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The reaction of different *Sorbus* L. species to low temperatures during thaw in the Orel region

Zoya Ozherelieva*, Olga Emelianova

Russian Research Institute of Fruit Crop Breeding (VNIISPK), Orel, Russia
Corresponding author: ozherelieva@vniispk.ru

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Abstract: Five *Sorbus* L. species of different ecological and geographical origin growing in the VNIISPK arboretum were studied. The Institute is located 368 km southwest of Moscow, on the Central Russian upland in the European part of Russia. The studies were carried out in 2014–2016. The reaction of different *Sorbus* L. species to a three-day thaw +2°C with a subsequent decrease in temperature to –25°C in February and –30°C in March was studied in order to identify adapted species to the climatic conditions of the Orel region for use in ornamental horticulture. As a result of the experiment, we recommend *Sorbus aria* (L.) Crantz, *Sorbus aucuparia* L. and *Sorbus alnifolia* (Siebold. et Zucc.) K. Koch. as adapted species for the Orel region to create sustainable landscape compositions.

Keywords: artificial freezing; adaptation; frost hardiness

Low temperature is a key environmental factor determining the evolution and distribution of plants (Hawkins et al. 2014). Frost can damage plants through xylem embolism and the formation of extracellular ice, which causes cell dehydration and disruption of cell membranes (Zwiazek et al. 2001; Willson, Jackson 2006). Woody plants show remarkable differences in frost tolerance which are frequently related to the minimum temperatures within their distribution range (Kreyling et al. 2014). At a plant scale, organs also differ in frost tolerance, with aboveground vegetative parts having greater frost tolerance than roots (Bigras et al. 2001). Plants have developed specific adaptations to low temperatures (Larcher 2005). Perennial plants undergo a complex cold acclimation process during fall in which they experience deep reversible physiological changes to survive the cold season (Charrier et al. 2015). When the temperature becomes higher for three or more days in winter, the physiological condition of trees changes and their resistance to frost decreases (Groffman et al. 2001; Schaberg et al. 2008; Ozherelieva, Sedov 2017). Thus in nature, slight freezing or death of trees is observed as a consequence of sharp temperature declines during thaws in February and March which cause trees to break deep dormancy. The ability of plants to withstand frost during a thaw is of great importance against the background of prolonged thaws.

Decorative woody plants play the main environment-forming role in the system of green spaces of cities, both in ecological and architectural-planning aspect. One of the main ways to improve urban greening is to enrich existing plantings with new fast-growing, highly decorative and environmentally sustainable forms and species. The representatives of the genus *Sorbus* L. are promising valuable species for landscaping.

The broad genus *Sorbus* L. belongs to the apple tribe of the family Rosaceae (Campbell et al. 2007; Potter et al. 2007). The genus *Sorbus* L. includes approximately 127 species in Europe and North Africa and approximately 250 species widespread in the north-

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ern hemisphere (Aldasoro et al. 2004). In the territory of Russia 34 species of the genus *Sorbus* L. grow. Rowan (*Sorbus* L.) is a decorative and berry-bearing tree used also for medicinal purposes. It occupies a special place among the ornamental trees and shrubs used for landscaping in urban areas. Rowan plants are used both in single and group plantings, and for the construction of hedges.

In 1968 in the Orel region, an arboretum was established near the central building of the Institute. The area of the arboretum was 7 ha. Currently, the collection of the arboretum contains more than 250 species, forms and varieties of plants from different ecological and geographical zones. Scientific research aimed at expanding the range and conservation of biodiversity through the naturalization and acclimatization of the introducents is carried out in the arboretum (Dubovitskaya, Pavlenkova 2015). Significant achievements in the field of introduction and selection of ornamental crops have opened wide opportunities for the transformation of natural plantations by saturating them with new original species and varieties adapted to local climatic conditions (Nigmatianova 2011; Nigmatianova, Mursalimova 2015, 2016).

When choosing the assortment of woody plants to create sustainable landscape structures, along with decorativeness as one of the main properties that lead to widen their introduction into cultivation in the Orel region, is their frost resistance. Frost resistance of the plants depends on many factors: sharp temperature changes, snow depth, age, condition of plants, etc. (Ozherelieva, Pavlenkova 2011; Ozherelieva et al. 2013). In the Orel region the introduced *Sorbus* L. species react differently to low temperatures during thaws, depending on their origin. In this regard, studies of the resistance of *Sorbus* L. species of native and introduced flora of the arboretum to repeated frosts after thawing by artificial freezing are relevant.

The aim of the research was to determine the reaction of different *Sorbus* L. species to low temperatures during thaws and to identify the best adapted species to climatic conditions of the Orel region.

MATERIAL AND METHODS

Study area

The study of the frost resistance of *Sorbus* L. of different ecological and geographical origin was carried out at the VNIISK Laboratory of Physiology of Fruit Plant Resistance and in the arboretum in 2014–2016. The experimental station is located in the central part of the Central Russian Upland (53°00'N, 36°00'E). VNIISPK is located 368 km southwest of Moscow, on the Central Russian upland in the European part of Russia (Fig. 1).

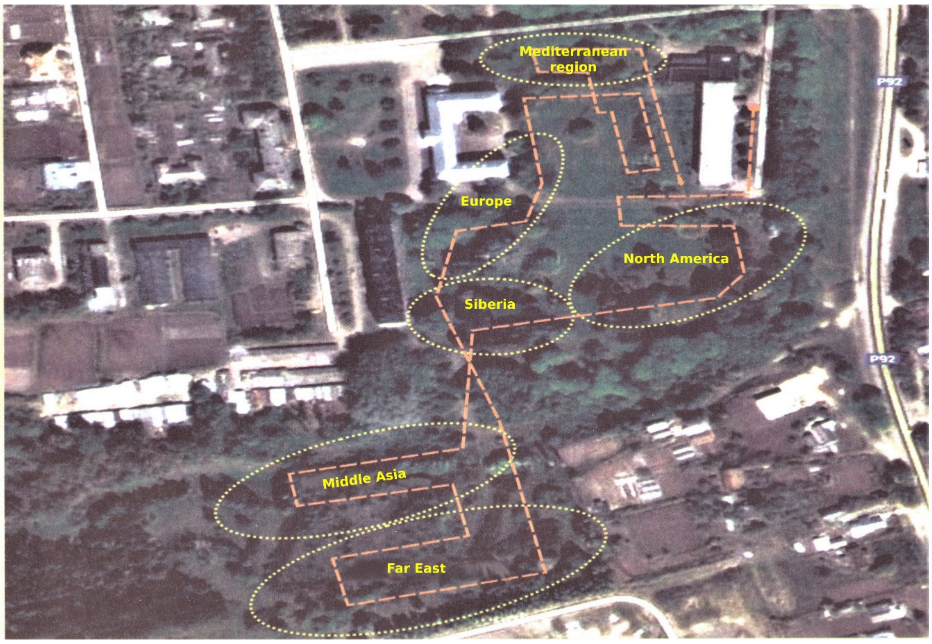

Fig. 1. Ecological and geographical zones of the VNIISPK arboretum (Orel region) (Dubovitskaya, Pavlenkova 2015)

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Table 1. Maximal and minimal temperatures of the autumn-winter periods of studied years

Temp (°C)	2014			2015						2016					
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Oct.	Nov.	Dec.
Max	20.8	11.5	5.2	4.0	4.5	14.5	23.7	12.0	10.5	4.0	6.5	10.3	22.5	12.2	3.0
Min	–15.2	–19.8	–23.3	–24.5	–20.5	–11.2	–10.0	–16.0	–12.0	–29.3	–12.4	–11.0	–8.8	–19.0	–20.6

Winter weather conditions in the Orel region

The climate in the Orel region is moderately continental. The average annual temperature is 4–5°C. The average daily temperature of the coldest month (January) is –10 °C. The absolute minimum temperature for the last 20 years was –39°C. The average dates of autumn frosts fall at the end of September (the earliest beginning of frosts was noted in the first decade of September, and the latest in the third decade of October). The average duration of the frost-free period is 135–150 days. On average for the year, precipitation is 490 to 580 mm (40–50 mm in September and October; 30–40 mm in November and December; 25–35 mm in January; and 20–25 mm in February and March). The snow cover reaches maximum depth from mid-February to mid-March. Its average thickness is 20–25 cm (Gidrometeo 1972). In the Orel region a sharp drop in temperature to –25°C after a three-day thaw +2°C is observed from mid-December to March. Frequency of occurrence of such adverse effects was noted in winter 2006/2007, 2008/2009, 2009/2010, 2010/2011, 2013/2014 and 2014/2015. The return of frosts –30°C after a three-day thaw +2°C and re-hardening were observed in winter 2007/2008, 2010/2011, 2011/2012, 2012/2013, 2015/2016 and 2016/2017. The ability to maintain resistance to temperature drops during thaws is of great importance, as prolonged thaws in winter have become more frequent in recent years.

Maximal and minimal temperatures of the autumn-winter periods of studied years are given in Table 1. *Sorbus americana* and *Sorbus sibirica* begin to vegetate before other studied *Sorbus* L. species in conditions of the Orel region. Vegetative buds in these species begin to burst in early April and flower buds begin to bloom in late April. *Sorbus aria, Sorbus aucuparia* and *Sorbus alnifolia* begin to vegetate later (mid-to late April).

Materials

Annual shoots of five *Sorbus* species of different ecological and geographical origin that are growing in the VNIISPK arboretum were studied (Table 2). The ecological and geographical zones of species growth in the arboretum are shown in Fig 1. Annual shoots of five *Sorbus* L. species which were harvested at the end of November for all variants of the experiment were taken for artificial freezing. Annual shoots were cut at the rate of 10 pieces of each species. Then they were divided into 5 cuttings for each version of the experiment. One annual cutting is one repetition. The base of annual shoots was wrapped in wet cloth to prevent them from drying out and placed in plastic bags. The experimental material was stored at a temperature of –3°C before the experiment.

Method

Simulation of damaging factors in the winter season was carried out by the method of artificial freezing (Turina et al. 2002).

Table 2. Material of studies

Species	Ecological and geographical origin
Sorbus americana Marsch.	Northern America
Sorbus aria (L.) Crantz	Western Europe
Sorbus aucuparia L.	Europe (to the Far North), Middle Asia, Caucasus
Sorbus alnifolia (Siebold. et Zucc.) K. Koch	Far East
Sorbus sibirica Hedl.	Siberia, Far East, Northern Mongolia

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Simulation of hardening of plants

Hardening was simulated in the "Espec" PSL-2KPH climate chamber (Japan). Hardening was carried out in two stages. The temperature in the climate chamber was first lowered to –5°C, and the *Sorbus* L. annual shoots were tempered at this temperature for 5 days, then the temperature was lowered to –10°C and the annual shoots were tempered at this temperature for 5 days.

To determine the reaction of *Sorbus* L. plants to low temperatures after the thaw, two modes of artificial freezing were carried out.

The first mode of freezing

In February after hardening (–5°C during 5 days; –10°C during 5 days), a three-day thaw +2°C with the following lowering of the temperature to –25°C was simulated. The temperature was reduced at a rate of –5°C per hour. The duration of freezing at –25°C was 8 hours. Then the growing of the annual shoots was carried out in vessels with water. The assessment of damage to the buds and tissues of the annual shoots was carried out after 5 days using an MBS-2 binocular microscope.

The second mode of freezing

In March after hardening (–5°C during 5 days; –10°C during 5 days), a three-day thaw +2°C. was simulated. Re-hardening (–5°C during 5 days; –10°C during 5 days) was simulated after the thaw with the subsequent lowering of the temperature to –30°C. Herewith, the temperature was reduced at a rate –5°C per hour. The duration of freezing at –30°C was 8 hours. Then the growing of the annual shoots was carried out in vessels with water. The assessment of damage to the buds and tissues of the annual shoots was carried out after 5 days using an MBS-2 binocular microscope.

Damage assessment

Damage was assessed depending on the degree of colour change of the annual shoot tissues and buds at the longitudinal and transverse sections on the following scale: 0.0 – no lesions; 1.0 – slight damage, up to 10 percent of the tissue changed colour to light yellow; 2.0 – reversible damage, up to 25% of the tissue changed colour to light brown; 3.0 – mean damage, up to 30–40% of the total area of the tissue incision of the annual shoot and buds changed colour to brown; 4.0 – the tissues of annual shoot and buds were severely damaged, the colour of the tissues changed to brown by more than 50%; 5.0 – the buds and tissue of annual shoot died, the annual shoot and the buds were dark brown.

Statistical analysis

All results were tested by one-way analysis of variance ANOVA (Version 22, SPSS) (Dospekhov 1985). To evaluate the effect of genotypes, the least significant difference ($LSD_{0.05}$) was calculated.

RESULTS

The first mode of freezing

According to the results of the first experiment after +2°C thaw simulation and the subsequent temperature reduction to –25°C in February, insignificant damage of buds and tissues was found in *Sorbus alnifolia*. Reversible damage of the buds (not more than 2.0 points) was noted in *Sorbus aria* and *Sorbus aucuparia*. Bud damage from 2.8 to 2.9 points was identified in *Sorbus americana* and *Sorbus sibirica* at –25°C after a three-day thaw +2°C (Fig. 2). During the period of a sharp temperature drop from +2°C to –25°C, bark and wood were more affected to 1.2 points in *Sorbus sibirica*. The rest of the studied species showed slight damage to the tissues of annual shoots – not more than 1.0 point. The wood was not damaged by frost –25°C after a three-day thaw +2°C in *Sorbus aria* and *Sorbus alnifolia*. By the ANOVA the essential difference between the studied *Sorbus* L. species was noted in the degree of bud, bark and wood damage at a 5% significance level (Table 3).

The second mode of freezing

In another version of the experiment, after a three-day thaw +2°C and re-hardening, all the studied *Sorbus* L. species were characterized by frost resistance to the return of frost –30°C in March. Slight damage to buds and tissues of the annual shoots was identified in *Sorbus alnifolia* and *Sorbus aria* (not more than 1.0 point). *Sorbus americana, Sorbus aucuparia* and *Sorbus sibirica* showed the frost resistance of buds (dam-

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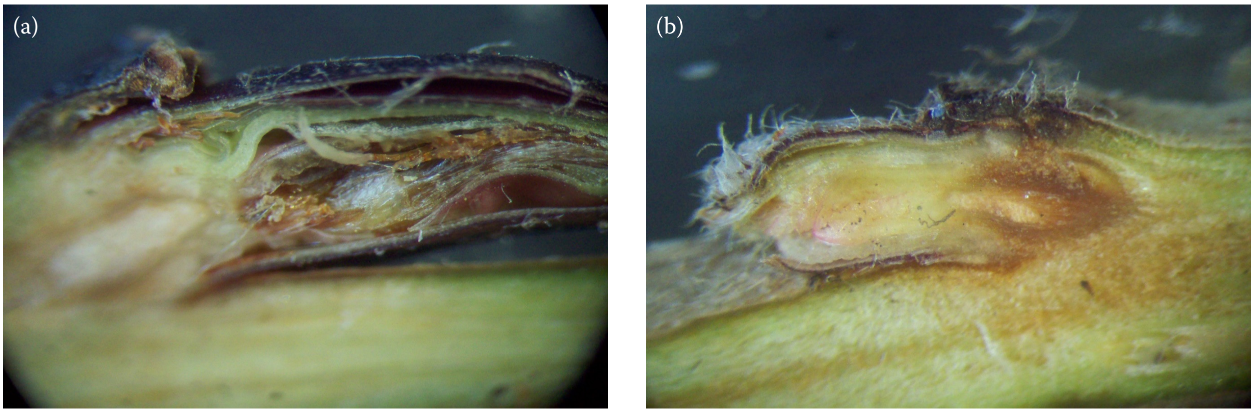

Fig. 2. Damage to the buds of *Sorbus* L. – *Sorbus sibirica* (a), *Sorbus americana* (b) after +2°C thaw simulation and the subsequent temperature reduction to –25°C (8× magnification)

age not more than 2.0 points) in late winter. Bark and wood of annual shoots of the studied species showed slight damage not more than 0.5 point. It follows that the tissue of the annual shoots of the studied *Sorbus* species lost frost resistance to a lesser extent than the buds during the thaw at the end of winter. ANOVA processing of the results of artificial freezing indicated that the significant difference between the studied *Sorbus* L. species was revealed only by the degree of bud damage at a 5% significance level. The interspecific difference in the degree of bark and wood damage to annual shoots in the studied *Sorbus* L. species was inauthentic (Table 3).

DISCUSSION

Frost determines the evolution and distribution of plants in temperate and cold regions. Several environmental factors can influence frost acclimation of woody plants. Some studies have reported that high N availability reduces frost tolerance (Schaberg et al. 2002; Villar-Salvador et al. 2013; Heredia-Guerrero et al. 2014). In contrast, other evidence suggests that plant frost tolerance increases with N availability in trees from temperate climates (Andivia et al. 2012; Taulavuori et al. 2014; Toca et al. 2018). Other studies have reported seasonal changes in water-soluble carbohy-

Table 3. Bud, bark and wood damage score of *Sorbus* L. annual shoots

	Buds	Bark	Word
The 1st mode of freezing (–5°, –10°, +2°, –25°C)			
Sorbus alnifolia	1.0 ± 0.30	0.3 ± 0.16	0.0 ± 0.00
Sorbus aucuparia	1.2 ± 0.16	0.2 ± 0.13	0.2 ± 0.12
Sorbus aria	1.9 ± 0.25	0.5 ± 0.18	0.1 ± 0.05
Sorbus sibirica	2.8 ± 0.35	1.2 ± 0.35	1.2 ± 0.33
Sorbus americana	2.9 ± 0.16	1.0 ± 0.28	0.4 ± 0.18
$LSD_{0.05}$	0.7	0.7	0.6
The 2nd mode of freezing (–5°, –10°, +2°, –5°, –10°, –25°C)			
Sorbus alnifolia	0.7 ± 0.19	0.0 ± 0.00	0.3 ± 0.13
Sorbus aria	0.8 ± 0.33	0.5 ± 0.28	0.2 ± 0.10
Sorbus sibirica	1.1 ± 0.48	0.2 ± 0.10	0.0 ± 0.00
Sorbus aucuparia	1.2 ± 0.17	0.0 ± 0.00	0.1 ± 0.10
Sorbus americana	1.8 ± 0.29	0.4 ± 0.23	0.2 ± 0.10
$LSD_{0.05}$	0.8	$F_f < F_t$	$F_f < F_t$

$LSD_{0.05}$ – least significant difference at $P \leq 0.05$, F_f – factual value of Fisher criterion, F_t – theoretical value of Fisher criterion

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drates, free proline and resistance to freezing and water deficiency have been studied in laurel cherry leaves (*Prunus laurocerasus*) and ivy (*Hedera helix*) (Bandurska et al. 2009)**.** The basic biometric parameters (height, DBH, social position, fertility) of the population were assessed in the wild service tree *Sorbus torminalis* (L.) Crantz in the research area in the Hádecká planinka National Nature Reserve (Maděra et al. 2012). Researchers also estimated the distribution of *Sorbus domestica* in the White Carpathians. They noted the role of people and their influence on the distribution of species based on regional climate, ecology and dendrometric parameters (Špíšek et al. 2018). Genetic diversity was evaluated after the natural regeneration of *Sorbus* L. obtained from a small population of parent trees, and the results were analysed in the context of conservation (Bednorz et al. 2012, 2015).

In our research we determined the reaction of different *Sorbus* L. species to winter thaws at a subsequent temperature decrease to identify adapted species to the climatic conditions of the Orel region. The adaptability of trees provides plant resistance in the thaw period. Buds, bark and cambium consisting of active metabolic cells are more damaged than wood during thaw periods. It is very important for plants in late winter to retain hardening to low temperature after thaw. Thaws in March are dangerous for plants since they are in exogenous dormancy and higher temperatures activate bud growth processes, while a gradual temperature decline after a thaw favours the restoration of cambium and bark resistance. Buds are less able to restore the hardening state after prolonged thaws. Wood responds less to thaws and does not lose frost resistance during thaws (Turina 2000).

In the Orel region at the end of winter, thaws are observed repeatedly, as a result of which plants can reduce frost resistance, although the return of frosts does not always cause significant damage, since the temperature decrease occurs gradually, and the frost resistance is restored.

For the first time, studies of frost resistance during thawing of five species of the genus *Sorbus* L. were carried out under introduction into a temperate continental climate of the Orel region.

Winter damage factors in the Orel region were simulated in the controlled conditions. As a result of artificial freezing, the response of *Sorbus* L. species of different ecological and geographical origin to low temperature was determined. After sudden changes in temperature from positive to low, the buds suffered more in *Sorbus* L. species. At the same time the tissues of the annual shoots showed adaptability to the climatic conditions of the Orel region to a greater extent. It should be noted that among the studied *Sorbus* L. species, three species were characterized by the highest stability of the buds and tissues of the annual shoot over the years studied. These are *Sorbus aria*, the natural area of which is located in the mountain-forest belt of Europe, *Sorbus aucuparia* growing in Europe in natural conditions from Middle Asia to the Far North and *Sorbus alnifolia*, which is native to the Far East.

Species with better introduction stability in the climatic conditions of the Orel region have been identified. Selected species of the genus *Sorbus* L. are of great practical interest as important components of dendroflora. Therefore, the question of their introduction and acclimatization in the Central region of Russia is relevant.

CONCLUSIONS

For the first time, studies of frost resistance during thawing of different of species of the genus *Sorbus* L. were carried out. As a result of the first experiment, a weak reaction to a sharp decrease in temperature to –25°C after a three-day thaw +2°C was determined in the species *Sorbus alnifolia, Sorbus aucuparia* and *Sorbus aria*. In another version of the experiment, after a three-day thaw +2°C and re-hardening, these *Sorbus* L. species were characterized by relatively high frost resistance to the return of frost –30°C in March. They were classified as the best adapted species to the conditions of the Orel region. Accordingly, the selected species are recommended as an additional range in the landscape design of squares, parks and forest parks in the Central region of Russia. Central Russia is characterized by long, relatively warm autumn and winter with temperature changes and deep thaws. These conditions lead to the disruption of homeostasis and reduction of the high frost resistance in *Sorbus americana* and *Sorbus sibirica*.

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