.5
Desnianskij 8	PGR0008203	2	9.1	27.5	20.8	16.2	17.7	4.2	2.7	...
Zaoshu 3	PGR0017043	2	8.0	27.1	18.7	20.5	17.8	4.2	6.3	7.5
Hassan	PGR0001975	2	4.3	12.7	31.6	32.1	17.9	4.2	3.0	0.3
CIho 1686 Swedish star	CIho001686	6	8.6	18.5	34.4	14.8	17.9	4.2	1.4	1.0
Bacchus	PGR0013327	2	2.4	23.8	41.1	17.6	18.1	4.3	5.1	0.2
Atlanta	PGR0005017	2	3.0	36.9	43.9	7.5	18.4	4.3	2.5	0.7
Rhodes	PGR0022313	6	3.9	38.9	37.6	8.3	18.5	4.3	12.1	5.7
Sever 1	PGR0008204	2	3.5	29.2	27.3	22.6	18.6	4.3	2.1	0.5
Odesskij 46	PGR0008205	6	2.0	43.8	31.3	13.8	18.8	4.3	6.0	0.5
PI48133 Coast	CIho001430	6	4.4	33.2	30.3	16.2	18.9	4.3	6.9	8.4
PI25671 Ireland	CIho001603	6	12.0	24.6	30.8	12.5	19.2	4.4	10.9	0.2
Aizao 3	PGR0026738	2	11.2	11.3	18.9	41.8	19.2	4.4	16.6	17.1
Glenn	PGR0012235	6	25.5	15.4	22.9	15.9	19.7	4.4	6.4	3.7
Trompillo	PGR0021256	2	6.3	27.9	45.2	10.5	19.7	4.4	1.7	8.4
Helena	PGR0018007	2	3.8	28.8	62.0	6.7	19.8	4.4	10.2	3.9
PI48195 Mecknes Maroc	CIho001379	6	6.6	20.3	43.1	17.6	19.9	4.5	5.5	2.8
Georgie	PGR0013380	2	3.9	35.7	23.4	25.9	20.0	4.5	5.9	0.6
Bowers	PGR0012231	6	24.8	24.8	38.2	3.2	20.1	4.5	17.2	1.5
Jupiter	PGR0013330	2	8.1	25.5	43.4	13.6	20.6	4.5	2.0	2.3
Stavropol	PGR0004963	6	24.0	25.4	37.0	4.7	20.7	4.5	6.3	1.2
Kym	PGR0016073	2	7.9	24.4	28.9	27.5	21.1	4.6	2.4	0.3
PI38887 Barbican	CIho001265	6	2.1	43.4	47.2	12.5	21.3	4.6	10.5	1.1
Liang lan ging ke	PGR0000308	6	12.4	14.2	33.6	29.2	21.4	4.6	3.2	0.6
CIho 1118 Featherston	CIho001118	6	6.2	26.3	62.2	9.3	21.5	4.6	15.9	0.3
Omskij 13709	PGR0013300	2	7.2	53.5	39.0	5.4	21.5	4.6	8.3	0.2
CIho 1654 Chili	CIho001654	6	7.9	15.2	47.4	27.0	22.1	4.7	10.6	0.8
Hankkija 34003	PGR0002047	2	10.3	26.5	20.8	35.4	22.2	4.7	1.7	8.1
PI31765 Haua	CIho000734	6	6.8	26.3	52.2	16.3	22.6	4.7	11.9	6.7
CIho 1370 Spain	CIho001370	6	10.6	33.3	32.0	19.8	22.9	4.8	10.4	1.5
CIho 1397 Mansury	CIho001397	6	4.8	26.1	81.0	8.4	23.0	4.8	9.6	0.4
Zao Shu no. 3 (Early)	PGR0000304	2	10.8	30.6	21.3	34.8	23.4	4.8	7.4	5.2
CIho 2203 Boehmes Beardless	CIho002203	6	6.7	25.3	47.5	...	23.4	4.8	14.6	...
Candice	PGR0016072	2	7.2	50.4	30.9	17.1	23.7	4.9	6.0	1.1
Otro	PGR0001959	6	3.5	26.9	40.4	36.9	23.7	4.9	14.8	8.4
Triumph	PGR0013387	2	3.9	25.0	41.6	37.9	24.0	4.9	4.3	1.3
CIho 1871 Turkish	CIho001871	2	8.2	25.5	70.7	11.8	24.4	4.9	8.9	0.3
Katsu	PGR0004955	6	16.4	15.0	47.1	25.3	24.5	5.0	7.2	6.2
45	PGR0000600	2	6.7	9.6	43.4	57.0	24.6	5.0	11.0	14.0
Hankkija 673	PGR0001960	6	5.9	35.2	39.2	27.1	24.6	5.0	13.1	6.6
PI48135 Chilean C	CIho001432	6	5.9	19.5	82.4	16.0	24.8	5.0	16.8	6.9
PI42100 Cape	CIho001268	6	10.0	26.8	43.6	25.1	24.9	5.0	4.3	6.6
Hellas	PGR0012712	2	7.3	18.6	54.6	31.5	25.0	5.0	6.1	...
Bavaria	PGR0002136	2	10.9	15.6	48.6	34.1	25.2	5.0	1.6	0.8
PI29003 Turkestan	CIho000711	6	34.9	12.9	55.0	10.9	25.5	5.1	0.7	0.3
Jotun	PGR0002058	6	3.8	29.9	57.4	28.0	25.7	5.1	12.1	4.1
Zita	PGR0015585	2	6.2	56.0	36.4	18.7	25.8	5.1	4.4	0.4
CIho 1351 Andrew	CIho001351	6	8.9	25.1	63.0	19.8	26.0	5.1	15.9	5.0
Betzes ms16	PGR0002823	2	10.6	41.0	30.2	27.8	26.1	5.1	1.1	0.5
CIho 927 Odessa	CIho000927	6	8.5	24.3	73.7	18.0	26.7	5.2	13.4	1.6
Xarkovscij 60	PGR0004102	6	39.0	...	34.8	11.5	26.8	5.2	1.8	0.5
Koru	PGR0013381	2	9.5	57.2	37.9	15.6	26.9	5.2	2.5	13.6
Varunda	PGR0012734	2	4.8	56.4	29.2	32.1	27.0	5.2	3.2	24.2
Paavo	PGR0002107	6	5.8	60.7	23.3	36.7	27.8	5.3	4.9	1.1
Sultan	PGR0002131	2	11.9	35.2	54.9	18.6	27.8	5.3	3.4	0.4
Luc	PGR0001597	2	12.8	33.6	28.4	44.8	28.6	5.3	2.2	...
Bai lang Sanging ke	PGR0000316	6	14.3	8.9	44.7	63.5	28.7	5.4	1.3	1.2
PI38321 Pasha	CIho000984	6	...	18.7	48.1	23.6	28.9	5.4	10.3	4.4
140 Pin Xi	PGR0000311	6	9.2	27.0	27.7	64.8	29.0	5.4	5.7	1.4
Celinnij 5	PGR0012989	6	5.8	51.9	60.1	22.8	30.6	5.5	12.0	3.2
CIho 1357 Minorca	CIho001357	6	22.7	29.0	45.0	29.3	31.0	5.6	15.8	4.2
Hankkijan Pokko	PGR0016366	6	10.4	39.1	47.1	36.0	31.2	5.6	6.9	1.6
PI48641 Fidel	CIho001445	2	12.7	53.2	61.4	13.9	31.4	5.6	58.7	0.1
Du Li-huang	PGR0016598	6	9.0	52.3	41.3	33.9	31.6	5.6	4.7	1.1

(continued on next page)

Table 1. (continued from preceding page)

Cultivar	Designation	Row	FHB index (%)				Mean ^b	Transformed mean ^c	DON (ppm)	
			1995	1996	1997	1998			1997	1998
Brachytic	PGR0002083	6	8.3	39.6	42.3	46.9	31.7	5.6	9.2	13.3
Rabat	PGR0005019	6	12.2	48.7	53.0	23.5	31.9	5.6	6.8	14.0
Minskij	PGR0001777	2	10.7	18.6	60.6	52.4	31.9	5.7	2.9	...
CIho 1556 Minsturdi	CIho001556	6	29.9	21.5	69.5	21.0	33.1	5.8	18.7	7.9
CIho 1576 Early Indian	CIho001576	6	19.7	38.4	43.3	34.0	33.2	5.8	19.4	3.5
Dissa	PGR0015533	6	6.5	70.1	59.2	26.2	35.2	5.9	14.4	...
N33	PGR0000800	6	3.7	62.2	32.4	68.8	35.4	5.9	22.2	14.1
Suvi	PGR0008368	6	25.0	53.8	16.7	61.4	36.8	6.1	12.1	15.7
Nan fan no. 4	PGR0000305	6	7.1	54.0	42.0	61.4	37.0	6.1	5.6	3.5
Beecher	PGR0004979	6	50.5	31.4	32.7	35.4	37.1	6.1	15.0	1.4
Pohto	PGR0019986	6	14.1	...	54.0	56.0	38.4	6.2	20.7	7.3
Hankkijan Potra	PGR0016367	6	16.3	60.3	36.3	57.4	40.3	6.4	12.6	16.1
Pomo	PGR0008366	6	28.7	30.5	54.5	61.5	42.6	6.5	3.0	...
Etu	PGR0008365	6	7.9	54.9	61.1	65.1	42.6	6.5	8.9	6.9
Hiproly	PGR0002099	2	17.6	53.9	47.2	62.0	43.2	6.6	25.3	...
Hx690	PGR0007182	6	54.5	56.7	50.9	21.2	44.4	6.7	19.6	5.0
PI39400 Czech	CIho001023	6	...	58.2	31.8	77.9	54.2	7.4	30.0	4.7
PI38307 Rasput	CIho000996	6	...	62.5	68.5	49.6	59.9	7.7	10.9	6.3
Bai liu ling	PGR0000307	6	53.5	55.2	...	78.8	62.0	7.9	4.6	...
Mean	...	...	8.6	26.5	35.2	19.9	20.5	4.4	7.1	3.5

determine the mean infected spikelets. The total spikelets per spike also were counted for a subset of 20 spikes, randomly selected from the original sample of 30 mature spikes, and averaged to determine the mean total spikelets for each line.

Based on their FHB index values in 1995 and 1996, a subset of 18 lines with low FHB index values (LFHB) and 12 lines with relatively high FHB index values (HFHB) from the original sample of 158 was selected for comparison with 27 barley accessions (resistance sources [RS]). The RS lines included 20 cultivars previously reported to have some level of FHB resistance (2,9,13) or thought to have resistance, and 7 Canadian cultivars or lines (AC Sterling, AC Stephen, T-186-1, DB 202, DB 192, Morrison, and AB 159-2). Many of these Canadian cultivars or lines are related to Symko (one of the LFHB lines). These 57 barley lines (LFHB + HFHB + RS) were grown in single 1.5-m rows and evaluated for FHB reaction in inoculated, irrigated nurseries at Morden, MB during 1997 and at Glenlea, MB during 1998, using the methods described above. These accessions also were evaluated under natural FHB infection conditions without artificial inoculation or irrigation at Carman, MB in 1997 and 1998. The plots were grown and visual FHB was determined as described previously for the inoculated nurseries, except spikes were sampled when symptoms of FHB were evident because no exogenous inoculum was applied.

Samples for DON analysis were obtained from the 1997 and 1998 trials by harvesting the remainder of each row at maturity. Harvested grain (20 g) was subsampled from each line and ground using a UDY Cyclone (UDY Corporation Fort Collins, CO) with a 0.5-mm screen. The ground sample was mixed, and a 1.0-g subsample was dispensed into a 12.5-ml

centrifuge tube and analyzed for DON content by enzyme-linked immunosorbent assay (11).

The data were analyzed using SAS program PROC GLM (version 6.12; SAS Institute, Cary NC). The FHB index values were transformed using the square root transformation ($\text{index} = \sqrt{\text{index}}$) and the DON values were transformed using a log transformation ($\text{DON} = \log [0.5 + \text{DON}]$) to stabilize the variance. Spearman rank correlation statistics based on FHB index values and DON were determined using PROC CORR.

RESULTS

The FHB index and DON content for 158 barley lines from the *F. graminearum* inoculated nurseries from 1995 to 1998 are listed in Table 1. For the FHB index, the effects of year, two-rowed versus six-rowed type, and cultivar were all significant ($P \leq 0.05$). The average FHB index varied from 8.6 in 1995 to 19.9 in 1998, 26.5 in 1996, and 35.2 in 1997 (Table 1). The nursery is located in an area in which FHB occurs regularly at relatively high levels; therefore, there is a background of natural inoculum and disease pressure that affects the level of FHB within the inoculated nursery plants. The infection level of FHB also is affected by environmental conditions such as humidity, precipitation, and temperature (6). Therefore, the actual inoculum pressure varied from year to year despite efforts to quantify the exogenously supplied inoculum and irrigation.

The 77 two-rowed cultivars had significantly lower average FHB index values than the 81 six-rowed cultivars. The average FHB index also was lower for two-rowed than for six-rowed cultivars in each of the four years of testing (5.7 versus 11.4 in 1995, 23.8 versus 29.0 in 1996, 31.2 versus 38.9 in 1997, and 16.4 versus 23.3 in 1998). The lines are ranked in Table 1

according to their square root transformed mean. The least significant difference between lines is 1.8 at $P \leq 0.05$.

For DON, the effects of year, two-rowed versus six-rowed, and cultivar were significant ($P \leq 0.05$). The average DON for the two-rowed cultivars was lower than the average for the six-rowed cultivars for both years (5.2 versus 8.8 ppm in 1997 and 3.1 versus 3.9 ppm in 1998). The average level of DON was higher in 1997 (7.1 ppm) than in 1998 (3.5 ppm), and was similar to the differences in FHB index between the 2 years. Cultivar comparisons using DON alone were not as useful as comparisons based on FHB index because only 2 years of data were available for DON, but they are listed for comparison with the FHB index in Table 1.

While the FHB index and DON concentration varied among years, the ranks of the barley lines generally were correlated ($P \leq 0.05$) among years of testing using FHB index or DON and between FHB index and DON concentration (Table 2). The rankings of lines based on FHB index were correlated between each pair of years except for 1997 and 1995. Although DON content levels were measured only in 1997 and 1998, the rankings of lines based on DON were correlated between the 2 years of testing. The lines generally also were correlated with rankings based on FHB index, except that those based on DON in 1998 were not significantly correlated with rankings based on FHB index in 1996 and 1997. This may have resulted from poor separation of the lines based on DON in 1998 because the average DON level was relatively low (3.5 ppm).

Based on the average FHB index from 1995 and 1996, the original 158 barley lines were ranked from lowest to highest FHB index. During 1997 and 1998, two subsets of lines comprising the most resistant lines (18 lines with LFHB: 0.2 to 8.0

in 1995 and 1.9 to 12.9 in 1996) and the most susceptible lines (12 lines with HFHB: 4.8 to 54.5 in 1995 and 31.4 to 70.1 in 1996) were selected for comparison with 27 RS lines that included 20 cultivars reported or thought to have resistance and 7 Canadian lines or cultivars. The effects of year, location, year–location interaction, two-rowed versus six-rowed type, and cultivar were significant ($P \leq 0.05$) for both FHB index and DON. The 42 two-rowed cultivars had lower average FHB index values (14.0) than the 15 six-rowed cultivars (30.1). The LFHB lines generally had lower FHB index values and DON concentrations than the HFHB lines over both locations and both years (1997 and 1998) of testing (Table 3). The LFHB line 45, which appeared to have some resistance during tests in 1995 and 1996, was fairly susceptible in all tests during 1997 and 1998. Some of the LFHB lines, such as Nepolegajuscij, Krasnojarskij, Nordic, Murasaki-mochi, Golozernyj 1, Maris Mink, Symko, Ussurijskij 8, Suvenir, ZAO-SU 3 and Akka W6039 and the Canadian cultivars or lines AC Sterling, T-186-1, DB 202, DB 192, and Morrison were not significantly different ($P \leq 0.05$) from the best resistance sources Zhedar1, Seijo II, and Chevron. Of these lines, Nepolegajuscij, Krasnojarskij, Nordic, Murasaki-mochi, Golozernyj 1, Maris Mink, Symko, Ussurijskij 8, Suvenir, AC Sterling, and Morrison also had consistently low DON content.

The average FHB index and DON concentration were higher for both years of testing in the inoculated nurseries than under natural infection at Carman. The rankings of the lines based on FHB index or DON generally were correlated ($P \leq 0.05$) between different years and locations of testing (Table 4). Rankings based on DON levels from Carman in 1998 were less correlated with the other rankings, although most rank correlations still were significant. The DON levels were low for these lines grown at Carman in 1998 (0.1 to 2.2 ppm, average = 0.3 ppm), which resulted in poor separation of the lines.

DISCUSSION

There was a wide range of resistance to FHB among a group of 158 barley lines from diverse origins. Although the average level of FHB fluctuated among the four years of testing, the ranks of the lines were positively correlated between each pair of years tested except between 1995 and 1997. Lines with fewer visual symptoms of FHB may not have been distinguished in 1995 as well as they were in the other years due to the low average FHB index (8.6%). Therefore, although the environment has a strong influence on FHB, the barley genotype also contributes significantly to the final level of FHB.

The 77 two-rowed cultivars, as a group, were significantly more FHB resistant than

Table 2. Spearman rank correlation coefficients among Fusarium head blight (FHB) index and deoxynivalenol (DON) concentration from 158 barley lines inoculated with *F. graminearum* in 1995, 1996, 1997, and 1998^a

	FHB index			DON	
	1996	1997	1998	1997	1998
FHB index 1995	0.16*	0.14	0.37**	0.25**	0.29**
FHB index 1996	...	0.31**	0.34**	0.33**	0.15
FHB index 1997	...	...	0.18*	0.33**	0.02
FHB index 1998	...	...	...	0.26**	0.37**
DON 1997	...	...	...	...	0.34**

^a * and ** = Significant at $P \leq 0.05$ and 0.01, respectively.

the 81 six-rowed cultivars (Table 1). Takeda and Heta (13) compared 1,244 two-rowed cultivars and 3,637 six-rowed cultivars and also found that the two-rowed cultivars, as a group, were more FHB resistant than the six-rowed cultivars. The relationship between inflorescence type (two- or six-rowed) and FHB resistance in barley has not been explained fully, but Zhu et al. (17) found negative correlations between the number of seed per inflorescence and the severity of FHB in a cross between a pair of two-rowed cultivar. Most of the quantitative trait loci (QTL) for FHB resistance coincided with QTL for morphological traits, such as the type of inflorescence or plant height; therefore, Zhu et al. (17) concluded that plant architecture should be considered when breeding barley for FHB resistance. Steffenson et al. (12) compared two sets of paired isogenic barley lines with the members of each pair differing from each other for the two-rowed/six-rowed character and found that the two-rowed lines had slightly lower FHB and DON than the six-rowed lines in both isogenic pairs; however, these differences were not statistically significant.

Differences in the time of heading are always important when screening for FHB resistance. Our method of inoculation and harvesting heads for visual analysis in the inoculated nurseries was done for all lines over a 21-day period, starting at the heading date for each line; therefore, these differences between lines should be minimized. Because this 21-day window is different for lines with different heading dates, the naturally occurring rainfall and *F. graminearum* inoculum may not be the same for lines with different heading dates. Also, because DON analysis was conducted on grain from fully mature plants, the early heading lines would have been exposed to naturally occurring rainfall and *F. graminearum* inoculum over a longer period than lines that headed later.

One of the factors that could confound the visual FHB index ratings in barley is the presence of other fungi, particularly *Cochliobolus sativus* (Ito & Kuribayashi) Drechs. ex Dastur (anamorph: *Bipolaris sorokiniana* (Sacc.)), the causal agent of barley spot blotch, which also can attack barley spikes and produce symptoms similar in appearance to those of FHB. If a spike is heavily infected with *C. sativus*, it

may appear to have high levels of FHB, while in fact the level of seed colonization with *F. graminearum* is low (16). The DON measurement, therefore, is not only an important factor for barley marketability, but also provides an important indicator of the actual level of FHB and seed colonization by *F. graminearum*. Spot blotch also is a serious barley disease in the eastern Canadian prairies; therefore, cultivars suited to this region ideally would have a combination of resistance to *F. graminearum*, low DON accumulation, and resistance to *C. sativus*.

To determine the relative FHB resistance among a group of lines reliably has been difficult in barley because of the confounding effects of maturity, infection with other pathogens, variability from spike to spike, and other factors. It also is difficult to compare different sources of resistance if they are not evaluated under the same conditions. Based on the results from 1995 and 1996, the subset of 18 LFHB lines and 12 HFHB lines were compared along with 20 lines with reported FHB resistance and 7 Canadian cultivars or lines (RS) in both natural and artificially inoculated nurseries in 1997 and 1998. Generally, the LFHB and RS lines had lower FHB symptoms than the HFHB lines (Table 3), which were consistently susceptible, demonstrating that these two groups of lines (LFHB and HFHB) could be reliably distinguished. However, these differences were not absolute because the LFHB line 45 was relatively susceptible and the HFHB lines Varunda and Koru had FHB levels comparable to some of the resistant lines. LFHB lines Nepolegajuscij, Krasnojarskij, Nordic, Murasaki-mochi, Golozernyj 1, Maris Mink, Symko, Ussurijskij 8, Suvenir, ZAO-SU 3, and Akka W6039 had FHB index values that were not significantly different from the cultivars with the highest level of FHB resistance, Zhedar 1, Seijo II, and Chevron (Table 3). These lines also had consistently low DON levels, except for ZAO-SU 3 and Akka W6039. Additional lines from the original set of 158, such as Dziugaj, PI25744 Franconian, and Nosovskij 6, also may have useful levels of FHB resistance. Some cultivars thought to have resistance (CIMMYT 6A, Fuji Nijo, and Zaoshu 3) were not very resistant under our testing conditions. This may reflect differences in

Table 3. Fusarium head blight (FHB) index and deoxynivalenol (DON) for 18 low FHB index lines (LFHB), 12 high FHB index lines (HFHB), and 27 resistance sources (RS) under natural conditions at Carman MB and in inoculated, irrigated nurseries in 1997 and 1998^a

Cultivar	Source ^b	Row	FHB index (%)		DON (ppm)			
			Carman		Nursery		Carman	
			1997	1998	1997	1998	1997	1998
					Mean ^c	Tr. mean ^d		
Zhedar 1	RS ^e	2	0.4	1.4	10.4	1.3	2.4	1.6
Seijo II	RS ^f	2	0.2	1.7	10.6	3.9	3.0	1.8
Chevron	RS ^g	6	0.4	1.8	11.7	4.4	3.5	1.9
Nepolegajuscij	LFHB	2	0.6	1.3	10.2	5.7	3.5	1.9
Krasnojarskij 1	LFHB	2	1.3	1.3	10.7	5.5	3.9	2.0
Nordic	LFHB	6	2.5	1.2	14.6	2.0	3.9	2.0
Harbin	RS ^f	2	0.2	2.1	16.2	4.1	3.9	2.0
Murasaki-mochi	LFHB	6	0.3	4.4	9.4	8.4	4.6	2.2
Golozernyj 1	LFHB	2	0.6	1.9	19.3	5.0	4.8	2.2
Svansota	RS ^{f,g}	2	0.8	2.3	15.8	6.1	4.9	2.2
Maris Mink	LFHB	2	0.3	2.0	17.1	8.5	5.1	2.3
AC Sterling	RS ^h	2	0.2	1.8	23.4	5.7	5.1	2.3
Frederickson	RS ^f	2	0.7	5.8	18.4	2.9	5.3	2.3
Svanhals	RS ^{f,g}	2	0.1	4.8	23.1	4.2	5.5	2.3
TI86-1	RS ^h	2	0.8	1.9	32.0	2.5	5.7	2.4
Symko	LFHB	2	1.5	0.8	32.9	2.9	5.7	2.4
Niedzica 1	RS ^f	2	0.3	2.6	24.3	8.6	6.3	2.5
DB 202	RS ^h	2	1.1	5.7	23.3	4.2	6.6	2.6
Gobernadora	RS ^e	2	4.6	3.0	23.9	5.0	7.6	2.8
Ussurijskij 8	LFHB	2	0.2	2.2	31.6	12.9	7.8	2.8
Suvenir	LFHB	2	4.3	2.3	10.9	19.3	8.0	2.8
CI 8826	RS ^f	2	5.9	6.2	15.7	6.0	8.0	2.8
DB 192	RS ^h	2	1.0	2.6	44.1	5.9	8.5	2.9
Morrison	RS ^h	2	0.4	9.6	31.9	7.8	9.3	3.0
Kyoto Nakate	RS ^f	2	8.3	6.5	19.7	5.4	9.3	3.1
ZAO-SU 3	LFHB	2	2.6	6.5	24.9	12.2	10.0	3.2
Akka W6039	LFHB	2	0.8	1.8	39.4	22.7	11.0	3.3
Tristan	LFHB	2	26.9	0.9	32.8	3.7	11.9	3.4
Horní Peseky 2	RS ^{f,g}	2	4.3	3.2	59.4	5.8	12.2	3.5
Wing	LFHB	2	5.3	2.4	16.7	39.5	12.6	3.6
Manker	LFHB	2	9.8	3.0	18.8	25.4	12.7	3.6
Hazen	LFHB	6	7.6	3.6	49.8	7.5	13.0	3.6
Varunda	HFHB	2	0.6	7.2	29.2	32.1	13.2	3.6
Hassan	LFHB	2	3.5	3.6	31.6	32.1	14.2	3.8
Clho 1554 Hanna	LFHB	2	11.4	5.7	54.4	4.0	14.3	3.8
Koru	HFHB	2	7.4	6.0	37.9	15.6	14.6	3.8
Maja	RS ^f	2	6.9	17.4	27.0	14.6	15.6	4.0
AB 159-2	RS ^h	2	5.9	9.0	45.4	18.3	16.9	4.1
Asahi 5	RS ^f	2	1.6	16.2	40.0	23.5	16.9	4.1
Fuji Nijo	RS ^{f,g}	2	27.6	6.9	32.8	9.1	17.3	4.2
Primus	RS ^f	2	1.2	16.7	44.7	27.5	18.3	4.3
AC Stephen	RS ^h	2	15.3	6.5	50.5	13.2	18.5	4.3
Zaoshu 3	RS ⁱ	2	3.2	33.9	26.9	22.7	19.3	4.4
Beecher	HFHB	6	10.6	11.7	32.7	35.4	21.0	4.6
Paavo	HFHB	6	3.6	31.4	23.3	36.7	21.1	4.6
Zita	HFHB	2	5.0	37.5	36.4	18.7	21.9	4.7
Korsbyg	RS ^j	6	37.2	27.1	16.9	14.6	23.1	4.8
Hx690	HFHB	6	42.8	3.3	50.9	21.2	25.2	5.0
Dissa	HFHB	6	10.5	20.8	59.2	26.2	26.6	5.2
B 3152A	RS ^j	6	12.8	12.1	91.0	29.9	30.4	5.5
PI48641 Fidel	HFHB	2	53.3	21.6	61.4	13.9	34.6	5.9
Cimmyt 6A	RS ^j	6	75.3	11.4	83.8	20.8	41.5	6.4
Du Li-huang	HFHB	6	38.9	53.6	41.3	33.9	41.6	6.5
Hankkijan Potra	HFHB	6	54.2	39.1	36.3	57.4	46.3	6.8
Suvi	HFHB	6	65.8	53.0	16.7	61.4	46.6	6.8
45	LFHB	2	65.7	27.2	43.4	57.0	47.1	6.9
Etu	HFHB	6	69.3	75.8	61.1	65.1	67.7	8.2
Averages	...	...	12.7	11.5	31.9	17.0	15.8	3.7

^a ... Indicates missing data or not applicable.

^b LFHB = lines with low FHB index values in 1995 (0.2 to 8.0) and 1996 (1.9 to 12.9), HFHB = lines with high FHB index values in 1995 (4.8 to 54.5) and 1996 (31.4 to 70.1), RS = reported sources of FHB resistance (2,9,16) and Canadian cultivars or lines.

^c Means were obtained by squaring the transformed mean.

^d Transformed mean: the mean of the FHB index transformed by square root. The least significant difference ($P \leq 0.05$) between the transformed mean for any two lines is 1.7.

^e Resistance source identified by Gilchrist et al. (2).

^f Resistance source identified by Takeda and Heta (13).

^g Resistance source identified by Prom et al. (9).

^h Canadian cultivar or breeding line.

ⁱ Line provided by Ruth Dill-Mackay, Department of Plant Pathology, University of Minnesota.

^j Lines provided by George Fedak, Agriculture and Agri-Food Canada.

F. graminearum isolates used as inoculum, environmental conditions, or inoculation methods used between our study and others.

Of the 23 FHB-resistant two-rowed barley lines identified by Takeda and Heta (13), 13 were tested for FHB resistance (Table 3). These lines were Seijo II, Harbin, Svansota, Frederickson, Svanhals, Niedzica 1, CI 8826, Kyoto Nakate, Horni Peseky 2, Maja, Asahi 5, Fuji Nijo, and Primus. Although Takeda and Heta (13) listed these lines among the resistant lines from the 5,000 they tested, they did not indicate the relative levels of FHB resistance among these lines. Seijo II, Svansota, Frederickson, and Svanhals were among the most resistant of the lines tested (Table 3), but other lines identified by Takeda and Heta (13), such as Maja, Asahi 5, Fuji Nijo, and Primus, were not highly resistant in our tests.

Malting barley cultivars grown in western Canada have been predominantly two-rowed types dominated by the popular cv. Harrington (7). There appears to be a more diversified pool of two-rowed FHB-resistant cultivars than for six-rowed cultivars. The FHB indices for the Canadian two-rowed cultivars Symko, AC Sterling, T186-1, DB 202, DB 192, and Morrison were not different ($P \leq 0.05$) from Zhedar 1, Seijo II, and Chevron, which were reported to be resistant (2,9,13; Table 3). Resistance in these lines may have resulted from selection for disease resistance in eastern Canada where these cultivars and lines were developed. Tests of additional Canadian barley cultivars conducted in the same FHB nurseries as those used in this study demonstrated that western Canadian two-rowed cultivars AC Oxbow and AC Metcalfe had similar levels of resistance to AC Sterling (A. Tekauz, unpublished data). Some of the Canadian two-rowed cultivars had resistance levels similar to sources reported to have resistance; therefore, it may be difficult to substantially improve the level of FHB resistance in Canadian two-rowed cultivars through plant breeding. However, if different sources of resistance acted in an additive or complementary fashion, when these Canadian cultivars were crossed with effective two-rowed sources of resistance like Zhedar 1 or Seijo II, some transgres-

sive segregation for resistance may be found in the progeny. Further research is needed to determine the genetic basis for FHB resistance in barley.

Feed barley cultivars in western Canada include two-rowed types, but six-rowed types are predominant in the eastern prairie region (7). Most of the six-rowed cultivars grown in the eastern prairies of Canada, such as Excel and Robust, are more susceptible to FHB than two-rowed cultivars grown in the same area (16). Barley breeding programs in the United States, which are focussed primarily on six-rowed barley, have extensively used Chevron as a source of FHB resistance (10). Chevron was among the most resistant lines in our tests (Table 2). The six-rowed cultivars Murasaki-mochi and Nordic appeared to have good levels of resistance (Tables 1 and 3) and could be used in addition to Chevron as sources of resistance within the six-rowed pool of germ plasm. Crosses between adapted high-quality six-rowed cultivars and FHB-resistant two-rowed cultivars also have been attempted both in Canada and in the United States.

The lines in this study were characterized only for their reaction to FHB and DON accumulation. Although many of these lines may have useful levels of FHB resistance, their suitability as parents in breeding programs could depend on a number of other factors, such as plant height, head architecture, maturity, yield, and quality. It is encouraging to note that some Canadian two-rowed cultivars appear to have useful levels of FHB resistance and already are well adapted agronomically to the areas of Canada and the northern United States where FHB is a major problem.

ACKNOWLEDGMENTS

We thank M. Stulzer, E. Mueller, I. Mohamed-nur, R. Kaethler, J. Noll, and U. Kromer for technical assistance; M. Savard and his staff for analysis of DON; G. Fedak and R. Dill-Macky for providing seed for many of the RS lines; and J. Menzies, S. Woods, T. Fetch, and J. Gold Steinberg for advice on the manuscript.

LITERATURE CITED

1. Fernandez, M. R., Pearce, P. G., Holzgang, G., and Hughes, G. R. 2001. Fusarium head blight of barley in Saskatchewan in 2000. Can. Plant Dis. Surv. 81:61-62.
2. Gilchrist, L., Rajaram, S., Mujeeb-Kazi, A.,

- van Ginkel, M., Vivar, H., and Pfeiffer, W. 1997. Fusarium scab screening program at CIMMYT. Pages 7-12 in: Fusarium Head Blight: Global Status and Future Prospects. H. J. Dubin, L. Gilchrist, J. Reeves, and A. McNab, eds. CIMMYT, Mexico D.F.
3. McCallum, B., Tekauz, A., Gilbert, J., Gold, J., Idris, M., Mueller, E., Kaethler, R., Stulzer, M., and Kromer, U. 2000. Fusarium head blight of barley in Manitoba in 1999. Can. Plant Dis. Surv. 80:36.
4. McCallum, B., Tekauz, A., Gilbert, J., Mueller, E., Kaethler, R., Stulzer, M., and Kromer, U. 1998. Fusarium head blight of barley in Manitoba in 1997. Can. Plant Dis. Surv. 78:74.
5. McCallum, B., Tekauz, A., Gilbert, J., Mueller, E., Kaethler, R., Stulzer, M., and Kromer, U. 1999. Fusarium head blight of barley in Manitoba in 1998. Can. Plant Dis. Surv. 79:75-76.
6. McMullen, M., Enz, P., Lukach, J., and Stover, R. 1997. Environmental conditions associated with Fusarium head blight epidemics of wheat and barley in the Northern Great Plains, North America. Cereal Dis. Commun. 25:777-778.
7. Metcalfe, D. R. 1995. Barley. Pages 82-97 in: Harvest of Gold—The History of Field Crop Breeding in Canada. A. E. Slinkard and D. R. Knott, eds. University Extension Press, University of Saskatchewan, Saskatoon, SK, Canada.
8. Paulitz, T. C. 1999. Fusarium head blight: a re-emerging disease. Phytoprotection 80:127-133.
9. Prom, L. K., Steffenson, B. J., Salas, B., Fetch, Jr., T. G., and Casper, H. H. 1996. Evaluation of selected barley accessions for resistance to Fusarium head blight and deoxynivalenol concentration. Pages 764-766 in: Proc. 5th Int. Oat Conf. and 7th Int. Barley Genet. Symp. G. Scoles and B. Rosnagel, eds. University Extension Press, University of Saskatchewan, SK, Canada.
10. Rudd, J. C., Horsley, R. D., McKendry, A. L., and Elias, E. M. 2001. Host plant resistance genes for Fusarium head blight: sources, mechanisms, and utility in conventional breeding systems. Crop Sci. 41:620-627.
11. Sinha, R. C., Savard, M. E., and Lau, R. 1995. Production of monoclonal antibodies for the specific detection of deoxynivalenol and 15-acetyldeoxynivalenol by ELISA. J. Agric. Food Chem. 43:1740-1744.
12. Steffenson, B. J., Prom, L. K., Salas, B., Fetch, T. G., Wesenberg, D. G., and Bockelman, H. E. 1996. Severity of Fusarium head blight and concentrations of deoxynivalenol in near-isogenic lines of barley differing for several agronomic characters. Pages 774-776 in: Proc. 5th Int. Oat Conf. and 7th Int. Barley Genet. Symp. G. Scoles and B. Rosnagel, eds. University Extension Press, University of Saskatchewan, SK, Canada.
13. Takeda, K., and Heta, H. 1989. Establishing the testing method and a search for resistant varieties to Fusarium head blight in barley. Jap. J. Breed. 39:203-216.
14. Tekauz, A., Gilbert, J., Gold, J., Mueller, E.,

Table 4. Spearman rank correlation coefficients among Fusarium head blight (FHB) index (%) and deoxynivalenol (DON, ppm) content from 57 barley lines under natural conditions at Carman, MB and in nurseries inoculated with *Fusarium graminearum* in 1997 and 1998^a

	FHB			DON			
	Carman 1998	Nursery 1997	Nursery 1998	Carman 1997	Carman 1998	Nursery 1997	Nursery 1998
Carman FHB index 1997	0.60**	0.54**	0.52**	0.65**	0.22	0.54**	0.37**
Carman FHB index 1998	...	0.47**	0.70**	0.45**	0.30*	0.52**	0.38**
Nursery FHB index 1997	...	...	0.38**	0.37**	0.01	0.56**	0.30*
Nursery FHB index 1998	...	...	...	0.45**	0.53**	0.35**	0.44**
Carman DON 1997	...	...	...	...	0.27*	0.72**	0.45**
Carman DON 1998	...	...	...	...	...	0.16	0.28*
Nursery DON 1997	...	...	...	...	...	...	0.46**

^a * and ** Significant at $P \leq 0.05$ and 0.01, respectively.

- Idris, M., Stulzer, M., Beyene, M., and Nedohin, E. 2001. Fusarium head blight of barley in Manitoba and south-east Saskatchewan in 2000. *Can. Plant Dis. Surv.* 81:65.
15. Tekauz, A., Gilbert, J., Mueller, E., Stulzer, M., Kaethler, R., and Nedohin, E. 2002. Fusarium head blight of barley in Manitoba in 2001. *Can. Plant Dis. Surv.* 82:57-58.
16. Tekauz, A., McCallum, B., and Gilbert, J. 2000. Review: Fusarium head blight of barley in western Canada. *Can. J. Plant Pathol.* 22:9-16.
17. Zhu, H., Gilchrist, L., Hayes, P., Kleinhofs, A., Kudrna, D., Liu, Z., Prom, L., Steffenson, B., Trojinda, T., and Vivar, H. 1999. Does function follow form? Principal QTLs for Fusarium head blight (FHB) resistance are coincident with QTLs for inflorescence traits and plant height in a doubled haploid population of barley. *Theor. Appl. Genet.* 99:1221-1232.