NOTE
Soilborne pathogens / Agents pathogènes telluriques

Host range and mycotoxin production by *Fusarium equiseti* isolates originating from ginseng fields[1]

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Abstract: *Fusarium equiseti* is prevalent in soil and straw mulch in ginseng (*Panax ginseng*) fields in British Columbia and causes a reddish brown discolouration on ginseng roots. The pathogenicity of two isolates of *F. equiseti* from ginseng fields to other plant species belonging to different families was evaluated. Mycelial plugs and spore suspensions were used to inoculate seeds and roots in laboratory, growth room, and greenhouse experiments. Seed decay and reddish brown to black lesions were observed on hypocotyls and roots of kidney bean (*Phaseolus vulgaris*), bush bean (*Phaseolus lunatus*), broad bean (*Vicia faba*), chickpea (*Cicer arietinum*), and pea (*Pisum sativum*). A brownish discolouration and water-soaking symptoms developed on roots of alfalfa (*Medicago sativa*), canola (*Brassica napus*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), and oat (*Avena sativa*) seedlings. Tomato (*Lycopersicon esculentum*), pepper (*Capsicum annum*), carrot (*Daucus carota*), and cucumber (*Cucumis sativus*) plants did not exhibit any visible symptoms. Diseased tissues from several affected plant species contained the mycotoxins nivalenol and (or) zearalenone at concentrations ranging from 0.3 to 11 ppm. This study shows that the host range of *F. equiseti* includes several members of the Leguminoseae, in addition to some cereals. The fungus may be one of the potential causes of damping-off and root rot on these plant species.

Key words: root rot, trichothecene, zearalenone.

Résumé : *Fusarium equiseti* est courant dans les sols et les paillis de paille utilizés dans la culture du ginseng (*Panax ginseng*) en Colombie-Britannique et en fait roussir les racines. La pathogénicité de deux isolats de *F. equiseti* obtenus de champs de ginseng a été évaluée par rapport à d'autres espèces de plantes appartenant à des familles différentes. Des disques de mycélium et des suspensions de spores ont été utilizés pour inoculer des semences et des racines lors d'expériences menées en laboratoire, en chambre de culture et en serre. On a observé de la pourriture sur les semences ainsi que des lésions dont la couleur variait du roux au noir sur les hypocotyles et les racines de haricot (*Phaseolus vulgaris*), de haricot nain (*Phaseolus lunatus*), de féverole à gros grains (*Vicia faba*), de pois chiche (*Cicer arietinum*) et de pois (*Pisum sativum*). Une coloration brunâtre et des symptômes caractéristiques des lésions aqueuses sont apparus sur les racines de luzerne (*Medicago sativa*), de canola (*Brassica napus*), de blé (*Triticum aestivum*), d'orge (*Hordeum vulgare*) et des plantules d'avoine (*Avena sativa*). Les plants de tomate (*Lycopersicon esculentum*), de poivron (*Capsicum annum*), de carotte (*Daucus carota*) et de concombre (*Cucumis sativus*) n'ont affiché aucun symptôme apparent. Les tissus endommagés de différentes espèces de plantes affectées contenaient les mycotoxines nivalénol et/ou zéaralénone à des concentrations variant de 0,3 à 11 ppm. Cette étude montre que le spectre d'hôtes de *F. equiseti* inclut plusieurs légumineuses en plus de quelques céréales. Chez ces espèces, le champignon peut être une des causes probables de la fonte des semis et du pourridié.

Mots-clés : pourriture des racines, trichothécène, zéaralénone.

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Introduction

Fusarium equiseti (Corda) Sacc. is considered to be a weak pathogen on cereals and is occasionally found to be associated with fusarium head blight-infected kernels (Xue et al. 2006). This species commonly occurs in tropical and subtropical areas (Booth 1978; Bosch and Mirocha 1992), but it has also been recovered from cereals in temperate regions, including the Soviet Union, Europe, and North America (Kosiak et al. 2003; Stack et al. 1997; Tekauz et al. 2005; Wing et al. 1993; Xue et al. 2006). *Fusarium equiseti* is a soil inhabitant and can infect seeds, roots, tubers, and fruit of several crop plants. It has been previously implicated as a causal agent of disease on diverse plant species, such as cotton (*Gossypium hirsutum* L.; Chimbekujwo 2000), cowpea (*Vigna unguiculata* (L.) Walp.; Rodrigues and Menezes 2005), lentils (*Lens culinaris* Medik.; Chaudhary and Kaur 2002), sugar beet (*Beta vulgaris* L.; Stojsin et al. 2001), potato (*Solanum tuberosum* L.; Rai 1979; Theron and Holtz 1989) and pine (*Pinus* spp.; Ocamb and Juzwik 1995). This fungus can also produce mycotoxins in culture and in planta. Previous reports indicate its capacity to produce various forms of nivalenol, diacetoxyscirpenol, and the estrogenic mycotoxin zearalenone (Bosch and Mirocha 1992; Bottalico and Perrone 2002; Jimenez et al. 1997; Morrison et al. 2001; Tseng and Tu 1997). However, a comparative assessment of the host range of this pathogen has not been made, and the potential of this pathogen to produce these toxins in different susceptible plant species is unknown.

According to recent reports, *F. equiseti* was found to be associated with a root discolouration in ginseng (*Panax quinquefolius* L.), a previously unknown host, where it was transferred through straw mulch (Punja et al. 2007, 2008). Moreover, lentils following a cereal crop were affected by root rot due to *Fusarium* species, including *Fusarium acuminatum* Ellis & Everh., *Fusarium sporotrichioides* Sherb., and *F. equiseti* (Rauf and Banniza 2007).These findings highlighted the need to assess the potential host range of this fungus to avoid pathogen carry-over and also to help set up a baseline for monitoring possible changes in the host specificity of the pathogen in future. Therefore, the objective of this study was to evaluate the pathogenicity of two *F. equiseti* isolates originating from ginseng fields on a range of cultivated plant species and to assess the potential for mycotoxin production in planta.

Materials and methods

Fungal cultures and plant materials

The hosts selected for this study included the following members of the Leguminoseae: kabuli and desi-type chickpea (*Cicer arietinum* L.), bush bean (*Phaseolus lunatus* L. 'Butterbean OP'), kidney bean (*Phaseolus vulgaris* L. 'Montcalm'), mung bean (*Vigna radiata* L.), broad bean (*Vicia faba* L. 'Broad Winsor'), garden pea (*Pisum sativum* L. 'Sugar Snap OP'), soybean (*Glycine max* L. 'Edmamme'), and alfalfa (*Medicago sativa* L.). Other hosts also tested were canola (*Brassica napus* L.), tomato (*Lycopersicon esculentum* Mill. 'Longkeeper OP'), carrot (*Daucus carota* L. 'Nantes Coreless OP'), and pepper (*Capsicum annum* L. 'Northstar F1'). Three graminaceous species, wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), and oats (*Avena sativa* L.), were also included in the study. In cases where the cultivar names are not indicated, they were undetermined.

Two isolates of *F. equiseti* (S5A (DAOM identifcation No. DQ842061) and S9 (DAOM identification No. AJ543569)) previously isolated from ginseng fields were used for inoculation. The isolates were grown on potato dextrose agar (PDA; Difco laboratories, Detroit, Mich.) with 300 mg/L streptomycin sulfate for 7–10 days prior to inoculation with mycelial plugs (6 mm diameter). Agar plugs from these colonies were also used to initiate broth cultures in conical flasks containing 50 mL of mung bean broth (Evans et al. 2000) and maintained on a shaker (150 rpm) at 21–23 °C for 7 days. The spores were collected by straining the liquid culture through cheesecloth, and adjusting the concentration to 1×10^4 and 1×10^6 spores/mL using a haemacytometer.

Seed and hypocotyl inoculations

Seeds were soaked in 1% NaOCl for 10 min, followed by three rinses in sterile distilled water. They were then placed in Petri dishes containing three layers of autoclaved filter paper moistened with sterile distilled water. Petri dishes of 10 cm or 25 cm diameter were used, depending on the size of the seeds. The Petri dishes containing the seeds were placed in a dark chamber for 7 days to allow the seeds to germinate and the radicals to emerge. Mycelial plugs from 10-day-old colonies of *F. equiseti* growing on PDA were placed on the germinating seeds, roots, and hypocotyls and maintained at room temperature (21–23 °C) under ambient light. The filter papers were kept moist throughout the duration of the experiment. One week after inoculation, the PDA plugs were removed, and symptoms were recorded. Control Petri dishes received PDA plugs without any fungal mycelium. At least 15 seeds per plant species were inoculated with each isolate, and the experiment was conducted three times over a period of 3 months.

Growth room and greenhouse inoculations

Initial growth room experiments were conducted on small seedlings of various plant species. These seedlings were initiated from sterilized seeds, which were sown in 8 cm diameter plastic pots containing approximately 70 g of autoclaved vermiculite and maintained at 21 ± 2 °C (mean ± SD) in a growth chamber with a 12 h light : 12 h dark cycle for 14 days. Fifty millilitres of spore suspension containing 1×10^5 spores/mL was added to each pot, and the plants were grown for another 4 weeks before disease symptoms were assessed. Seed plus drenching inoculations were used in subsequent sets of experiments. Sterilized seeds were soaked in a *F. equiseti* spore suspension containing 1×10^6 spores/mL for 10 min prior to being placed in 8 cm diameter pots filled with autoclaved vermiculite. A 50 mL aliquot of spore suspension containing 1×10^4 spores/mL was added to each pot after planting. These pots were placed in trays and covered with plastic sheets for 72 h. They were then watered at regular intervals and allowed to grow for 6 weeks under a 12 h light : 12 h dark cycle in the growth room. For the greenhouse experiments, seed plus soil drench inoculations were conducted as described above. Inoculated plants were maintained for 6 weeks at 22 ± 4 °C with ambient light. After this period, the plants were exam-

ined for foliar symptoms; the plants were removed from the pots; the vermiculite was washed off under running water; and the roots were examined for presence of symptoms including water soaking, softening, or disintegration of tissue and various forms of discolouration. A portion of the diseased roots was used to reisolate the pathogen to fulfill Koch's postulates. The experiment was conducted at least three times in the growth room and twice in the greenhouse (March–May 2006 and 2007). Inoculations on wheat 'Norm' heads during anthesis and ginseng roots were conducted using mycelial plugs instead of spore suspensions as described by Goswami and Kistler (2005) and Punja et al. (2007), respectively.

Mycotoxin analysis

Diseased root tissues and lower parts of inoculated plants (see Fig. 3), as well as inoculated wheat heads and ginseng roots were screened for the presence of deoxynivalenol, nivalenol, 15- and 3-acetyl-deoxynivalenol, and zearalenone as described by Goswami and Kistler (2005). Two replicate samples of each tissue type of the host were assayed. The experiment was conducted twice. Controls included tissues inoculated with PDA plugs only.

Results and discussion

Pathogenicity of *F. equiseti* on various hosts

In the Petri dish inoculations, lesions and browning of the hypocotyl was observed below and around the inoculum plugs on all leguminous species inoculated with both isolates of *F. equiseti* (Figs. 1 A and B). Reddish brown lesions were most pronounced on bush beans, kidney beans, and broad beans. The kabuli-type chickpea and soybean were also found to be susceptible to seed and hypocotyl rot and exhibited profuse fungal growth. Mung beans exhibited pronounced rotting of the hypocotyls, whereas the peas were more tolerant to the pathogen and showed a lower amount of browning or rotting. The seedling inoculation experiments in growth room trials using a spore suspension drench alone did not provide sufficient symptom development prior to initiation of maturity in most of the host plants. On soybean, the seedling inoculation produced distinct root rot symptoms, whereas the seed and drench inoculation resulted in a preemergence seed rot.

Inoculation of seeds followed by a drench of spore suspension was found to result in disease development on all hosts also found to be susceptible in Petri dish inoculations. In both growth room and greenhouse trials 6 weeks postinoculation, broad bean (Fig. 1C), field pea (Fig. 1F), bush bean (Fig. 1G), mung bean (Fig. 1H), soybean (Fig. 1I), and kidney bean (Fig 1J) developed reddish brown lesions on the hypocotyl. These spread to the taproot to cause a reddish brown to black discolouration, which eventually led to rotting of the roots. The kabuli-type chick pea showed very severe seed and hypocotyl rot (Fig. 1D), whereas the desi-type chickpea seeds germinated but had browning and disintegration of the roots (Fig. 1E). Broad beans showed browning and blackening of the roots, and the root tips appeared to be most affected (Fig. 1C). In most legumes, including bush beans, mung beans, kidney beans, soybeans, and peas, rotting and water-soaking symptoms were observed in addition to the reddish brown discolouration (Figs. 1F–1J). Alfalfa seedlings grown in pots showed some discolouration of the root tissue. Disease incidence data (percentage of plants with symptoms) are shown in Fig. 2 for the growth room and greenhouse trials. The data from the two different growing environments confirmed the susceptibility of a number of leguminous species to *F. equiseti*.

The cereals and other plant species such as canola, tomato, pepper, and carrots were overgrown by the fungus in the Petri dish experiments, and therefore, disease symptoms could not be evaluated. Germinating cucumber (*Cucumis sativus* L.) seeds did not support fungal growth or show any symptoms of discolouration or rotting. In the growth room experiments, seedlings of wheat (Fig. 1L), barley (Fig. 1M), and oat (Fig. 1N) showed water-soaking and slight browning of the roots and rotting of the seeds. Tomato, pepper, carrots, and canola did not show any disease symptoms, except for a slight browning on the canola roots. In greenhouse experiments, none of these plant species developed any symptoms except for a general browning of the roots of wheat, oat, and barley. Both isolates of *F. equiseti* induced similar symptoms on all hosts and the fungus was reisolated from the symptomatic tissues of each of the susceptible host species. Inoculation of the *F. equiseti* strains on ginseng roots resulted in the development of a reddish brown discolouration below the plug (Fig. 1O), as reported by Punja et al. (2007). In some cases, this discolouration spread to adjacent tissues. Discolouration was observed under all the mycelial plugs placed on ginseng roots but not under the control plugs. In wheat heads inoculated with both strains of *F. equiseti* at anthesis, typical head blight symptoms were observed at 14 days after inoculation (Goswami and Kistler 2005). However, the spread of symptoms was restricted to the one or two spikelets above and below the point of inoculation (Fig. 1K), thereby indicating restricted spread of the pathogen.

Mycotoxin analysis

The mycotoxins nivalenol and zearalenone were detected in wheat heads inoculated with *F. equiseti*. These mycotoxins were also produced upon infection by both *F. equiseti* strains on a range of inoculated hosts with disease symptoms produced under laboratory conditions (Fig. 3). Control tissues not exposed to *F. equiseti* inoculum contained no mycotoxins. Preliminary results also suggested accumulation of nivalenol in the roots of chick pea and field pea plants inoculated in the growth chamber and greenhouse at levels ranging from 0.03 to 1.5 ppm.

Our results demonstrate that many leguminous species are susceptible to *F. equiseti*. Symptoms on different hosts ranged from a dry rot, as previously reported in potato tubers (Rai 1979) and the ornamental plant *Cycas beddomi* Dyer (Subramanyam et al. 1974) to a soft rot, similar to that seen in aboveground tissues affected by this pathogen (Elmer 1996; Ramachandran et al. 1982; Singh et al. 1975). These symptoms are likely to result from the production of cell wall degrading enzymes widely produced by *Fusarium* species (Collmer and Keen 1986; Kang and Buchenauer 2002). The reddish brown discolouration on diseased roots seen on several legumes is probably due to phenolic induction during disease development (Punja et al. 2007;

Fig. 1. Root lesions (marked by arrows) on plant species inoculated with *Fusarium equiseti*: (A and B) Petri dish inoculations and (C–O) growth room and greenhouse inoculations. (A) Chick pea, desi type; (B) field pea; (C) broad bean; (D) chick pea, kabuli type; (E) chick pea, desi type; (F) field pea; (G) bush bean; (H) mung bean; (I) soybean; (J) kidney bean; (K) wheat heads inoculated at the central spikelet; (L) wheat seedlings; (M) barley; (N) oats; and (O) ginseng root. In all photographs, healthy plants are shown on the left compared with inoculated ones on the right.

Fig. 2. Percentage of symptomatic plants inoculated with *Fusarium equiseti* in growth room and greenhouse trials. Symptoms were scored based on aboveground and belowground disease assessments. Error bars are SDs.

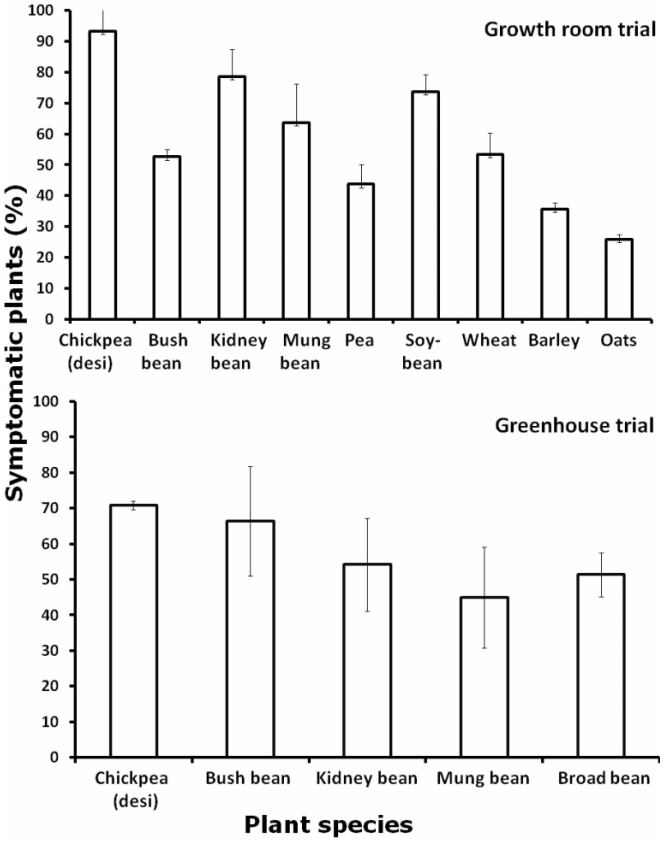
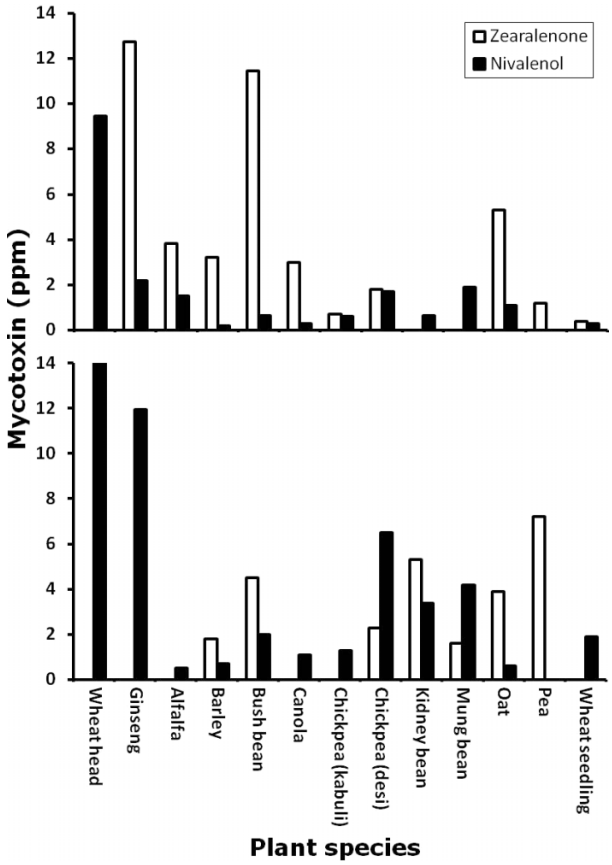


Fig. 3. Mycotoxin accumulation in plant tissues inoculated with *Fusarium equiseti*: (top) isolate S5A and (bottom) isolate S9.



Shankarlingam et al. 1980). The symptoms on many leguminous hosts bore a striking resemblance to those caused by *Rhizoctonia solani* Kühn (Rizvi and Yang 1996; Howard et al. 1994). The discolouration observed in the subcrown stems and roots of cereal species in this study is similar to that reported by Fernandez and Jefferson (2004) for *F. equiseti* and some other *Fusarium* species on wheat.

The seed and seedling rot observed on soybeans and kabuli-type chickpea resembles the preemergence seed rot in soybeans attributed to *Fusarium* species (Barasubiye et al. 2005; Schlub and Lockwood 1981). The accumulation of mycotoxins in the inoculated roots of leguminous species confirms previous reports on the occurrence of *Fusarium*-associated mycotoxins in cowpea (Kritzinger et al. 2003) and mung beans (Tseng and Tu 1997). Because *F. equiseti* has a wide host range, the spread of the fungus from belowground parts to fruits and pods, or other portions of the plant, suggests the possibility for potential mycotoxin contamination in these tissues following fungal colonization.

The ability of *F. equiseti* to colonize seed and eventually cause pre- and post-emergence rot, root rot and hypocotyl rot, as shown in this study, makes it a well-adapted pathogen in many cropping systems. On ginseng farms in British Columbia, *F. equiseti* is commonly found colonizing straw mulch placed on the soil surface (Punja et al. 2008). Minimum tillage practices and colonization of surface plant residues would likely enhance the inoculum potential of *F. equiseti*, a well-known soil inhabitant. Rotation of leguminous crops following ginseng or other cereals, in which *F. equiseti* may be prevalent, could result in the development of disease symptoms as described in this study.

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