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POWDERY MILDEWS (*ERYSIPHACEAE*) ON WOODY PLANTS IN URBAN HABITATS OF SVERDLOVSK REGION (RUSSIA)

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Based on the results of the authors' research and revisions of previous information, modern species diversity has been established and the first annotated list of powdery fungi on woody plants in urban habitats of Sverdlovsk Region (Ekaterinburg and several cities of the region) has been compiled. Totally, 29 species of *Erysiphaceae* have been recorded, among which the majority belong to the genus *Erysiphe* (17 species), and other belong to the genera *Podosphaera* (7), *Phyllactinia* (3) and *Sawadaea* (2). Six species were first found in Sverdlovsk Region: *Erysiphe ehrenbergii*, *E. euonymi*, *E. lonicerae*, *E. viburni*, *Podosphaera myrtillina*, and *P. spiraeae*. Almost half of all identified species (14 of 29) are alien to Sverdlovsk Region, while 6 species can be considered as invasive, of which two species originate from North America (*Erysiphe necator* and *Podosphaera mors-uvae*) and four species – from East Asia (*Erysiphe alphitoides*, *E. corylacearum*, *E. palczewskii*, and *E. vanbruntiana*), and another eight species can be considered as unintentionally introduced from neighboring regions together with their host plants. The growth of most species occurs in the period from mid-June to the end of September. The majority of recorded *Erysiphaceae* species (25 out of 29) form both anamorph and teleomorph, and only four species (*Erysiphe aquilegiae*, *E. necator*, *Podosphaera pannosa* и *P. spiraeae*) are recorded in the anamorphic stage only.

Keywords: alien species, fungal biodiversity, Russia, Urals, urban plantings

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INTRODUCTION

Powdery mildews, or erysiphous fungi (division *Ascomycota*, order *Helotiales*, family *Erysiphaceae*) are common plant pathogens that infect various woody angiosperms worldwide as obligate plant parasites of photosynthetic organs of host plants, mainly leaves, and in some cases – young shoots or twigs, flowers, and immature fruits (Gorlenko, 1983; Heluta, 1989). Their presence is usually easy to detect by white patches of mycelium on the surface of affected plant organs – "powdery mildew" (Gorlenko, 1983; Heluta, 1989; Braun, Cook, 2012). Although the damage caused by powdery mildew fungi usually does not lead to the death of the affected plants, they can often cause a significant weakening of host plants, and, consequently, significant yield losses in fruit and berry crops and especially reduction in the decorative effect of ornamental plants (Gorlenko, 1983), including woody plants – trees and shrubs (Stepanova, Sirko, 1970). The grand nature transforming in the boreal zone of Eurasia (Leskinen, 2020), and relocation of a huge number of cultivated plants in the last two centuries in the Middle Urals (Tretyakova, 2016) also caused a movement of many plant pathogenic fungi, including powdery mildews (Desprez-Loustau, 2009). In addition, global climate warming has led to an increase in the number and to an expansion of the areas of many cultivated and invasive woody plants over the past decades (Tretyakova, 2016), and at the same time, the further expansion of new, previously unknown fungal plant pathogens to the north in the boreal zone of Eurasia (Shiryaev et al., 2022) and big changes of the mycobiota of Volga-Ural macroregion (Shiryaev, 2009).

Sverdlovsk Region is located in the south boreal subzone in the east part of middle Urals on the border of Europe and Asia and its area is 194.800 km^2 (Kapustin, Kornev, 2006). The natural zonal vegetation of the northern and central parts of the region is represented by pine and birch forests and mixed broad-leaved-coniferous forests, typical for middle and southern taiga zone; northern forest-steppe vegetation dominates in the forest-steppe zone in the south part of the region (Kapustin, Kornev, 2006). The climate of Sverdlovsk Region is continental, with sharp variability in weather conditions and clearly defined seasons: warm rainy summer (the average monthly temperature in July is 19°C) and cold snow winter (the average monthly temperature in January is –13°C). The average annual temperature is 3.5°C; the average annual rainfall is 600 mm, with a maximum in the summer months (RIHMI-WDC, 2022).

Scientific researches of powdery mildew fungi in the Urals started at the beginning of the 20th century by famous Russian mycologist A.A. Yachevsky and his disciples. Some information those first records of powdery mildew fungi in the territory of the Urals (mainly modern Perm Region, Komi Republic, Republic of Bashkortostan, Sverdlovsk Region and Chelyabinsk Region) is available in "Pocket keybook of fungi. Part 2: Powdery mildew fungi" (Yachevsky, 1927). However, there was no one special study of this group of phytopathogenic microfungi on the territory of Sverdlovsk Region and Ekaterinburg City until the 1930s, when the first information about this group had appeared in the framework of the first scientific forest pathological studies (Pentin, 1939). The next step followed in the 1960s, when N.T. Stepanova and A.V. Sirko obtained and published the most complete checklist of plant-associated fungi of the Urals that included all available information on powdery mildew fungi for Sverdlovsk Region too (Stepanova, Sirko, 1970). However, those data were very incomplete (especially in comparison with other regions of the Urals): only seven species of powdery mildew fungi were recorded on trees and shrubs in Sverdlovsk Region, and only four species were found in the Ekaterinburg city (named Sverdlovsk in 1924–1991). After a long break, E.D. Karelina performed the short study of powdery mildew fungi in Ekaterinburg in the summer 2016. Despite this research project was short, the total number of *Erysiphaceae* species known in Ekaterinburg on woody plants has reached 10 species – counting the seven species first recorded in Ekaterinburg (Karelina, 2017).

However, those data needs to be revised due to the significantly changes in the taxonomy of powdery mildews during the last two decades. New molecular phylogenetic and morphological approaches have helped to distinguish morphologically similar *Erysiphaceae* species and to create an actual system of the family based on natural relationships of the species (Braun, 1999; Braun, Cooke, 2012; Braun et al., 2019). Thus, all powdery mildews are treated within the *Erysiphaceae* family (Braun, Takamatsu, 2000), which is placed in *Helotiales* now (Johnston et al., 2019). The former sections of the genus *Erysiphe* were raised to the genus level and considered as distinct genera, such as *Golovinomyces* and *Neoerysiphe* (Braun, Takamatsu, 2000; Takamatsu et al., 2008). Conversely, the genera *Microsphaera* and *Uncinula* were both reduced to the morphological sections of the genus *Erysiphe* (Braun, 1999; Braun, Cook, 2012), and the same way the genus *Sphaerotheca* is treated as morphological section of the genus *Podosphaera* now (Braun, Takamatsu, 2000). Many complex species were resolved, and many new highly specialized species were described as distinct fungal species, and many previously described anamorphic *Erysiphaceae* species were replaced in holomorphic genera (Braun, Cooke, 2012; Braun et al., 2018, 2019; Meeboon et al., 2020).

Due to the insufficient completeness of the data on the diversity of powdery mildews in Sverdlovsk Region, A.G. Shiryaev and T.S. Bulgakov had continued these studies since 2020 as part of the study of all plant pathogenic fungi. Some results of these researches were published earlier (Bulgakov, Shiryaev, 2021). The main purpose of the research is to study the modern diversity of powdery mildew fungi in Sverdlovsk Region (including its capital – Ekaterinburg City) parasitizing on woody plants, and to study their main ecological and biological features.

MATERIALS AND METHODS

The materials for the study were specimens containing generative fungal structures (mycelium, conidia and/or chasmothecia) on affected wild-growing and cultivated woody plants (leaves, flowers, immature fruits, and young twigs). The authors also analyzed all available previous published information on powdery mildews in Sverdlovsk Region for the last century (Demidova, 1925; Yachevsky, 1927; Stepanova, Sirko, 1970; Karelina, 2017). All specimens were collected by A.G. Shiryaev in Ekaterinburg City and some other towns of Sverdlovsk Region since June to October in 2020 and 2021 in natural (forests) and anthropogenic locations (public parks, arboreta, block parks, forest parks, squares and streets), including parks and the arboretum of the Botanical Garden of the Ural Branch of the Russian Academy of Sciences. The collected specimens – leaves, flowers and fruits affected by powdery mildews – were labeled, dried at 22–24°C and packed in paper envelopes according to the standard methods for the taxon (Heluta, 1989). Totally, 67 fungal specimens of Erysiphaceae on woody plants were collected and processed in the Institute of Plant and Animal Ecology of Ural Branch of the Russian Academy of Sciences (Ekaterinburg) and in the Department of Plant Protection of the Federal Research Center "Subtropical Scientific Center of the Russian Academy of Sciences" (Sochi), and later deposed in the fungarium of the Institute of Plant and Animal Ecology [SVER (F)].

The morphological features of fungal species were studied according to the standard methods for *Erysiphaceae* (Heluta, 1989; Braun, Cook, 2012). All dried herbarium specimens were examined under optical microscopes MBI-3 and MICMED-6 ("LOMO", Russia) in according to the standard procedures for light microscopy of temporary preparations (Heluta, 1989; Braun, Cook, 2012) for the further identification of fungal species by the morphological examinations of sexual (chasmothecia) and asexual (conidia) morphs.

The powdery mildew species were identified by the fundamental keybook "Taxonomic manual of the *Erysiphales*" (Braun, Cook, 2012), and some additional publications devoted to the later performed taxonomical revisions of the complex species: *Erysiphe adunca* (Darsaraei et al., 2021), *E. lonicerae* (Bradshaw et al., 2020a), *E. viburni* (Bradshaw et al., 2020b), and *Podo-*

sphaera tridactyla (Meeboon et al., 2020). The host plant species were identified by the keybook "Keys to vascular plants of the Middle Urals" (1994) by the standard methods; the plant species are given according to the open nomenclatural database "Plant of the World" (POWO, 2022).

RESULTS

The annotated checklist of *Erysiphaceae* on woody plants in urban planting of Ekaterinburg and other cities of Sverdlovsk Region is presented (2022). The fungal genera and species are arranged in alphabetical order. The fungal species first found in Sverdlovsk Region are marked with asterisk; ones new for the region because of taxonomic revisions of previously recorded species are marked with hash; ones previously known on herbaceous plants but first recorded on woody plants are marked with plus; ones known from previous publications but not found during authors' researches marked with empty round.

The species annotation is given in the following sequence: currently accepted fungal species name (the previously used synonyms are given in parentheses), host plant name(s), location(s), date(s) of collection, collection number(s) in the local fungal herbarium [SVER (F)] or reference(s) for previous record(s); the note (an.) – if only anamophic stage of the fungal species was found; origin for Sverdlovsk Region – for alien *Erysiphaceae* species introduced or invaded in Sverdlovsk Region (or Europe or Eurasia at general) during the last century (Desprez-Loustau, 2009; Braun, Cook, 2012; Farr, Rossman, 2022).

The abbreviations of the locations for the specimens collected in the Ekaterinburg city: BG – The Botanical Garden of the Ural Branch of the Russian Academy of Sciences; BUM – urban microdistrict 'Botanichesky'; SFP – forest park 'Shartashsky'; other locations in Ekaterinburg city are given without abbreviations.

Erysiphe adunca (Wallr.) Fr. s.str. [= *Uncinula salicis* (DC.) G. Winter f. *populorum* Rabenh.] – *Populus* species (*Salicaceae*): *P.* × *canadensis* Moench: 8 March street, 26.09.2021, SVER (F) 96771; *P.* × *sibirica* G.V. Krylov et G.V. Grig. ex A.K. Skvortsov (Salicaceae): BG, arboretum, 16.10.2020, SVER (F) 96602 (Bulgakov, Shiryaev, 2021); ibid., 12.08.2021, SVER (F) 96724; Southern tram depot, 02.08.2021, SVER (F) 96723; BUM, 19.10.2021, SVER (F) 96776; *Populus balsamifera* L., *P. deltoides* W. Bartram ex Marshall, *P. nigra* L., and *P. tremula* L.: BG, park, September 1960 (Stepanova, Sirko, 1970).

E. alphitoides (Griffon et Maubl.) U. Braun et S. Takam. (≡ *Microsphaera alphitoides* Griffon et Maubl.) – *Quercus* species (*Fagaceae*): *Q. robur* L.: BG, 29.07.2021, SVER (F) 96726 (an.); SFP, 08.08.2016 (Karelina, 2017); Artinsky district, forest park near Beryozovskaya, 02.09.2021, SVER (F) 96767; Krasnoufimsk district, near Sokolye village, Nizhneirginsk oak forest, 03.09.2021, SVER (F) 96768. Invasive alien species: invaded Europe and Siberia from Southeast Asia around 1920 (Takamatsu et al., 2007; Bradshaw et al., 2022); recorded in Sverdlovsk Region since 1920s (Demidova, 1925; Pentin, 1939).

+*E. aquilegiae* DC. – *Clematis* species (*Ranunculaceae*): *Clematis alpina* (L.) Mill. subsp. *sibirica* (L.) Kuntze (≡ *Atragene sibirica* L.): BG, arboretum, 14.08.2021, SVER (F) 96757 (an.); *Clematis* sp.: BG, arboretum (near greenhouse), 14.10.2020 (Bulgakov, Shiryaev, 2021); recorded on other herbaceous *Clematis* species and many herbaceous *Ranunculaceae* (*Aconitum*, *Aquilegia*, *Delphinium*, *Ranunculus* species) in the whole territory of the Urals (Yachevsky, 1927; Stepanova, Sirko, 1970).

E. berberidis DC. – *Berberis* species (*Berberidaceae*): *B. heteropoda* Schrenk: BG, meadow, 17.09.2020; DES, private garden, 28.09.2020 (Bulgakov, Shiryaev, 2021); *B. vulgaris* L.: BG, arboretum, 11.06.2021, SVER (F) 96712; ibid., 26.10.2020, SVER (F) 96613; BUM, block park, 07.07.2020, SVER (F) 96612; ibid., 28.06.2021, SVER (F) 96728 (an.); ibid., 28.07.2021, SVER (F) 96727 (an.); ibid., 29.07.2021, SVER (F) 96729; Vikulova str., 04.08.2016 (Karelina, 2017).

E. capreae DC. – *Salix* subgen. *Vetrix* sect. *Vetrix* (*Salicaceae*) (Darsaraei et al., 2020): *Salix caprea* L.: BG, 19.10.2021, SVER (F) 96775; Artinsky district, forest park near Beryozovskaya, 02.09.2021, SVER (F) 96766; *Salix* sp.: SFP, 08.08.2016 (Karelina, 2017).

°*E. divaricata* (Wallr.) Schltdl. (≡ *Microsphaera divaricata* (Wallr.) Lév.) – *Frangula alnus* Mill. (*Rhamnaceae*): the whole territory of the Urals in the habitats of the host plant (Yachevsky, 1927).

**E. ehrenbergii* (Lév.) U. Braun, M. Bradshaw et S. Takam. (≡ *E. lonicerae* DC. var. *ehrenbergii* (Lév.) U. Braun et S. Takam.) – *Lonicera* species subgen. *Lonicera* (syn. *Chamaecerasus*) (*Caprifoliaceae*): *L. caucasica* Pall.: BUM, block park, 22.07.2020 (Bulgakov, Shiryaev, 2021). Introduced alien species: native for Eurasia (Bradshaw et al., 2021a), but was introduced in Sverdlovsk Region with the host plants.

**E. euonymi* DC. – *Euonymus* species (*Celastraceae*): *E. europaeus* L.: BG, arboretum, 14.08.2021, SVER (F) 96758 (an.); ibid., 22.08.2021, SVER (F) 96759. Introduced alien species: native for Eurasia (Braun, Cook, 2012), but was introduced in Sverdlovsk Region with the host plant.

**E. lonicerae* DC. s. str. [≡ *Microsphaera lonicerae* (DC.) G. Winter] – *Lonicera* species subgen. *Caprifolium* (*Caprifoliaceae*): *L. caprifolium* L.: BG, arboretum, 20.20.2021, SVER (F) 96777 (an.); *Lonicera reticulata* Raf.: BG, arboretum, 11.06.2021, SVER (F) 96713 (an.); ibid., 11.06.2021, SVER (F) 96714 (an.); *Lonicera* sp.: BUM, 24.07.2021, SVER (F) 96732 (an.). Introduced alien species: native for Eurasia (Bradshaw et al., 2021a), but was introduced in Sverdlovsk Region with the host plants.

E. necator Schwein. [≡ *Uncinula necator* (Schwein.) Burrill] – *Vitis* species (Vitaceae): *V. amurensis* Rupr.: urban microdistrict 'Seven fountains', garden, 21.08.2021, SVER (F) 96760 (an.); *V. vinifera* L.: BG, arboretum, 10.09.2017 (Bulgakov, Shiryaev, 2021); Invasive alien species: invaded in Europe from North America in the middle of XIX century; known in the Urals since 1900s (Demidova, 1925; Yachevsky, 1927).

°*E. ornata* (U. Braun) U. Braun et S. Takam. var. *europaea* (U. Braun) U. Braun et S. Takam. (= *Microsphaera betulae* Magnus) – *Betula* species (Betulaceae): *B. pubescens* Ehrh.: Achit district, forest park near Achitsky, 12.09.1960 (Stepanova, Sirko, 1970); *Betula* sp.: Vikulova str., 04.08.2016 (Karelina, 2017).

E. palczewskii (Jacz.) U. Braun et S. Takam. – *Caragana* species (Fabaceae): *C. arborescens* Lam. BUM, block park, 01.07.2021, SVER (F) 96734; ibid., 11.07.2021, SVER (F)

96735; Academichesky av., street shrubs, 27.07.2021, SVER (F) 96736; near the Circus, street shrubs, 07.08.2021, SVER (F) 96733; Tatishcheva str., block park, 30.07.2016 (Karelina, 2017); Invasive alien species: invaded in European Russia and Siberia from East Asia about 1980 (Heluta, Gorlenko, 1984).

E. salicis DC. – *Salix* species (excluding subgen. *Vetrix* sect. *Vetrix*) (Salicaceae): *S. viminalis* L.: BG, arboretum, 03.08.2020 (Bulgakov, Shiryaev, 2021).

E. syringae-japonicae (U. Braun) U. Braun et S. Takam. (≡ *Microsphaera syringae-japonicae* U. Braun) – on *Syringa* species (Oleaceae): *S. josikaea* J. Jacq. ex Rchb.: BG, arboretum, 27.07.2021, SVER(F) 96779; *S. villosa* Vahl: BUM, street shrubs, 29.07.2021, SVER (F) 96737 (an.); *S. vulgaris* L.: Nagornaya str., street shrubs, 04.08.2016 (Karelina, 2017). Invasive alien species: invaded in Europe and western Asia in 1980s from Japan (Seko et al., 2008; Takamatsu et al., 2016); first recorded in Sverdlovsk Region after 2000 (Karelina, 2017).

+*E. trifoliorum* (Wallr.) U. Braun (= *E. trifolii* Grev.) – on *Fabaceae* species: *Chamaecytisus ruthenicus* (Fisch. ex Wol.) Klásk.: Krasnoufimsk district, Sokolye village, Nizheirginsk oak forest, 03.09.2021, SVER (F) 96769 (an.). This species is known on herbaceous *Fabaceae* plants in Sverdlovsk Region (Yachevsky, 1927; Stepanova, Sirko, 1970; Karelina, 2017), but first recorded on *Chamaecytisus ruthenicus* in the Urals.

E. vanbruntiana (W.R. Gerard) U. Braun et S. Takam. var. *sambuci-racemosae* (U. Braun) U. Braun et S. Takam. – *Sambucus* species: *S. racemosa* L.: BG, park, 18.06.2021, SVER (F) 96715; ibid., 12.08.2021, SVER (F) 96738 (an.); ibid., 23.07.2021, SVER (F) 96739; SFP, 08.08.2016 (Karelina, 2017); *S. sibirica* Nakai: BG, park, 22.09.2021, SVER (F) 96770; Invasive alien species: invaded Europe and Siberia from East Asia about 1980 (Heluta, Gorlenko, 1981).

**E. viburni* Duby – *Viburnum* species (*Viburnaceae*)*: V. lantana* L.: GES, private garden, 30.09.2020 (Bulgakov, Shiryaev, 2021). Introduced alien species: native for Eurasia (Braun, Cook, 2012), but was introduced in Sverdlovsk Region with its host plant.

#*?Phyllactinia alnicola* U. Braun (= *Ph. suffulta* Sacc. f. *alni* Hammarl.) – on *Alnus* species (Betulaceae): *A. incana* (L.) Moench. and *A. glutinosa* (L.) Gaertn.: the whole territory of the Urals (Yachevsky, 1927); Krasnoufimsky district, near Ufa river, September 1960 (Stepanova, Sirko, 1970).

#°*Ph. betulae* (DC.) Fuss (= *Ph. suffulta Sacc.* f. *betulae* Thüm.) – *Betula* species (Betulaceae): *B. pendula* Roth. and *B. pubescens* Ehrh.: the whole territory of the Urals (Yachevsky, 1927); Krasnoufimsky district, Nizhneigrisk oak forest, August 1960 (Stepanova, Sirko, 1970).

°*Ph. guttata* (Wallr.) Lév. (= *Ph. suffulta Sacc* f. *corylli-avellanae* Jacz.) – *Corylus avellana* L. (Betulaceae): the whole territory of the Urals (Yachevsky, 1927).

+*Podosphaera aphanis* (Wallr.) U. Braun et S. Takam. – *Dasiphora* species (Rosaceae): *D. fruticosa* (L.) Rydb.: BG, arboretum, 29.07.2021, SVER (F) 96740 (an.); BG, 03.08.2021, SVER (F) 96741 (an.); 8 March str., Arboretum, 29.08.2021, SVER (F) 96763 (an.); *D. glabrata* (Willd. ex Schltdl.) Soják: near buildings of 'Russian Copper Plant', flowerbed, 29.08.2021, SVER (F) 96762. This fungal species was recorded in the Urals (as several forms of *Sphaerotheca macularis* (Wallr.) Magnus) on many herbal Rosaceae plants – *Alchemilla*, *Agrimonia*, *Geum*, and *Potentilla* species (Yachevsky, 1927; Stepanova, Sirko, 1970; Karelina, 2017).

P. clandestina (Wallr.) Lév. (= *P. oxyacanthae* De Bary f. *crataegi* Jacz.) – *Crataegus* species (Rosaceae): *C. mollis* (Torr. et A. Gray) Scheele: BG, arboretum, 05.07.2021, SVER (F) 96742 (an.); *C. sanguinea* Pall.: BG, arboretum, 06.07.2021, SVER (F) 96743; BUM, block park, 15.06.2021, SVER (F) 96716 (an.); ibid., 15.07.2021, SVER (F) 96746.; *Crataegus* sp.: Nagornaya str., block park (Karelina, 2017).

P. mors-uvae (Schwein.) U. Braun et S. Takam. [≡ *Sphaerotheca mors-uvae* (Schwein.) Berk. et M.A. Curtis] – *Ribes* species (*Grossulariaceae*): *R. uva-crispa* L. (= *Grossularia reclinata* (L.) Mill.): BG, arboretum, 15.06.1956 (Stepanova, Sirko, 1970); BG, arboretum, 14.09.2020 (Bulgakov, Shiryaev, 2021); urban microdistrict "Seven fontaines", 06.06.2021, SVER (F) 96717 (an.); *Ribes nigrum* L., urban microdistrict "Seven fontaines", 01.07.2021, SVER (F) 96744 (an.); *Ribes rubrum* L., the Arboretum on 8 March str., 04.07.2021, SVER (F) 96745 (an.). Invasive alien species: invaded Europe from North America in 1900s (Heluta, 1989; Braun, Cook, 2012); presents in the Ural macroregion since 1913 (Yachevsky, 1927) and in Sverdlovsk Region at least since 1956 (Stepanova, Sirko, 1970).

* *P. myrtillina* Kunze – *Vaccinium myrtillus* L. (*Ericaceae*): Pervouralsk city district, forest park near Glukhoye lake, 08.08.2021, SVER(F) 96756.

P. pannosa (Wallr.) de Bary – *Rosa* species (*Rosaceae*): *R. acicularis* Lindl.: BUM, 24.07.2021, SVER (F) 96747 (an.); *R. canina* L.: BG, park, 24.09.2021, SVER (F) 96772 (an.); *R. chinensis* Jacq.: BUM, 29.07.2021, SVER (F) 96748 (an.); *Rosa* sp.: BG, arboretum, 12.08.2021, SVER (F) 96761 (an.); Kraul str., block park, 04.08.2016 (an.) (Karelina, 2017).

**P. spiraeae* (Sawada) U. Braun et S. Takam. – *Spiraea* species (*Rosaceae*): *S. chamaedryfolia* L.: BG, arboretum, 20.10.2020 (Bulgakov, Shiryaev, 2021); GES, private garden, 21.09.2020; ibid., 28.09.2020 (Bulgakov, Shiryaev, 2021); BUM, block park, 23.09.2020 (Bulgakov, Shiryaev, 2021); *S. media* Schmidt, BUM, 29.07.2021, SVER (F) 96749 (an.); *Spiraea* sp., BUM, 06.08.2021, SVER (F) 96750 (an.). Status and origin of this species is unclear (Braun, Cook, 2012); previous publications did not mention this species for Sverdlovsk Region, however, it is known in East Europe (Braun, Cook, 2012) and in West Siberia (Tomoshevich, 2015).

P. tridactyla (Wallr.) de Bary s. str. [= *P. tridactyla* (Wallr.) De Bary f. *padi* Jacz.] – *Prunus padus* L. (Rosaceae): BG, park, 18.06.2021, SVER (F) 96718 (an.); ibid., 05.07.2021, SVER (F) 96752; ibid., 28.07.2021, SVER (F) 96751.

**Sawadaea bicornis* (Wallr.) Homma (=*Uncinula aceris* DC.) – *Acer* species (Sapindaceae): *A. negundo* L.: BUM, block park, 22.07.2020; BG, arboretum, 14.10.2020 (Bulgakov, Shiryaev, 2021); BG, arboretum, 06.06.2021, SVER (F) 96721 (an.); ibid., 11.06.2021, SVER (F) 96719 (an.); ibid, 23.07.2021, SVER (F) 96753 (an.); ibid., 23.07.2021, SVER (F) 96755 (an.); ibid, 12.08.2021, SVER (F) 96764; BUM, 23.07.2021, SVER (F) 96754 (an.); ibid., 14.06.2021, SVER (F) 96720 (an.); 8 March str., near the theatre "Shchelkunchik", street trees, 21.06.2021, SVER (F) 96722 (an.); *A. platanoides* L.: BG, arboretum, 22.08.2021, SVER (F) 96765 (an.). Introduced alien species: native for Eurasia, but came in Sverdlovsk Region from the Southern Urals together with its host plants (*Acer campestre* and *A. negundo*).

S. tulasnei (Fuckel) Homma – *Acer* species (Sapindaceae): *A. platanoides* L.: BUM, block park, 25.10.2020 (Bulgakov, Shiryaev, 2021); *A. tataricum* L.: SFP, 08.08.2016 (an.) (Karelina, 2017). Introduced alien species: native for Eurasia, but was introduced in Sverdlovsk Region from the Southern Urals together with its host plants (*Acer platanoides* and *A. tataricum*). *S. tulasnei* was previously recorded on *Ac-*

er negundo in Ekaterinburg (Karelina, 2017); however, these records are doubtful and require verification because this species does not usually affect this plant species (Heluta, 1989).

DISCUSSION

The number of powdery mildew fungi recorded on woody plants in Sverdlovsk Region reached 29 species of four genera in 2022, according to the modern taxonomy of the family *Erysiphaceae* (Braun, Cook, 2012). Totally, five species are new for the region as first found after our researches (Bulgakov, Shiryaev, 2021), and four species – *Erysiphe ehrenbergii*, *E. salicis*, *Phyllactinia alnicola*, and *Ph. betulae* – can be considered as new ones because of taxonomic revisions of previously known species; three species – *Erysiphe aquilegiae*, *E. trifoliorum*, and *Podosphaera aphanis* – are first recorded on woody host plants in the region, but previously they were known here on herbaceous plants only (Yachevsky, 1927; Stepanova, Sirko, 1970; Karelina, 2017). We have also included in the list five species still known only from old collections and references: *Erysiphe divaricata*, *E. ornata*, *Phyllactinia alnicola*, *Ph. betulae*, and *Ph. guttata*; almost all of them were collected in southwestern districts of Sverdlovsk Region in 1920–1960s (Stepanova, Sirko, 1970).

The most numerous genus is *Erysiphe* (17 species, 58.6%), and other three genera are represented by a lesser number of species (41.4% only): *Podosphaera* (7 species), *Phyllactinia* (3) and *Sawadaea* (2). Such diversity and taxonomic structure are typical for woody plants in other boreal regions in the zone of mixed forests of the European Russia with well-studied diversity of *Erysiphaceae*: Moscow City and Moscow Region (Gorlenko, 1983; Blagoveshchenskaya, 2015), Saint-Petersburg City and Leningrad Region (Cherapanova, Cherepanov, 2004; Popov et al., 2007; Bulgakov et al., 2014), Ulyanovsk Region (Churakov et al., 2018), and Novosibirsk Region (Tomoshevich, 2015). Thus, based on the species composition of the regional dendroflora, we can assume that the species composition of *Erysiphaceae* on woody plants in Sverdlovsk Region has been studied quite completely.

However, we should note that several more *Erysiphaceae* species on woody plants in Sverdlovsk Region with a high degree of probability can be found, as they are recorded in the neighboring regions in similar biomes on the woody host plants, and are common fungi in the whole middle Urals: *Erysiphe prunastri* DC. (= *Uncinula prunastri* Sacc.) – was recorded in Chelyabinsk Region on *Prunus padus* (Stepanova, Sirko, 1970), and three other species: *Erysiphe penicillata* (Wallr.) Link [= *Microsphaera alni* (DC.) G. Winter] on *Alnus incana*, *Phyllactinia mali* (Duby) U. Braun [= *Ph. suffulta* (Rebent.) Sacc. f. *oxyacanthae* Roum.] on *Crataegus sanguinea*, and *Podosphaera aucupariae* Erikss. (= *P. oxyacanthae* De Bary f. *sorbi* Jacz.) on *Sorbus aucuparia* L. – were found in Republic of Bashkortostan (Yachevsky, 1927). Potentially, two additional 'cryptic species' would be found in Sverdlovsk Region: *Erysiphe syringae* Schwein. – hardly differentiated from *E. syringae-japonicae* by conidial stage (Takamatsu et al., 2016), and *E. hypophylla* (Nevod.) U. Braun et Cunningt. – hardly differentiated from *E. alphitoides* by chasmothecia (Braun, Cook, 2012).

Phenological observations have shown that the development of almost all powdery mildew fungi occurs mainly in the period from mid-June to the end of September. Moreover, most species regularly formed chasmothecia (teleomorph, or sexual stage), and only four species developed exclusively in the asexual stage (anamorph): *Erysiphe aquilegiae*, *E. necator*, *Podosphaera pannosa*, and *P. spiraeae*; some other species: *Erysiphe alphitoides*, *E. syringae-japonicae*, *E. lonicerae*, *E. trifoliorum*, *Podosphaera aphanis*, and *Sawadaea bicornis* formed chasmothecia extremely rarely. Just all species formed chasmothecia (teleomorph) mainly since the mid-July to the mid-September.

The identified species are found on 49 species of woody plants from 24 genera and 15 families, among which the largest number of species was noted on the species of Betulaceae, Rosaceae and Salicaceae (table 1). Each woody plant can be infected by a single powdery mildew species, excluding *Acer*, *Betula*, *Corylus*, *Lonicera*, and *Salix*, which can be infected with two *Erysiphaceae* species (table 1). Three woody plant species known as host plants for two *Erysiphaceae* species: *Acer platanoides* (*Sawadaea bicornis* and *S. tulasnei*), *Betula pubescens* (*Erysiphe ornata* and *Phyllactinia betulae*), and *Corylus avellana* (*Erysiphe corylacearum* and *Phyllactinia guttata* s. str.).

As our observations have shown, at least 14 species (48.3%, or almost a half of known species) can be considered as alien for the region, including seven invasive species that have come mainly from North America (mainly United Stated of America): *Erysiphe necator* and *Podosphaera mors-uvae*, and East Asia, including Northeast China, Korea, Japan, and Russian Far East: *Erysiphe alphitoides*, *E. corylacearum*, *E. palczewskii*, *E. syringae-japonicae*, and *E. vanbruntiana* (Desprez-Loustau, 2009; Braun, Cook, 2012). All of them are the most common and harmful plant pathogens having a high annual disease incidence and disease severity, significantly reducing the decorative effect of their host plants in Ekaterinburg. Also all of them have invaded the region (as well as many European countries) over the last century. Only three alien powdery mildew species were known in Ekaterinburg (Sverdlovsk) before 1970 (Stepanova, Sirko, 1970): *Erysiphe necator* – since 1900s (Yachevsky, 1927), *Podosphaera mors-uvae* – since 1910s (Yachevsky, 1927), and *E. alphitoides* – since 1920s (Pentin, 1939). Other four new recorded East Asian alien species (previously reliably not recorded in Sverdlovsk and in the Urals) have invaded the region during the last 50 years (1971–2021): *Erysiphe vanbruntiana* in 1970s (Gorlenko, Heluta, 1984), *E. palczewskii* in 1980s (Heluta, 1981), *E. syringae-ja-*

Table 1. Woody plants as hosts of the powdery mildews (*Erysiphaceae*) in Sverdlovsk Region

Host plants			Recorded fungal species, number
Families	Genera	Species (hybrids), number	
Berberidaceae	*Berberis*	2	1
Betulaceae	*Alnus*	2	1
	Betula	2	2
	Corylus	1	2
Celastraceae	*Euonymus*	1	1
Caprifoliaceae	*Lonicera*	3	2
Ericaceae	*Vaccinium*	1	1
Fabaceae	*Caragana*	1	1
	Chamaecytisus	1	1
Fagaceae	*Quercus*	1	1
Grossulariaceae	*Ribes*	3	1
Oleaceae	*Syringa*	3	1
Ranunculaceae	*Clematis*	2	1
Rosaceae	*Crataegus*	2	1
	Dasiphora	2	1
	Prunus	1	1
	Rosa	3	1
	Spiraea	3	1
Salicaceae	*Populus*	4 (2)	1
	Salix	3	2
Sapindaceae	*Acer*	3	2
Viburnaceae	*Sambucus*	2	1
	Viburnum	1	1
Vitaceae	*Vitis*	2	1
Total: 15	24	49 (2)	29

ponicae in 1990s (Seko et al., 2008), and *E. corylacearum* in 2010s (Bradshaw et al., 2021b) – all of them are invasive species that spread in Europe during the same periods.

Seven powdery mildews can be considered as alien introduced species: *Erysiphe berberidis*, *E. ehrenbergii*, *E. euonymi*, *E. lonicerae*, *E. viburni*, *Podosphaera spiraeae*, *Sawadaea bicornis*, and *S. tulasnei* – this species are native for Eurasia (Braun, Cooke, 2012) and known in European Russia (Gorlenko, 1983), Kazakhstan (Rakhimova et al., 2015), and even Southwestern Urals (Stepanova, Sirko, 1970). However, their appearance in Sverdlovsk Region may be a consequence of their host plant invasion in local plant communities (*Sawadaea bicornis* on *Acer negundo*), or introduction and expanded cultivation of their host plants in regional urban plantings and private gardens (other powdery mildews). All of the above-mentioned invasive species are widespread and significantly reduce the decorative effect of their host plants in Ekaterinburg. It should be noted that all these alien species originate from East or Southeast Asia (Braun, Cook, 2012); they are known as native species in the Russian Far East (mainly Primorsky and Khabarovsk regions), China, Korea, and Japan (Farr, Rossman, 2022).

We should note the first record of *Erysiphe corylacearum* in the territory of Sverdlovsk Region, which was first found in Ekaterinburg in 2021. This invasive species have come from the East Asia near 2010, and quickly spread throughout the habitat of hazels (*Corylus* spp.) in the North America, Europe and West Asia, including Asia Minor, the Caucasus, and Iran (Bradshaw et al., 2021). This harmful hazel pathogen was first recorded in Russia on the Black Sea coast of the Krasnodar region in 2013 (Bulgakov, 2018), and by 2016–2017 was found in other regions of Southern European Russia: the rest part of the Krasnodar region, in the Crimea and Rostov region (Bulgakov, Karpun, 2020), and in Ukraine (Heluta, 2019) and Donetsk People's Republic (Bondarenko-Borisova, Bulgakov, 2019). The discovery of *E. corylacearum* in Ekaterinburg can be considered as evidence that this species has

now spread throughout European Russia within the range of common hazel (*Corylus avellana* L.) and entered in Asian Russia throw Urals. The growth of *Erysiphe corylacearum* on affected host plants leads to deformation of young leaves and shoots, and worsens the phytosanitary condition of the hazel.

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Мучнисторосяные грибы (*Erysiphaceae*) на древесных растениях в городских местообитаниях Свердловской области (Россия)

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По результатам авторских исследований и ревизии предыдущих сведений установлен современный видовой состав и составлен первый аннотированный список мучнисторосяных грибов на древесных растениях в городских местообитаниях Свердловской обл. (г. Екатеринбурга и нескольких городов области). Всего в настоящее время выявлено 29 видов *Erysiphaceae*, среди которых большинство относится к роду *Erysiphe* (17 видов), а остальные распределяются между родами *Podosphaera* (7), *Phyllactinia* (3) и *Sawadaea* (2). Шесть видов выявлены в Свердловской обл. впервые: *Erysiphe ehrenbergii*, *E. euonymi*, *E. lonicerae*, *E. viburni*, *Podosphaera myrtillina*, and *P. spiraeae.* Почти половина всех выявленных видов (14 из 29) являются чужеродными для Свердловской обл., при этом 6 видов могут рассматриваться как инвазивные, из которых 2 вида происходят из Северной Америки (*Erysiphe necator* and *Podosphaera mors-uvae*) и 4 вида – из Восточной Азии (*Erysiphe alphitoides*, *E. corylacearum*, *E. palczewskii*, and *E. vanbruntiana*), а еще 8 видов могут рассматриваться как непреднамеренно интродуцированные из соседних регионов вместе с их растениями-хозяевами. Развитие большинства отмеченных видов *Erysiphaceae* приходится на период с середины июня до конца сентября. Большинство видов (25 из 29) развиваются как в стадии анаморфы, так и телеоморфы, и только 4 вида (*Erysiphe aquilegiae*, *E. necator*, *Podosphaera pannosa* и *P. spiraeae*) отмечены исключительно в стадии анаморфы.

Ключевые слова: биоразнообразие грибов, городские насаждения, Россия, Урал, чужеродные виды