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PEAR (*PYRUS COMMUNIS* L.) GENOTYPES AND THEIR HYBRIDS EVALUATION FOR WINTER HARDINESS IN THE CENTRAL REGION OF RUSSIA

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SUMMARY

This study comprises the selection of winter-hardy to highly winter-hardy pear (*Pyrus Communis* L.) hybrid seedlings procured from various genetic origins. The development of pear hybrids resulted from intraspecific, interspecific, and distant hybridization. The simulation of the most damaging factors in the artificial climate chamber ensued according to the second and third components of winter hardiness - maximum frost resistance in a hardened state and stability of resistance to frost during the thaw. Critical temperatures affected the same seedlings, successively applying the specified modes, i.e., hardening at -10°C, freezing at -37°C (12 h), hardening at -10°C, thaw at +2°C (5 days), and freezing at -25°C (12 h). Combining genetically related variants to the highly winter-resistant cultivar, Phorun established the high breeding value for the yield of hybrid seedlings resistant to frost on the 2 + 3 components of winter hardiness. Thus, in the family 17-43-30 (Phorun - free pollination) × Shihan, 5.0% of transgressive genotypes came up, which withstood the given modes without damage to the buds and central tissues, showing 48.3% of highly winter-resistant forms. In a hybrid combination of 24-45-45 (Phorun × Olivier de Serre) × (Gervais + Olivier de Serre + Dekanka Zimnyaya), 33.3% of seedlings with frost resistance at the level of the highly winter-resistant control cultivar Tonkovetka attained selection. Remote hybridization opens up new opportunities in the pears' selection for frost resistance. In total, and as a result of distant hybridization, 5.47% of the genotypes (with frost resistance for the 2 + 3 components of winter hardiness above Tonkovetka), 18.24% (at the level of Tonkovetka with freezing to 1.0 point), and 20.73% types (at the level of winter-resistant control cultivar Bessemyanka with freezing to 2.0 points) gained distinction.

Keywords: Pear, breeding, hybrid seedlings, frost resistance, winter hardiness components

Key findings: A comparative assessment was done on the winter hardiness of pear (*Pyrus Communis* L.) cultivars and their hybrids obtained through intraspecific, interspecific, and distant hybridization. New donors of winter hardiness and their hybrids received identification. Pear populations with highly winter-hardy traits gained selection from the genotypes of different genetic origins, i.e., *Pyrus communis, P. ussuriensis,* and *P. bretschneideri*.

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INTRODUCTION

At the present stage of resource-saving gardening, the role of a cultivar with good potential is significantly increasing. Winter hardiness is one of the most vital components of the adaptive capacity of the pear (*Pyrus Communis* L.) genotypes. An indispensable condition for the horticulture industry intensification is to enhance environmental and economic efficiency based on the maximum use of the biological, resource, and genotypic potentials of varietal-stock combinations and the management of the main energy-converting process– photosynthesis (Bohan, 2014).

Fruit crop assortment and replenishing are very discriminating since the old-growth trees of cultivars that do not meet the requirements of modern adaptive gardening dominate the majority of industrial plantations. The pear selection program for a complex of characteristics assumes the presence of high winter hardiness in new cultivars because winter hardiness largely determines the durability and productivity of plantations (Sedov and Dolmatov, 1997; Rezvyakova, 2008; Bohan, 2014; Trunov, 2015).

Pyrus ussuriensis is the most winter-hardy species, and breeders widely use this species and its derivatives in managing breeding programs. Hence, in the Middle Urals, the cultivars Tema, Polya, Vnuchka, Tikhonovka, Malyutka, Bere Zheltaya, and their elite forms, such as, Dibrovskaya, Arabka, Vestnitsa, and Beta, which are Ussuri pear hybrids of the first generation, are used. In the Southern Urals, the cultivars Krasulya, Skazochnaya, Larinskaya, Vekovaya, Krasnobokaya, Dekabrinka, Bolshaya, and Chelyabinskaya Zimnyaya, with good taste qualities (tasting score = 4.2–4.5 points) were developed based on interspecific hybridization between the varieties of Ussuri pear and French pear of Western European origin (Rezvyakova, 1998). In Altai cultivars of medium winter hardiness, such as, Lel, Svarog, Kupava, Karataevskaya, and Perun, with good taste qualities and a fruit mass of 72–135 g have been developed (Kashin, 2000).

In the middle zone of horticulture, the variety replenishment of pear cultivars includes Lada, Chizhovskaya, Kafedralnaya, Rusanovskaya, Pamyati Parshina, Rumyaya, Marsianka, Pamyati Yakovleva, Osennyaya Mechta, Michurinskaya Krasavitsa, and Svetlyanka (Sedov and Dolmatov, 1997; Tonkikh *et al*., 2005; Trunov and Tsukanova, 2011). Many of these pear cultivars gained research for the important characteristics of winter hardiness under the environmental conditions for future breeding programs' use in the Central Black Earth Region, Russia. The latest study aimed to identify the donors of winter hardiness and select the most frost-resistant pear genotypes for further advanced breeding research work in Russia.

MATERIALS AND METHODS

Plant material

The pear (*Pyrus Communis* L.) cultivars of various origins and their hybrid seedlings served as the research material (Table 1).

Study location

The study performed the experiments at the All-Russian Research Institute of Selection of Fruit Crops located in Orel oblast, Orel District, Russia, according to the standard Program and Methodology (1995). A two-year-old hybrid fund, created at the Institute under the great leadership of Academician E.N. Sedov, encouraged the selection of pear frost-resistant genotypes. Experimental plantations utilized dark-gray forest soils, with a humus content of 3%–4% and a humus horizon capacity of 30–35 cm. The soil acidity is close to neutral. The soil-forming rock is loess loam, with high moisture capacity, medium water permeability, and high capillarity.

Meteorological conditions

The climate in the area of the institute is typical for the whole Central Black Earth region, Russia, i.e., moderately continental and characterized by an uneven distribution of precipitation, temperature, and air humidity by seasons. The average annual air temperature was +4.9°C, while the annual relative average humidity (13 h) was 79%. The growing season has an average of 180 days and the sum of effective temperatures was above 5°C–1750°C. On an annual average, the magnitude of precipitation was 571 mm. In the years of research, the growing season weather conditions did not exceed the long-term average.

Table 1. The studied varieties and hybrid combinations

No.	*Pyrus communis* L. Varieties
1	First generation of *Pyrus ussuriensis* Maxim. ex Rupr.: Veselinka, Dekabrinka, Larinskaya, Tema, Yablokovidnaya
2	Second generation of *Pyrus ussuriensis* Maxim. ex Rupr.: Kafedralnaya, Krasnobokaya, Lada, Marsianka, Mramornaya, Pamyati Parshina, Pamyati Yakovleva, Rumyanaya, Rusanovskaya, Skazochnaya, Chizhovskaya
	Hybrid combinations
1	24-45-45 (Phorun x Olivier de Serre) × (Gervais + Olivier de Serre + Dekanka Zimnyaya)
2	Oszi rordas × Seedling of Yakovlev 111
3	20-11 (Ussurijskaya Sladkaya × Henomeles Yaponskiy) × 20-11(Ussurijskaya Sladkaya × Henomeles Yaponskiy)
4	17-43-30 (Phorun– free pollination) × Shihan
5	Pamyati Yakovleva x 15-10-110 [10-57-103 (s. of Yakovlev 111 × Elena) × Olivier de Serre]
6	Moonglow x pear Berezolistnaya
7	24-46-199 (Severyanka × Tayushchaya Krymskaya) x Skorospelka iz Trevu
8	Belorusskaya Posdnyaya × Biryuzovaya
9	Seedling of Yakovlev 111 × Gervais
10	24-47-71 (Severyanka × Tayushchaya Krymskaya) × Skorospelka iz Trevu
11	Maslyanistaya Letnyaya × Konferentsia
12	24-61-119 (Voskovka × Vansan) × 17-62-26 (Zin-yu – free pollination)
13	Eseninskaya × Orlovskaya Letnyaya
14	Chizovskaya × Luuberskaya
15	Pamyati Yakovleva × Eseninskaya
16	Belorusskaya Pozdnyaya × Bere Russkaya
17	Pamyati Yakovlevax 15-10-110 [10-57-103 (s. of Yakovleva 111 × Elena) v Olivier de Serre]
18	Noyabrskaya × Lyuberskaya
19	Belorusskaya Posdnyaya × Biryuzovaya
20	24-61-119 (Voskovka × Vansan) x 17-62-26 (Zin-yu – free pollination)
21	17-43-30 (Phorun – free pollination) × Shihan
22	Oszi rordas x Seedling of Yakovlev 111
23	24-45-45 (Phorun × Olivier de Serre) × (Gervais + Olivier de Serre + Dekanka Zimnyaya)
24	24-46-199 (Severyanka × Tayushchaya Krymskaya) × Skorospelka iz Trevu
25	Belorusskaya Posdnyaya × Trevu Tetra
26	24-47-71 (Severyanka × Tayushchaya Krymskaya) x Skorospelka iz Trevu
27	Seedling of Yakovlev 111 × Gervais
28	Lira × Belorusskaya Posdnyaya
29	Maslyanistaya Letnyaya × Konferentsia
30	40-2 (Bretfelps × Irga Kolosistaya) x 40-4 (Bretfelps × Irga Kolosistaya)
31	40-3 (Bretfelps × Irga Kolosistaya) x 21-1 (Yablokovidnaya × Henomeles Yaponskiy)
32	31-1 (Bretfelps x Henomeles Yaponskiy) v 21-1 (Yablokovidnaya × Henomeles Yaponskiy)
33	20-11 (Ussurijskaya Sladkaya × Henomeles Yaponskiy) ×19-2 (Ussurijskaya Sladkaya × Henomeles Yaponskiy)
34	20-11 (Ussurijskaya Sladkaya × Henomeles Yaponskiy) × 20-11 (Ussurijskaya Sladkaya × Henomeles Yaponskiy)
35	21-1 (Yablokovidnaya × Henomeles Yaponskiy) × Lyuberskaya
36	20-11 (Ussurijskaya Sladkaya × Henomeles Yaponskiy) × Biryuzovaya

Research methodology

For assessing fruit crops for winter hardiness, the most comprehensive methodology is still the field conditions in the research institutions. However, modeling damaging factors of the winter period in the laboratory by artificial freezing allows the researchers to obtain the results that most closely correlated with the observations obtained in the field studies (Rachenko *et al*., 2013; Sedov and Dolmatov, 1997; Rezvyakova, 2005; Bandurko and Kotov, 2013; Rachenko, 2019). Physiologists have identified the following main components of the sign "winter hardiness" (Brierly, 1947):

1 – the resistance of the cultivar to early winter frosts

2 – maximum frost resistance in the hardened state in the middle of winter

3 - the ability to maintain high resistance to frost during thaws

4 – the resistance to return frosts, which occur sometime after thaws

In different periods of over-wintering, the frost resistance fluctuates in individual tissues and organs of plants. In autumn, with a sudden sharp drop in temperature, especially after the rainy and cold second half of the growing season, the cambium and bark cells became less resistant to frost than the cells of secondary and primary wood (Solovyova, 1988). As a result, in late autumn, a severe frost can damage stems and skeletal branches.

In the middle of winter, the cambium, bark, and buds have the maximum frost resistance (Khvalin, 1981; Kvamme, 1983; Solovyova, 1988). Large-fruited wood tissues get damaged in temperatures ranging from -35°C to -42°C. In late winter and early spring, with sharp fluctuations in temperature, the frost resistance of buds, bark, and cambium drops sharply (Bulatova, 1973; Rajametov and Kang, 2014). The experiments on artificial freezing were carried out in the climatic chamber "Feytron - 2101" with a volume of 800 liters, following Tyurina and Gogoleva (1978). The operating temperature was from -70°C to +150°C with accuracy and uniformity at ±0.3°C.

In genotype evaluation for winter hardiness, the choice of the plant parts used for freezing plays an important role. Experimentally, studies reported that annual branches being sensitive to frost effects were found most suitable for assessing the winter hardiness in any fruit tree (Tyurina and Gogoleva, 1978; Kvamme, 1983; Kichina, 1999). The harvested annual branches during the period when the average daily air temperature was below 0°C helped determine the components of winter hardiness under controlled conditions. These are then stored in polyethylene bags with snow in refrigeration chambers with a temperature of -5°C. Subsequent exposure to the standard quenching regime of -10°C for seven days was carried out before freezing at a critical temperature. In fruiting trees, the annual branches were cut from the peripheral parts of the crown, having a height of about 1.5 m with a length of 25–40 cm at the rate of four pieces per variant, and two to three shoots can be cut from two-year-old seedlings, keeping the trunk and several smaller sprouts on it.

Simultaneously with the tested material, the branches of control pear cultivars viz., Bessemyanka and Tonkovetka were harvested. In each bag with a batch of the studied cuttings, four control cultivar cuttings were added. When setting up the experiment, the control version shows how methodically sustained the reduction and direct impact of the critical temperature was gone. With the further growth of the tested material in vessels with water, the unfrozen control branches will show whether there were any deviations in the process of growing. The scheme of experiments on artificial freezing is shown in Table 2. The damage assessment got observed according to the degree of tissue browning on longitudinal and transverse sections on a 6-point scale, where a 0 point means that the tissue is healthy and five points dead.

Table 2. The scheme of experiments on artificial freezing of annual pear shoots.

No.	Winter hardiness components	Terms	Modes
1	Resistance to early winter frosts	the first day of December	-5 ºC (7 days), -10 ºC (7 days), -25 ºC
2	Maximum frost resistance in a hardened state	January	-10 ºC (7 days), -40 ºC
3	Ability to maintain resistance to frost during thaws	March	-10 ºC (7 days), +2 ºC (5 days), -25 ºC
4	Ability to restore frost resistance after thaws	March	-10 ºC (7 days), +2 ºC (5 days), -5 ºC (7 days), -10 ºC (7 days), -35 ºC

Statistical analysis

Statistical analysis was performed using the Excel and Statistica (v. 7.0) packages.

RESULTS AND DISCUSSION

In adaptive horticulture and biological technologies for the cultivation of fruit crops, the cultivar has the leading position for giving quality fruits. The use of winter-hardy cultivars that are resistant to the most common diseases and have a high genetic potential for productivity makes it possible to obtain stable yields (Sedov and Dolmatov, 1997; Drudze, 2000; Guchapshev and Satibalov, 2006; Liu *et al*., 2007; Branişte *et al*., 2008; Brewer and Palmer, 2011; Dondini and Sansavini, 2012; Sedov *et al*., 2017; Zurn *et al.,* 2020; Lacis *et al.*, 2021).

In the conditions of the Central Black Earth region of Russia, the All-Russian Institute of Selection of Fruit Crops has been carrying out pear selection for more than 70 years. During this period, pear cultivars Yeseninskaya, Lira, Muratovskaya, Orlovskaya Krasavitsa, Orlovskaya Letnyaya, Pamyatnaya, Pamyati Parshina, and Tyutchevskaya were developed and zoned (Sedov *et al*., 2017). Cultivars Annushka, Velesa, and Rossoshanskaya Krupnaya were characterized by fairly high winter hardiness, resistance to scab pathogens, brown and white spots, and high yielding (Rezvyakova *et al*., 2020). In the selection and genetic center of the Federal State Budgetary Institution named after I.V. Michurin, new winter-hardy pear cultivars with complex resistance to scab, septoriosis, and entomosporiosis, Avgustovskaya Rosa, Karmen, Svetlyanka, Nezhnost, Krasavitsa Chernenko, Irishka, Nika, Gera, and Yakovlevskaya were bred (Akimov *et al.,* 2017).

The dynamics of winter temperatures needs analysis to simulate the damaging factors of the winter period in the artificial climate chambers. Over the past 45 years, the absolute minimum air temperature was recorded in the winter of 2005-–2006 at -39.5°C. However, the winter of 1996–1997 had the minimum air temperature dropped to -37.5°C. According to the sum of negative air temperatures, the coldest winters were during 1975–1976 (-1193.8°C), 1978–1979 (-1023.1°C), 1979–1980 (-1085°C), 1984–1985 (-1392.8°C), 1986–1987 (-1235°C), 1995–1996 (-1241°C), and 2002–2003 (-1096.5°C), with a minimum number of days with thaws (5–15). Over the years of research in the field, a report stated that the minimum air temperature for Orel oblast dropped to a critical value of -37.5°C in December 1997, which corresponds to the second component of winter hardiness.

As the winter period starts, the studied pear cultivars can harden quickly enough and, as a result, withstand a drop in temperature (-30°C) in the first half of December (the 1st component) with less and moderate damage to the vegetative buds. The buds of cultivars Tema and Yablokovidnaya were kept healthy. At the level of the highly winter-resistant control cultivar Tonkovetka (up to 0.5 points), minimum damage was noted in the cultivar Pamyati Yakovleva. In buds-frost resistance, the cultivar Bessemyanka's degree of winter-hardiness showed at cultivars Veselinka, Chizhovskaya, Krasnobokaya, Larinskaya, Dekabrinka, Pamyati Parshina, Skazochnaya, Lada, and Marsianka. The level of damage varied between 0.7–1.5 points. Pear cultivars Rusanovskaya, Rumyanaya, and Mramornaya, were inferior to the control ones in terms of resistance to early frosts.

Pear cultivar Skazochnaya exhibited outstanding frost resistance in a hardened state in the middle of winter (the 2nd component). It surpasses the folk selection cultivar Tonkovetka for the level of maximum frost resistance. The degree of the buds and wood damage after freezing (-40°C) was 0.5 and 1.2 points, respectively, and the bark showed no damage. In cultivar Tonkovetka, the wood froze more strongly by 2.3 points. The level of Tonkovetka frost resistance in the 2nd component showed in the pear cultivars viz., Tema, Veselinka, Krasnobokaya, Yablokovidnaya, Dekabrinka, and Pamyati Yakovleva. The level of the bud damage varied between 0.3–0.8 points, in wood at 1.9–2.5 points, and the bark had no damage at all. Pear cultivars Kafedralnaya, Chizhovskaya, and Lada, have frost resistance in the buds, bark, and wood at the level of Bessemyanka. The level of the bud damage varied between 0.8–1.1 points, in wood at 2.9–3.3 points, and in the bark at 0.2–0.4 points.

The pear genotype's ability to maintain frost resistance during thaw (the 3rd component), the pear cultivars subjected were Tema and Yablokovidnaya. They withstood a drop in temperature (-25°C) after a five-day thaw at 2°C with no damage to buds and bark. At the level of Tonkovetka, the reaction to thaw gave results in pear cultivars Larinskaya, Veselinka, Skazochnaya, Krasnobokaya, Kafedralnaya, Lada, Pamyati Yakovleva, Pamyat Parshina, and Rusanovskaya. The level of bud damage did not exceed 1.0 points. At the level of Bessemyanka, the frost resistance during the thaw period resulted in pear cultivars Dekabrinka, Marsianka, and Chizhovskaya, and the freezing of the buds was 0.9–1.3 points. Cultivar Mramornaya showed as the most sensitive one to thaw.

The pear cultivars vary considerably with their ability to re-harden after thaw (the 4th component). The highest capacity of re-hardening resulted in the pear cultivar Veselinka, which surpassed Tonkovetka for the features under study. Decreasing the temperature to -35°C after a five-day thaw at 2°C and re-hardening at -5°C and -10°C for seven days in each mode, the buds, bark, and cambium remained healthy, and the freezing of wood was at 0.5 points. At the given temperatures, Tonkovetka's wood froze by 1.9 points. The same high frost resistance of wood as the level of Veselinka was also noted in the pear cultivar Skazochnaya, but the buds froze at the level of Tonkovetka (0.9 points).

Pear cultivars Chizhovskaya, Krasnobokaya, Kafedralnaya, Dekabrinka, and Tema, showed the ability to re-harden after thawing at the level of Tonkovetka. The vegetative bud damage varied between 0.9–1.2 points and wood (1.6–2.3 points). At the level of Bessemyanka, the ability to re-harden also resulted in the pear cultivars Larinskaya, Pamyati Yakovleva, and Lada. The buds freezing was recorded at 0.2–1.8 points, the bark (0.1–0.8 points), and the wood at 2.0–2.8 points. Pear cultivar Yablokovidnaya was significantly inferior to the control ones at the level of the 4th component. The freezing levels of the buds, bark, and wood were respectively at 3.2, 2.5, and 4.5 points.

Thus, pear cultivars with a highly winter-hardy achieved selection among both derivatives of the first and the second generation of *P. ussuriensis*. Pear cultivars Skazochnaya, Veselinka, Dekabrinka, Krasnobokaya, and Tema, possessed all the components at the level of Tonkovetka and surpassed them (for individual components). Cultivars Chizhovskaya, Kafedralnaya, Lada, and Pamyati Yakovleva gave results at the level of Bessemyanka. These pear cultivars serve as potential donors of high winter hardiness and need focus for further breeding work for the complex features. The average freezing scores of the pear cultivars of species *P. ussuriensis* with first and second generations are shown in Figures 1 and 2. The second-generation pear cultivars were found inferior to the first-generation individuals at the level of frost resistance (-40°C) in the middle of winter by 1.1 points.

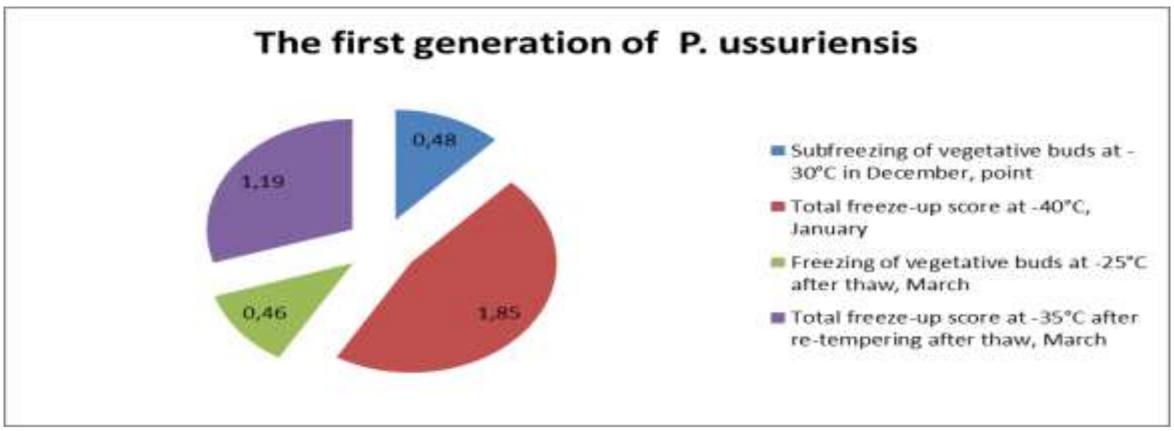

Figure 1. Freezing for cultivars of pear derivatives of the first generation from *P. ussuriensis* under different modes of artificial freezing on average, in points.

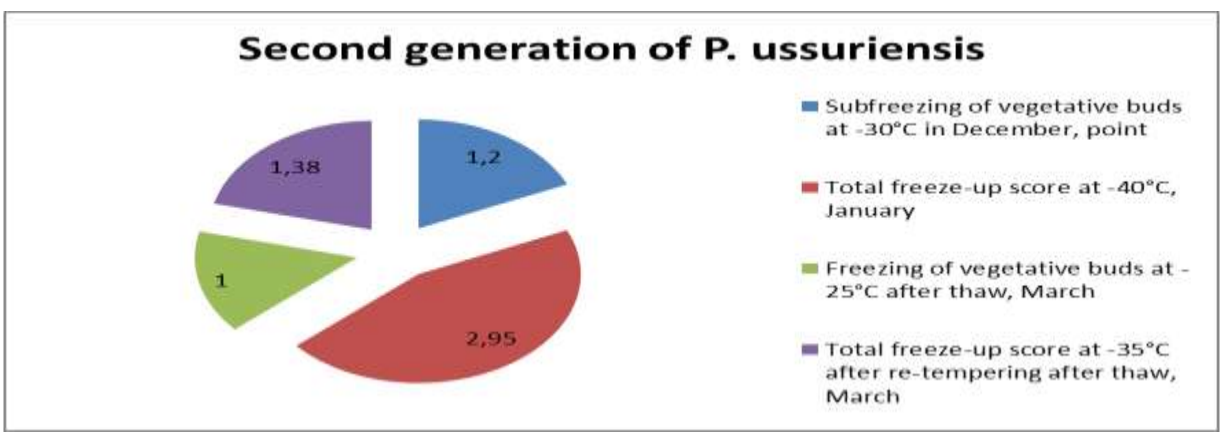

Figure 2. Subfreezing of second generation pear cultivars of P. ussuriensis under different modes of artificial freezing, in points.

Table 3. Features of splitting in hybrid offspring of pears according to the degree of resistance of the buds and tissues to -37.5°C frost in the field (II component of winter hardiness).

Family No.	Family name	Seedlings quantity, pcs.	Including the resistance at the level of				Total number of winter-hardy hybrids, %
			Tonkovetka (without freezing)		Bessemyanka 0.1–1.0 points		
			pcs.	%	pcs.	%	
1192	24-45-45 (Phorun x Olivier de Serre) x(Gervais + Olivier de Serre + Dekanka Zimnyaya)	26	19	73.1	3	11.5	84.6
1204	Oszi rordas × Seedling of Yakovlev 111	67	41	61.2	12	17.9	79.1
1227	20-11(Ussurijskaya Sladkaya × Henomeles Yaponskiy) x 20-11(Ussurijskaya Sladkaya × Henomeles Yaponskiy)	15	9	60.0	2	13.3	73.3
1195	17-43-30 (Phorun– free pollination) × Shihan	69	31	44.9	15	21.7	66.6
1176	Pamyati Yakovleva x 15-10-110 [10-57-103 (s. Of Yakovlev 111 × Elena) × Olivier de Serre]	28	9	32.1	7	25.0	57.1
1211	Moonglow x pear Berezolistnaya	34	11	32.4	4	11.8	44.2
1118	24-46-199 (Severyanka × Tayushchaya Krymskaya) × Skorospelka iz Trevu	19	5	26.3	3	15.8	42.1
1180	Belorusskaya Posdnyaya × Biryuzovaya	23	4	17.4	4	17.4	34.8
1203	Seedling of Yakovlev 111 × Gervais	38	7	18.4	5	13.2	31.6
1217	24-47-71 (Severyanka x Tayushchaya Krymskaya) x Skorospelka iz Trevu	35	8	22.9	2	5.7	28.6
1222	Maslyanistaya Letnyaya × Konferentsia	10	0	0.0	1	10.0	10.0
1191	24-61-119 (Voskovka x Vansan) × 17-62-26 (Zin-yu – free pollination)	122	0	0.0	3	2.5	2.5
Totally		486	144	29.63	61	12.55	42.18

The latest evaluation of the freezing level in the hybrid offsprings of different origins made it possible to identify a significant cultivar according to the feature under study (Table 3). The most resistant to maximum frost in the hardened state of spring pointed to the following families, i.e., 24-45-45 (Phorun × Olivier de Serre) × (Gervais + Olivier de Serre + Dekanka Zimnyaya) with 84.6% of frost-resistant seedlings; Oszi rordas × seedling of Yakovleva 111, with 79.1%, and 20-11 (Ussurijskaya Sladkaya × Henomeles Yaponskiy) × 20-11 (Ussurijskaya Sladkaya × Henomeles Yaponskiy), with 73.3%. Noteworthy in each family, 73.1%, 61.2%, and 60.0% of seedlings withstood the critical frost without damage, including the control highly winter-resistant cultivar of folk selection Tonkovetka, respectively. In hybrid combination No. 1192, the maternal form the genotype 24-45-45 stood out as a donor of high winter hardiness.

An essentially large yield of winter-hardy seedlings got marked in the offsprings genetically related to winter-hardy pear cultivars, such as, Phorun, Pamyati Yakovleva, the seedling of Yakovleva 111, and pear Berezolistnaya. Thus, in the family of 17-43-30 ([Phorun - free pollination] × Shihan), 44.9% of seedlings with frost resistance at the level of Tonkovetka and 21.7% at the level of Bessemyanka, got distinguished. In the family of Pamyati Yakovleva × 15-10-110 (10-57-103 [s. of Yakovleva 111 × Elena] × Olivier de Serre) and the family of Moonglow × pear Berezolistnaya, 32.1% and 32.4% of highly winter-resistant seedlings, and 25.0% and 11.8% of winter-hardy seedlings attained selection, respectively.

In the families of 1118 and 1217, the genetically related and highly winter-resistant cultivar Severyanka, 26.3% and 22.9% of seedlings were noted from Ussuri pear, respectively with no damage on buds and main tissues at -37.5°C frost. The participation of the winter-hardy cultivar, Belorusskaya Pozdnyaya as the maternal producer procured 17.4% (Belorusskaya Pozdnyaya × Biryuzovaya) and 13.3% (Belorusskaya Pozdnyaya × Trevu Tetra) of highly winter-resistant seedlings. The hybrid combination of Yeseninskaya × Orlovskaya Letnyaya (winter-hardy × medium winter-hardy) insufficiently gave winter-hardy offsprings. In the selected 15.7% frost-resistant seedlings, 6.3% displayed the level of Tonkovetka and 9.4% the level of Bessemyanka.

The hybrid combinations Maslyanistaya Letnyaya × Konferentziya and 24-61-119 (Voskovka × Vansan) × 17-62-26 (Zin-yu - free pollination) possessed the least selected value for the yield of frost-resistant seedlings. In the offspring of these families, it was not possible to select a single seedling with frost resistance at the level of Tonkovetka, yet, only 10.0% and 2.5% of hybrids exhibited resistance to maximum frosts at the level of Bessemyanka. Sedov and Dolmatov (1997) noted that when using the Korean cultivars Zin-yu, Cholsan Skorospelyj, and Kilchu as maternal parents, the offspring turned out to be less winter-resistant. Relatedly, winter-hardy offspring of pears resulted in using cultivars, such as, Bergamot Ossenniy, Severyanka, Zagadka, Vakhta, Voskovka, Voshchanka, the seedling of Yakovleva 104 and Yakovleva 111, Phorun, and Funtovka as maternal parents.

Totally, for all hybrid combinations, 25.96% of highly winter-resistant (at the level of Tonkovetka) and 12.34% of winter-hardy seedlings (at the level of Bessemyanka) attained selection after the exposure to -37.5°C frost in the field. In the laboratory conditions, two-year-old pear seedlings were exposed to the maximum frost of -37°C in mid-January and -25°C after a five-day thaw in the second half of February (2 + 3 components of winter hardiness). The studies on interspecific and intervarietal crosses showed that for most hybrid combinations, after exposing to two damaging factors, the yield of highly winter-resistant seedlings significantly decreases compared with the effect of only critical frost according to the 2nd component (Table 4).

Table 4. Features of splitting in hybrid offspring of pears according to the level of resistance of the buds and tissues to -37°C frost in January and -25°C frost after a five-day thaw at + 2°C in February (II + III components of winter hardiness) in laboratory conditions.

Family No.	Family name	Seedlings quantity, pcs.	Including the resistance at the level of				Total number of winter-hardy hybrids, %
			Tonkovetka (0.1–1.0 points)		Bessemyanka (1.1–2.0 points)		
			pcs.	%	pcs.	%	
1189	Eseninskaya × Orlovskaya Letnyaya	31	5	16.1	10	32.3	48.4
1190	Chizovskaya × Luuberskaya	82	9	11.0	27	32.9	43.9
1177	Pamyati Yakovleva × Eseninskaya	26	3	11.5	7	26.9	38.4
1179	Belorusskaya Pozdnyaya × Bere Russkaya	38	3	7.9	9	23.7	31.6
1176	Pamyati Yakovlevax 15-10-110 [10-57-103 (s. of Yakovleva 111 x Elena) × Olivier de Serre]	27	1	3.7	5	18.5	22.2
1188	Noyabrskaya × Lyuberskaya	74	2	2.7	9	12.2	14.9
1180	Belorusskaya Posdnyaya × Biryuzovaya	22	0	0.0	2	9.1	9.1
1191	24-61-119 (Voskovka x Vansan) x 17-62-26 (Zin-yu – free pollination)	123	2	1.6	8	6.5	8.1
1195	17-43-30 (Phorun– free pollination) x Shihan	60	29	48.3	20	33.3	86.7* (5.0)
1204	Oszi rordas x Seedling of Yakovlev 111	65	27	41.5	21	32.4	77.0* (3.1)
1192	24-45-45 (Phorunx Olivier de Serre) x (Gervais + Olivier de Serre + Dekanka Zimnyaya)	24	8	33.3	8	33.3	66.7
1118	24-46-199 (Severyanka x Tayushchaya Krymskaya) x Skorospelka iz Trevu	15	4	26.7	5	33.3	60.0
1221	Belorusskaya Posdnyaya x Trevu Tetra	28	5	17.9	7	25.0	42.9
1217	24-47-71 (Severyanka × Tayushchaya Krymskaya) x Skorospelka iz Trevu	30	2	6.7	9	30.0	36.7
1203	Seedling of Yakovlev 111 × Gervais	34	0	0.0	6	17.6	17.6
1187	Lira x Belorusskaya Posdnyaya	8	0	0.0	1	12.5	12.5
1222	Maslyanistaya Letnyaya × Konferentsia	10	0	0.0	0	0.0	0.0
	Totally	697	95	13,63	154	22,09	35,72

* - the percent of the hybrid seedlings without frost damages

Another way of splitting pear hybrid offspring according to the degree of stability for two + 3rd components of winter hardiness could be traced in families, i.e., 1176, 1180, and 1222. The offspring of these families turned out to be very sensitive to sudden changes in temperature during the thaw. The ability to maintain frost resistance during thaw (the 3rd component) is a limiting factor determining the frost resistance of the offspring of these families as a whole. Thus, in the pear hybrid combination of Pamyati Yakovleva × 15-10-110 (10-57-103 [s. of Yakovleva 111 × Elena] × Olivier de Serre), the yield of high-winter-resistant hybrids decreased from 32.1% to 3.7%, and winter-hardy hybrids from 25.0% to 9.1%. The overall selection of seedlings with frost resistance at the level of Tonkovetka and Bessemyanka decreased from 57.1% to 22.2%.

After the exposure to two modes of artificial freezing, the bud freezing increased, and the bark damage got marked in the seedlings, which was not observed after only a critical frost in the second component. In the cross combination, Belorusskaya Pozdnyaya × Biryuzovaya, it was not possible to select a single seedling with frost resistance at the level of Tonkovetka, and the percentage of winter-hardy decreased from 17.4% to 9.1%. In the family Maslyanistaya Letnyaya × Konferentziya, none of the seedlings showed withstanding -37°C in a hardened state and -25°C during thaw displaying damage of the buds and main tissues up to 2.0 points. i.e., at the level of Bessemyanka. This hybrid combination gave no breeding value for the features under study.

The high-breeding value for the yield of pear hybrid seedlings resistant to frost for the 2 + 3 components of winter hardiness stemmed from the combinations genetically related to the highly winter-resistant cultivar Phorun. Thus, in the family 17-43-30 (Phorun - free pollination) × Shihan, 5.0% of transgressive genotypes and 48.3% of highly winter-resistant forms gained selection, which withstood the given modes without damage to the buds and main tissues. In a hybrid combination of 24-45-45 (Phorun × Olivier de Serre) × (Gervais + Olivier de Serre + Dekanka Zimnyaya), 33.3% of seedlings with frost resistance at the level of Tonkovetka attained selection.

The combination of genes of both parental forms determined frost resistance of the pear offspring. The value of the combination of crossing can only be determined by the analysis of the offspring. For example, in family 1204, 77.0% of winter-hardy seedlings resulted in using a highly winter-resistant form, seedling of Yakovlev 111, as a paternal parent, and in family 1203, using Yakovleva 111 as a maternal producer, only 17.6% of its seedlings passed selection. The last hybrid combination showed a predominantly split results of the medium- and slightly winter-hardy forms. Based on the artificial freezing under controlled conditions, the highly winter-resistant breeding forms of pear, which withstood -37°C in a hardened state in the middle of winter and -25°C during the thaw at the end of wintering, reached selection. These cultivars showed damage to the vegetative buds and wood up to 1.0 points, and at the same time, the bark and cambium were preserved without freezing (Table 5).

As a result of distant hybridization, more frost-resistant pear genotypes passed selection for the 2 + 3 components of winter hardiness (Table 6), compared with offsprings from intervarietal and interspecific crosses.

Table 5. Selected highly winter-hardy pear seedlings and their origin.

Seedling origin	Selected seedlings
Pamyati Yakovleva x 15-10-110	61556
Pamyati Yakovleva x Eseninskaya	61569, 61578, 61580
Belorusskaya Pozdnyaya x Bere Russkaya	61614, 61615, 61619, 61632
Noyabrskaya x Lyuberskaya	61750, 61770
Eseninskaya x Orlovskaya Letnyaya	61832, 61835, 61841, 61850, 61857
Chizhovskaya × Lyuberskaya	61867, 61869, 61875, 61876, 61892, 61895, 61943
24-61-119(Voskovka x Vansan) x 17-62-26	62019, 62044
24-45-45(Phorun x Olivier de Serre) x (Gervais + Olivier de Serre + Dekanka Zimnyaya)	62074, 62077, 62081, 62083, 62084, 62090, 62096
17-43-30(Phorun – free pollination) x Shihan	62134, 62141, 62144, 62145, 62152, 62182, 62184
24-47-71(Severyanka x Tayushchaya Krymskaya) x Skorospelka iz Trevu	62550
24-46-199(Severyanka x Tayushchaya Krymskaya) x Skorospelka iz Trevu	62571

Belorusskaya Pozdnyaya x Trevu Tetra	62584, 62587, 62598, 62609

Table 6. The output of winter-hardy hybrid pear seedlings at -37°C in January and -25°C after a five day thaw at + 2°C in February (II + III components of winter hardiness).

Family No.	Family name	Seedlings quantity, pcs.	Including						Total number of winter-hardy hybrids, %
			Without damages		with damages				
					0.1-1.0 points		1.1-2.0 points		
			pcs.	%	pcs.	%	pcs.	%	
1242	40-2 (Bretfelps × Irga Kolosistaya) x 40-4 (Bretfelps × Irga Kolosistaya)	30	12	40.0	16	53.3	0	0.0	93.3
1243	40-3 (Bretfelps × Irga Kolosistaya) x 21-1 (Yablokovidnaya x Henomeles Yaponskiy)	40	2	5.0	25	62.5	9	22.5	90.0
1247	31-1 (Bretfelps x Henomeles Yaponskiy) x 21-1 (Yablokovidnaya x Henomeles Yaponskiy)	40	2	5.0	6	15.0	27	67.5	87.5
1228	20-11 (Ussurijskaya Sladkaya × Henomeles Yaponskiy) x 19-2 (Ussurijskaya Sladkaya × Henomeles Yaponskiy)	167	17	9.9	49	29.3	70	42.0	80.8
1227	20-11 (Ussurijskaya Sladkaya × Henomeles Yaponskiy) x 20-11 (Ussurijskaya Sladkaya × Henomeles Yaponskiy)	15	0	0.0	5	33.3	2	13.3	46.6
1232	21-1 (Yablokovidnaya x Henomeles Yaponskiy) x Lyuberskaya	80	0	0.0	6	7.5	13	16.3	23.8
1229	20-11 (Ussurijskaya Sladkaya × Henomeles Yaponskiy) x Biryuzovaya	231	0	0.0	3	1.3	4	1.7	3.0
	Totally	603	33	5.47	110	18.24	125	20.73	44.44

Thus, in a hybrid combination of 40-2 (Bretfelps × Irga Kolosistaya) × 40-4 (Bretfelps × Irga Kolosistaya), both parental forms were genetically related to highly winter-resistant Irga Kolosistaya. As a result, 40.0% of seedlings attained selection in their offsprings, which withstood the specified modes without damage, i.e., exceeded the level of the control highly winter-resistant cultivar Tonkovetka. At the level of Tonkovetka, the damage to the buds and basic tissues (up to 1.0 points) was noted in 53.3% of the forms. The 93.3% of frost-resistant seedlings of 2 + 3 components got selected in this family.

A significant variation came out in the output of frost-resistant genotypes in hybrid combinations using derivatives of Henomeles Yaponskiy. The high breeding value of the families, 40-3 (Bretfelps × Irga Kolosistaya) × 21-1 (Yablokovidnaya × Henomeles Yaponskiy), 31-1 (Bretfelps × Henomeles Yaponskiy) × 21-1, and 20-11 (Ussurijskaya Sladkaya × Henomeles Yaponskiy) × 19-2 (Ussurijskaya Sladkaya × Henomeles Yaponskiy) stood out. The percent value of these hybrid combinations passed the selection of seedlings with frost resistance for 2 + 3 components above the level of Tonkovetka (5.0%–9.9%), hybrids at the level of Tonkovetka (15.0%–29.3%), and forms at the level of Bessemyanka (22.5%–42.0%). An 80.8%–90.0% of frost-resistant seedlings gained selection in these pear families.

By using the same form as a maternal and paternal producer, the yield of frost-resistant seedlings significantly reduced. Therefore, in the family 20-11 (Ussurijskaya Sladkaya × Henomeles Yaponskiy) × 20-11 (Ussurijskaya Sladkaya × Henomeles Yaponskiy), no identified hybrid forms withstood -37°C in the middle of winter and -25°C during the thaw at the end of the winter season without any damage. The 33.3% of pear seedlings passed selection with frost resistance at the level of Tonkovetka, and

13.3% at the level of Bessemyanka. Overall, 46.6% of frost-resistant forms passed selection in this family.

When using Southern less frost-resistant pear cultivars Lyuberskaya and Biryuzovaya as a paternal component in the Central regions of Russia, the yield of frost-resistant seedlings decreased to 23.8% in the family 21-1 (Yablokovidnaya × Henomeles Yaponskiy) × Lyuberskaya and up to 3.0% in the family, 20-11 (Ussurijskaya Sladkaya × Henomeles Yaponskiy) × Biryuzovaya. Neither family identified with seedlings that withstood the given temperatures without freezing. The 7.5% (63294, 63308, 63323, 63333, 63342, and 63357) and 1.3% (62891, 63008, and 63054) of hybrid forms got selected with frost resistance at the level of Tonkovetka, and the 16.3% and 1.7% of seedlings at the level of Bessemyanka.

The genotypes with frost resistance for the 2 + 3rd components of winter hardiness (5.47%) showed above the control cultivar Tonkovetka, 18.24% of forms at the level of Tonkovetka (with freezing to 1.0 points), and 20.73% at the level of Bessemyanka (with freezing to 2.0 points) as a result of distant hybridization. These data open up new opportunities in the selection of pears for a high level of resistance to frost. In Altai, the Research Institute of Siberia named after Lisavenko developed four pear cultivars with high economically valuable features through geographically and systematically remote hybridization. The cultivars underwent the State Variety Testing, and seven new pear cultivars of different ripening periods got included in the State Register of Breeding Achievements, i.e., Lel, Sibiryachka, Kuyumskaya, Karataevskaya, Kupava, Svarog, and Perun (Semeykina, 2017).

In the Middle Urals, researchers studied 10 new pear cultivars of improved forms of local selection in comparison with the control cultivars, i.e., summer - Talitsa and late autumn - Berezhnaya. As a result, cultivars Letnyaya Zolotistaya, Chesovaya, Sultan, and the breeding form DL-33-307, which were resistant to late spring frosts, came out (Tarasova, 2020). Six cultivars were regionalized and another six ones underwent the State Variety Testing. A new cultivar Tais possesses the best winter hardiness and yield, as a result of the crossing of cultivars Dyumovochka and Janna d'Ark. In the conditions of the Middle Urals, Russia, the average yield was 9.42 t ha^{-1} (Tarasova *et al*., 2021).

In the Lower Volga Region, works are underway to improve the assortment of pears using classical and analytical breeding methods. Highly winter-hardy cultivars with low- quality fruits of local selection and high-quality ones with less stability of Western origin were used as parent forms. The research achieved cultivars and hybrids with high taste qualities and increased resistance to abiotic and biotic stress factors. It resulted in three pear cultivars recognized regionally in eight regions of Russia (Solonkin *et al*., 2020).

The Belarus Institute of Fruit Growing, Russia bred seven Belarusian new pear cultivars, i.e., Prosto Mariya, Spakusa, Yasachka, Viliya, Kudesnitsa, Kupala, and Zaveya, with resistance to fungal diseases and winter frosts in combination with high yields and good quality. The best parental forms and combinations of the crossing were exhibited using pear cultivars of the species *P. communis, P. ussuriensis, P. pyrifolia,* and *P. bretschneideri* (Kozlovskaya and Yakimovich, 2017). In Belarus, the cultivar Belorusskaya Pozdnyaya was studied as a maternal parent for winter hardiness, and more hybrids with high winter hardiness passed selection with the inclusion of the following paternal forms, i.e., the seedling of Yakovleva 104, Bergamot, Mlievskaya, Lyubimitsa, Osennyaya, Mramornaya, Gervais, Dekanka Novaya, and 12/229 (Bretfelps × Vesnyanka) (Myalik and Yakimovich, 2000).

Winter hardiness serves as the main limiting factor in pear cultivation under the climatic conditions of Northeastern Europe (Kviklys D, 2021). At the Horticulture Institute of the Lithuanian Research Centre for Agriculture and Forestry, 12 pear cultivars on the rootstock QS1 got studied to find a replacement for the less winter-hardy cultivar Konferentsia in the Baltic States. It revealed that the cultivar Mramornaya was characterized by significant winter hardiness, yield, and good quality of fruits in these climatic conditions. Two hybrids BP-8965 and BP-10529 received from the crossing of the cultivars Clapp's Favourite and Beurre Blumenbach, which had complex resistance to abiotic factors viz., scab, European rust, and high-quality fruits, passed selection in Latvia (Lace, 2016).

CONCLUSIONS

In the pear family of 24-45-45 (Phorun × Olivier de Serre) × (Gervais + Olivier de Serre + Dekanka Zimnyaya), the yield of highly winter-resistant seedlings decreased from 73.1% to 33.3%, i.e., more than half of the hybrids that did not freeze after exposure to -37.5°C frost were damaged after sudden changes in temperature during the thaw. The yield of pear seedlings with resistance to frost at the level of Bessemyanka increased from 11.5% to 33.3%. Results revealed that frost damaged several hybrids, which fell into the category of highly winter-hardy (at the level of Tonkovetka) at the second component, during the thaw (the 3rd component) and their stability decreased to the level of Bessemyanka – the freezing of the buds and main tissues did not exceed 2.0 points. Similar results were received in the pear hybrid combination Oszi rordas × seedling of Yakovleva 111. The yield of high-winter-hardy hybrids decreased from 61.2% to 44.6%. At the same time, 3.1% of genotypes that withstood the given regimes without damage were selected. The yield of seedlings with the level of stability of Bessemyanka increased from 17.9% to 32.4%. The study identified new donors of winter hardiness components for pears for the offspring. Highly winter-hardy pear genotypes were selected in populations of the different genetic origins of the pear species, *P. communes, P. ussuriensis,* and *P. bretschneideri*. Thus, the past findings also showed that the selection for winter hardiness is an actual direction in different climatic zones, despite the certain successes achieved, such research work needs continuing in this direction.

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