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A study of introduced apple cultivars according to the main components of winter hardiness by simulating damaging factors under controlled conditions

Anna M. Galasheva, Nina G. Krasova, Zoya E. Ozherelieva

All-Russian Research Institute of Fruit Crop Breeding, Orel Province, Russia

Corresponding author: Anna M. Galasheva, galasheva@vniispk.ru

Background. Most of the plantings of fruit crops in Russia are located in the zone of risky agriculture. In the European part of Russia, in winter, fruit crops are affected by the impacts of weather conditions (spring frosts, droughts, early frosts, low-temperature stress, a short growing season, and thaws). Frosts cause 98% of the damage to fruit trees.
Methods. One-year-old branches were frozen in a Japanese Espec PSL-2KPH climate chamber after prehardening under –5°C and –10°C for 5 days, and damaging factors of the winter period were simulated.
Results. The bioresource collection of the All-Russian Research Institute of Fruit Crop Breeding (VNIISPK) contains 730 apple-tree cultivars from various domestic and foreign institutions. Apple cultivars from Ukraine, Belarus, Latvia, Moldova, USA, France, Czech Republic, Sweden and Canada were analyzed for frost resistance components. The resistance of plants to early frosts of–25°C without hardening and after hardening in early winter (Component I) showed that the main tissues (bark, cambium and wood) suffered minor damage in all studied cultivars. In cv. 'Belarusskoye Sladkoye', the damage to the bark scored 2.3 points. Among the studied apple cultivars whose one-year-old branches were frozen at –38°C and –40°C (Component II), 'Coremolda' (Moldova) showed the highest frost resistance to the negative mid-January temperature of –38°C (damage to the buds and main tissues scored 0.3–1.0 points). Under–40°C (Component II), 'Coremolda' (Moldova) and 'Aivaris' (Latvian breeding) demonstrated bark, cambium and wood resistance with damages at the level of 2.0 points. These cultivars can be used in breeding programs as sources of frost resistance. Freezing of one-year-old branches under –25°C after a 3-day artificial thaw at +2°C revealed bud and tissue resistance in the American cv. 'Red Free' and in cv. 'Coremolda' (Component III).

Keywords: winter hardiness, frost, thaw, buds, bark, cambium, wood

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Научная статья
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Изучение интродуцированных сортов яблони по основным компонентам зимостойкости методом моделирования повреждающих факторов в контролируемых условиях

А. М. Галашева, Н. Г. Красова, З. Е. Ожерельева

Всероссийский научно-исследовательский институт селекции плодовых культур, Орловская область, Россия

Автор, ответственный за переписку: Анна Мироновна Галашева, galasheva@vniispk.ru

Актуальность. В России большая часть насаждений плодовых культур находится в зоне рискованного земледелия. В европейской части России в зимний период на плодовые культуры влияют воздействия погодных условий (весенние морозы, засухи, ранние морозы, низкотемпературный стресс, короткий вегетационный период, оттепели). Морозы причиняют 98% повреждений плодовым деревьям.
Методы. Однолетние ветки промораживали в японской климатической камере марки Espec PSL-2KPH после предварительной закалки при –5°С и –10°С в течение пяти суток; проводили моделирование повреждающих факторов зимнего периода.
Результаты. Биоресурсная коллекция ВНИИСПК содержит 730 сортов яблони из различных научных российских и зарубежных учреждений. Проведен анализ по компонентам морозостойкости сортов, полученных из зарубежных стран: Беларусь, Украина, Латвия, Молдавия, США, Канада. Устойчивость растений к ранним морозам –25°С без закалки и после закалки в начале зимы (I компонент) выявила, что основные ткани (кора, камбий, древесина) имели незначительные повреждения у всех изучаемых сортов. Промораживание однолетних веток у изучаемых сортов яблони при температуре –38°С, –40°С (II компонент), показало: устойчивость максимальной морозостойкости к отрицательной температуре в середине января –38°С у сорта молдавской селекции ‘Coremolda’ (повреждение почек и основных тканей – 0,3–1,0 балла). При температуре –40°С (II компонент) устойчивость коры, камбия и древесины (с повреждениями на уровне 2,0 балла) проявили сорта ‘Coremolda’ (молдавской селекции), ‘Aivaris’ (латвийской селекции), которые могут участвовать в селекции как морозостойкие сорта. Промораживание однолетних ветвей при температуре –25°С после 3-дневной искусственной оттепели при +2°С выявило устойчивость почек и тканей у американского сорта яблони ‘Red Free’ и у сорта молдавской селекции ‘Coremolda’ (III компонент).

Ключевые слова: мороз, оттепель, почки, кора, камбий, древесина

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Introduction

Most of the fruit crop plantings in Russia are located in the zone of risky agriculture. In the European part of Russia, in winter, fruit crops are affected by the impacts of weather conditions (spring frosts, droughts, early frosts, low-temperature stress, a short growing season, and thaws). Frosts cause 98% of the damage to fruit trees (Kichina, 1999; Savelyev et al., 2010; Ozherelieva, Sedov, 2017; Ulyanovskaya, Bogdanovich, 2018). Winter hardiness is a significant biological property that allows fruit trees to withstand low winter temperatures and other adverse conditions in the cold season (Nenko et al., 2013).

Four types of frost effects on fruit plants are clearly distinguished during the winter season in Russia:

1) critical frosts in late autumn (November) / early winter (December), around the time when the temperature is set below 0°C;

2) plants are exposed to severe frosts (–40°C/–38°C) in the middle of winter until long thaws (December, January, February). During these periods fruit plants are in dormancy, they experience maximum hardening before thaws, which means that they are able to withstand maximum frosts (Brierley, 1947; Weiser, 1970; Savelyev et al., 2010; Chen et al., 2014; Krasova, 2015; Ozherelieva et al., 2019);

3) the impact happens during the thaw: the frost is not very strong but it affects fruit plants quite harshly against the background of abrupt daily temperature differences; and

4) recurrent frosts, occurring at some time after the thaw and a gradual decrease in temperatures. Frosts of this type can be quite severe; they befall in January, February, or March (Kichina, 1999).

The bioresource collection maintained at the All-Russian Research Institute of Fruit Crop Breeding (VNIISPK) contains 730 apple cultivars from various Russian and foreign research institutions. Studies of the VNIISPK apple gene pool allowed us to evaluate the cultivars for winter hardiness by simulating frost damaging factors to identify the best cultivars according to frost resistance components in order to use these apple cultivars in the breeding process (Krasova et al., 2020).

The purpose of this study was to assess the main components of winter hardiness in introduced apple cultivars by simulating damaging factors under controlled conditions.

Materials and methods

The studies were carried out at VNIISPK. The following apple cultivars were tested:

1. ‘Antonovka Obyknovennaya’ (Russia);
2. ‘Anthey’, ‘Belorusskoye Sladkoye’, ‘Darunok’, ‘Imant’ and ‘Pamyat Kovalenko’ (Institute of Fruit Growing, Belarus);
3. ‘Svitlitsa’ and ‘Elegia’ (Ukraine);
4. ‘Coremolda’ (Moldova);
5. ‘Aivaris’, ‘Andris’, ‘Ausma’, ‘Ella’ and ‘Saiva’ (Latvia);
6. ‘Delikates’ (Poland);
7. ‘Priam’ (France);
8. ‘Topaz’ (Czech Republic);
9. ‘Nora’ (Sweden);
10. ‘Liberty’ and ‘Red Free’ (USA); and
11. ‘McIntosh’ (Canada).

One-year-old apple-tree branches were harvested simultaneously for all tests when the average daily air temperature was below 0°C, wrapped in a damp cloth and placed into bags under–3°C to –5°C. One-year branches were frozen in a Japanese Espec PSL-2KPH climate chamber after prehardening under –5°C and –10°C for 5 days, and the damaging factors of the winter period were simulated:

Component I – plant resistance to early frosts (–25°C) without hardening and after hardening in autumn (late November) and December;

Component II – maximum frost resistance of plants to negative temperatures in mid-January (–38 and –40°C);

Component III – plants had the ability to maintain resistance to frosts down to 25°C in February with thaws; and

Component IV – plants restored resistance to frosts down to –35°C when they rehardened after the thaw (March). One-year-old branches were frozen for 8 hours, and the temperature was reduced at a rate of 5°C per hour (Kashin, 2002).

After the climate chamber, the one-year apple-tree branches were placed in containers with water for growing. The damage to the tissue of the branches was assessed by the longitudinal and transverse sections (according to the degree of browning) using a 0–5 scale: from 0 (no damage) to 5 (the tissue died). Statistical data processing was carried out using the analysis of variance (Dospekhov, 1985).

Results and discussion

The study of introduced apple cultivars showed that they demonstrated a fairly high ability to acquire a hardened state under simulated frosts of mid-December with a temperature drop to –25°C after hardening without damage to the bark and cambium tissues and with minor damage to the buds.

Freezing of one-year-old branches to –30°C led to bud damage in most cultivars, scoring from 0.6 to 1.5 points. Significant bud damage, higher than 2.0 points, was observed in ‘McIntosh’ (2.3), ‘Darunok’ (2.5), ‘Priam’ (2.9) and ‘Red Free’ (3.4). Minor bark, cambium and wood tissue damages were recorded (0.4 to 1.6 points). Among all studied cultivars, the highest degree of bark freezing was observed in ‘Belarusskoye Sladkoye’ (2.3 points). The wood of all cultivars was slightly damaged (Fig. 1).

In Orel Province (Central Region of Russia), for example, in the winter of 2012/2013, the minimum air temperature in January dropped to –40.0°C, and on the snow surface to –34°C, according to the data of VNIISPK’s weather station (Fig. 2).

The maximum frost resistance could be developed by the studied cultivars in a hardened state by the middle of winter under simulated temperatures of –38°C/ –40°C. Under –38°C, ‘Coremolda’ was at the level of ‘Antonovka Obyknovennaya’ (reference) in the level of resistance of the buds and main tissues (0.3–1.0 points). In most of the studied cultivars, the bud damage by frost reached 2.0–3.1 points. Under –38°C, buds were frozen strongly in ‘Priam’ (2.9 points) and ‘Topaz’ (3.1 points). The bark of ‘Priam’, ‘Topaz’ and ‘Nora’ froze within the score of 2.3 to 2.8 points. Severe wood freezing was observed in ‘Andris’ (2.8 points), ‘Ausma’ (2.6 points), and ‘Priam’ (3.5 points) (Fig. 3).

Among the studied apple cultivars, freezing of one-year-old branches under –40°C (Component II) entailed damage to the buds and tissues. The bud damage at the level of ‘Antonovka Obyknovennaya’ turned out to occur in ‘Antey’ and ‘Pamyat Kovalenko’. ‘Coremolda’ and ‘Aivaris’ showed sufficient resistance in bark, cambium and wood (with the damage at the level of 2.0 points). These cultivars can be used in breeding as sources of frost resistance. ‘Ausma’, ‘Priam’ and ‘Liberty’ manifested strong freezing of their wood (3.0–3.1 points). Wood damage in cultivar ‘Delikates’ reached 4.0 points (Fig. 4).

An abrupt drop in temperature after prolonged thaws greatly affects the freezing and even leads to the complete death of the entire apple tree. Freezing of one-year branches with a frost of –25°C after a 3-day artificial thaw of +2°C re-

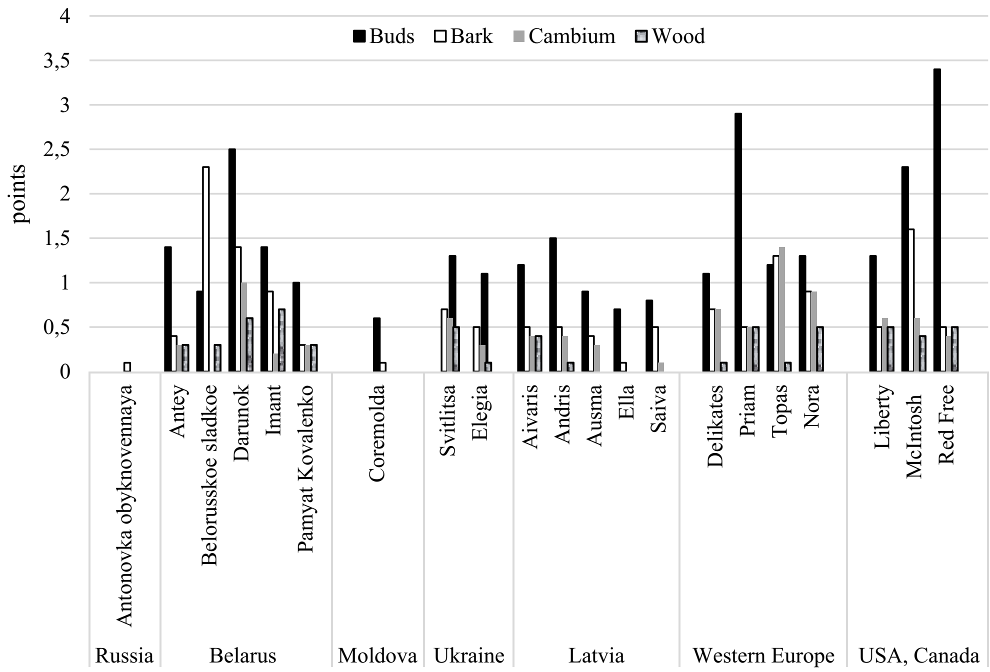

Fig. 1. The degree of freezing in one-year-old apple-tree branches in December (–5°C; –10°C; –30°C)
(Component I, HCP_{05}: buds = 0.4; bark = 0.5; cambium = 0.4; wood = 0.2)

Рис. 1. Степень подмерзания однолетних ветвей яблони в декабре (–5°C; –10°C; –30°C)
(I компонент, $НСР_{05}$: почки = 0,4; кора = 0,5; камбий = 0,4; древесина = 0,2)

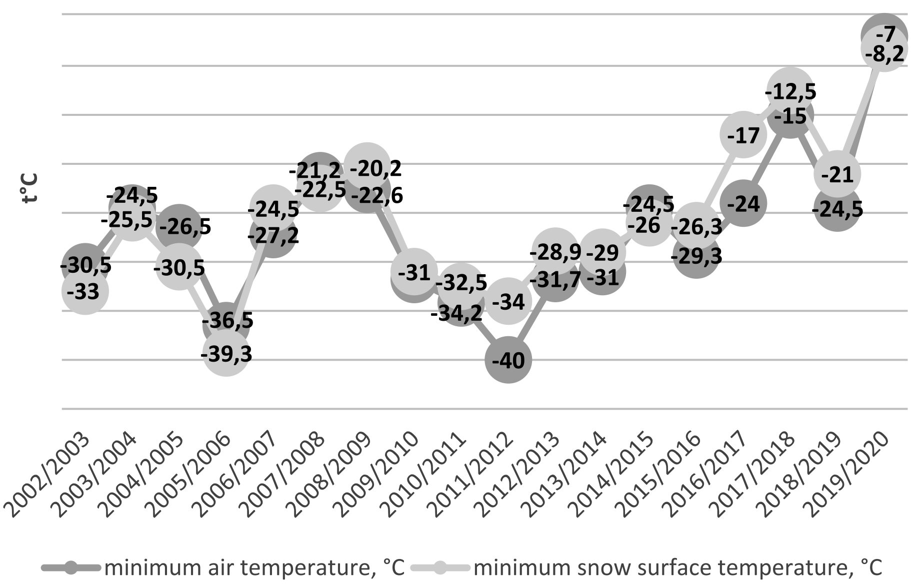

Fig. 2. Minimum air and snow surface temperatures, 2002–2020 (Orel)

Рис. 2. Минимальные температуры воздуха и на поверхности снега, 2002–2020 гг. (г. Орел)

vealed resistance of the buds and tissues in 'Red Free' and 'Coremolda' (Component III). In Belarusian cultivars, bud damage was observed in 'Antey' (2.3 points) and 'Imant' (1.7 points). The rest of the studied cultivars showed minor damage to the buds (0.3 to 1.0 points) and vital tissues (up to 1.3 points) (Fig. 5).

The ability of a cultivar to have high resistance to recurrent frosts occurring at some time after thaws is an important indicator. Repeated frosts after thaws are much stronger than the ones during thaws. The plant begins to harden and show resistance after thawing under cold weather (Kichina, 1999).

After the artificial thaw of +2°C and rehardening with a possible frost of –30°C, 'Pamyat Kovalenko' and 'Coremolda' showed high ability to restore the frost resistance of tissues and buds at the level of 'Antonovka Obyknovennaya'. Bud damage was observed in 'Antey' (2.6 points), 'Andris' (2.4 points), 'Aivaris' (1.7 points) and 'Ella' (1.6 points). The Latvian cultivars and the West European cv. 'Topaz' were characterized by weak resistance of their tissues to recurrent frosts. (Fig. 6).

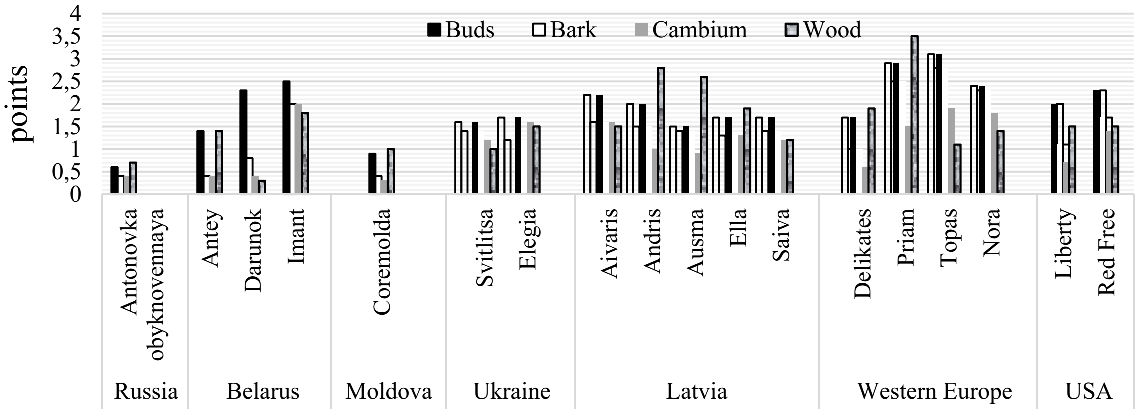

Fig. 3. The degree of freezing of cultivars under the simulated temperature of –38°C in the middle of winter (Component II, HCP_{05}: buds = 0.4; bark = 0.5; cambium = 0.5; wood = 0.5).

Рис. 3. Степень подмерзания сортов при моделировании температуры минус 38°C в середине зимы (компонент II, $НСР_{05}$: почки = 0,4; кора = 0,5; камбий = 0,5; древесина = 0,5).

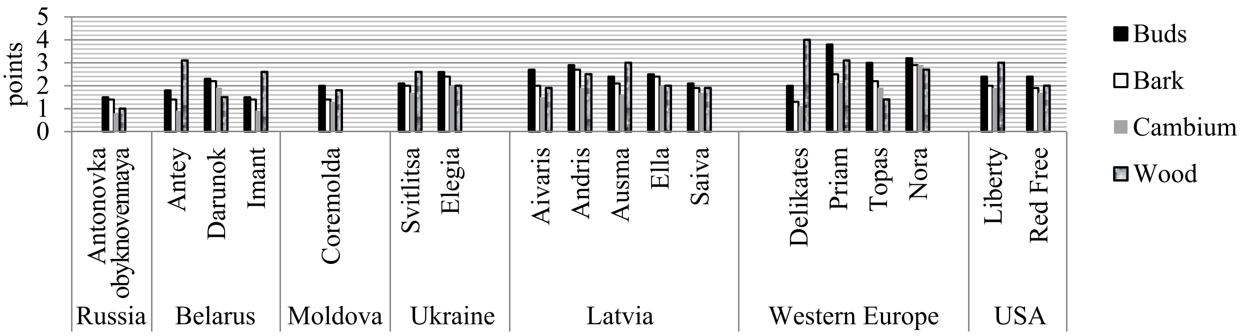

Fig. 4. The degree of freezing in the tissues of one-year-old apple-tree branches under –40°C in the middle of winter (Component II, HCP_{05}: buds = 0.4; bark = 0.4; cambium = 0.4; wood = 0.4)

Рис. 4. Степень подмерзания тканей однолетних ветвей сортов яблони при температуре –40°C в середине зимы (компонент II, $НСР_{05}$: почки = 0,4; кора = 0,4; камбий = 0,4; древесина = 0,4)

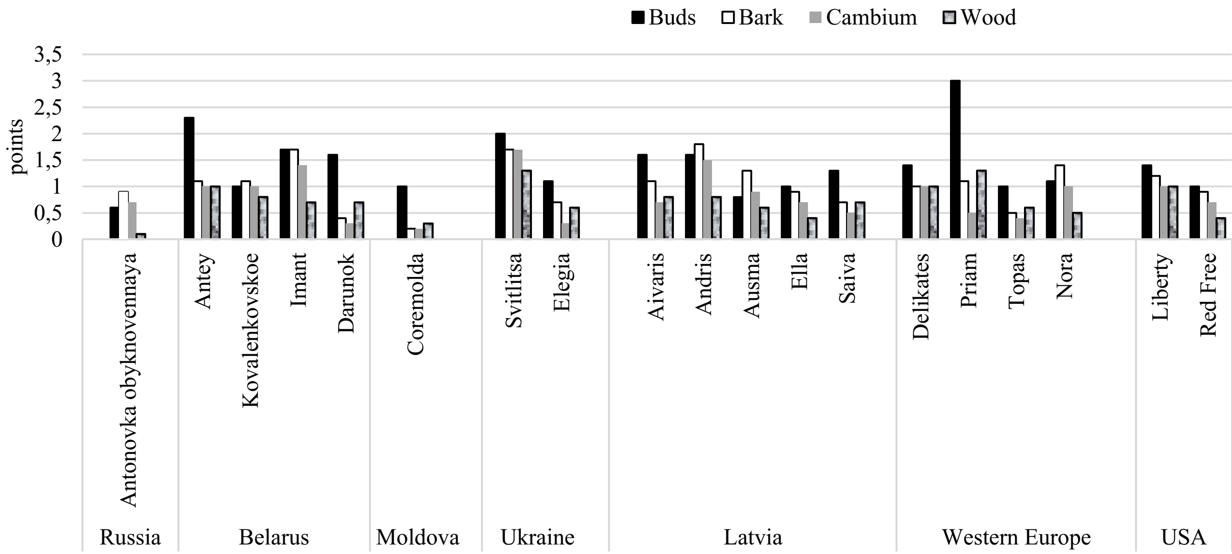

Fig. 5. The degree of freezing in the tissues of one-year-old apple-tree branches under –25°C (Component III, HCP_{05}: buds = 0.4; bark = 0.4; cambium = 0.4; wood = 0.4)

Рис. 5. Степень подмерзания тканей однолетних ветвей сортов яблони при температуре –25°C (компонент III, $НСР_{05}$: почки = 0,4; кора = 0,4; камбий = 0,4; древесина = 0,4)

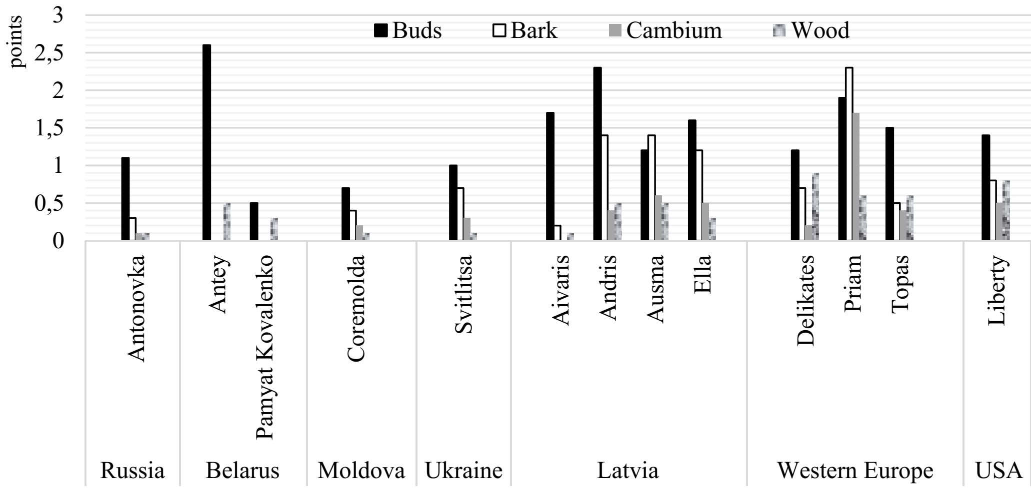

Fig. 6. The degree of freezing in the tissues of one-year-old apple-tree branches under –30°C
(Component IV, HCP_{05}: buds = 0.5; bark = 0.7; cambium = 0.6; wood = 0.3)

Рис. 6. Степень подмерзания тканей однолетних ветвей сортов яблони при температуре –30°C
(компонент IV, $НСР_{05}$: почки = 0,5; кора = 0,7; камбий = 0,6; древесина = 0,2)

Conclusion

The resistance of plants to early frosts (–25°C) without hardening and after hardening in early winter (Component I) exhibited that the Belarusian cultivars had bud damage from 0.9 points ('Belarusskoye Sladkoye') to 2.5 points ('Darunok'). Among the West European cultivars, severe bud damage was observed in 'Priam' (2.9 points). The main tissues (bark, cambium and wood) were slightly damaged in all of the studied cultivars, except for 'Belarusskoye Sladkoye': bark damage scored 2.3 points.

In the studied apple cultivars, the exposure of one-year-old branches to a temperature of –38°C/–40°C (Component II) showed bud and tissue freezing. The highest frost resistance to negative temperatures in mid-January (–38°C) was manifested by 'Coremolda': the damage to the buds and main tissues (0.3–1.0 points) was at the level of 'Antonovka Obyknovennaya' (reference). Under the temperature of –40°C (Component II), bud damage at the level of 'Antonovka Obyknovennaya' was observed in 'Antey' and 'Pamyat Kovalenko'. 'Coremolda' (Moldova) and 'Aivaris' (Latvia) showed sufficient resistance of bark, cambium and wood (with the damage at the level of 2.0 points), so these genotypes can be used in breeding as sources of frost resistance. Freezing of one-year-old branches with a frost of –25°C after a 3-day artificial thaw of +2°C revealed bud and tissue resistance in 'Red Free' and 'Coremolda ' (Component III). After the artificial thaw of +2°C and rehardening at a possible frost of –30°C (Component IV), 'Pamyat Kovalenko' and 'Coremolda' showed high ability to restore the frost resistance of tissues and buds at the level of 'Antonovka Obyknovennaya'.

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Information about the authors

Anna M. Galasheva, Cand. Sci. (Agriculture), Leading Researcher, Head of a Department, All-Russian Research Institute of Fruit Crop Breeding, Zhilina Village, Orlovsky District, Orel Province 302530, Russia, galasheva@vniispk.ru, https://orcid.org/0000-0001-8795-9991

Nina G. Krasova, Dr. Sci. (Agriculture), Chief Researcher, Head of a Laboratory, All-Russian Research Institute of Fruit Crop Breeding, Zhilina Village, Orlovsky District, Orel Province 302530, Russia, krasovang@vniispk.ru, https://orcid.org/0000-0001-7896-0149

Zoya E. Ozherelieva, Cand. Sci. (Agriculture), Leading Researcher, Head of a Laboratory, All-Russian Research Institute of Fruit Crop Breeding, Zhilina Village, Orlovsky District, Orel Province 302530, Russia, ozherelieva@vniispk.ru, https://orcid.org/0000-0002-1730-4073

Информация об авторах

Анна Мироновна Галашева, кандидат сельскохозяйственных наук, ведущий научный сотрудник, зав. отделом, Всероссийский научно-исследовательский институт селекции плодовых культур, 302530 Россия, Орловская область, Орловский район, д. Жилина, galasheva@vniispk.ru, https://orcid.org/0000-0001-8795-9991

Нина Глебовна Красова, доктор сельскохозяйственных наук, главный научный сотрудник, зав. лабораторией, Всероссийский научно-исследовательский институт селекции плодовых культур, 302530 Россия, Орловская область, Орловский район, д. Жилина, krasovang@vniispk.ru, https://orcid.org/0000-0001-7896-0149

Зоя Евгеньевна Ожерельева, кандидат сельскохозяйственных наук, ведущий научный сотрудник, зав. лабораторией, Всероссийский научно-исследовательский институт селекции плодовых культур, 302530 Россия, Орловская область, Орловский район, д. Жилина, ozherelieva@vniispk.ru, https://orcid.org/0000-0002-1730-4073

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