Change in Snow Mold Flora in Eastern Hokkaido and its Impact on Agriculture

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Introduction

A group of fungi cause disease on dormant plants under snow. They are referred to as snow molds. Snow mold fungi are taxonomically diverse and vary ecologically (Matsumoto 2009). Snow cover protects plants from freezing but provides snow molds with optimal conditions to prevail (Matsumoto 1994). The environment under snow is characterized by constant low temperatures at about 0 °C, darkness, and high moisture, which bring about the following features of the habitat of snow molds: (1) low temperature restricts species diversity and only psychrophiles can grow (Matsumoto and Hoshino 2009), (2) reserve carbohydrates are depleted through respiration and plant resistance decreases with time (Nakajima and Abe 1994), and (3) resources, i.e., plant tissues, do not increase under snow (Matsumoto 1994).

The life cycle of snow mold is clearly divided into active and dormant stages based on the presence or absence of snow cover (Hsiang et al. 1999). The life cycle of two major snow molds, *Typhula ishikariensis* and *Sclerotinia borealis* is schematically presented along with factors critical for disease incidence (Fig. 1). The duration of persistent snow cover is most important and changing winter climate concerns us most seriously. The timing of persistent snow cover affects plant resistance through plant cold hardiness. Humid and cloudy summer climate reduces snow mold resistance of alfalfa through foliar disease in some areas.

Tomiyama (1955) divided Hokkaido into two, according to the major snow mold fungi (Fig. 2). The *Sclerotinia* snow mold fungus, *S. borealis* was prevalent in eastern Hokkaido characterized by severe soil frost and thin snow cover, whereas little or slight soil frost and deep snow cover favored the occurrence of *Typhula* spp.

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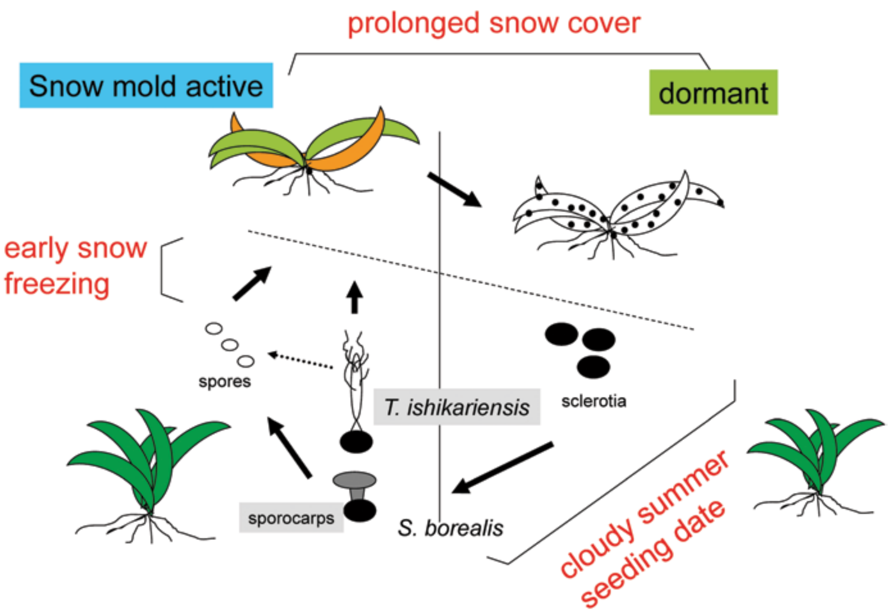


Fig. 1 Life cycle of the two major snow mold fungi, *Sclerotinia borealis* and *Typhula ishikariensis*. Cloudy summers predispose forage crops to snow mold through the incidence of leaf disease. Seeding date is critical for both winter cereals and forage crops

in western Hokkaido. This pattern is not absolute and simply represents the outcome of host–parasite interactions, especially in the case of *Sclerotinia* snow mold; the disease could occur even in Sapporo, western Hokkaido when less hardy plants such as perennial ryegrass (*Lolium perenne*) were grown (Matsumoto and Araki 1982). Matsumoto et al. (1982) found that *T. ishikariensis* biotype B occurred in less snowy areas, including eastern Hokkaido. They further revealed that biotype A was prevailing in eastern Hokkaido presumably due to the change in winter climate (Matsumoto et al. 2000).

Sclerotinia borealis

Persistent snow cover occurred much later than usual in eastern Hokkaido in the 1974–1975 winter with frozen soil more than 30 cm deep, which predisposed orchardgrass (*Dactylis glomerata*) to *Sclerotinia* snow mold (Araki 1975). To make matters worse, deep snowfall in late March prolonged thawing for about a month. Nearly, a half of grasslands in eastern Hokkaido suffered from *Sclerotinia* snow mold and 10 % of the affected fields required reseeding and planting with other crops or were abandoned.

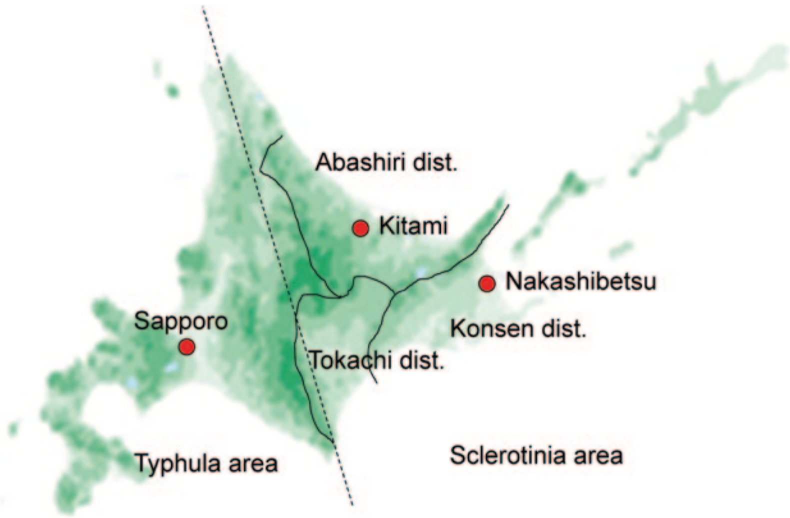


Fig. 2 Hokkaido is divided into the *Typhula* and *Sclerotinia* areas. Districts in eastern Hokkaido are shown in the map. Summer in districts of Abashiri and Tokachi is warm enough for upland crops such as wheat, beans, etc., whereas forage grasses and legumes are exclusively cultivated in the Konsen district due to its damp and cool summer climate. Breeding and experimental cites are indicated by *red* dots

Sclerotinia borealis is an epidemic snow mold fungus and occurs irregularly (Fig. 3). Recent climate change has reduced soil frost indicative of the *Sclerotinia* area in eastern Hokkaido (Hirota et al. 2006). Also, orchardgrass was replaced with more hardy, timothy (*Phleum pratense*). These facts, along with improved cultivation methods, minimized the occurrence of *Sclerotinia* snow mold.

Seeding date is critical to *Sclerotinia* snow mold on grasses as is the case with *Typhula* snow mold on winter wheat (Bruehl et al. 1975). Delay in seeding significantly impairs overwintering of timothy (Nissinen 1996; Sato et al. 2009). The critical issue has been ignored, inciting outbreak of *Sclerotinia* snow mold on first-year timothy in the Tokachi district, eastern Hokkaido in 2008. Timothy is sown after corn to renovate grasslands in Tokachi, but corn plants are left unharvested in the field as late as possible to attain full maturity, which results in the delay of seeding timothy. Timothy should have been sown at least by early September (Sato et al. 2009). Thus, cultivation methods established for snow mold control are liable to be ignored or forgotten due to changes in agroeconomic situation.

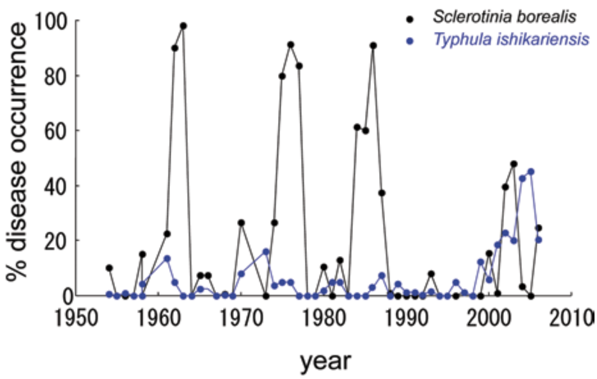
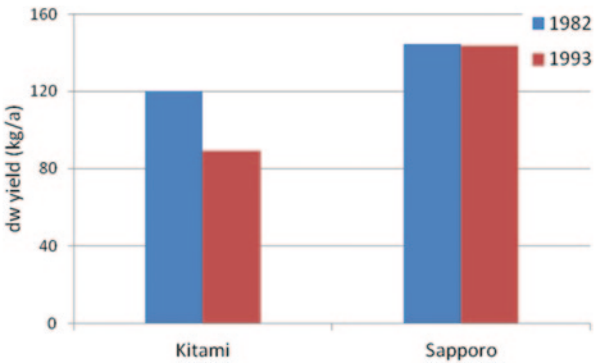


Fig. 3 Occurrence of *Typhula ishikariensis* and *Sclerotinia borealis* on winter wheat in Kitami. No chemical was sprayed. Note that *T. ishikariensis* has been increasing during the last decade. *T. ishikariensis* biotype B, originally prevalent there, is considered to have been replaced by biotype A before that. The assumption was supported by the yield decrease of alfalfa between 1982 and 1993 (see Fig. 4)

Fig. 4 Yield of Kita-wakaba alfalfa in 1982 and 1993 in Kitami and Sapporo. Note that yield decreased between 1982 and 1993 in Kitami. (Ueda et al.1985; Yamaguchi et al. 1995)



Typhula ishikariensis

Tomiyama (1955) did not recognize intraspecies differentiation in the *Typhula ishikariensis* complex in Japan (Matsumoto et al. 1982). *T. ishikariensis* that he referred was considered to be biotype A with a broader host range. Biotype A can attack dicots such as canola and alfalfa, as well as monocots and prevails in snowy western Hokkaido. Biotype B exists in less snowy areas, including eastern Hokkaido and is excluded from monocots when biotype A coexists (Matsumoto and Sato 1983). Two examples are illustrated below that relate to the change in snow mold flora from *T. ishikariensis* biotype B to biotype A in eastern Hokkaido.

Typhula ishikariensis occurred consistently at low levels till 1998 in eastern Hokkaido (Fig. 3) and biotype B was regarded as the principal taxon of the *T. ishikariensis* complex (Matsumoto et al. 1982). Biotype B predominated over

Fig. 5 Severe damage of *Typhula ishikariensis* biotype A on alfalfa lines selected for Lept leaf spot resistance in Nakashibetsu, Konsen

biotype A mainly due to shallow snow cover, and possibly foliage application of fungicides favored biotype B, which could also attack wheat roots. However, snow cover occurred 1 month earlier in eastern Hokkaido in the winter of 1998–1999. Farmers were unable to spray fungicides on winter wheat. Consequently, biotype A caused serious damage and 30 % of wheat crop had to be abandoned (Matsumoto et al. 2000).

Alfalfa (*Medicago sativa*) used to grow well in the districts of Abashiri (Fig. 4) and Tokachi except mountainous areas in Tokachi where *T. ishikariensis* biotype A caused significant damage (Komatsu 1983). Scientists tried to extend alfalfa cultivation to the Konsen district where freezing tolerance was at first considered most critical. Sixty cultivars, including Canadian cultivars were tested in the field. Many Canadian cultivars with strong fall dormancy failed to survive the first winter due to soil heaving before winter (Takeda and Nakajima 1997a). Second-year experiments revealed that Lepto leaf spot caused by *Leptosphaerulina briosiana* reduced growth and winter survival (Takeda and Nakajima 1997b). Damp, cool summer climate in the Konsen district favored the leaf disease and alfalfa plants were unable to harden enough. *T. ishikariensis* biotype A was not observed.

Consequently, breeding objectives shifted to Lept leaf spot resistance. Freezing-tolerant cultivars were susceptible to the disease since they were bred under dry summer conditions (Takeda and Nakajima 1997c). Takeda et al. (1998) found resistant alfalfa plants among commercially available cultivars and lines. They conducted further field screening. Unusually, snowy winter in 1998–1999 favored the outbreak of *T. ishikariensis* biotype A even in Nakashibetsu, Konsen, and all the experimental lines were badly damaged by snow mold (Fig. 5).

Sapporo represents one of the alfalfa breeding cites and is located in snowy western Hokkaido (Fig. 2). Field experiments there naturally select snow mold resistance. They were also aware of the significance of Lepto leaf spot and released "Hisa-wakaba" in collaboration with the breeding cites in eastern Hokkaido (Yamaguchi et al. 1995). "Hisa-wakaba" alfalfa improved the productivity in Kitami and made alfalfa cultivation possible in the Konsen district (Fig. 6).

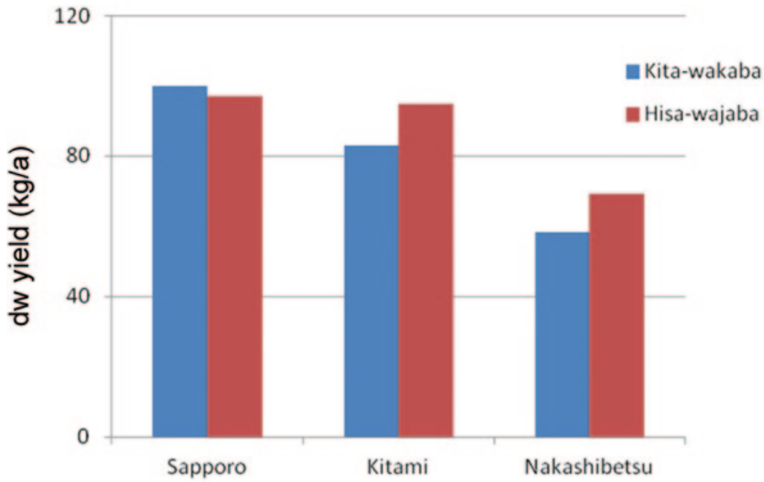


Fig. 6 Yield of Kita-wakaba and Hisa-wakaba in three alfalfa cites, Sapporo in western Hokkaido, Kitami in the Abashiri district, and Nakashibetsu in the Konsen district (see Fig. 2). Figures indicate average annual yield during 1990–1993.(Yamaguchi et al. 1995)

Conclusion

Persistent snow cover occurs much earlier than before in eastern Hokkaido, which has alleviated severe soil frost (Hirota et al. 2006). Contrasting winter climate in Hokkaido is no longer obvious in terms of snow mold flora. Farmers and scientists have established agricultural methods suitable for eastern Hokkaido and some of them are not effective. We illustrated some examples.

Winter climate, as well as summer climate, is likely to fluctuate more seriously than ever. Snow mold fungi are dependent on snow cover and physiologic conditions of plants may vary every year. These parameters affect host–parasite interactions, resulting in the need for novel strategies against snow molds.

Breeding is doubtlessly most effective and the diversity in agro-ecosystem should also be remembered. These two issues are not mutually exclusive but difficult to harmonize. Multidisciplinary collaboration is essential to cope with unpredictable climate change.

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