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Evaluation of the main biological and production traits of Latvian apple cultivars in the conditions of Central Russia

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Abstract. Apple selections of Latvian breeding were evaluated in the Central zone of Russia since 1980, in total 32 cultivars and hybrids. After long-term evaluation, the following can be recommended for use in breeding of scab resistant cultivars with high quality fruits - 'Dace' (gene *Rvi6*), 'Arona', and good storage - 'Edite' (*Rvi6*), 'Forele', 'Olga', 'Madona', for breeding of early cultivars - 'Roberts' and DI-93-4-8, both resistant to scab (gene *Rvi6*) and fruit rots. Cultivars and hybrids with the best cold resistance of vital tissues were selected by artificially modelling winter-hardiness components − early colds (1st component) and mid-winter colds up to -38 °C (2nd component), showing reversible damages not exceeding 2.0 points: 'Daina', 'Ella', 'Atmoda', 'Gita', 'Saiva', of which the last 3 maintained high hardiness of bark, cambium and xylem with slight increase of bud damages also at -40 °C. Cultivars 'Daina' and 'Ella' showed resistance of buds and vital tissues on the level of 'Antonovka' after modelling a thaw with following freezing to -25 °C (3rd component), which suggests tolerance to fluctuating winter temperatures. These cultivars demonstrated good adaptation to different environment conditions and may be considered in breeding of new adaptive apple cultivars with high fruit quality.

Key words: winter-hardiness, disease resistance, productivity, fruit quality, storage, breeding.

INTRODUCTION

Cultivars with good adaptation potential to various environment conditions, maintaining both productivity and fruit quality, have the highest chances of success in growing. Success of breeding work significantly depends on right evaluation and choice of parent material possessing high levels of valuable traits and ability to transfer these traits to their descendants. Already N. I. Vavilov had stated the problem of initial material for research in genetics and breeding. He wrote: 'Success of breeding work, as it is known, to a high degree depends on the initial material. This refers equally to self-pollinating and cross-pollinating plants'. Presenting a scientific base for the necessity to preserve and use the enormous diversity of the world's genetic resources, he stressed: 'The need for fundamental change of cultivars, in accordance with our harsh continental climate conditions, gives a first rate importance to wide involvement of new breeding material' (Vavilov, 1951). At present, problems of preservation and utilisation of plant genetic resource collections are of national and strategic importance for every country (Evans et al., 2012; Dzyubenko, 2015; Bramel & Volk, 2019).

Long-term experience of breeders worldwide shows the high effectivity of the right choice of hybridization parents and donors of valuable traits in the creation of new adaptive, competitive cultivars. In this aspect, comprehensive research of apple-tree winter-hardiness, tolerance to diseases and pests is necessary, along with other economically valuable traits, followed by genetic research and selection of sources and donors of these traits.

Most preferable for apple breeding is the involvement of promising cultivars and genotypes with maximal expression of valuable traits in their phenotype, having high genetic stability, low variability of characteristics in changeable environment conditions. To expand the genetic diversity of breeding and pre-breeding material, the modern apple breeding programs involve genetic material obtained by inter-species hybridization and complex pyramiding crosses (F2, F3 and F4), combining a range of valuable traits (winter-hardiness, scab resistance etc.) transferred through breeding to new adaptive, high quality apple cultivars (Evans, 2013; Kazlauskaya et al., 2013; Sansavini & Tartarini, 2013; Kozlovskaya, 2015; Kellerhals et al., 2020).

The oldest pomological institution in Russia - All-Russian Research Institute of Fruit Crop Breeding (further - VNIISPK) in 2020 will celebrate its 175-year anniversary. For all this time, VNIISPK maintains the established traditions. The genetic resources collection at the Institute is regularly extended with new genotypes from Russia and abroad. The main goal has always been not mechanical collecting, but obtaining of breeding material for hybridization, along with selection of sources and donors for most valuable traits.

The pomological collection of VNIISPK at present includes 860 accessions of apple cultivars and genotypes of different genetic origin from various geographic zones. Primary and collection evaluation is done for the main agronomical and biological characteristics: winter-hardiness, precocity, productivity, fruit market and consumption quality, length of storage, resistance to diseases, and suitability for growing in modern intensive plantations.

In the Central Russian zone of horticulture, the main limiting factor for successful cultivation of fruit trees are severe winters with low temperatures in autumn and mid-winter, thaws at the end of winter and deficit of warmth in summer. Other stress situations (drought, leaf water potential loss, soil water logging etc.) also have negative influence on fruit trees (Bhusal et al., 2019 and 2020). In these unfavourable conditions cultivars able to combine production characteristics with tolerance to abiotic factors have a special value.

Western European apple cultivars in this zone have shown sensitivity to low winter temperatures and perish after severe winters. Many-year investigations have shown that these cultivars are unsuitable for cultivation in the Central Russia zone also because of insufficient positive temperatures for fruit development. For this reason, a priority of research is investigation and choice of pre-breeding material and donors for creation of competitive new Russian apple cultivars, to establish intensive, profitable and adaptive orchards in this zone of fruit growing. The base for breeding is selection of initial material which is winter-hardy, drought resistant and tolerant to main diseases (Sedov, 2014; Sedov et al., 2014).

Since 1980 the collection includes hybrids and cultivars from Latvia, Institute of Horticulture. They originate from the Latvian apple breeding program aimed at disease tolerance, fruit quality, productivity, winter-hardiness and adaptation to the local climate (Ikase & Dumbravs, 2004; Ikase & Lacis, 2013). These cultivars and hybrids were obtained in the cool climate of Latvia with active growth period (temperatures over 10 °C) of 135−150 days and active temperature sum of 1,700−2,100 °C (Kļaviņš, 2016). Winter temperatures below −30 °C repeat each 5−10 years. The average annual air temperature is 6.4 °C, in February -3.7 °C, in July 17.4 °C, annual precipitation 692 mm. As Latvia is situated in the Northern European apple growing region with specific demands, apple cultivars are selected for their winter-hardiness and necessary length of vegetation period. Winter and spring temperature fluctuations as well as relatively abundant precipitation make these problems deeper. Results of their investigation at VNIISPK present significant interest in determining their value as initial material for further breeding in Russia, as well as their adaptability to climatic conditions more severe than in their homeland.

The aim of the study was to evaluate winter-hardiness of Latvian cultivars and hybrids by use of modelling of the components of winter-hardiness, as well as their productivity, disease resistance, fruit quality and storage, and to select cultivars suitable for use in further breeding.

MATERIALS AND METHODS

Samples of apples of Latvian breeding were studied in collection plots of All-Russian Research Institute of Fruit Crop Breeding (VNIISPK) in Orel region from 1980 till 2017. The Latvian cultivars and hybrids evaluated at VNIISPK included three groups. Cultivars selected before 1990 are ‘Aivariņš’, ‘Alro’, ‘Ausma’, ‘Dainis’, ‘Forele’, ‘Iedzenu’, ‘Ilga’, ‘Sando’, ‘Stars’. The next group was obtained in repeated crosses of Latvian cultivars ‘Iedzenu’, ‘Forele’ etc. with ‘Lawfam’, ‘Lobo’, ‘Melba’, ‘Starkrimson’, ‘Stark’, ‘Slava Peremozhtsam’ and others. It includes cultivars ‘Agra’, ‘Atmoda’, ‘Baiba’ (Co), ‘Daina’, ‘Eksotika’, ‘Ella’, ‘Madona’, ‘Olga’, ‘Saiva’, ‘Sapnis’, hybrids AMD-12-15-15 (Andris), AMD-19-15-21 (Arona), AMD-12-9-13, AMD-12-9-16, DI-93-13-16. Further, these were involved in crosses with scab resistance donors (*Rvi6*) ‘Liberty’ and BM41497. This newest group includes scab resistant cultivars and hybrids ‘Dace’, ‘Edite’, ‘Gita’, ‘Paulis’, ‘Roberts’, DI-2-90-117, DI-93-4-8, and relatively resistant hybrids - DI-93-4-14 (‘Dobeles Sidrābols’), D-18-94-15. The total number of evaluated cultivars and hybrids was 32.

VNIISPK is situated in the middle of Central Russian highlands at 203 m above sea level, in a zone of temperate continental climate. The average annual air temperature is 4.6 °C, absolute minimum -39.9 °C, absolute maximum 40 °C (2012). Sum of temperatures above 10 °C is 2,250 °C. The average annual precipitation is 550 mm, in April and May droughts and dry winds occur. The vegetation season is 175−185 days, active growth season (above 10 °C) is 130−149 days. Periodical extreme weather conditions in winter negatively affect the productivity of fruit crops, showing the need for adaptive cultivars. Comparing with Latvia, summer temperatures are slightly higher, but the climate is drier, with colder winters and more constant snow cover.

The harshness of winter colds can be characterized by a sum on average negative temperatures from November to March. During the research period the most unfavourable winters had sum of negative temperatures over 1,000 °C, continuing colds below -30 °C and average air temperature in winter below 0 °C (Table 1).

Table 1. Characteristics of winter conditions in Orel (Meteorological Station of VNIISPK)

Year	Sum of average negative temperatures, °C	Minimal temperature, °C		Average temperature in winter, °C	Days with thaws (December to February)
		air	at snow level		
1990/1991	605.4	-26.8	-25.3	-5.7	30
1991/1992	425.1	-22.1	-25.0	-4.7	40
1992/1993	592.9	-25.3	-25.2	-5.0	33
1993/1994	932.1	-29.7	-30.0	-5.8	48
1994/1995	537.6	-31.5	-36.7	-5.4	39
1995/1996	1,225.7	-32.0	-31.6	-10.3	8
1996/1997	708.5	-37.5	-28.0	-6.8	38
1997/1998	635.4	-31.6	-24.7	-6.0	35
1998/1999	832.6	-33.0	-34.2	-5.3	41
1999/2000	640.6	-28.4	-23.5	-4.6	54
2000/2001	642.7	-26.8	-28.3	-5.8	31
2001/2002	681.7	-30.0	-32.0	-6.2	42
2002/2003	1,099.6	-30.5	-33.0	-10.2	8
2003/2004	502.5	-24.5	-25.5	-5.2	17
2004/2005	746.8	-26.5	-30.5	-4.9	21
2005/2006	1198.1	-36.5	-39.3	-9.3	6
2006/2007	421.0	-27.2	-24.5	-3.1	43
2007/2008	424.4	-21.2	-22.5	-4.2	15
2008/2009	536.4	-19.5	-19.7	-4.9	16
2009/2010	1,033.0	-32.0	-31.0	-9.8	23
2010/2011	946.0	-34.2	-34.5	-8.6	5
2011/2012	694.1	-39.9	-34.0	-6.8	26
2012/2013	951.5	-31.7	-28.9	-6.6	35
2013/2014	576.1	-31.0	-29.3	-5.9	20
2014/2015	486.1	-24.5	-26.0	-5.1	31
2015/2016	499.3	-29.3	-26.3	-4.3	62
2016/2017	601.5	-24.0	-17.0	-6.6	28

Evaluation of the main agronomical and biological characteristics was done in trials planted in 1980 and 2005 on vigorous rootstocks (‘Antonovka’ seedlings) at distances 6×3 m, as well as top-grafted on a hardy, low-vigour frame-builder 3-17-38 in 2004–2006, planted at distances 5×2 m. For each cultivar 5 trees were planted. Cultivar ‘Antonovka’ was used as control. Evaluation was performed according with the accepted methods of cultivar testing (Sedov et al., 1999; Tyurina, 2002).

It must be noted that fruit look and taste were rated by a 5-point scale. The taste panel included 7–8 persons. Tasting was done at optimal eating maturity. Fruit look was rated as follows: 5 – fruits large, with regular shape, bright ground and over colour; 4 – fruits of acceptable size, attractive; 3 – fruits below medium size, mediocre attractivity; 2 – fruits small, poor colour and shape; 1 – fruits very small and unattractive. Fruit taste was rated as: 5 – excellent taste, dessert apple; 4 – good taste, table apple; 3 – mediocre taste; 2 – not suitable for fresh eating; 1 – inedible. The flesh structure was evaluated as coarse or fine, firm, soft or mealy. Flesh juiciness was evaluated as juicy, medium juicy or dry.

In field trials, winter damages of plant tissues (xylem, bark) and organs (buds, annual shoots, framework branches, trunk) were evaluated by a 5-point scale, where: 0 − no visual winter damage; 1 − very weak damages: xylem yellowish, small superficial bark damages on trunk and branches; 2 − weak damages: xylem light brown, weak superficial scald of bark, drying-out of annual shoots; 3 − significant damages: xylem brown, significant damages of bark with necrosis to xylem, die-back of some branches; 4 − very strong damages: xylem dark brown, heavy scald of bark, loss of a large part of tree crown; 5 − tree perished. All 5 trees of a cultivar were evaluated, with 'Antonovka' as control.

The apple cultivar testing program included evaluation of cold damages both in field and in controlled conditions, to determine the resistance potential by the following main components of the winter-hardiness complex (Krasova et al., 2013): 1st − resistance to early colds at end of November and beginning of December (with gradual temperature decrease to -5 °C, -10 °C, -25 °C and -5 °C, -10 °C, -30 °C); 2nd − maximum level of cold resistance after adaptation in January and February (-5 °C, -10 °C, -38 °C and -5 °C, -10 °C, -40 °C; -5 °C, -10 °C, -42 °C); 3rd − resistance in periods of thaw (-5 °C, -10 °C, +2 °C, -25 °C and -5 °C, -10 °C, +2 °C, -30 °C); 4th − ability to restore resistance by renewed adaptation after thaws (-5 °C, -10 °C, +2 °C, -5 °C, -10 °C, -30 °C).

Artificial freezing by modelling the damaging factors was done for Latvian cultivars and hybrids together with other cultivars in the genetic resources collection during 2009−2011 in freezing chamber ESPEC PSL-2KPN. Standard size annual shoots were collected in two replications. The length of temperature regimes was as following: adaptation at -5 °C (5 periods of 24 hours) and -10 °C (5 periods of 24 hours); after that decreasing temperature by 5 °C an hour till the critical temperature; critical temperatures for 8 hours; thaw +2 °C (2 periods of 24 hours).

Evaluation of damages of bud and shoot tissues was done by binocular microscope MBS-2 by the degree of browning, using a 5-pont scale: 0 − no damage, 5 − tissues and buds perished after the recovery period.

Evaluation of apple scab (*Venturia inaequalis* (Cooke) G. Winter) damages was done in field on the background of natural infection, in years favourable for disease development. The scab damage degree was evaluated by a 5-point scale, where: 0 − no visible infection, 1 − very weak infection with single lesions on leaves, small point-like lesions on fruits; 2 − up to 10% leaves with few, small lesions, on fruits small lesions, sporulation weak tor medium; 3 − up to 25% of leaf surface with infection, on fruits small and large lesions, sporulation medium; 4 − strong infection to 50% of leaves, lesions large, with dark abundant sporulation, on fruits many large lesions with cracking; 5 − very strong infection with large lesions on > 50% leaf surface, on fruits numerous merging lesions with cracks and dark sporulation. The average rating of leaf infection was determined by evaluation of 5 trees (25 leaves from 4 sides of tree). For evaluation of scab infection of fruits, a sample of 100 fruits from different trees was taken during harvest.

By the results of leaf and fruit scab infection levels evaluation, the cultivars were classified into the following groups: highly resistant (including gene *Rvi6* carriers), resistant, medium resistant and susceptible. The presence of resistance gene Rvi6 was determined at Institute of Horticulture, Latvia by molecular markers (Ikase & Lacis, 2013).

Processing of experimental data was done by dispersion analysis using *Microsoft Excel*, with significance level p = 0.05.

RESULTS

Winter-hardiness

Apple cultivars and hybrids of Latvian breeding demonstrated different resistance to unfavourable winter conditions in Orel region. During the trial period, the most unfavourable was winter of 2009–2010 with a sum of average negative temperatures 1,033 °C and average temperature in winter -9.8 °C (lower than the long-term average by 5.2 °C). January was the coldest, with average -16.4 °C which is 7.2 °C lower than the long-term average. Air temperature below -20 °C held for a long period and at the end of January fell to -32 °C. The soil freezing was insignificant. Also, in the winter 2011/2012 the minimum temperature was -39.9 °C. The autumn months before these winters were favourable for fruit tree adaptation. Significant winter damages of fruit tree vegetative parts were observed after extended warm autumn periods or in the end of winter when colds occurred after long-term thaws (years 2010, 2014 and 2015).

Artificial freezing by modelling factors of damage by components of winter-hardiness was done in 2009–2011. In common autumn conditions with gradual decrease of air temperature till the end of November or mid-December, most local cultivars developed resistance to early colds (1st winter-hardiness component). This was true also for most Latvian cultivars subjected to artificial freezing, which showed high ability to increase resistance at modelling a temperature fall in mid-December to -25 °C after adaptation, without injury to buds, bark, cambium and xylem. When the shoot freezing temperature was lowered to -30 °C in the beginning of winter, the observed damages of buds were 0.7–1.5 points (control 'Antonovka' - no damage), damages of cambium, bark and xylem were insignificant (Table 2).

Table 2. Damage degree of Latvian apple cultivars and hybrids after modelling of damage factors in controlled conditions in mid-winter (average in 2009−2011), points

Cultivar, hybrid	Damage degree of buds: bark: cambium: xylem in points											
	-5°, -10°, -38 °C				-5°, -10°, -40 °C				5°, -10°, -42 °C			
	buds	bark	cambium	xylem	buds	bark	cambium	xylem	buds	bark	cambium	xylem
'Antonovka' (control)	0.6^{e}	0.4^{d}	0.4^{c}	0.7^{d}	1.5^{e}	1.4^{d}	0.8^{c}	1.0^{e}	1.9^{d}	1.9^{c}	1.4^{d}	2.2^{c}
'Aivariņš'	2.2^{ab}	1.6^{b}	1.6^{a}	1.5^{c}	2.7^{a}	2.0^{b}	1.5^{b}	1.9^{c}	2.7^{b}	2.0^{c}	1.9^{c}	2.6^{bc}
'Andris'	2.0^{b}	1.5^{b}	$1,0^{b}$	2.8^{a}	2.9^{a}	2.7^{a}	1.9^{a}	2.5^{b}	2.9^{b}	2.8	2.8	3.4^{a}
'Atmoda'	1.6^{c}	1.5^{b}	0.9^{bc}	1.1^{d}	2.0^{c}	1.8^{c}	1.3^{b}	1.5^{d}	2.3^{c}	2.0^{c}	1.8^{c}	4.0^{a}
'Ausma'	1.5^{c}	1.4^{c}	0.9^{bc}	2.6^{a}	2.4^{b}	2.1^{b}	1.6^{ab}	3.0^{a}	2.9^{b}	2.2^{c}	2.0^{c}	3.4^{a}
D-18-94-15	2.6^{a}	2.5^{a}	1.9^{a}	1.1^{d}	–				–			
'Daina'	1.8^{bc}	1.5^{b}	1.1^{b}	1.1^{d}	–				–			
'Dainis'	2.1^{b}	1.8^{b}	1.7^{a}	2.2^{b}	–				–			
DI-93-4-8	2.1^{b}	1.8^{b}	1.5^{a}	1.6^{c}	2.2^{b}	2.0^{b}	1.8^{a}	1.6^{d}	2.4^{c}	2.1^{bc}	2.1^{b}c	3.5^{a}
'Ella'	1.7^{c}	1.3^{c}	1.3^{b}	1.9^{b}	2.5^{ab}	2.4^{a}	2.0^{a}	2.0^{c}	3.4^{a}	3.1^{a}	3.1^{a}	3.3^{ab}
'Gita'	1.9^{b}	2.0^{b}	1.2^{b}	1.5^{c}	2.2^{b}	1.9^{bc}	1.5^{b}	1.7^{d}	3.6^{a}	3.1^{a}	2.1^{bc}	2.4^{c}
'Saiva'	1.7^{c}	1.4^{c}	1.2^{b}	1.2^{d}	2.1^{bc}	1.9^{bc}	1.7^{a}	1.9^{c}	3.2^{a}	2.7^{a}	2.6^{ab}	3.1^{b}

Note: different letters in the same column show significant differences between cultivars at p = 0.05 significance level.

Freezing to -38 °C showed that majority of tested cultivars had stronger damages than 'Antonovka'. Statistical analysis showed that the tissue damage levels differed significantly (Ff > Ft) at $p = 0.05$ level. Yet damages of vital tissues and buds did not exceed 2.0–2.5 points and were reversible. Low damages at the level of 'Antonovka' had 'Atmoda', 'Daina', 'Saiva', D-18-94-15 for xylem, 'Atmoda' and 'Ausma' - for cambium (Table 2).

Artificial freezing of shoots to -40 °C increased bud and tissue damages. Most cultivars were injured stronger than 'Antonovka', and significant differences of damage degree of vital tissues were observed - for bark from 1.8 points ('Atmoda') to 2.7 points ('Andris'), for xylem from 1.5 ('Atmoda') to 3.0 points ('Ausma'). Yet for all tested cultivars the damages of cambium after artificial freezing at -40 °C were reversible - from 1.3 ('Atmoda') to 2.0 points ('Ella'). Reversible (not exceeding 2.0 points) also were the bark damages of cultivars 'Aivariņš', 'Gita', 'Saiva', 'Atmoda', hybrid D-93-4-8 (Table 2).

Some cultivars had tissue damages on the level of 'Antonovka' also after artificial freezing to -42 °C. Damages of bark and cambium for 'Atmoda' and 'Aivariņš' and cultivar 'Ausma' for cambium did not exceed 2.0 points, and for 'Aivariņš' damages of xylem also were relatively low. Their buds showed slightly higher damages. Other cultivars and hybrids were damaged stronger than 'Antonovka'. Significantly higher damages of buds and tissues were observed for 'Andris', 'Ella', 'Saiva', 'Gita', much exceeding control 'Antonovka'.

In the end of winter and early spring as well as after thaws plant resistance to cold decreases, and if lower temperatures occur later, tree vegetative and generative parts can be damaged. Resistance of fruit trees to drying out due to water loss and tissue damage in this period is critical. Modelling of temperature below -25 °C after 2-day thaw at +2 °C (3rd component) allowed to ascertain the hardiness of buds and tissues on the level of 'Antonovka' for cultivars 'Dainis' and 'Ella', hardiness of bark, cambium and xylem for 'Atmoda', 'Daina', 'Gita', bark and cambium for 'Saiva'. Higher damages than 'Antonovka' and other tested cultivars had 'Andris' and D-18-94-15 (Table 3). If modelling thaw was done with lower following temperature of -30 °C, all evaluated cultivars had damages of buds stronger than for 'Antonovka'. By hardiness of cambium, bark and xylem cultivars 'Atmoda' and 'Saiva' were equal to 'Antonovka'.

Table 3. Damage degree of Latvian apple cultivars and hybrids after modelling of returned cold after thaw in controlled conditions (temperature regime -5 °C, -10 °C, +2 °C, -25 °C), average in 2009−2011, points

Cultivar, hybrid	Damage degree of buds: bark, cambium: xylem in points			
	buds	bark	camb	xylem
'Antonovka' (control)	0.6^{c}	0.9^{c}	0.7^{d}	0.1^{b}
'Aivariņš'	1.6^{a}	1.8^{a}	1.5^{ab}	0.8^{a}
'Andris'	1.6^{a}	1.8^{a}	1.5^{ab}	0.8^{a}
'Atmoda'	1.5^{a}	0.9^{c}	0.4^{d}	0.5^{b}
'Ausma'	0.8^{c}	1.3^{b}	0.9^{c}	0.6^{a}
D-18-94-15	1.8^{a}	1,7^{a}	1.9^{a}	0.9^{a}
'Daina'	1.5^{a}	1.0^{c}	0.7^{d}	0.4^{b}
'Dainis'	0.9^{c}	0.2^{d}	0.0^{d}	0.2^{b}
DI-93-4-8	1.6^{a}	1.2^{b}	0.8^{c}	0.6^{a}
'Ella'	1.0^{c}	0.9^{c}	0.7^{d}	0,4^{b}
'Gita'	1.2^{b}	1.0^{c}	0.6^{d}	0.5^{b}
'Saiva'	1.3^{a}	0.7^{c}	0.5^{d}	0.7^{a}

Note: different letters in the same column show significant differences between cultivars at $p = 0.05$ significance level.

Some cultivars were tested also for the ability to restore cold resistance of tissues after artificial thaw and following decrease of temperature in a regime -5 °C, -10 °C, +2 °C, -5 °C, -10 °C, -30 °C (4th winter-hardiness component). High restoration ability had 'Aivariņš', 'Ausma', 'Andris', 'Atmoda', 'Ella'. When temperature was decreased to -35 °C, 'Agra', 'Daina', 'Magone' and 'Iedzenu' had severe damages of buds.

Resistance to diseases

Most Latvian apple cultivars and hybrids by their resistance to apple scab (*Venturia inaequalis* (Cooke) G. Winter) significantly surpassed 'Common Antonovka', fruits and leaves of which could be damaged to 2.0–2.5 points (5-point scale). High resistance to scab and fruit rots was found for 'Dace', 'Edite', 'Gita', 'Paulis', 'Roberts', DI-93-4-8, DI-2-90-117, with scab resistance determined by the oligogene *Rvi6*. Highly resistant to scab and fruit rots were also 'Agra', 'Arona' and 'Forele' (Tables 4−6).

Productivity

Evaluation of apple cultivars in the trial planted in 1980 allowed to select the earliest yielding cultivars - 'Forele' which gave 5.8 kg per tree on seedling rootstock in 3rd year, and 'Stars' which yielded in 4th year. Other cultivars in this trial bore fruits much later. During long-term evaluation 'Forele' showed average productivity on the level of 'Antonovka' (26.9 kg per tree), from 20 to 50 kg annually. Similar productivity had also 'Iedzenu' (27 kg). Significantly lower and biennial production had 'Stars', AMD-12-9-13 and 'Alro' (Table 4).

Table 4. Productivity and fruit quality of Latvian apple cultivars and hybrids grown on vigorous seedling rootstocks (planted 1980, evaluated 1999−2002)

Cultivar, hybrid	Average yield, kg per tree*	Average fruit mass, g	Type of flavour	Fruit look/ taste, points 1−5	Flesh	Scab resistance	Length of storage, days
'Alro'	10.6^{a}	130	subacid	4.2/4.2	firm	good	65
AMD-12-9-13	17.8^{c}	120	subacid to acid	4.4/4.3	medium firm, fine	good	65
'Forele'	26.9^{a}	150	subacid to sweet	4.5/4.5	firm, crisp, aromatic	high	180
'Iedzenu'	27.1^{a}	150	subacid	4.5/4.3	firm, crisp, fine	medium	85
'Stars'	25.6^{b}	130	subacid	4.3/4.2	medium firm, fine	medium	65
'Antonovka' (control)	30.7^{a}	130	subacid to acid	4.3/4.2	medium firm, very aromatic	medium	65
LSD_{05}	4.7						

* differences of average yield are significant at p = 0.05 level.

In the trial planted in 2005 the earliest yielding cultivars were 'Dobeles Sidrābols', 'Edite', 'Gita', 'Paulis', 'Roberts', DI-93-13-16, having first flowers and fruits in 3rd year. In the age of 5−10 years 'Dobeles Sidrābols', 'Edite', 'Paulis', DI-93-13-16 as well as DI-2-90-117, D-18-94-15 had average yields significantly higher than 'Antonovka'. Other cultivars and hybrids gave yields like the control (Table 5).

Table 5. Productivity and fruit quality of Latvian apple cultivars grown on vigorous seedling rootstocks (planted 2005, evaluated 2009−2012)

Cultivar, hybrid	Average yield, kg per tree*	Average fruit mass, g	Type of flavour	Fruit look/ taste, points 1−5	Flesh	Scab resistance **	Length of storage, days
'Baiba' (Co)	7.0^{d}	160	sub-acid	4.3/4.5	juicy, fine	good	80
'Dace'	8.2^{d}	160	sub-acid	4.3/4.5	fine, mild, juicy, aromatic	high (*Rvi6*)	110
DI-18-94-15	12.0^{c}	180	sweet to sub-acid	4.7/4.3	fine, mild, juicy	good	150
DI-2-90-117	12.0^{c}	160	sub-acid	4.3/4.2	firm, juicy	high (*Rvi6*)	90
DI-93-13-16	13.9^{b}	130	sweet	4.4/4.2	medium firm, juicy	good	10 (very early)
DI-93-4-8	9.4^{d}	150	sub-acid to acid	4.3/4.2	melting, juicy	high (*Rvi6*)	120
Dobeles Sidrābols	16.1^{a}	130	sub-acid	4.3/4.3	firm, crisp	good	150
'Edite'	15.1^{b}	135	sub-acid	4.3/4.3	firm, juicy, aromatic	high (*Rvi6*)	90
'Gita'	10.1^{c}	140	sub-acid	4.3/4.2	firm, juicy	good (*Rvi6*)	90
'Paulis'	19.1^{a}	140	sub-acid	4.4/4.4	crisp, juicy	high (*Rvi6*)	90
'Roberts'	10.2^{c}	150	sub-acid	4.8/4.3	crisp, juicy, aromatic	high (*Rvi6*)	40 (early)
'Antonovka' (control)	8.0^{d}	130	sub-acid to acid	4.3/4.2	medium firm, very aromatic	medium	65
LSD_{05}	3.2						

* differences of average yield are significant at p = 0.05 level; ** − *Rvi6* − scab resistance oligogene.

In the top-grafted trial established in 2004−2006, first flowers and fruits in the 2nd year had 'Arona', 'Ella', 'Gita' and 'Olga'. In the age of 5−10 years 'Gita' significantly surpassed the control. Its average yield was 36 kg per tree (36 tons per ha). Other evaluated cultivars yielded on the level of the highly productive control 'Antonovka'. Among them 'Agra', 'Atmoda', 'Daina', 'Edite', 'Ella' exceeded 20 tons per hectare (Table 6).

Fruit quality and consumption period. Of the evaluated cultivars the earliest ripening was 'Agra', harvested in the end of July or early August, like 'White Transparent'. Its fruits were of medium size (130 g), with bright red over-colour, sub-acid, firm flesh, below medium juiciness. Fruits of hybrid DI-93-13-16 matured a few days later, but before 'Melba', its fruits were attractive and sweet. Late summer cultivar 'Baiba' with columnar tree had fruits of high market quality, medium to large, with attractive colour and fine, juicy and very tasty flesh; fruits could be stored till beginning of December, like 'Melba'. Fruits of the other late summer apple 'Roberts' were distinguished by attractive elongated shape and attractive, uniform dark red over-colour, juicy flesh and balanced taste (Tables 4−6).

Table 6. Productivity and fruit quality of Latvian apple cultivars on low-vigour frame builder 3-17-38 (top-grafted 2004–2006, evaluated 2009−2012)

Cultivar	Average yield, kg per tree*	Average fruit mass, g	Type of flavour	Fruit look/taste, points	Flesh	Scab resistance **	Length of storage, days
'Agra'	23.8^{b}	130	sub-acid	4.4/4.2	low juiciness	high	12 (very early)
'Aivariņš'	12.5^{c}	160	sub-acid	4.4/4.3	soft, fine	good	120
'Sapnis'	15.7^{c}	120	sub-acid	4.3/4.2	firm, fine	high	120
'Andris'	9.5^{d}	130	sub-acid	4.4/4.3	Firm	good	130
'Arona'	18.8^{c}	120	sweet	4.5/4.5	firm, juicy	high	110
'Atmoda'	21.3^{b}	125	sub-acid to acid	4.2/4.1	firm, juicy, aromatic	good	180
'Ausma'	19.5^{c}	140	sub-acid	4.4/4.3	medium firm	good	80
'Daina'	21.3^{b}	140	sub-acid	4.6/4.5	juicy, fine	good	95
'Edite'	24.7^{b}	160	sub-acid	4.4/4.5	firm, juicy, fine, aromatic	high (*Rvi6*)	160
'Ella'	21.7^{b}	150	sub-acid to sweet	4.3/4.5	soft, juicy, fine	good	130
'Gita'	36.0^{a}	160	sub-acid	4.5/4.4	firm, juicy	high (R*vi6*)	110
'Ilga'	18.0^{c}	160	sub-acid	4.5/4.5	firm, juicy, fine	good	105
'Madona'	19.7^{c}	150	sub-acid	4.5/4.3	juicy, aromatic	good	160
'Olga'	18.8^{c}	150	sub-acid	4.3/4.5	firm, juicy	good	160
'Saiva'	19.8^{c}	130	sub-acid	4.5/4.5	medium firm, juicy	good	95
'Sando'	18.8^{c}	140	sub-acid	4.4/4.3	firm, juicy	good	110
'Antonovka' (control)	18.0^{c}	140	sub-acid to acid	4.3/4.2	medium firm, very aromatic	medium	65
LSD_{05}	8.0						

* differences of average yield are significant at p = 0.05 level; ** − *Rvi6* − scab resistance oligogene.

The midseason cultivar 'Gita' had high market quality, large or over medium size, attractive, with dark red over-colour and greyish bloom, juicy, fine, pleasant flesh, and could be stored till beginning of January. 'Ausma' also ripened in autumn and in some years could be stored till end of January. Its fruits were of medium size, with attractive blush, pleasantly subacid, sometimes with excess acidity which decreased during storage. Short storage period (mostly till end of November) had midseason cultivars 'Stars', 'Alro' and hybrid AMD-12-9-13.

Cultivars ‘Daina’, ‘Ilga’, ‘Saiva’ had balanced sub-acid taste, juicy, fine flesh and high evaluation both of taste and appearance. Their fruits could be consumed till end of December or mid-January. Very good sweet taste with slight pleasant acidity, as well as bright attractive colour had late ripening ‘Ella’ and hybrid DI-18-94-15. Late cultivar ‘Iedzenu’ was strongly affected by storage diseases.

For full year fruit supply the cultivar ability to maintain good quality over an extended period is essential. Among the tested cultivars, good storage till end of February or beginning of March had ‘Edite’, ‘Madona’ and ‘Olga’. The longest storage had ‘Forele’ with attractive fruits keeping till April.

DISCUSSION

In the climate of Central Russia (Orel region) Latvian apple cultivars showed different levels of field resistance to unfavourable winter conditions. Previous investigation of Latvian apple genotypes in field (Krasova et al., 2014) allowed to find cultivars with good winter-hardiness on the level of old local cultivars from Central Russia and Baltic region - ‘Antonovka’ (‘Common Antonovka’), ‘Borovinka’ (‘Charlamowsky’), ‘Papirovka’ (‘White Transparent’) and ‘Osenneye Polosatoye’ (‘Streifling Herbst’). These were ‘Agra’, ‘Iedzenu’, ‘Dainis’, ‘Magone’. During unfavourable winters in the trial period they had low injury of xylem to 1.5 points. In Latvia, ‘Agra’ and ’Iedzenu’ also have shown high winter-hardiness in field, while data on ‘Dainis’ are insufficient, as its plantings are very few and only in the best orchard areas.

In the field study, a number of cultivars and hybrids showed medium winter-hardiness with regeneration of damages when evaluated in field, in the range of 2.1–2.5 points (stronger than for ‘Antonovka’): ‘Aivariņš’, ‘Arona’, ‘Baiba’, ‘Dace’, ‘Dobeles Sidrābols’, ‘Eksotika’, ‘Ella’, ‘Gita’, ‘Madona’, ‘Olga’, ‘Paulis’, ‘Roberts’, ‘Saiva’, ‘Sapnis’, AMD-12-9-16, DI-2-90-117. When temperature in field conditions fell below -30 °C and especially after thaws, stronger damages (3.0 points) had ‘Andris’, ‘Ausma’, ‘Daina’, ‘Edite’, ‘Sando’, DI-93-13-16, D-18-94-15, DI-93-4-8 (Krasova et al., 2014). In the milder climate of Latvia, all these have shown good or very good winter-hardiness in field (Drudze, 2000 and 2004; Ikase & Dumbravs, 2001).

To obtain more precise evaluation, the cold resistance potential of individual cultivars was determined by artificially modelling the components of winter-hardiness. The investigated Latvian cultivars and hybrids demonstrated high ability to reach adapted condition when subjected to modelling of gradual temperature decrease till -25 °C and -30 °C in mid-December, without damages of buds, bark, cambium and xylem (1st component).

Modelling of freezing temperatures -38 °C, -40 °C and -42 °C in mid-winter allowed establish the cultivar and hybrid resistance potential to very low temperatures and select the best genotypes by this component of winter-hardiness (2nd component).

In mid-winter (2nd component) after modelling of gradual temperature decrease to -38 °C, for majority of cultivars damages of vital tissues did not exceed 2.0 points and were reversible. Cultivars and hybrids with damages on the level of ‘Antonovka’ were ‘Daina’, ‘Saiva’, D-18-94-15 for xylem, ‘Atmoda’ and ‘Ausma’ for cambium. When temperature was lowered to -40 °C, several cultivars also showed good resistance of cambium, bark and xylem with damages of 2.0 points - ‘Aivariņš’, ‘Atmoda’, ‘Gita’, ‘Saiva’, hybrid DI-93-4-8. For these cultivars -40 °C is the threshold of hardiness after temperature adaptation. These data in general comply with previous field investigations (Krasova et al., 2014), but part of these cultivars in field had demonstrated only medium hardiness, which may be explained by the more complex character of field conditions.

Cultivars combining good resistance of all vital tissues to early colds and negative temperatures to -38 °C in mid-winter, with reversible damages not exceeding 2.0 points, were ‘Ella’, ‘Daina’, ‘Atmoda’, ‘Gita’, ‘Saiva’. The last 3 maintained good resistance of bark, cambium and xylem with slight increase of bud damages also at -40 °C. It must be noted that in the Baltic climate these cultivars are considered to be only medium hardy (Drudze, 2000 and 2004; Univer & Univer, 2015), which may be explained by a shorter vegetation period and more frequent temperature fluctuations in winter.

Cultivars ‘Atmoda’ and ‘Aivariņš’ had bark and cambium damages on the level of ‘Antonovka’ even at -42 °C, and for ‘Ausma’ cambium damages also did not exceed 2.0 points. Other cultivars at this temperature had stronger injuries, and tissue damages of ‘Andris’, ‘Ella’, ‘Saiva’ were significantly higher than for ‘Antonovka’. At the same time, while damages of bark and cambium for ‘Atmoda’ and DI-93-4-8 were low, their xylem showed poor hardiness at modelling temperature fall to -42 °C (damages 3.6–4.0 points). This complies with their low field hardiness observed during strong (below -40 °C) and prolonged colds in mid-winter (Krasova et al., 2014).

Modelling of thaws with following lowering of temperature to -25 °C (3rd component) showed good bud and tissue hardiness on the level of ‘Antonovka’ for cultivars ‘Dainis’ and ‘Ella’.

In conditions of relatively high humidity favourable for the development of fungal diseases, selection of highly disease resistant cultivars gains increased importance. High resistance to scab and fruit rots was found for Latvian cultivars and hybrids with gene *Rvi6* inherited from BM 41497 and ‘Liberty’, which complies with authors’ data (Ikase & Dumbravs, 2001, 2004). Highly resistant in the conditions of Orel were also some cultivars not possessing known resistance oligogenes - ‘Agra’, ‘Arona’ and ‘Forele’. The first two have shown high disease resistance also in the moister climate of Latvia, while ‘Forele’ there is susceptible both to scab and fruit rots (Drudze, 2000). Reported cases of breakdown of gene *Rvi6* scab resistance with appearance of more virulent pathogen races (Kazlauskaya et al., 2009; Bus et al., 2011; Masny, 2017; Fisher et al., 2018) raises the need for search and utilisation in breeding of new sources of monogenic and high polygenic resistance sources.

High precocity and productivity surpassing control ‘Antonovka’ were found in ’Gita’, ‘Edite’, ‘Dobeles Sidrābols’, DI-93-13-16. Equal to ‘Antonovka’ in this aspect were ‘Arona’, ‘Forele’, ‘Olga’. Medium precocity, but fast production increase showed ‘Paulis’, D-2-90-117, D-18-94-15, while ‘Agra’, ‘Ausma’, ‘Ella’, ‘Ilga’, ‘Madona’ gave average, but annual yields. These last cultivars in Latvia have shown higher, but less regular production (Drudze, 2000 and 2004).

Fruit quality of the evaluated cultivars was good and similar to observations in Latvia. So, lack of juiciness for ‘Agra’ has been observed also in Latvia during hot, dry summers. On the other side, influence of climate differences was observed for some cultivar maturing and storage. Cultivar ‘Ausma’ in Orel ripens in autumn, while in Latvia it is a late cultivar with long storage. Also, fruits of ‘Ilga’ in Latvia after cooler summers develop poor colour but can be stored till March or longer. In Orel the longest storage had ‘Atmoda’, ‘Edite’, ‘Forele’, ‘Madona’ and ‘Olga’. They show good storage potential also in Latvia (Drudze, 2000 and 2004), but ‘Edite’ there is sensitive to physiological disorders (Juhnevica-Radenkova et al., 2016). Cultivar 'Edite' in Orel had larger and brighter fruits on low vigour frame builder.

Cultivar 'Gita' showed very good results when top-grafted on a low-vigour frame builder - very early start of bearing, yields significantly higher than 'Antonovka', uniform ripening, bright colour, while on vigorous seedling rootstocks the yields did not surpass control, fruits were smaller and had weaker colour. In Latvia it shows some promise for commercial plantations and has been highly productive on dwarfing rootstocks (Rubauskis et al., 2015; Rubauskis & Skrivele, 2017).

CONCLUSIONS

- A number of Latvian cultivars showed good performance in the colder and more continental climate of central Russia, thus demonstrating good adaptation potential to different environment conditions, and may be considered in breeding of new adaptive apple cultivars with high fruit quality.
- By the results of many-year evaluation in Central Russia, the following can be recommended for use in breeding of scab resistant cultivars with high quality fruits - 'Dace' (gene *Rvi6*), 'Arona', and good storage - 'Edite' (*Rvi6*), 'Forele', 'Olga', 'Madona'. These cultivars after gradual cold adaptation can tolerate early colds to -30 °C and mid-winter colds to -38 °C with reversible damages.
- For breeding of early cultivars can be recommended 'Roberts' and hybrid DI-93-4-8 ('Liberty' x 'Latkrimson'), both resistant to scab and fruit rots.
- Cultivars and hybrids with the best cold resistance of buds, bark, cambium and xylem by artificially modelling winter-hardiness components - early colds (1st component) and mid-winter colds to -38 °C (2nd component) - were: 'Daina', 'Ella', 'Atmoda', 'Gita', 'Saiva'; the last 3 maintained high hardiness of bark, cambium and xylem with slight increase of bud damages also at -40 °C.
- Cultivars 'Daina' and 'Ella' showed resistance of buds and vital tissues on the level of 'Antonovka' after modelling a thaw with following freezing to -25 °C (3rd component), which suggests good adaptation to fluctuating winter temperatures.

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