Snow mold diseases and their distribution on winter wheat in Ontario in 1982-84[1]

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Field surveys in **1982-84** showed that damage from snow mold fungi occurred chiefly within three areas of white winter wheat production in southern Ontario. The most frequently occurring pathogens were ***Microdochiurn nivale*** var. ***nivale. Typhula incarnata, T. ishikariensis*** var. ***ishikariensis,*** and ***T. phacorrhiza. Myriosclerotinia borealis*** occurred only near the northern limit of production, and ***T. ishikariensis*** var. ***canadensis*** was found only once. Most fields were affected by more than one of the pathogens. During the winter, ***M. nivale*** was first isolated in mid December from naturally infected plants and from fall-inoculated plants in the field. ***T. incarnata*** was first isolated in mid January, and ***T. ishikariensis*** var. ***ishikariensis*** and ***T. phacorrhiza*** in mid March. Damage from snow mold occurred in **25%** of fields examined in **1982** and **1984,** with losses of up to **80%.** averaging **12-15%** each year. In **1983** a persistent snow cover was lacking in many areas throughout most of the winter, resulting in only isolated incidences of snow mold damage. All four snow mold fungi were widely distributed and mixed infections of two or more were common within fields and on individual plants.

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Des inventaires aux champs en **1982-84** ont démontré que les dommages causes par les moisissures nivales sont répartis principalement dans trois regions productrices de blé d'hiver du sud de l'Ontario. Les pathogènes les plus répandus sont ***Microdochiurn nivale*** var. ***nivale, Typhula incarnata, T. ishikariensis*** var. ***ishikariensis*** et ***T. phacorrhiza. Myriosclerotinia borealis*** ne croît qu'à la limite septentrionale de production et ***T. ishikariensis*** var. ***canadensis*** n'a été identifié qu'une seule fois. La plupart des champs contenait plus d'un pathogène. Durant l'hiver, ***M. nivale*** a été isolé pour la premiere fois a la mi-décembre, a partir de plants infectés naturellement et de plants inoculés a l'automne. L'on a isolé pour la premiere fois ***T. incarnata*** à la mi-janvier et ***T. ishikariensis*** var. ***ishikariensis*** ainsi que ***T. phacorrhiza*** à la mi-mars. **25%** des champs examines en **1982** et **1984** montraient des signes de dommage causes par la moisissure nivale, avec des pertes moyennes annuelles de **12** à **15%** pouvant aller jusqu'à **80%** dans certains cas. En **1983,** l'absence d'une couche de neige au sol pour une grande partie de l'hiver dans plusieurs regions a eu pour consequence une incidence très faible de dommage dûe à la moisissure nivale. Les quatre organismes responsables de la moisissure nivale avaient une disttibution Btendue et des infections de deux de ces organismes ou plus étaient choses courantes dans les champs et sur les plants individuels.

Introduction

In Canada soft white winter wheat production is centered in southern Ontario, with about 80% being produced in the southwestern counties of Lambton, Essex, Kent and Huron. In that area and elsewhere abiotic stresses such as low temperature, flooding, desiccation and ice encasement during winter and early spring have an adverse effect on winter survival. In parts of Huron, Simcoe and other counties where snow cover is more persistent, biotic stresses during winter are caused chiefly by snow mold fungi. During 1980-1984 disease surveys and inoculation tests were undertaken to determine the extent of damage from snow mold diseases and to isolate and identify the causal fungi.

Materials and methods

Disease surveys of field-grown winter wheat were carried out in fall, winter and spring. During October-December, plants were collected at 3-week intervals from experimental plots and commercial fields within 100 km of Ottawa to determine whether fungal pathogens were associated with visible plant injury. In all three survey periods, plants also were collected from a naturally infested snow mold plot in a field near Hyndford in Renfrew Co. During the winter, from early December to snow nnelt, samples were collected at 4-week intervals from fields to determine the time of infection by snow mold fungi. These observations were supplemented with data from an experiment using inoculated plants (Schneider and Seaman, 1986). Fiber pots (20 cm diam.) containing a sterilized greenhouse soil mix were seeded to winder wheat, ***Triticum aestivum*** L. cv. Fredrick (25 seeds/pot, 2cm deep). A 1 cm deep layer of white silica sand was added to the soil surface of each pot and laboratory-produced inoculum (Table 1) was mixed into the sand. Inoculum consisted of sclerotia of ***Typhula incarnata, T. ishikariensis*** var. ***ishikariensis, T. phacorrhiza,*** and ***Myriosclerotinia borealis,*** produced on rye seed substrate (Smith. 1981); inoculum of ***Microdochiurn nivale*** var. ***nivale*** included a mixture of mycelium, conidia, and rye seed substrate. The pots were maintained in a greenhouse for germination and early plant growth and then transferred outdoors for hardening. In late November, the pots were placed in a field plot with about 2 cm of the rims above the soil surface and the plot was enclosed by snow fence to maintain snow cover. Permanent snow cover in 1983 began on 3 December and melt occurred on 15-16 April 1984 At intervals pots were retrieved for sampling of plant tissues and original inoculum and then placed in a greenhouse to observe regrowth of the plants. Tissues were examined microscopically for signs of colonization and were plated on agar medium with or without surface sterilization as described for field samples.

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Table 1. Pathogenic fungi and their frequency of isolation from winter wheat plants during the fall (mid October to early December).

Pathogen	No. of isolates
Fusarium tricinctum (Corda) Sacc.	**4**
F. graminearum (Schwabe)	2
F. avenaceum (Fr.) Sacc.	**1**
F. equiseti (Corda) Sacc.	**1**
F. moniliforme Sheldon	**1**
F. oxysporum Schlecht	1
Cylindrocarpon sp.	**2**
Phoma sp.	**2**
Stemphyllium sp.	**1**
Acremonium strictum W. Gams	**1**
Alternaria sp.	**1**
Cladosporium sp.	**1**
Helminthosporium sp.	**1**
Verticillium sp.	**1**

During the spring surveys, from mid April to early May, commercial winter wheat fields were assessed for snow mold damage. Fields were examined in all winter wheat growing areas of southern Ontario except the Niagara Peninsula and the southwestern counties of Essex, Kent and Elgin, which were found to be relatively free from snow mold damage in preliminary surveys in 1980 and 1981. In 1983, warm weather in January resulted in the loss of snow cover throughout the survey area and damage from snow mold fungi was uncommon. During the spring surveys, on-site visual estimates were made of the percentage of field area damaged by snow molds.

In each field, samples were taken from symptomless plants, from plants showing leaf necrosis, and from necrotic plants. Preliminary identificaiton of snow mold fungi was based on the presence of sclerotia or sporodochia on necrotic tissues. The samples were kept cool and dry until examined in the laboratory. Sclerotia and pieces of tissue from leaves and crowns were sterilized in 70% ethanol for 1 minute, washed three times in sterile distilled water and plated onto potato-sucrose- agar (PSA) or an antibiotic medium (Schneider and Seaman, 1986). The plates were maintained in the dark at 12°C and hyphal tips from the colonies were subcultured onto PSA for identification.

Observations and discussion

The snow mold pathogens associated with damage to winter wheat were ***Typhula incarnata*** Lasch ex Fr.; ***T. ishikariensis*** Imai var. ***ishikariensis*** Arsvoll and Smith; ***T. phacorrhiza*** Reichard ex Fries; ***Myriosclerotinia borealis*** (Bub. and Vleug.) Kohn; and ***Microdochium nivale*** (Fries) var. ***nivale*** Samuels and Hallett (Syn. ***Gerlachia nivalis*** (Ces. ex Sacc.) Gams and Muller var. ***nivalis. Fusarium nivale*** Ces. ex. Sacc.).

Annually various types of injury including chlorosis, discoloration or necrosis of leaves, crowns and subcrown internodes were observed on winter wheat plants during the fall. The amount of injury varied considerably but plant necrosis was rare. Plant-pathogenic fungi were isolated from only 4% of 500 plants showing some degree of necrosis of leaf, crown or subcrown internode tissues (Table 1). Six species of ***Fusarium*** were isolated from the plants, the most common ones being ***F. tricinctum*** and ***F. graminearum; F. avenaceum, F. equiseti, F. moniliforme.*** and ***F. oxysporum*** were isolated from one plant each. Of more than 50 other fungi isolated, only 8 were considered to be potential plant pathogens (Table 1); however none was tested for pathogenicity. Bruehl ***et al.*** (1966) reported isolating a large number of fungi from injured tissues, including four of the ***Fusarium*** spp. isolated here, but none was pathogenic in tests at low temperature. Snow mold fungi were not isolated from plants sampled before snow cover. In Japan Matsumoto and Araki (1981) isolated ***T. iskikariensis*** and ***T. incarnata*** from non-surface-sterilized leaves but not from surface sterilized leaves of meadow fescue and perennial ryegrass prior to a persistant snow cover. In Belgium Detiffe ***et al.*** (1981) isolate ***T. incarnata*** in November from winter barley growing in inoculated field plots. This is apparently the earliest that ***T. incarnata*** has been reported from plants under natural conditions and, in part, may be due to an adaptation of the pathogen to the mild climate in that region.

During the winter, marked differences were observed in the times at which the snow mold fungi were first isolated from plants in the naturally infested snow mold plot, and these results generally were in agreement with those from the pot experiment (Table 2). In mid December ***M. nivale*** var. ***nivale*** was first isolated from plants that were watersoaked and dark green in appearance, and by mid January 96% of the inoculated plants failed to produce new growth when moved to a greenhouse. Plants inoculated with ***M. nivale*** var. ***nivale*** that were collected from under snow cover between January and mid April had dark green, water soaked leaves, with sporodochia of the fungus on the surface. However the typical pink color associated with this disease (Smith, 1981; McBeath, 1985) developed only in plants in the field following snow melt. The leaf spot symptom caused by ***M. nivale*** var. ***nivale*** (Smith, 1981) was observed occasionally in the field following snow melt but was not seen in inoculated plants. One isolate of ***M. nivale*** var. ***major*** from a lawn grass was used in the inoculation tests but it was not recovered from the plants, and plant survival was equal to that of the uninoculated control. This pathogen was not found on winter wheat in Ontario.

T. incarnata was first isolated from inoculated and naturally infected plants in mid January (Table 2), and 98% of the inoculated plants collected in mid February failed to produce new growth in the greenhouse. Both ***T. ishikariensis*** var. ***ishikariensis*** and ***T. phacorrhiza*** were first isolated in mid March, and at snow melt a month later 96% and 97%, respectively, of the inoculated plants were dead. Plants inoculated with each of the three ***Typhula*** species were symptomless when the ***Typhula*** spp. were first isolated but in each case watersoaked leaves with newly formed sclerotia were observed on plants sampled one month later. Symptoms were similar to those described for the typhula snow molds on winter cereals (Smith, 1981; Schneider and Seaman, 1986) but were not as clearly defined as symptoms on plants in the field at snow melt.

The role of temperature, moisture and snow cover in initiating colonization and infection by snow mold fungi is not clear. In Japan ***T. incarnata*** colonized tissues before snow cover but was first isolated from surface-sterilized tissues of meadow fescue and perennial ryegrass after 6-8 weeks of snow cover,

Table 2. Plant survival and inoculum viability in the field following inoculation with snow mold fungi; plants and inoculum were sampled at monthly intervals following seeding and inoculation in pots in October and placement in the field on November 25.

Pathogen	Time of first isolation from plants	Plant Survival in spring (%)	Inoculum survival (%)[a] December	March
Uninoculated control		96		
Typhula incarnata	Jan	2	84	80
T. ishikariensis var. ***ishikariensis***	Mar	4	86	78
T. phacorrhiza	Mar	3	***88***	84
Myriosclerotinia borealis	b	96	90	64
Microdochium nivale				
var. ***nivale***	Dec	4	100	0
var. ***major***	b	93	**100**	0

a Inoculum was sclerotia of ***Typhula*** spp. and M. ***borealis*** produced on rye seed, and rye seed colonized by ***M. nivale.*** Survival = average of values recorded each month from December to March for the ***Typhula*** spp. and ***M. borealis; M. nivale*** inoculum was recovered only in the December samples.

b ***M. borealis*** and ***M. nivale*** var. ***major*** were not isolated from plants.

in late January to early February (Matsumoto and Araki, 1981). The good agreement between the times of first isolation of ***T. incarnata*** observed here and in Japan may be related to the period that the plants were under a snow cover, about 6 weeks and 6-8 weeks respectively. The duration of snow cover also is an important factor in the overall incidence and severity of snow mold diseases in the USA (Bruehl ***et al.,*** 1966), but the role of snow cover may be much less important in determining when some snow mold pathogens become active in regions where the fall and winter climate is less severe. Above-freezing mean monthly temperatures and lack of a persistent snow cover (Arlery, 1970) in the region of Belgium where ***T. incarnata*** affects winter barley (Dentiffe ***et al.,*** 1981) suggests that the role of snow cover may be indirect. Perhaps in areas of Canada, Japan, Scandinavia and the USA that have a colder fall and winter climate than in Belgium a snow cover is necessary to maintain suitable temperatures for growth of the pathogens at the soil surface. The rarity of snow mold in Ontario in 1983 may have been due to the low soil temperatures that prevailed on the bare soil surface. A snow cover-temperature relationship also may be required in regions with cold winter climates for germination of ***Typhula sclerotia.*** The results in Table 2 show that the viability of sclerotia of all three ***Typhula*** species remained high (84-88%) throughout the winter months. Germinated sclerotia were first recovered from the soil at the same sampling times that the respective pathogen was first isolated from inoculated plants, and at each subsequent sampling 12-20% of the sclerotia recovered showed signs of germination.

In each species germination of sclerotia was myceliogenic, except that 12% of ***T. incarnata*** sclerotia had short (less than 2 mm) immature sporophore-like outgrowths at each sampling date. In contrast, in Belgium. where germination of sclerotia of ***T. incarnata*** in the field was **28%** in November and 100% by early December, germination up to early December was myceliogenic, but by late December all of the sclerotia recovered had produced sporophores (Detiffe ***et al.,*** 1981). In this study and in the one in Belgium (Detiffe ***et al.,*** 1981) the ***Typhula inoculum*** consisted of laboratory-produced sclerotia; whether similar experimental results would be obtained with naturally produced sclerotia is unknown. In this study, germinated sclerotia of ***T. ishikariensis*** var. ***ishikariensis*** and ***T. phacorrhiza*** were not found until the March sampling, 2 months later than for ***T. incarnata*** sclerotia. In Japan ***T. ishikariensis*** was not isolated from grasses during the winter but sclerotia were found on plants occasionally after snow melt (Matsunnoto and Araki, 1982). ***T. phacorrhiza*** has been regarded as a saprotroph but recently it was shown to be pathogenic on winter wheat at several locations in Ontario (Schneider and Seaman, 1986).

Myriosderotinia borealis was isolated from several fields near the northern limit of winter wheat production (areas A and C, Fig. 1) in Ontario (Schneider and Seaman, 1987). One isolate of M. ***borealis*** was used in the pot experiment, but none of the test plots became infected under the conditions of the test and none of the sclerotia recovered from the pots showed signs of having germinated. However viability of sclerotia of ***M. borealis*** recovered from the pots was 90% in December and 64% in March (Table 2).

During previous spring surveys in 1980-81 Seaman (unpublished] observed that although abiotic injury to winter cereals was common throughout Ontario, counties in the southwest appeared to be relatively free of damage from snow mold

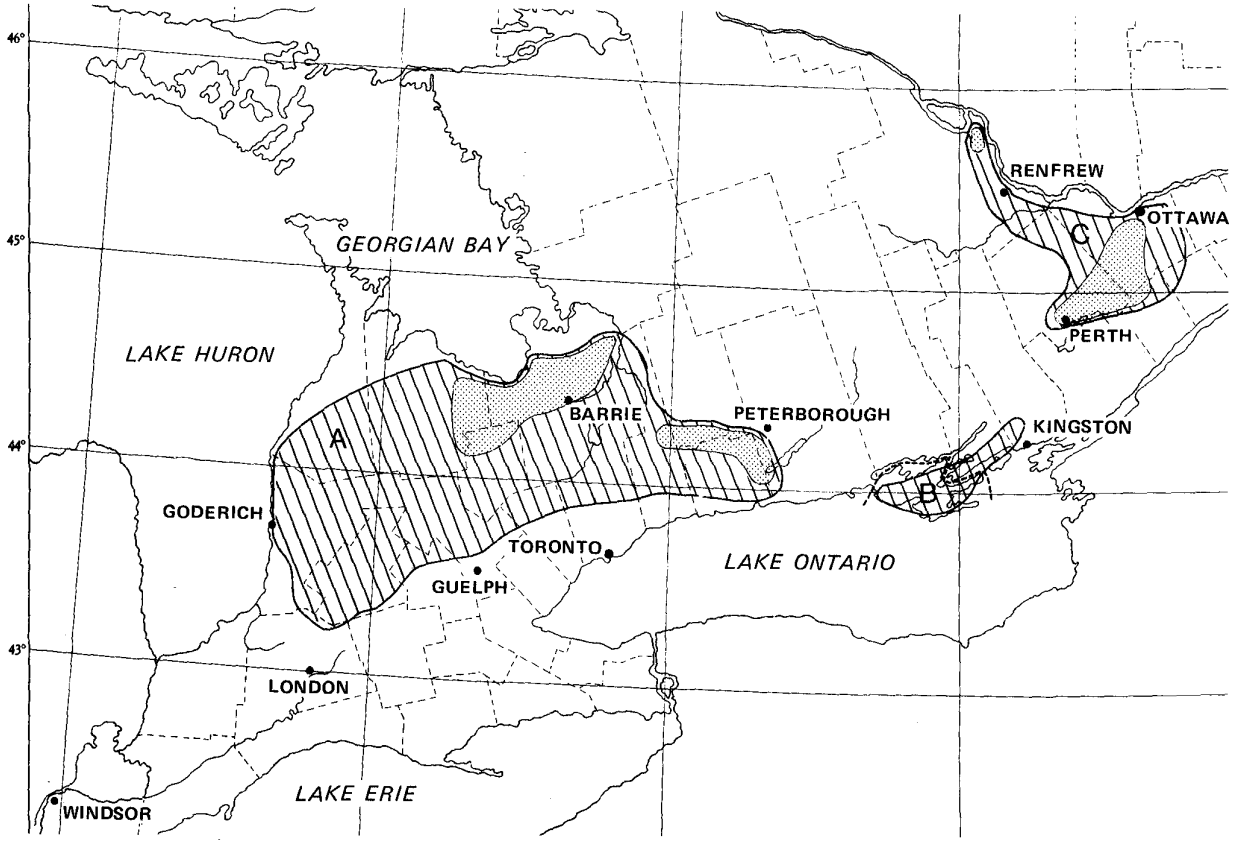

Figure 1. Snow mold region of southern Ontario (Areas A, B and C). Stippled areas represent centers of higher incidence examined in 1981-84.

fungi, with damage observed in only 3 of 212 fields in Essex and Kent counties. In the 1982 and 1984 surveys snow mold damage was observed in 109 of 418 fields. For convenience, the snow mold region is shown in Figure 1 as three distinct areas, with stippling indicating locations of highest incidence. The southern boundary of the snow mold regions approximates the lines for 2700-2900 corn heat units (CHU) (Ontario Ministry of Agriculture and Food, 1985). Area A (Fig. 1) extends northward to about 2500 CHU and includes the 2300-2500 CHU zone in Dufferin, Grey, and Wellington counties. Area B is essentially on the 2900 CHU line, while Area C extends from about 2500 to 2700 CHU. These three areas lying between 43° and 46° latitude are those in which snow mold damage has been found most years; damage from snow mold fungi has been found on wheat outside these areas, but both prevalence and severity have been low, with few cases of economic loss encountered.

The three *Typhula* spp. and M. *nivale* were observed on plants throughout the snow mold region, and most of the fields were affected by two or more of these pathogens. The northern limit for snow mold activity is unknown at present; all five snow mold pathogens involved in southern Ontario were isolated from test plots of winter wheat grown in 1984 at the Agriculture Canada Experimental Farm at Kapuskasing (latitude 49°25') in northeastern Ontario. A limited production of hard red winter wheat occurs in the Rainy River District of northwestern Ontario, but snow mold surveys have not been carried out in that area. Within the snow mold region described here, plant mortality in individual fields varied from a trace (less than 2%) to over 80%, with an estimated average annual plant loss of 12-15%. This estimate does not include other variables that have an adverse role in winter wheat production. For example when plant stands are reduced by 30% or more many fields are disked in early spring and sown to spring crops. Similarly little is known of the effects of different patterns of snow mold damage, which may vary from a thinning of plants throughout a field in which snow cover was uniform to conspicuous areas of complete killing where terrain or other factors result in snow drifts which persist for lengthy periods during snow melt, thus extending the period of pathogen activity (Bruehl *et al.*, 1966).

During the period of these surveys, the soft white winter wheat cultivar Fredrick comprised more than 80% of the fields. However snow mold fungi were also observed in fall-seeded fields of other white wheat cultivars, red wheat, barley, triticale, rye, and winter rape. In all of the cereal crops the symptoms observed after snow melt were as described by Smith (1981) on winter cereals in western Canada.

Other snow mold fungi reported on winter wheat and rye in western Canada include T. ishikariensis var. canadensis Smith and Arsvoll and *Coprinus psychromorbidus* Redhead and Traquair, formerly known as LTB (Smith, 1981). In Ontario *T. ishikariensis* var. canadensis occurs on turf grasses in the area

around Guelph and Barrie (Fushtey, 1980) and was isolated from wheat plants grown in one field near Ottawa in 1984. *Coprinus psychromorbidus* was not observed during these surveys.

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