Pathogenicity of *Fusarium* Species on Different Plant Parts of Spring Wheat Under Controlled Conditions

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ABSTRACT

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Most of the *Fusarium* species responsible for Fusarium head blight of wheat in Saskatchewan, Canada, have also been isolated from discolored subcrown internodes/crowns of wheat. It was therefore of interest to compare the susceptibility of heads and ground/underground tissue of wheat to isolates of *Fusarium* species from different sources. Controlled-environment pathogenicity tests were conducted on heads, seeds, and seedlings of spring wheat. Overall, *F. culmorum* and *F. graminearum* were the most pathogenic species, although the former was more pathogenic than the latter. *F. equiseti* and *F. poae* were the least pathogenic species, whereas *F. avenaceum* had intermediate pathogenicity in the head and seed tests, but low pathogenicity in the seedling test. There was a similar pathogenicity among isolates of each *Fusarium* species from different sources to heads and ground/underground plant parts, indicating a lack of adaptation of these isolates. Our observations suggest that *Fusarium* inoculum on or in infected seed or plant debris might infect plants at or below soil level, which could then become a source of inoculum for infection of heads in the following season(s). Survival of fungal inoculum in underground plant parts might be important during dry conditions.

Some of the most common fungi isolated from common (*Triticum aestivum* L.) and durum (*T. turgidum* L. var. *durum*) wheat heads affected by Fusarium head blight (FHB) in Saskatchewan, Canada, were *Fusarium avenaceum* (Fr.:Fr.) Sacc., *F. culmorum* (Wm.G. Sm.) Sacc., *F. graminearum* Schwabe (*Gibberella zeae* (Schwein.:Fr.) Petch), and *F. poae* (Peck) Wollenweb. (8,10). The same fungi were also frequently found in infected grain from the same FHB-affected areas (5). *F. graminearum* is the most important causal agent of FHB in the eastern Prairies, including eastern Saskatchewan (11), whereas *F. avenaceum* is the most widespread FHB pathogen in Saskatchewan (5,10).

According to disease surveys conducted across Saskatchewan in 1998 to 1999 (9), most of the *Fusarium* spp. isolated from FHB-affected heads of wheat were also isolated from lesioned ground/underground plant parts, although at different frequencies. *F. avenaceum*, *F. culmorum*, and *F. equiseti* (Corda) Sacc. were among the most commonly isolated *Fusarium* spp. from discolored subcrown internodes and crowns/lower culms of common and

durum wheat sampled across the province. *F. graminearum* and *F. poae* were found at low frequencies, and the former fungus was only found in the most FHB-affected areas of the province.

Pathogenicity tests of *Fusarium* spp. on cereal heads or roots and crowns have been conducted before (1,6,12–14,16–18,20–23). In general, most of these studies found that the most pathogenic species were *F. culmorum* and *F. graminearum*, although *F. avenaceum* was also reported as equally or more pathogenic than *F. culmorum* and *F. graminearum* (1,12). In some of these studies, isolates from different sources of each of the species were tested. However, no studies have compared the pathogenicity of individual *Fusarium* isolates on above- and underground tissue of wheat. Arseniuk et al. (1) found a negative correlation between head blight and seedling blight of winter wheat caused by a spore mixture of several *Fusarium* spp.

This study was undertaken to compare the relative pathogenicity of *Fusarium* isolates on heads, seeds, and seedlings of spring wheat. Isolates of the most important and/or common *Fusarium* spp. isolated from heads and subcrown internodes/crowns of common and durum wheat across Saskatchewan, Canada (9,10) were used in this study.

MATERIALS AND METHODS

Fungal isolates. Fungal isolates were obtained from glumes and subcrown internodes/crowns of wheat randomly selected

from fields surveyed across Saskatchewan in the summers of 1998 and 1999. Plant tissue was surface-sterilized in a 0.6% NaOCl solution for 1 min, rinsed in sterile distilled water, and plated on modified potato dextrose agar (PDA) (12 g of Bacto agar and 5 g of PDA per liter of distilled water) amended with streptomycin sulfate (160 mg/liter), chlortetracycline (60 mg/liter), and dichloran (2,6-dichloro-4-nitroaniline) (6.5 mg/liter) (4). Plates were incubated for 7 days under cool-white fluorescent and near-UV lights (300 to 400 nm) at 15°C night/22°C day and a 16-h photoperiod. Fungal cultures were identified and transferred to fresh media, and a single-spore culture was obtained.

Pathogenicity test on heads. Head pathogenicity tests of *Fusarium* spp. were conducted on the durum wheat cultivar AC Avonlea and the common wheat cultivar AC Elsa. Plants were grown in pots (7 × 7 × 18 cm) using a 1:1 mixture of local Swinton loam soil (2) and peat moss. Plants were grown under a 16-h photoperiod (22°C day/15°C night) and fertilized every 2 weeks using 1,300 ppm NPK (20-20-20).

At mid-anthesis, Zadoks' growth stage (ZGS) 65 (24), heads of the main and first tiller were sprayed to runoff with a spore suspension (1×10^5 conidia per ml) of each of four isolates of *F. avenaceum* and *F. culmorum*, two isolates of *F. graminearum*, and three isolates each of *F. equiseti* and *F. poae*. Fungi were grown on modified PDA, as above, for about 7 days. A drop of Tween 20 (polyoxyethylene sorbitan monolaurate) was added to every 250 ml of spore suspension. Control plants were sprayed in a similar manner with sterile distilled water. Plants were incubated in the dark at constant 100% relative humidity and 22°C for 24 h. After incubation, plants were kept until maturity under the same light and temperature conditions used prior to inoculation.

Each head was visually rated for percent surface area with FHB symptoms at 7, 14, and 21 days after inoculation. At maturity, heads were harvested and threshed individually. Kernel weight (g) and percent *Fusarium*-damaged kernels (FDK) were determined for each head. Each test was replicated three times (each replicate consisting of a pot with two plants) in a randomized complete block design (RCBD). The tests were repeated to give two trials each.

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Pathogenicity test on seeds. Pots were prepared as above using soil autoclaved at 148°C at 102 kPa for 45 min. The same isolates of *F. avenaceum*, *F. culmorum*, and *F. graminearum*, two of the isolates of *F. poae* and *F. equiseti* used in the pathogenicity test on heads, and *Cochliobolus sativus* (Ito & Kuribayashi) Drechs. ex Dastur, the most common cereal root pathogen in Saskatchewan (9), were each grown on V8 juice agar (15% V8 juice, 2% agar) for about 7 days. An agar plug (1 cm diameter) with mycelium only was cut from the periphery of the agar cultures and placed agar-side-up at the bottom of four 4-cm-deep holes made previously in each pot. A seed of AC Elsa, surface-sterilized for 1 min in an aqueous solution of 0.6% NaOCl and rinsed twice in sterile distilled water, was then placed on top of the agar plug and covered with soil. An agar plug with no fungus on it was used for the control treatment. The pots were watered daily with sterilized tap water and kept until harvest under the same conditions as the pathogenicity test on heads. Harvest was done when at least half of all plants in the test were at late anthesis (ZGS 69). Treatments were arranged in a RCBD with five replicates (each pot was a replicate) each, and the trial was repeated once. Plant emergence was determined 2 weeks after planting. Plant survival, or postemergence mortality, and growth stage were determined at harvest. Growth stage was rated on a 1 to 3 scale as follows: 1 = ZGS 12 to 23 (seedling to tillering), 2 = ZGS 45 to 53 (early booting to early heading), and 3 = ZGS 55 to 69 (heading to late anthesis). At harvest, each of the plants was carefully pulled out, and roots and crowns were washed under tap water and dried thoroughly at room temperature. Each plant was then rated for discoloration of subcrown internodes and crowns/lower culms based on percent tissue area discolored. A 0 to 3 scale (15) was used for subcrown internodes: 0 = no discoloration, 1 = trace to 25% of surface area discolored, 2 = 25 to 50%, and 3 = >50%. A 0 to 4 scale was used for crowns/lower culms: 0 = no discoloration, 1 = trace to 25% of surface area discolored, 2 = 25 to 50%, 3 = >50% and usually encircling the crown/lower culm, and 4 = same as 3 but plant tissue was rotted or started to rot. For both subcrown internodes and crowns/lower culms, a discoloration index was then calculated for each pot by summing the products of the number of plants in each category multiplied by the disease category value, then dividing the sum by the number of plants sampled.

Pathogenicity test on seedlings. Two surface-sterilized seeds of AC Elsa were sown 4 cm deep in pots prepared in a similar manner as the pots used for the pathogenicity test on seeds. At the four- to six-leaf stage (ZGS 14 to 16), a small hole (1 cm diameter) was aseptically dug in the

soil next to the crown of each seedling, and an agar plug with mycelium of each of the fungal isolates, prepared as for the test on seeds, was placed next to the crown. The agar plug was then covered with soil. An agar plug with no fungus was used for the control treatment pots. Plants were kept under the same conditions, and harvested at the same average growth stage, as in the test on seeds. Each test had five replicates (each pot was a replicate) arranged in a RCBD, and was done twice. Assessment of plant survival, growth stage, and ratings of subcrown internode and crown/lower culm discoloration were done as for the pathogenicity test on seeds. In addition, the total number of tillers per pot was also determined at harvest.

Statistical analysis. Based on the percent FHB and FDK, discoloration ratings, kernel weight, emergence, survival, and growth stage for each plant, average values were calculated for each pot (replicate). The effects of wheat cultivar, trial, fungal species, and isolate on percent FHB, percent FDK, and 100-kernel weight in the head test, and the effects of trial, fungal species, and isolate on seedling emergence, plant survival, growth stage, number of tillers, and discoloration ratings of subcrown internodes and crowns/lower culms in the seed and seedling tests, were tested using Proc GLM procedures (SAS Release Version 8.0, SAS Institute, Cary, NC). Treatment (fungal species/isolates) and wheat cultivar effects were regarded as fixed effects, whereas trial and its interactions with treatment, wheat cultivar, or both were considered to be random effects. Percentage data were arcsine-transformed prior to analysis. When *F* values were significant ($P \leq 0.05$), least significant differences were calculated. Simple correlations were done to make comparisons among percent FHB, FDK, and 100-kernel weight in the head test, and among plant emergence, plant survival, growth stage, number of tillers, and discoloration of subcrown internodes and crowns/lower culms in the seed and seedling tests.

RESULTS

Pathogenicity test on heads. The interactions of wheat cultivar $\times$ fungal species

$\times$ trial and wheat cultivar $\times$ fungal isolate $\times$ trial were not significant ($P > 0.05$) for any of the measurements taken, except for percent FHB at 7 days after inoculation ($P \leq 0.01$). The only two-way interaction that was significant was cultivar $\times$ trial ($P \leq 0.01$); however, differences among trials were only quantitative in nature. The cultivar effect was not significant ($P > 0.05$) for any of the measurements. When wheat cultivars and trials were analyzed together, the effects of fungal species and isolate were significant ($P \leq 0.01$) for each of the measurements taken.

Analysis by fungal species showed that *F. culmorum* and *F. graminearum* caused the highest percent FHB and FDK at 21 days after inoculation (Table 1). *F. equiseti* and *F. poae* were the least pathogenic. When measurements were analyzed by fungal isolate, pathogenicity was in general similar for isolates within most of the species, except for isolates of *F. avenaceum*, which varied the most (Table 2). Isolate A of *F. avenaceum* appeared to be more pathogenic to heads than the other isolates of the same species.

For all fungal species and two wheat cultivars combined, percent FHB for 7 to 21 days after inoculation was positively correlated with percent FDK ($r = 0.82$ to 0.92 , $P \leq 0.01$), and both percent FHB and FDK were negatively correlated with 100-kernel weight ($r = -0.66$ to -0.78 , $P \leq 0.01$).

Pathogenicity test on seeds. Analysis of the seed test of AC Elsa showed that the interaction of fungal species $\times$ trial was not significant ($P > 0.05$) for the disease and plant growth measurements taken, except for crown/lower culm discoloration ($P \leq 0.05$). The interaction of fungal isolate $\times$ trial was in most cases not significant ($P > 0.05$) either, except for measurements of plant growth stage and discoloration of crown/lower culms ($P \leq 0.05$). However, differences between trials were of a quantitative nature rather than of rank order. When trials were analyzed together, the effects of fungal species and isolate were significant ($P \leq 0.05$ to $P \leq 0.01$) for all measurements taken. *F. culmorum* had the greatest effect on plant emergence and survival (Tables 3 and 4). Few plants

Table 1. Mean percent Fusarium head blight (FHB) caused by *Fusarium* species at 7, 14, and 21 days after inoculation, percent *Fusarium*-damaged kernels (FDK), and 100-kernel weight (g) averaged over cultivars

Treatment	FHB (%)			FDK (%)	100-kernel weight (g)
	7 ^y	14	21		
<i>F. avenaceum</i>	6 b ^z	13 b	18 b	15 b	3.4 b
<i>F. culmorum</i>	41 a	65 a	78 a	61 a	1.6 c
<i>F. equiseti</i>	1 c	3 c	5 c	7 c	3.6 a
<i>F. graminearum</i>	35 a	62 a	79 a	63 a	1.7 c
<i>F. poae</i>	2 c	4 c	6 c	6 c	3.6 a
Water	0 c	1 d	2 d	4 d	3.7 a

^y Days after inoculation.

^z Values in a column followed by the same letter are not significantly different ($P > 0.05$) according to LSD tests.

emerged from seeds inoculated with isolates of this pathogen, or were still alive at harvest. Growth of the surviving plants was retarded most by *F. culmorum* and *F. graminearum*. Similar to the head test, the pathogenicity of *F. avenaceum* was intermediate, whereas *F. poae* and *F. equiseti* had the least effect on plant emergence and development, which was not significantly different ($P > 0.05$) from the control.

All fungal isolates caused discoloration of the subcrown internodes and crowns/lower culms. *F. culmorum* and *F. gramin-*

earum caused the greatest discoloration on both plant parts, whereas *F. avenaceum*, *F. equiseti*, and *F. poae* caused the least discoloration, which was not different ($P > 0.05$) from the control treatments (Tables 3 and 4).

There were some differences in pathogenicity among isolates within some of the *Fusarium* species (Table 4); however, in general these were not consistent across all measurements taken. Pathogenicity of *C. sativus* was similar to that of the *F. graminearum* isolates, except for discol-

oration of crowns/lower culms, which was similar ($P > 0.05$) to the control treatment.

Pathogenicity test on seedlings. Observations made in the seedling test were similar to those in the seed test, although there appeared to be fewer differences in pathogenicity among species in the seedling than in the seed test (Table 3). The interaction of fungal species $\times$ trial was not significant ($P > 0.05$) for any of the disease and plant development measurements taken, except for number of tillers ($P \leq 0.05$), whereas the interaction of fungal

Table 2. Mean percent *Fusarium* head blight (FHB) caused by *Fusarium* isolates at 7, 14, and 21 days after inoculation, percent *Fusarium*-damaged kernels (FDK), and 100-kernel weight (g) averaged over cultivars

Treatment	Isolate source ^y	FHB (%)			FDK (%)	100-kernel weight (g)
		7	14	21		
<i>F. avenaceum</i>						
A	Head	19 c ^z	37 d	52 c	26 c	2.8 c
B	Head	1 ef	3 gh	4 ef	12 de	3.3 b
C	Crown	2 de	9 e	13 d	10 d-f	3.5 ab
D	Subcrown internode	4 d	9 ef	13 d	13 d	3.6 ab
<i>F. culmorum</i>						
A	Head	42 a	62 a-c	76 ab	64 a	1.6 de
B	Head	42 a	60 bc	73 b	52 b	1.8 d
C	Subcrown internode	37 ab	68 ab	80 ab	65 a	1.4 e
D	Subcrown internode	43 a	71 a	80 ab	64 a	1.4 de
<i>F. equiseti</i>						
A	Head	1 d-f	4 g	7 e	11 d	3.5 ab
B	Subcrown internode	2 d-f	3 gh	5 e	4 g	3.5 ab
C	Crown	1 d-f	2 gh	4 ef	6 fg	3.8 a
<i>F. graminearum</i>						
A	Head	40 ab	66 ab	82 a	65 a	1.6 de
B	Head	31 b	58 c	76 ab	61 ab	1.8 de
<i>F. poae</i>						
A	Head	1 e-g	3 gh	5 e	5 fg	3.4 ab
B	Head	1 d-f	4 g	6 e	6 fg	3.7 a
C	Crown	2 d-f	4 fg	6 e	6 e-g	3.7 ab
Water		0 f	1 h	2 f	4 g	3.7 ab

^y Fungal isolates were obtained from discolored heads, crowns, or subcrown internodes of spring wheat across Saskatchewan in 1998 and 1999.

^z Values in a column followed by the same letter are not significantly different ($P > 0.05$) according to LSD tests.

Table 3. Seedling emergence at 2 weeks after planting, plant survival and growth stage at harvest, and discoloration of subcrown internodes and crowns/lower culms of wheat cultivar AC Elsa inoculated at planting (seed test) and seedling stage (seedling test) with *Fusarium* species and *Cochliobolus sativus*

Test/ treatment	Seedling emergence ^y	Plant survival ^w	Growth stage ^x	Number of tillers/pot	Discoloration	
					SI ^z	CLC
Seed test						
<i>F. avenaceum</i>	2.5 b ^z	2.3 b	2.6 ab	—	0.5 b	0.5 b
<i>F. culmorum</i>	0.6 d	0.5 d	2.2 c	—	1.5 a	1.5 a
<i>F. equiseti</i>	3.3 a	3.2 a	2.8 ab	—	0.1 b	0.2 b
<i>F. graminearum</i>	1.8 c	1.5 c	2.4 bc	—	1.1 a	1.4 a
<i>F. poae</i>	3.1 ab	3.1 a	2.7 ab	—	0.1 b	0.3 b
<i>C. sativus</i>	1.3 c	1.1 cd	2.5 a-c	—	1.6 a	0.6 b
Control	3.2 a	3.1 a	2.8 a	—	0.0 b	0.1 b
Seedling test						
<i>F. avenaceum</i>	—	2.0 a	2.4 ab	3.8 ab	1.1 a	1.1 c
<i>F. culmorum</i>	—	1.7 b	2.2 bc	3.1 c	1.3 a	3.0 a
<i>F. equiseti</i>	—	2.0 a	2.2 bc	3.8 ab	1.1 a	1.1 c
<i>F. graminearum</i>	—	1.9 ab	2.1 c	3.4 bc	1.3 a	2.5 b
<i>F. poae</i>	—	2.0 a	2.5 a	3.5 a-c	1.0 a	0.8 cd
<i>C. sativus</i>	—	2.0 a	2.2 bc	4.1 a	1.6 a	2.3 b
Control	—	2.0 a	2.3 a-c	4.1 a	0.1 b	0.4 d

^y Seedling emergence out of four seeds determined at 2 weeks after planting.

^w Plant survival out of four seeds in seed test and two seeds in seedling test, determined at harvest.

^x Growth stage measured on a scale of 1 to 3: 1 = Zadoks' growth stage (ZGS) 12 to 23, seedling to tillering; 2 = ZGS 45 to 53, early booting to early heading; 3 = ZGS 55 to 69, heading to late anthesis (24).

^z SI: subcrown internode; CLC: crown/lower culms.

^z Values in a column followed by the same letter are not significantly different ($P > 0.05$) according to LSD tests.

isolate $\times$ trial was only significant for discoloration of subcrown internodes ($P \leq 0.05$). However, differences between trials were not of rank order. When both trials were analyzed together, the effects of fungal species and isolate were significant ($P \leq 0.01$) only for plant survival and discoloration of crowns/lower culms. Only inoculation with *F. culmorum* caused a lower average plant survival than the control; however, plant survival after inoculation with most of the isolates of this fungus was similar to that of the rest of the treatments, including the control (Table 5). Inoculations with *F. culmorum* and *F. graminearum* caused the most discoloration and rotting of crowns/lower culms. In turn, *F. avenaceum* caused similar discoloration of crowns/lower culms as *F. poae* and *F. equiseti*. Again, there were not many differences among isolates of each of the species, except that isolate B of *F. avenaceum* caused less discoloration than most other isolates of the same species (Table 5).

Similar to the seed test, in general, the effect of *C. sativus* on discoloration of crowns/lower culms was comparable to that of *F. graminearum* (Tables 3 and 5).

For both the seed and seedling tests, the crown/lower culm discoloration observed at harvest extended up the plant stem on an average of 40% of the plants inoculated with *F. culmorum* and 29% of the plants inoculated with *F. graminearum*, although the discoloration rarely reached the first node. There was no apparent spread of the

discoloration up the stem caused by any of the other fungal species tested.

For all fungal treatments combined, there was a positive correlation between plant

emergence and survival in the seed test ($r = 0.95$, $P \leq 0.01$), and between plant survival and growth stage in the seed ($r = 0.53$, $P \leq 0.01$), but not in the seedling ($P > 0.05$) test.

Table 5. Plant survival and discoloration of crowns/lower culms of wheat cultivar AC Elsa inoculated at seedling stage with *Fusarium* isolates and *Cochliobolus sativus*

Treatment	Isolate source ^w	Plant survival ^x	CLC ^y discoloration
<i>F. avenaceum</i>			
A	Head	1.9 a ^z	1.4 de
B	Head	2.0 a	0.5 g
C	Crown	1.9 a	1.2 d-f
D	Subcrown internode	2.0 a	1.2 d-f
<i>F. culmorum</i>			
A	Head	1.8 a	2.7 bc
B	Head	1.7 a	3.0 ab
C	Subcrown internode	1.9 a	3.1 ab
D	Subcrown internode	1.3 b	3.4 a
<i>F. equiseti</i>			
A	Head	1.9 a	1.4 d
B	Subcrown internode	2.0 a	0.8 fg
<i>F. graminearum</i>			
A	Head	1.8 a	2.2 c
B	Head	1.9 a	2.8 bc
<i>F. poae</i>			
A	Head	2.0 a	0.7 fg
B	Crown	2.0 a	0.9 d-g
<i>C. sativus</i>			
A	Subcrown internode	2.0 a	2.3 c
Control		2.0 a	0.4 g

^w Fungal isolates were obtained from discolored heads, crown, or subcrown internodes of spring wheat across Saskatchewan in 1998 and 1999.

^x Plant survival out of two seedlings determined at harvest.

^y CLC: crown/lower culms.

^z Values in a column followed by the same letter are not significantly different ($P > 0.05$) according to LSD tests. *F* test was not significant for growth stage, number of tillers per pot, and subcrown internode discoloration.

Table 4. Seedling emergence at 2 weeks after planting, plant survival and growth stage at harvest, and discoloration of subcrown internodes and crowns/lower culms of wheat cultivar AC Elsa inoculated at planting with *Fusarium* isolates and *Cochliobolus sativus*

Treatment	Isolate source ^t	Seedling emergence ^u	Plant survival ^v	Growth stage ^w	Discoloration	
					SI ^x	CLC
<i>F. avenaceum</i>						
A	Head	2.8 b-d ^y	2.0 d-f	2.3 c-f	0.6 c-f	0.8 c-e
B	Head	3.3 ab	3.3 ab	2.9 ab	0.2 ef	0.2 ef
C	Crown	1.7 e-g	1.5 e-g	2.3 d-f	0.6 c-f	0.5 d-f
D	Subcrown internode	2.3 c-e	2.2 c-e	2.8 a-d	0.7 c-f	0.4 d-f
<i>F. culmorum</i>						
A	Head	1.0 gh	1.0 g-i	1.8 f	0.9 b-e+ ^z	1.8 a
B	Head	0.5 hi	0.3 ij	2.8 ab+	0.5 df+	1.3 a-c+
C	Subcrown internode	0.1 i	0.1 j	3.0 a+	0.0 f +	0.0 f+
D	Subcrown internode	0.7 hi	0.6 h-j	2.1 ef	3.0 a+	1.6 ab
<i>F. equiseti</i>						
A	Head	2.8 b-d	2.7 b-d	2.7 a-d	0.1 f	0.1 ef
B	Subcrown internode	3.8 a	3.7 a	2.9 ab	0.1 f	0.3 df
<i>F. graminearum</i>						
A	Head	2.0 d-f	1.6 e-g	2.4 b-e	1.3 bc	1.8 a
B	Head	1.6 e-g	1.3 f-h	2.4 b-e	0.9 b-d	1.0 b-d
<i>F. poae</i>						
A	Head	3.2 ab	3.2 ab	2.6 a-e	0.1 f	0.3 d-f
A	Crown	2.9 bc	2.9 a-c	2.8 a-c	0.1 f	0.4 d-f
<i>C. sativus</i>						
A	Subcrown internode	1.3 f-h	1.1 g-i	2.5 a-e	1.6 b	0.6 d-f
Control		3.2 ab	3.1 ab	2.8 a-c	0.0 f	0.1 ef

^t Fungal isolates were obtained from discolored heads, crowns, or subcrown internodes of spring wheat across Saskatchewan in 1998 and 1999.

^u Seedling emergence out of four seeds determined at 2 weeks after planting.

^v Plant survival determined at harvest.

^w Growth stage measured on a scale of 1 to 3: 1 = Zadoks' growth stage (ZGS) 12 to 23, seedling to tillering; 2 = ZGS 45 to 53, early booting to early heading; 3 = ZGS 55 to 69, heading to late anthesis (24).

^x SI: subcrown internode; CLC: crown/lower culms.

^y Values in a column followed by the same letter are not significantly different ($P > 0.05$) according to LSD tests.

^z + = Fewer than five observations.

Simple correlations performed among measurements taken in all tests showed that plant survival in the seed test was correlated with that in the seedling test for fungal species ($r = 0.94$, $P \leq 0.01$) and fungal isolates ($r = 0.67$, $P \leq 0.01$). There was also a high negative correlation between percent FHB at 14 days and seedling emergence and plant survival in the seed test ($r = -0.93$ to -0.95 , $P \leq 0.01$ for fungal species; $r = -0.84$ to -0.88 , $P \leq 0.01$ for fungal isolates), and between FHB at 14 days and plant survival ($r = -0.89$, $P \leq 0.05$ for fungal species; $r = 0.71$, $P < 0.01$ for fungal isolates) and number of tillers per pot ($r = -0.83$, $P \leq 0.01$ for fungal species; $r = -0.67$, $P \leq 0.01$ for fungal isolates) in the seedling test.

DISCUSSION

The greater pathogenicity on wheat heads of *F. graminearum* and *F. culmorum* than of the other fungal species tested in this study agrees with other reports in which a spore suspension was injected into, or dropped onto, a single spikelet (17,21–23). However, the apparent lack of a difference in pathogenicity between *F. culmorum* and *F. graminearum* found in our study does not agree with Balmas et al. (3), Mihuta-Grimm and Forster (16), or Wong et al. (23), who reported that *F. culmorum* was more pathogenic on heads than *F. graminearum*. Wilcoxson et al. (22) and Wong et al. (23) also found that *F. avenaceum*, *F. equiseti*, and/or *F. poae* were the species least pathogenic to wheat heads. The lower relative pathogenicity of *F. avenaceum* in their studies over ours might be, at least partly, attributed to the different inoculation methods used. When a spore suspension was brushed onto wheat heads in the field, Golinski et al. (12) found a greater effect of *F. avenaceum* than of *F. culmorum* on yield traits.

Overall, our results from the seed and seedling pathogenicity tests also agree with other reports on fungal pathogenicity on roots and/or crowns or lower culms, although relative differences among the *Fusarium* spp. have in some cases differed. Similar to our results, *F. culmorum* was reported as more pathogenic to wheat seedlings than *F. avenaceum* (1,6), more pathogenic to wheat and barley seeds than *F. graminearum*, *F. avenaceum*, or *F. poae* (20), and it caused crown and foot rot of durum wheat seedlings to a greater extent than *F. graminearum* (7). *F. culmorum*, *F. graminearum*, and *F. avenaceum* were also found to be more pathogenic to winter wheat seedlings than *F. equiseti* and *F. poae* (1). However, in contrast to our results, Arseniuk et al. (1) and Jenkinson and Parry (13) reported that *F. avenaceum* was as, or more, pathogenic to winter wheat seedlings than *F. culmorum* and *F. graminearum*, whereas Kane and Smiley (14) and Specht and Rush (17) reported

that there was no mortality of winter wheat caused by *F. avenaceum*.

This study has shown an overall similar relative susceptibility of heads and ground/underground plant parts of wheat to the *Fusarium* isolates tested. However, whereas *F. graminearum* and *F. culmorum* were equally pathogenic to heads and caused similar discoloration of subcrown internodes and crowns/lower culms in the seed test, *F. culmorum* affected plant emergence and growth to a greater extent than *F. graminearum*. The greater relative pathogenicity of *F. graminearum* on heads than on ground/underground plant parts might be related to stimulatory compounds present in anthers (19). Relative to the other species tested, *F. avenaceum* was less pathogenic to seedlings than to seeds or heads, although in the seed test this fungus also caused as little discoloration of subcrown internodes and crowns/lower culms as *F. equiseti* and *F. poae*. The observation that *F. avenaceum* was less pathogenic to seedlings than to seeds might be explained, at least partly, by differences in the maturity of plant tissue between seedling stems and germinating seeds.

Overall, although only a limited number of isolates from each fungal species was tested in this study, there appeared to be a lack of adaptation of isolates to different plant parts. Differences in pathogenicity among *F. avenaceum* isolates did not appear related to the source of the isolates. This observation, and the fact that *Fusarium* species derived from infected heads and subcrown internodes/crowns of wheat had similar relative pathogenicity on heads than on seeds or seedlings, suggest that infected seed and plant tissue might be contributing to root/crown infections, thus allowing fungal survival over time. Infected plant parts at or below soil level might then be a source of inoculum for infection of heads the following season(s), or might constitute a significant fungal survival mechanism under dry conditions.

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LITERATURE CITED

1. Arseniuk, E., Goral, T., and Czembor, H. J. 1993. Reaction of triticale, wheat and rye accessions to graminaceous *Fusarium* spp. infection at the seedling and adult plant growth stages. *Euphytica* 70:175-183.
2. Ayers, K. W., Acton, D. F., and Ellis, J. G. 1985. The soils of the Swift Current Map Area 72J Saskatchewan. University of Saskatchewan, Saskatoon, SK, Ext. Publ. 481.
3. Balmas, V., Corazza, L., and Santori, A. 1995. A comparison of the pathogenicity of *F. graminearum* Group 1, *F. graminearum* Group 2 and *F. culmorum* as casual agents of crown rot and head blight of wheat. International seminar on *Fusarium* mycotoxins, taxonomy

- and pathogenicity, Martina Franca, Italy, May 9-13. Book of Abstracts, 88-89.
4. Burgess, L. W., Liddell, C. M., and Summerell, B. A. 1988. Laboratory Manual for *Fusarium* Research, 2nd ed. University of Sydney, Sydney, Australia.
5. Clear, R. M., and Patrick, S. K. 2003. *Fusarium* head blight in western Canada. Canadian Grain Commission. Online publication.
6. Colhoun, J., Taylor, G. S., and Tomlinson, R. 1968. *Fusarium* diseases of cereals. II. Infection of seedlings by *F. culmorum* and *F. avenaceum* in relation to environmental factors. *Trans. Br. Mycol. Soc.* 51:397-404.
7. Corazza, L., Balmas, V., Santori, A., Vitale, S., Luongo, L., and Maccaroni, M. 2001. Head blight and foot rot of wheat in Italy. Pages 19-29 in: Sustainable systems of cereal crop protection against fungal diseases as the way of reduction of toxin occurrence in food webs. L. Tvaruzek, ed. A Healthy Cereals Proceedings, Kromeriz, Czech Republic, 2-6 July 2001. Agricultural Research Institute Kromeriz, Ltd., Kromeriz, Czech Republic. CD-ROM.
8. Fernandez, M. R., Holzgang, G., Celetti, M. J., and Hughes, G. 1999. The incidence of *Fusarium* head blight in barley, common wheat and durum wheat grown in Saskatchewan during 1998. *Can. Plant Dis. Surv.* 79:79-82.
9. Fernandez, M. R., and Jefferson, P. G. 2004. Fungal populations in roots and crowns of common and durum wheat in Saskatchewan. *Can. J. Plant Pathol.* 26:325-334.
10. Fernandez, M. R., Pearse, P. G., Holzgang, G., and Hughes, G. 2000. *Fusarium* head blight in common and durum wheat in Saskatchewan in 1999. *Can. Plant Dis. Surv.* 80:57-59.
11. Gilbert, J., and Tekauz, A. 2000. Review: Recent developments in research on *Fusarium* head blight of wheat in Canada. *Can. J. Plant Pathol.* 22:1-8.
12. Golinski, P., Kaczmarek, Z., Kiecana, I., Wisniewska, H., Kaptur, P., Kostecki, M., and Chelkowski, J. 2002. *Fusarium* head blight of common Polish winter wheat cultivars - comparison of effects of *F. avenaceum* and *F. culmorum* on yield components. *J. Phytopathol.* 150:135-141.
13. Jenkinson, P., and Parry, D. W. 1994. Isolates of *Fusarium* species from common broad-leaved weeds and their pathogenicity to winter wheat. *Mycol. Res.* 98:776-780.
14. Kane, R. T., and Smiley, R. W. 1987. Relative pathogenicity of selected *Fusarium* species and *Microdochium bolleyi* to winter wheat in New York. *Plant Dis.* 71:177-181.
15. Ledingham, R. J., Atkinson, T. G., Horricks, J. S., Mills, J. T., Piening, L. J., and Tinline, R. D. 1973. Wheat losses due to common root rot in the prairie provinces of Canada, 1969-71. *Can. Plant Dis. Surv.* 53:113-122.
16. Mihuta-Grimm, L., and Forster, R. L. 1989. Scab of wheat and barley in southern Idaho and evaluation of seed treatments for eradication of *Fusarium* spp. *Plant Dis.* 73:769-771.
17. Specht, L. P., and Rush, C. M. 1988. Fungi associated with root and foot rot of winter wheat and populations of *Cochliobolus sativus* in the Texas Panhandle. *Plant Dis.* 72:959-963.
18. Stack, R. W., and McMullen, M. P. 1985. Head blighting potential of *Fusarium* species associated with spring wheat heads. *Can. J. Plant Pathol.* 7:79-82.
19. Strange, R. N., Majer, J. R., and Smith, H. 1974. The isolation and identification of choline and betaine as the two major components in anthers and wheat germ that stimulate *Fusarium graminearum* *in vitro*. *Physiol. Plant Pathol.* 4:277-290.
20. Uoti, J. 1976. The effect of five *Fusarium* species on the growth and development of spring wheat and barley. *Ann. Agric. Fenniae Ser. Phytopathol.* No. 62. 15:254-262.
21. Walker, S. L., Leath, S., Hagler, W. M., Jr., and

- Murphy, J. P. 2001. Variation among isolates of *Fusarium graminearum* associated with Fusarium head blight in North Carolina. Plant Dis. 85:404-410.
22. Wilcoxson, R. D., Kommedahl, T., Ozmon, E. A., and Windels, C. E. 1988. Occurrence of *Fusarium* species in scabby wheat from Minnesota and their pathogenicity to wheat. Phytopathology 78:586-589.
23. Wong, L. S. L., Abramson, D., Tekauz, A., Leisle, D., and McKenzie, R. I. H. 1995. Pathogenicity and mycotoxin production of *Fusarium* spp. causing head blight in wheat cultivars varying in resistance. Can. J. Plant Sci. 75:261-267.
24. Zadoks, J. C., Chang, T. T., and Konzak, C. F. 1974. A decimal code for the growth stages of cereals. Weed. Res. 14:415-421.