Snow Mold Fungi in Russia

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Russia is a very large country and occupies 10 % of world's arable lands. Four-fifths of our arable lands are located in Central Volga, North Caucasus, Ural, and West Siberia. Areas with permafrost in Siberia and the Far East occupy 65 % of Russian territory, representing about 70 % of risky agriculture zone of the country. Therefore, most Russian territory is unfit for agriculture.

My Japanese colleagues and I studied sclerotial snow mold fungi in Russian territories at the beginning of this century. We investigated both typical agricultural areas and areas where agriculture was difficult or impossible because our interest also included fungi inhabiting natural ecosystem. The system of Russian botanical gardens helped us with our survey. We investigated sclerotial snow mold fungi in botanical gardens. Where botanical gardens were absent, we visited these regions by ourselves.

Investigations of snow molds have, as a rule, agricultural purposes. As in other countries, our snow mold research was first focused on winter cereals.

Sclerotinia spp.

The first record of snow mold fungi appeared in Russia at the beginning of last century. Trusova was the first to isolate and describe *Sclerotinia* sp. from winter rye as a separate taxon in 1901 (Khokhrjakov 1935). This fungus prevails on tissues of winter cereals severely damaged by freezing. Elenev made more detailed description of the fungus and named it *Sclerotinia graminearum* in 1918, and then Elenev and Solkina made complete description in Latin in 1939. Japanese scientists used the name *S. graminearum* for a long time (Tomiyama 1955). Bubác and Vleugel separately described *S. borealis* in 1917 in North Sweden (Saccardo 1925–1928).

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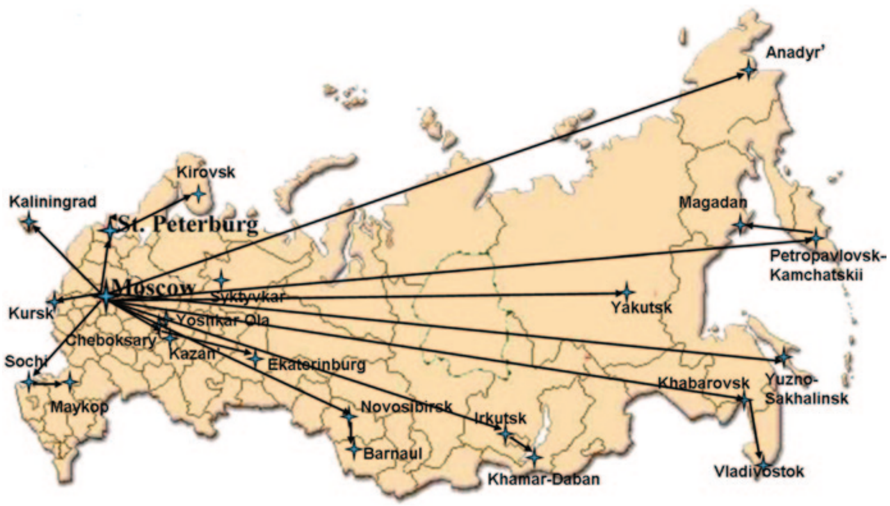

Fig. 1 Expedition routes

S. borealis was judged to have priority over *S. graminearum* in IX International Botanical Congress (Montreal, Canada) in 1959. Some Russian scientists still use the name *S. graminearum*.

Our expeditions showed that this fungus is widespread throughout Russia (Fig. 1). *S. borealis* is a necrotrophic fungus that colonizes damaged plant tissues in frost regions, such as Middle Volga, Siberia, North Russian Far East, and other Russian North regions. In these regions, gramineous plants grow despite severe frost. We could not find any low-temperature fungi in Yakutsk, where winter temperature falls as low as −45 to −55 °C. *Sclerotinia* snow mold is rare in Moscow region (approximately 1 %) on winter cereals (Anonymous 1968, 1969).

Saito, who made detailed investigations on *S. borealis* in Japan, was the first to find nongramineous host plants, including Asteraceae, Campanulaceae, Fabaceae, Iridaceae, and Liliaceae (Saito 1998). Gulaev found *S. graminearum* (*S. borealis*) even on 1-year Scots pine seedlings in Russia (Gulaev 1948). Pine plants were not killed but became freakish. We have no information on the *Sclerotinia* pine disease in countries other than Russia.

Sclerotinia nivalis was described by Saito in Hokkaido on several plants in 1997 (Saito 1997). I met him in the meeting next year in Sapporo and told him that this species existed in Russia. I sent him several specimens from Moscow, Saint Petersburg, and Novosibirsk, the following year. These isolates appeared to be *S. nivalis* (Tkachenko et al. 2003a). We later found this fungus in other Russian regions (Tkachenko 2006; Fig. 2).

Kohn made a monographic revision of the genus *Sclerotinia* in 1979 (Kohn 1979), in which she included only three pathogenic species of this genus: *S. sclerotiorum*, *S. trifoliorum*, and *S. minor*. Many low-temperature *Sclerotiniaceae*

Fig. 2 Place of detection of *Sclerotinia borealis* and *S. nivalis* during the expeditions

fungi have been recognized as synonyms of mesophile *S. minor*, such as taxonomically unknown *S. bulborum* on hyacinth from Holland (Wakker 1889), *S. sativa* on tulip and sweet clover from Canada (Drayton and Groves 1943), and *S. intermedia* on salsify from the USA (Ramsey 1924). *S. bulborum* was described in Main Botanical Gardens, Russian Academy of Science on tulips by Dr. Procenko in 1968 (Procenko 1968), but our study on this fungus showed that it was typical of *S. nivalis*. Saito and I visited Polar-Alpine Botanical Garden-Institute in Appatity (Kola Peninsula), where Shavrova had identified *Sclerotinia* fungus on 21 wintering plants, first as *Sclerotinia* sp. (Shavrova and Kislykh 1987) and then as *S. minor*, according to Kohn's revision (Shavrova 1989). We confirmed that these species were *S. nivalis*.

There are a large number of introduced plants in botanical gardens. These plants are usually not fully adapted to local conditions and are often affected by endemic diseases that are absent in their original habitat. Thus, the study of diseases of introduced plants may predict their success and difficulties on introduction. Cultivated plants are also often less resistant to pathogens than wild ones. All the above applies to snow mold pathogens, especially to *S. nivalis*. Saito's first record of *S. nivalis* was made on edible burdock, *Arctium lappa* var. *sativa*. Wild tulips and hyacinths, for example, cannot be damaged by this fungus in their original habitats. Most of the new host plants of *S. nivalis* were introduced plants. I can give only one example of wild plant damaged by this fungus—it is *Tripleurospermum perforatum* (Merat) M. Lainz (syn. *Matricaria inodora* Merat.). Our investigation and literature data have shown that *S. nivalis* infected 97 plant species of 54 genera and 19 families (Tkachenko 2006).

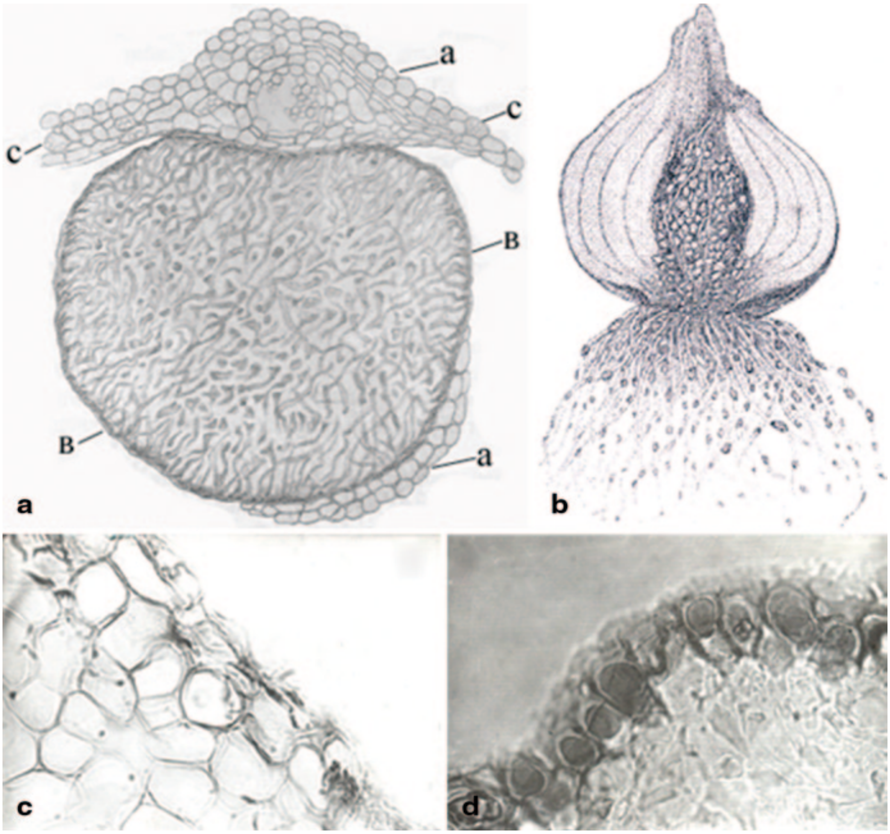

Fig. 3 **a** Cross section of sclerotia of *Sclerotium tuliparum* Kleb. through root (×80). *a* root tissue, *b* sclerotial tissue, *c* hyphae in root tissue cells (Elenkin 1911). **b** Longitudinal section of tulip bulb with sclerotia of *Sclerotium tuliparum* Kleb. (Elenkin 1911). **c** Cross section of pseudosclerotium of *Rhizoctonia tuliparum*. **d** Cross section of sclerotium of *Typhula ishikariensis* (Tkachenko 1983)

Typhula ishikariensis

Typhula ishikariensis S. Imai is the most devastating pathogen in the genus *Typhula*. I found a first description of *T. ishikariensis* tulip bulb rot in a Russian journal *Diseases of Plants* of 1911. Elenkin, mycologist of the Central Phytopathological Station of Imperial Saint Petersburg Botanical Garden (Elenkin 1911), described the sclerotial disease of tulip from the Botanical Garden in detail. He considered that tulip was damaged by *Sclerotium tuliparum* Kleb. (*Rhizoctonia tuliparum* (Kleb.) Whetz. et Arth.; Fig. 3a, b). The latter, in contrast to *T. ishikariensis*, never damaged roots of tulips (Gladders and Coley-Smith 1978). Sclerotia of *Rhizoctonia tuliparum* are really pseudosclerotia (resting bodies that do not have basic structure of sclerotia—cortex outside and medulla inside; Fig. 3c), consisting of large cells without distinct cell rind (only cell walls are pigmented) in contrast to the dense medulla cells and distinct rind cells (cortex) of *T. ishikariensis* sclerotia (Tkachenko 1983; Fig. 3d). These facts indicate that the fungus in Elenkin's drawings is *T. ishikariensis* S. Imai.

This fungal species has a large history of descriptions. H. Ekstrand described two species in Sweden: *Typhula borealis* and *T. hyperborea*; first based on morphological characters of anamorpha (Ekstrand 1934) and then using teleomorpha (Ekstrand 1955). Closely related *T. idahoensis* was described by R. Remsberg in the USA (Remsberg 1940). It turns out that S. Imai in Hokkaido (Japan) had described the fungus as *T. ishikariensis* in Japanese in 1929 (McDonald 1961), then he published in English (Imai 1930). Røed (1956) and Jamalainen (1957) compared the morphological characteristics of Japanese isolates of *T. ishikariensis*, North American *T. idahoensis*, and Finnish-Scandinavian *T. borealis* to conclude that they were synonymous. Investigations in Canada revealed three varieties of *T. ishikariensis*: *T. ishikariensis* var. *ishikariensis*, *T. ishikariensis* var. *idahoensis*, and *T. ishikariensis* var. *canadensis* (Årsvoll and Smith 1978). Matsumoto divided this species in Japan into three biotypes, i.e., biotypes A, B, and C (Matsumoto et al. 1982, 1983), then biotype C was considered as an ecotype of biotype B and referred to as small sclerotium (ss) form of biotype B (Matsumoto and Tajimi 1991). Matsumoto's conclusion is that the *T. ishikariensis* complex consists of two groups, species I and II (Matsumoto 1997; Matsumoto et al. 2001). In our work, we support his classification of the fungus.

Several *Typhula* species described in Russia, whose epithets were given from their host plants, appeared to be synonyms of *T. ishikariensis*. They are *T. humulina* from hop *Humulus lupulus* L. by Kuznetzova (1953) and *T. graminearum* by V.V. Gulaev (1948; this fungus was described on Scots pine young seedling, in addition to gramineous weeds). Potatosova (1960) was first, who considered that *T. humulina* and *T. graminearum* were synonymous with *T. idahoensis*. We confirmed that these fungi belonged to *Typhula ishikariensis* species I (Hoshino et al. 2004).

T. ishikariensis species I was known in Russia only in European part of the country before our expeditions in the last century (Tkachenko et al. 1997). We found the fungus during our expeditions in different parts of Russia (Fig. 4), even where we did not expect to find it due to deep frozen soil in winter, such as in Novosibirsk and Tomsk (West Siberia) (Tkachenko et al. 2003b). Hoshino et al. (2001) compared the survival of *T. ishikariensis* sclerotia after freeze–thaw cycles using Moscow and Novosibirsk isolates. Moscow isolates were killed after three cycles; significant deterioration of mycelial growth was observed. Novosibirsk isolates survived seven treatment cycles with a slight deterioration of mycelial growth, and Hoshino gave up further experiments.

We could not find *T. ishikariensis* in East Siberia near Irkutsk. This fungus was found near Baikal Lake at the foothill of Khamar-Daban. Khamar-Daban is, as some other Baikal regions (Salair ridge, Kuznetsk Alatau, and Western Sayan), a refugium of the glacial period (Epova 1956; Zarubin 2000; Krapivkina 2009). These areas were not affected by continuous glaciation. *T. ishikariensis* from Khamar-Daban belonged to species II designated by Matsumoto (1997). I think that this

Fig. 4 Place of detection of *Typhula ishikariensis* species I and II during the expeditions

species is the most primitive taxon of *T. ishikariensis* with only gramineous host plants.

We were surprised to find this fungus in the Chukotka region at Anadyr, which is situated at 64°4′N. It is a region of the continental tundra with almost no grasses (Poaceae), but *Poa ochotensis* Trin. damaged by *T. ishikariensis* was found on the shores of the Bering Sea, Anadyr Gulf.

Remarkably, *T. ishikariensis* species I damages underground plant tissues of hops (Kuznetzova 1953) and tulip (Procenko 1967) in Russia. Few reports of *Typhula* tulip disease are available from Canada and Sweden, but there are no reports of *Typhula* hop damage in areas other than Russia. The fungus produces secondary sclerotia (Tkachenko 1995), which may represent adaptation to environmental change.

Our investigation and literature data have shown that *T. ishikariensis* infected 97 plant species of 54 genera and 20 families (Tkachenko 1983, 2006, 2012; Seraya 2001).

Other Snow Mold Fungi

Lastly, I want to mention other snow mold fungi, which were subsidiary to our expedition. These are *Microdochium nivale*, *Phacidium infestans*, *Pythium* spp., *Sclerotinia trifoliorum*, *Sclerotium nivale*, *Typhula incarnata*, and *T. phacorrhiza*.

While *T. ishikariensis* is a biotroph, *T. incarnata* is a facultative saprophyte (Jacobs and Bruehl 1986). We did not see *T. incarnata* in areas with severe winters (Siberia), but the fungus was common even near Yamal Peninsula (Shiryaev 2006).

We found it in South Russian Far East (Vladivostok, Khabarovsk) and even in Caucasus, both at foots and at uplands in Adygea Republic. We have also recorded this fungus above the Arctic Circle at the Kola Peninsula in Polar-Alpine Botanical Garden-Institute at 67°7′N.

Typhula phacorrhiza is apparently widely spread in Russia. It was found in south tundra zone, the Polar Urals, and Novaya Zemlya (Shiryaev 2006), but detailed research or practical achievements using this species as biocontrol agent were not made. There was only one PhD thesis of Tazina (2005), where she successfully used this fungus against *T. ishikariensis* on winter wheat.

A cause of pink snow mold is a psychrotolerant fungus *Microdochium nivale*. The fungus has been much studied in Russia regarding its distribution and disease severity (Dmitriev and Saulich 2004). The disease is severe in wet areas. Russian scientists compared *Fusarium* rot and pink snow mold diseases (Ovsyankina 2000; Kostenko 2012). The term "snow mold" was applied only to the disease caused by *Fusarium* (*Microdochium*) *nivale* for a long time in Russia. We have never seen this fungus during our expeditions in Siberia.

Clover is, of course, widely grown in Russia and this plant is damaged by low-temperature pathogen *S. trifoliorum.* The fungus is found in most places where clover is grown.

Although not included in our investigations, snowy pine Schütte caused by *Phacidium infestans* is important. This disease is widely spread in Russia: European part of Russia, the Urals, and Siberia. Snowy pine Schütte damages Scots pine, rarely Siberian cedar, spruce, and juniper (Kuz'mina and Kuz'min 2009). The fungus can grow under the snow; hence, the name of the disease is snowy pine Schütte. The disease poses a great threat to seedlings both in nurseries and in natural ecosystem as well as regrowth of young trees, as the disease occurs almost exclusively in the winter under the snow. Plant loss in nurseries, in some cases, is up to 80%.

Pythium sp. has been recognized as a low-temperature pathogen only once on the Kola Peninsula in the 1980s in the former USSR. Petrov (1983) revealed that prevalence of *S. graminearum* (*S. borealis*) was largely dependent on the preconditioning by infection of *Pythium*, and that the fungus had no appreciable effect on perennial grasses.

Finally, about the fungus described by Elenev—*Sclerotium nivale* Elenev. I translate Russian name of this disease "Снеговая крупка" in English as "Snow tiny pellets" or "Snow tiny grain." I have not found the record on this fungus from abroad, although its record was cited in *Phytopathological Dictionary* (Diakova 1969) and the Internet in "Encyclopedias, dictionaries, reference books (Search)" (in Russian)[1] with translation into English (Sclerotium disease of rye), German (Sclerotium-Krankheit, Roggen), and French (sclérotiose du seigle). Although the disease is often found in more southern Russian areas of cultivation of winter cereals (Fig. 5a), it is also found in other gramineous plants (Fig. 5b, c). Symptoms of this low-temperature disease are characterized by white web-like mold with small, round, white sclerotia with a diameter of 0.5–1 mm on leaves and stems. The cause of disease is the imperfect

[1] Encyclopedias, dictionaries, reference books (Search) available at www.cnshb.ru/AKDiL/0040/k307340.shtm (in Russian).

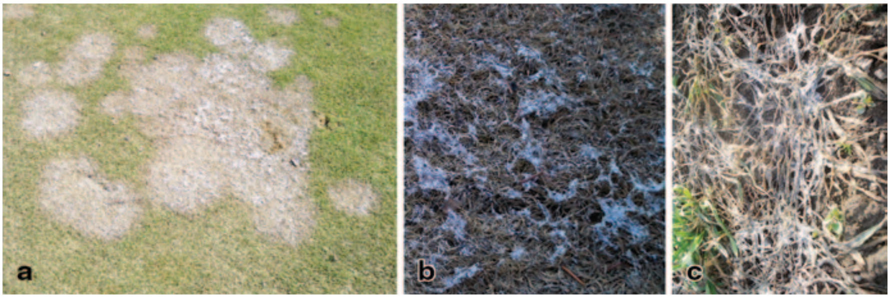

Fig. 5 *Sclerotium nivale* **a** on winter triticale, **b** on grasses, and **c** on turf. (Photographs by L. M. Sarycheva)

fungus *Sclerotium nivale*. The fungus forms only mycelium and sclerotia in its cycle. Sclerotia remain until an autumn and develop a new mycelium that infects plants in the presence of abundant moisture, causing rot and plant death. No resistant varieties are available. Obviously, this fungus has never been investigated deeply. Perhaps, this fungus exists in Russia (Khokhryakov et al. 1966; Semenkova and Sokolova 2003) but is regarded as "illegal" because it was not included even in the *Index Fungorum*.[2]

Conclusion

Global warming is likely to occur in Russia. Winters in Moscow district used to arrive about 1 month later in 1970s–1980s. Siberian climate has become much warmer. Weather forecast predicts that weather in European Part of Russia may become the same as in West Europe and that Siberian climate may become as in the European part. It means that large Siberian area will be developed for growing of winter cereals and that we need to work on snow mold there in the future. I welcome any collaboration with participants here.

But I doubt the reality of global warming using this site http://planeta.moy.su/blog/globalnoe_poteplenie_lozh_veka/2012-02-18-14885. According to expert evaluation of the National Oceanic and Atmospheric Administration (NOAA), USA, the average global temperature of the planet in 2011 is not among the 10 warmest.

Russian geographer Prof. Andrei Kapitsa (he had died in August 2011) said that global warming does not exist. On the contrary, it is slowly cooling for more than 30 years.

I think that there is warming in Russian territory, but Gulf Stream has become colder. I am not sure if warming is a universal issue of the whole globe, as I saw snowy

[2] Editors' note: Matsumoto et al. (1996) described a similar fungus in Norway, "Group II isolates from the Oppland locality often had abundant aerial mycelium. Their sclerotia were small and covered with thick mycelium. Those sclerotia developed normal sporocarps and produced basidiospores. Their mycelia produced on infected plants were usually, but not always, very fluffy."

Siberian pictures in a TV program of West European countries. I would say that different types of climate change should not be simply termed as global warming, but we should identify the differences to find countermeasures for sustainable agriculture.

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