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RUSSIAN ADAPTIVE APPLE (*Malus* × *domestica* Borkh.) VARIETIES OF VNIISPK — CONTINUITY OF GOALS AND DEVELOPED TECHNOLOGIES
(review)

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Abstract

Apple (*Malus* × *domestica* Borkh.) is one of the most economically important fruit crops with a predicted increase in global production. Apples are valued by nutritionists as an important source of sugars, ascorbic acid, other vitamins, trace elements, pectins and biologically active substances. Appearance (size, color) and aroma are the main factors of apple fruit attractiveness for the consumer. From an economic point of view, the main attention in recent decades has been paid to technological features, adaptability, productivity, keeping quality of fruits and resistance to diseases. Breeding research carried out in 1956-2021 at the oldest pomological All-Russian Research Institute of Fruit Crop Breeding (VNIISPK) which celebrated its 175th anniversary in 2020, resulted in 56 new apple cultivars, including 38 cultivars on a fundamentally new genetic basis. By the beginning of these studies in the orchards of central Russia, the main apple cultivars were landraces (Antonovka, Korichnoye Polosatoye, Osennye Polosatoye, Grushovka Moskovskaya and Papirovka) and the Michurin's cultivars Pepin Shafranny, Bellefleur Kitayka, Bessemyanka Michurinskaya, Doch Korichnogo and Kitayka Zolotaya Rannya. At the first stage of our breeding program, the main methods were re-hybridization and breeding based on geographically remote crosses and open pollination. Veteran, Orlik, Pamyat Voinu, Orlovskoye Polosatoye and a number of other cultivars were created and released. Apple breeding at the polyploid level has been carried out since 1970. Triploid cultivars are characterized by more regular fruiting over the years, large fruit size and high marketability of fruits, and increased self-fertility. We have developed a technique for creating triploid apple cultivars and obtained a series of triploid cultivars from intervalent crosses ($2n = 2\times$) × ($2n = 4\times$). To date, 18 triploid cultivars have been released of which six are immune to scab. The best are the triploid ciultivars Rozhdestvenskoye (immune to scab) and Sinap Orlovsky, derived from two diploid cultivars due to the absence of chromosome reduction in one of the parents. These cultivars have become widespread, and each of them is zoned in four regions of Russia. Breeding of cultivars immune to scab has been carried out since 1977. A technique for selecting scab-immune cultivars and seedlings under artificial infection background has been developed. Twenty-four scab-immune cultivars were created and released, including six immune and triploid cultivars and four scab immune and columnar cultivars. The best immune cultivars are Bolotovskoe, Venyaminovskoe, Imrus, and Svezhest; Alexander Boyko, Vavilovskoe, Rozhdestvenskoe, Maslovskoe and Yablochny Spas are scab immune and triploid cultivars. Breeding of columnar apple cultivars has been carried out since 1984 resulting in five columnar cultivars Vostorg, Girlanda, Priokskoye, Poeziya, and Orlovskaya Yesenia. All of them, except for Orlovskaya Yesenia, are immune to scab. Apple breeding to improve the biochemical composition of fruits has been carried out since 1970. According to long-term data, Vavilovskoye (13.0 %) and Ministr Kiselev (13.1 %) are the cultivars with a high content of sugars, Ivanovskoye (19.5 mg/100 g), Veteran (19.4 mg/100 g) and Pepin Orlovsky (15.3 mg/100 g) are enriched with vitamin C, and Kandil Orlovsky (558 mg/100 g), Orlovsky Pioner (514 mg/100 g), Pamyati Khitrovo (480 mg/100 g) and Radost' Nadezhdy (474 mg/100 g) have high content of P-active substances. In the future, we are planning to release new columnar triploid cultivars and triploid cultivars combining columnar habit and scab immunity (elite seedlings with such qualities have already been produced). Such apple hybrids have not yet existed either among cultivars or among wild forms.

Keywords: *Malus* × *domestica* Borkh., apple, breeding, repeated hybridization, polyploidy, cytoembriology, scab immunity, columnar habit, sugars, ascorbate, P-active substances

Apple (*Malus* × *domestica* Borkh.) is one of the most economically significant fruit crops [1, 2] with a projected increase in global production in 2021/2022 (due to increased production in China, Turkey, South Africa, Mexico) [3]. In 2000-2020, the main apple production was concentrated in China, the USA and Turkey; Russia ranked eighth in this list (https://www.atlasbig.com).

Apples are valued by nutritionists as an important source of sugars, ascorbic acid, other vitamins, microelements, pectins and biologically active substances, i.e., carotenoids, anthocyanins and phenolic compounds [4-6]. Such a composition of nutrients reduces the risk of chronic diseases, improves health and increases the adaptive capacity of the body [6, 7]. Appearance (size, color) and aroma are the main factors in the attractiveness of apple fruits for the consumer; from an economic point of view, the main attention, especially in recent decades, has been paid to technological features that determine, for example, the possibility of using modern methods of growing and harvesting, suitability for processing, as well as adaptability, productivity, flowering and ripening time, keeping quality of fruits, their uniformity in size, disease resistance [8-12]. Resistance to diseases, pests, abiotic factors, compact habit of the plant, marketability of fruits remain the most popular directions in the world selection of apple trees [13-17].

The selection development of the apple tree as a horticultural crop began with the use and improvement of local varieties of folk selection. For example, the Volga variety Astrakhan red (first described in 1780) under the name Roter Astrachan was the most common variety of Russian origin in Europe (in England since 1816, in Germany since 1840) and North America (https:// www.kob-bavendorf.de/sorten-detail/na-me/Roter%20Astrachan.html). In Sweden, an apple breeding program has been ongoing since the 1940s, with several varieties adapted to the Scandinavian climate developed for commercial and personal use [18, 19]. In Germany, a long-term breeding program began over 90 years ago. Its goals were fruit quality, high yield, resistance to scab, powdery mildew, bacterial burn, bacterial cancer, red spider mite, frost, new varieties are suitable, among other things, for integrated and organic fruit production [20]. The Fruit Gene bank (Research Institute For Fruit Breeding At Dresden-Pillnitz, Germany) preserves and characterizes as sources of scab resistance genes (*Rvi*) Russian cultivars Antonovka (popular selection cultivar of Russian origin, *Rvi14*, *Rvi17*), Antonovka Kamenichka (*Rvi14*, *Rvi17*), Bessemyanka Michurinskaya (*Rvi17*) (Antonovka, Antonovka Kamenichka, Bessemyanka Michurinskaв) [21]. At the University of Minnesota (USA), apple breeding has been going on since 1908, the first variety under this program, Minnehaha, bred in 1920, was obtained from seeds from free pollination collected from different regions [22]. In Japan, by the 1900s, about 300 varieties were imported from the USA, France, Canada and other Western countries, seven varieties - American Summer Pearmain, Ben Davis, Fameuse, Jonathan, Smith Cider, Ralls Janet and a variety of Russian origin Red Astrachan (Astrakhan red) became predominant. The Japanese variety Orin has been among the dominant varieties in Japan since 1952 [10].

In the All-Russian Research Institute of Fruit Crop Breeding (VNIISPK), purposeful large-scale research on apple tree breeding began in 1956. By this time, in the gardens of central Russia, the main varieties of apple trees were popular selection (Antonovka ordinary, Cinnamon striped, Autumn striped, Grushovka Moscow, Papirovka) and varieties of I.V. Michurina Pepin saffron, Bellefleur Chinese, Bessemyanka Michurinskaya, Daughter of Cinnamon, Chinese golden early. The listed varieties have played an important role in horticulture and are still officially approved for use, although they have lost their former popularity due to increased commercial requirements. The result of 65 years of research (1956-2021) was 56 new varieties of apple trees, which are included in the State Register of Breeding Achievements approved for use, including 38 varieties on a fundamentally new genetic basis. Many of their properties are described in detail [23]. In the presented communication, the creation of these varieties is considered from the standpoint of changing breeding tasks and methodological approaches developed to solve them [24-28].

Repeated, geographically distant crossings and free pollination. Rehybridization, free pollination and crosses of geographically distant forms are generally accepted methods of traditional breeding, the application of which is associated with the first stage of the program begun in 1956 to create competitive domestic apple varieties [28]. The first varieties bred were included in the State Register in 1986. We successfully used these methods to create varieties Veteran (King, free pollination), Orlik (Mekintosh × Bessemyanka Michurinskaya), Pamyat voinu (Welsey × Antonovka obyknovennaya), Orlovskoe polosatoe (Mekintosh × Bessemyanka Michurinskaya) (Table 1).

1. Apple varieties obtained by free pollination and re-crossings (All-Russian Research Institute of Fruit Crop Breeding, Orel, 1956-2021)

A	B	C	D	E	F	G
Veteran (King — free pollination)	w	Until mid March	130	4.4/4.4	1989	3, 4, 5, 7
Desired (Mekintosh — free pollination)	ls	Until mid September	140	4.3/4.3	2002	5
European Robin (Antonovka krasnobochka × SR0523)	au	Until December	130	4.3/4.3	1999	3
Kulikovskoe (King — free pollination)	w	Until the end of March	125	4.4/4.2	1997	3, 5, 7
Morozovskoe (Antonovka vulgaris × Mekintosh)	w	Until the end of January	160	4.7/4.3	2011	3, 5
Olympic (Mekintosh — free pollination)	w	Until February	130	4.3/4.2	1999	8
Orlik (Mekintosh × Bessemyanka Michurinskaya)	w	Until February	120	4.4/4.5	1986	2, 3, 5
Orlinka (Stark Earliest — Pervy sdlyut)	s	Until the second decade of September	140	4.3/4.3	2001	5
Orlovim (Antonovka obyknovennaya × SR0523)	s	Until mid September	130	4.4/4.5	1999	3
Orlovskaya Zarya (Mekintosh × Bessemyanka Michurinskaya)	w	Until the end of January	135	4.6/4.5	2002	3
Orlovsky pioneer (Antonovka krasnobochka × SR0523)	au	Until the end of October	140	4.3/4.3	1999	3
Oryol polosatoe (Mekintosh × Bessemyanka	lau	Until the end of December	150	4.6/4.3	1986	3, 5, 7
Michurinskaya)	w	Until the end of January	140	4.4/4.5	1997	5
Pamyat voinu (Welsey × Antonovka obyknovennaya)	lau	Until mid-December	150	4.5/4.3	2008	3
Memory of Isaev (Antonovka krasnobochka × SR0523)	w	Until mid-January	140	4.5/4.3	2001	3
Pepin Orlovsky (Pepin saffron — free pollination)	s	Until October	150	4.4/4.3	2011	5
Radost Nadezhdy (Welsey — free pollination)	s	Until mid September	130	4.5/4.4	1998	5
Ranneee aloe (Melba × Papirovka)	w	Until the end of December	150	4.5/4.3	2008	3
$X_{average}$			138.3			
LSD_{05}			12.5			

Note. A — variety and its origin (variety, crossing varieties), B — fruit ripening period, C — keeping quality of fruits, D — fruit weight, g, E — appearance taste of fruits, score (maximum score 5.0), F — year of inclusion in the State Register, F — region of admission (2 — North-West, 3 — Central, 4 — Volga-Vyatka, 5 — Central Black Earth, 6 — North Caucasian, 7 — Middle Volga, 8 — Lower Volga); s — summer, au — autumn, w — winter, lau — late autumn, ls — late summer.

All varieties had high productivity, fruit quality in terms of sugar content, sugar acid index, content of ascorbic acid and P-active substances, and different maturation periods, therefore, met the principle of "fruit conveyor" formation to provide the consumer with fresh produce for as long as possible [23]. Of course, due to the long life cycle of the apple tree, the traditional selection is a slow process [9, 10]. Genomic [8, 10, 29, 30] and transgenic technologies [9, 10] spead up breeding, however, these techniques do not exclude, but only supplement the traditional selection and phenotypic evaluation of samples, taking into account the effects of the genotype—environment interaction [5, 6], especially under the conditions of ongoing climate change [30].

Selection at the polyploid level. At the next stage of the program, success in creating varieties was associated with the development and application by us of a new methodological approach based on selection at the polyploid level, using data from genetic, cytological and embryological analysis. As a result of research started in 1970, we created for the first time in Russia and the world a series of triploid ($2n = 3\times$) varieties from intervalent crosses of diploids ($2n = 2\times$) with tetraploids ($2n = 4\times$).

The history of apple tree breeding at the polyploid level is associated with the work of Swedish scientists [31-33], who showed the advantages of triploid forms over diploid and tetraploid ones. For many centuries, triploid varieties that spontaneously arose in nature were distinguished by good fruit quality, increased viability and were cultivated. Thus, the Gravenstein variety, which was widely known in Denmark as early as the 17th century, is a triploid. Spontaneous triploids of American (Tompkins County King and Rhode Island Greening varieties) and British (Bramley and Ribston Pippin varieties) origin dating from the 17th-18th centuries are still grown today (https://www.apfga.org/triploid-apples/). However, spontaneous mutations of this kind rarely occur in nature. Purposeful obtaining of triploids by breeding methods is a promising way to create an "ideal variety". It was shown that by crossing diploid varieties with each other, it is possible to obtain up to 0.3% of triploid seedlings, while the yield of triploids when crossing tetraploid and diploid forms is much higher [31-35]. However, work on the mass production of triploid seedlings in order to breed varieties has not received proper development.

According to A.A. Zhuchenko, it is polyploidy that provides higher adaptability to many plant species [36]. Polyploidy is a genomic mutation that manifests itself in a spontaneous or induced increase in the diploid number of chromosome sets. Polyploidy is especially valuable when vegetative organs are used as the target product [37]. The use of polyploidy does not speed up the selection process, but increases the possibilities of selection due to the large range of hereditary variability. Polyploids serve as favorable material for natural and artificial selection [37]. Our long-term studies have shown that the yield of fruits in relation to pollinated flowers and the yield of seeds was lower with hybridization at the polyploid level (4.7 vs. 3.6%) than at the diploid level (8.6 vs. 6.4%). However, the breeding value of seedlings obtained from hybridization at the polyploid level is significantly higher than from hybridization at the diploid level. As it turned out later, with hybridization at the diploid level in comparison with the polyploid one, 4121 seedlings vs. 778 are needed to obtain one elite seedling, 86.6 thousand pollinated flowers and 16.7 thousand annual seedlings vs. 46.2 thousand flowers and 2.9 thousand seedlings are needed to create one variety. In other words, the selection efficiency increased, as the time, volume of work and, as a result, costs decreased.

Cytological and field studies allow us to establish that not all tetraploid varieties and forms can be used as donors of diploid gametes, but only homogeneous tetraploids in which all layers of somatic cells are tetraploid ($4n = 4\times$) [34, 38]. These are varieties Mekintosh tetraploid, Melba tetraploid, Alfa 68 and seedlings VNIISPK 13-6-106 (variety Suvorovets — free pollination), 25-37-45 (Orlovskaya girlyanda × Welsey tetraploid). Diploid-tetraploid chimeras of the 1st type are also suitable as donors of diploid gametes, for example, Antonovka ploskaya 2-4-4-4×, Papirovka tetraploid 2-4-4-4×, Welsey tetraploid 2-4-4-4×. The value of each specific form as a donor of diploid gametes varies and depends on the development of embryonic structures in its generative sphere. The results of cytoembryonic analysis are of decisive importance in the selection of initial forms for hybridization with the aim of mass production of triploids.

The study of the generative sphere in the Mekintosh tetraploid variety showed that the ovules and mature differentiated embryo sacs ready for fertilization develop at the same time in this form and in the diploid analogue. In both forms, the formation of a significant number of abnormal ovules and ovaries is observed; both forms are characterized by the formation of complex ovules with two or three nucelli enclosed in a common integument. The differences between the two forms of the Mekintosh variety associated with the level of ploidy are expressed in the fact that the linear dimensions of the structures of the generative sphere of the polyploid form are traditionally somewhat larger than those of the diploid form. The formation of supernumerary nuclei in the embryo sac of the polyploid form of the variety Mekintosh could result in formation of the haploid gametes instead of diploid. Consequently, part of the hybrid progeny when using this form in intervalent crosses of the type ($2n$ = 4×) × ($2n$ = 2×) will not be triploid [35] and the Mekintosh tetraploid variety is suitable for crosses (according to the results of 12 crosses with the participation of this variety, we singled out one selected seedling, a candidate for varieties). In breeding, the tetraploid form 13-6-106 (seedling of the Suvorovets variety) is also actively used. It is also characterized by the presence of a number of features in the development of the generative sphere, which in most cases do not serve as a significant obstacle to being used as a parental form during hybridization. Since abnormal ovules average only about 25%, the ovaries always contain a sufficient number of normal ovules with normally developed embryo sacs suitable for double fertilization. With the participation of the tetraploid form 13-6-106, 30 crossings were carried out and 15 selective and six elite forms were obtained.

It has been established that crosses of the type diploid × tetraploid, and not tetraploid × diploid, are the most effective. It is much more difficult to obtain triploid offspring of an apple tree, because in the hybrid offspring from crossing diploid varieties with tetraploid varieties or forms, the proportion of triploid seedlings is from 40 to 80%. The method developed by us for obtaining triploid seedlings and varieties takes into account all these features. Crosses of the tetraploid × diploid type are possible only with castration of the maternal tetraploid form, because the latter, as a rule, has a high self-fertility [35, 38].

An assessment of the physiological and biochemical parameters and fruit quality showed that the resulting triploid apple varieties (Table 2) are characterized by a lower frequency of fruiting over the years, improved fruit marketability, increased self-fertility, high yield and fruit quality in terms of biochemical composition [23, 39].

When optimizing protocols for polyploid crosses, we relied on the results of cytoembryological analysis. In our opinion, in the selection of apple trees at the polyploid level, one cannot do without cytoembryological control. We were unable to find examples of such an approach in the specialized literature. At the beginning of our study, the use of cytological methods to determine the level of ploidy and describe mitotic and meiotic events was discussed [40], in recent years, cytogenetic characteristics are considered in connection with the phenomenon of ploidy and genome size [41].

Obviously, the resulting polyploids can acquire new traits [11, 42, 43]. At the same time, in tetra- and hexaploid forms, many physiological and morphological parameters are lower than in diploid ones [11, 42, 43]. It is assumed that plant species have optimal ploidy, and its decrease or increase reduces their growth potential, but the manifestation of a number of traits, including those of breeding value, is enhanced in tetraploids [42], and they are considered as valuable breeding material for programs for obtaining triploid plants [42]. According to some economically significant properties, the apple tree is noted to have the superiority of tetraploids over diploids, for example, drought resistance [42] and scab resistance [11].

2. Triploid varieties of apple trees obtained by selection at the polyploid level (All-Russian Research Institute of Fruit Crop Breeding, Orel, 1970-2021)

A	B	C	D	E	F	G
Augusta (Orlik × Papirovka tetraploid)	ls	Until the end of September	160	4.4/4.4	2008	5
Bezhin lug (Severny synap × Welsey tetraploid)	w	Until February	150	4.4/4.3	2010	5
Darena (Melba × Papirovka tetraploid)	ле	Until the end of September	170	4.5/4.3	2011	5
Den Pobedy (Veteran × Horcoat)	w	Until mid March	140	4.4/4.3	2020	5
Ministr Kiselev (Chistotel × Welsey tetraploid)	w	Until mid March	170	4.4/4.4	2017	5
Nizkorosloe (Skryzhapel × Pepin saffron)	w	Until the end of February	130	4.3/4.2	1997	5
Orlovsky partisan (Orlik × 13-6-106 seedling of Suvorovets variety)	w	Until mid February	190	4.4/4.4	2010	5
Osipovskoe (Mantet × Papirovka tetraploid)	s	Until mid September	130	4.4/4.4	2013	5
Pamyati Semakina (Welsey × 11-24-28 seedling of Golden Greima variety)	ew	Until the end of December	160	4.5/4.3	2001	5
Patriot [16-37-63 (Antonovka krasnobochka × SR0523) × 13-6-106 seedling of Suvorovets variety]	w	Until the beginning of February	240	4.5/4.3	2013	5
Synap Orlovsky (ceverny Sinap × Pamyati Michurina)	lw	Until the end of April	150	4.3/4.4	1989	2, 3, 5, 7
Turgenevskoe (18-53-22 × Welsey tetraploid)	w	Till March	180	4.4/4.3	2021	5
$X_{average}$			164.1			
LSD_{05}			29.6			

N o t e. A — variety and its origin (variety, crossing varieties), B — fruit ripening period, C — keeping quality of fruits, D — fruit weight, g, E — appearance taste of fruits, score (maximum score 5.0), F — year of inclusion in the State Register, F — region of admission (2 — North-West, 3 — Central, 4 — Volga-Vyatka, 5 — Central Black Earth, 6 — North Caucasian, 7 — Middle Volga, 8 — Lower Volga); s — summer, w — winter, ls — late summer. lw — late winter, ew — early winter.

Creation of scab-immune apple cultivars. The problem of apple tree resistance to diseases while maintaining the high quality of fruits does not lose its relevance [44]. This is especially true for scab lesions [11, 21, 45]. Scab caused by *Venturia inaegualis* (Cke. Wint) is one of the most harmful diseases of the apple tree, and breeding for resistance to it is one of the most popular ways to improve varieties [13-17]. We have been doing this research since 1977. A great contribution to the theory and practice of selection of scab-immune seedlings was made by Vladilen V. Zhdanov, co-author of more than 20 scab-immune apple varieties, who developed a method for selecting resistant varieties and seedlings against an artificial infectious background [46].

In different countries, more than 200 scab-immune cultivars have been created on the basis of donors with the *Vf* gene (*Rvi6*) from *Malus floribunda* 821 using backcroses [16, 47-50]. Varieties Prima, Priscilla, Florina, Freedom, Redfree, Liberty, Gold Ruch were widely used in hybridization [15-17, 51, 52]. On the basis of our own hybrid fund, we created and released scab-immune varieties with the *Vf* (*Rvi6*) resistance gene (Table 3). In addition, triploid varieties immune to scab (see Table 3) and four immune columnar varieties were obtained. In our opinion, the best immune varieties are Bolotovskoye, Venyaminovskoye, Imrus, Svezhest and Stroevskoye, while immune and triploid varieties are Alexander Boyko, Vavilovskoye, Maslovskoye, Rozhdestvenskoye, Yubilyar and Yablochny Spas, which are of interest for production.

Varieties Rozhdestvenskoye and Sinap Orlovsky already occupy large areas of gardens and are zoned in four regions of Russia. A successful example of sustainable horticulture was the experience of growing scab-immune varieties Svezhest, Afrodita, Bolotovskoye, Venyaminovskoye, Imrus, Kandil Orlovsky, Rozhdestvenskoye, Stroevskoye in the Saratov region [53]. When studying the adaptability of the scab-immune apple varieties obtained by us in the conditions of Ukraine, Aphrodite, Venyaminovskoye, Kandil Orlovsky, Orlovskoye Polesye, Rozhdestvenskoye turned out to be the best [54]. Because *Venturia inaegualis* can mutate rapidly with new races, scab resistance is most likely to be maintained when immune varieties are planted alongside non-immune varieties and a minimal treatment cycle [55]. It is believed that the *Vf* (*R*vi6) gene is still capable of providing resistance against the pathogen [10, 45], but a long-term protective effect is more reliably provided by multiple resistance and pyramiding of several genes [8, 21, 45, 56]. The genes *Rvi5*, *Rvi11*, *Rvi12*, *Rvi14*, and *Rvi15* are considered promising [10, 45], as the sources of one of these genes, *Rvi14*, folk cultivars of Russian origin Antonovka obyknovennya and Antonovka-Kamenichka have been characterized [21], new sources of resistance genes to diseases [21]. All this is included in the range of tasks of proactive selection for scab resistance of apple trees [56].

3. Scab immune apple cultivars based on the *Vf* (*Rvi6*) gene donors, including polyploids (All-Russian Research Institute of Fruit Crop Breeding, Orel, 1977-2021)

A	B	C	D	E	F	G
Scab immune varieties (*Vf*)						
Aphrodite (814 — free pollination)	ew	Until the end of December	130	4.4/4.4	2006	5, 6
Bolotovskoye (Skryzhapel × 1924)	w	Until February	155	4.3/4.3	2001	3, 5
Venyaminovskoe (814 — free pollination)	w	Until the end of February	130	4.4/4.4	2008	2, 3, 5, 6
Zdorovye (Antonovka obyknovennaya × OR48T47)	w	Until mid February	140	4.3/4.3	2001	5
Ivanovskoe (Welsey × Prima)	w	Until mid February	150	4.4/4.4	2010	5
Imrus (Antonovka obyknovennaya × OR18T13)	w	Until mid February	140	4.3/4.4	1996	3, 5
Kandil Orlovsky (1924 — free pollination)	w	Until February	120	4.4/4.3	2001	3, 5, 6
Kurnakovskoe (814 × PA-29-1-1-63)	w	Until mid February	130	4.3/4.3	2002	3, 5
Oryol Polissya (814 — free pollination)	pз	Until mid-January	140	4.4/4.3	2001	3, 5
Pamyati Khitrovo (OR18T13 — free pollination)	w	Until the end of February	170	4.3/4.3	2001	5
Snezhet' (Antonovka krasnobochka × PR2T67)	lw	I'm at home	140	4.3/4.2	2001	3, 5
Solnyshko (814 — free pollination)	lau	Until December	140	4.4/4.3	2001	3, 5
Start (814 × Mekintosh tetraploid)	w	Until the end of February	140	4.3/4.3	2002	5
Stroevskoe (814 — free pollination)	w	Until the end of February	120	4.5/4.4	2001	3, 5
Yubilei Moskwy (814 — free pollination)	w	Until the end of February	120	4.3/4.3	2002	5
$X_{average}$			137,3			
LSD_{05}			21,3			
Scab immune triploid varieties						
Alexander Boyko (Prima × Welsey tetraploid)	w	Until the second decade of March	200	4.4/4.3	2013	5
Vavilovskoye [18-53-22 (Skryzhapel × OR18T13) × Welsey tetraploid]	w	Until the beginning of March	170	4.6/4.3	2015	5
Maslovskoye (Redfree × Papirovka tetraploid)	s	Until the end of September	220	4.3/4.3	2010	5
Rozhdestvenskoe (Welsey × BM 41497)	w	Until the end of January	140	4.4/4.3	2001	2, 3, 5, 6
Yubilar (814 — free pollination)	s	Until the end of September	130	4.4/4.3	2009	5
Yablochny Spas (Redfree × Papirovka tetraploid)	s	Until the end of September	200	4.4/4.3	2009	3, 5
$X_{average}$			176,6			
LSD_{05}			29,6			

Note. A — variety and its origin (variety, crossing varieties), B — fruit ripening period, C — keeping quality of fruits, D — fruit weight, g, E — appearance taste of fruits, score (maximum score 5.0), F — year of inclusion in the State Register, F — region of admission (2 — North-West, 3 — Central, 4 — Volga-Vyatka, 5 — Central Black Earth, 6 — North Caucasian, 7 — Middle Volga, 8 — Lower Volga); s — summer, w — winter, ls — late summer. lw — late winter, lau — late autumn, ew — early winter.

The development of scab-resistant apple varieties with acceptable consumer and commercial characteristics has proven to be a difficult task. It took almost 60 years to produce the first commercial *Vf*-generated Prima variety in the US (released in 1970) (the program started in 1914) [10, 57]. In recent decades, transgenic technologies have been used to solve these problems, but the practical application of varieties on this basis may be limited by local legislation [10]. Information about the creation of triploid and especially triploid scab-resistant apple varieties is not widespread. One such variety Sirius (UEB 3264/2) with the *Vf* gene was obtained from crossing Golden Delicious × Topaz, the trees are medium-sized, well branched, the fruits are large, juicy, with a well-balanced taste (https://extension.psu.edu/apple-cultivars-newer-scab-resistant-selections, accessed 09/29/2022), the triploid Initial (X 6163) has conical fruits, medium to large in size, prone to shedding, they are used for making cider and feeding deer (https:// extension.msu.edu, accessed 09/29/2022).

Selection of columnar apple varieties. The compactness of the tree is one of the requirements of modern intensive fruit growing [10, 58-61]. This property is possessed by columnar varieties of apple trees. Their creation is considered as one of the leading directions in apple breeding, which we have been developing since 1984. Columnar varieties allow to reduce the pre-fruiting period by 2-3 years, make it possible to significantly increase the gross yield per hectare, as well as to reduce manual labor to a minimum when caring for the garden. Therefore, this biological form is promising for intensive and super-intensive gardens [27, 62, 63]. The pioneers of the creation of columnar varieties in Russia are V.V. Kichina [64] and M.V. Kachalkin [65].

To date, five columnar varieties have been obtained and released: Vostorg, Poeziya, Priokskoe, Orlovskaya Yesenia, and Garlyanda (Table 4). All of them, except for the Orlovskaya Yesenia variety, are immune to scab. In recent years, columnar varieties have been widely grown not only in home gardens and summer cottages, but also in large industrial gardens. Cultivation of columnar scab-resistant apple varieties does not require traditional shaping and pruning of trees and 6-8-fold fungicide spraying, which not only reduces material costs by 1.5-2 times, but also reduces the burden on the environment [66].

4. Columnar apple varieties (All-Russian Research Institute of Fruit Crop Breeding, Orel, 1984-2021)

A	B	C	D	E	F	G
Vostorg [270-124 (Mayak × KV103) × 23-17-62 (814 — free pollination)]	w	Until February	170	4.3/4.3	2016	5
Girlyanda [224-18 (SR0523 × Vazhak) × 22-34-95 (814 × PA-29-1-1-63)]	w	Until the end of February	120	4.3/4.3	2018	5
Orlovskaya Yesenia [224-18 (SR0523 × Vazhak) × 22-34-95 (814 × PA-29-1-1-63)]	w	Until February	170	4.3/4.5	2019	5
Poeziya [224-18 (SR0523 × Vazhak) — free pollination]	w	Until February	140	4.4/4.3	2015	5
Priokskoye [224-18 (SR0523 × Vazhak) — free pollination]	w	Until February	150	4.5/4.4	2014	5
*X*average.			150			
LSD_{05}			26,7			

Note. A — variety and its origin (variety, crossing varieties), B — fruit ripening period, C — keeping quality of fruits, D — fruit weight, g, E — appearance taste of fruits, score (maximum score 5.0), F — year of inclusion in the State Register, F — region of admission (2 — North-West, 3 — Central, 4 — Volga-Vyatka, 5 — Central Black Earth, 6 — North Caucasian, 7 — Middle Volga, 8 — Lower Volga); w — winter.

Selection of apple trees to improve biochemical composition. The direction has been actively developing since 1970. Many of the apple cultivars we have created stand out for their fruit quality [23]. So, according to long-term data, the varieties Vavilovskoe ($2n = 3\times$, *Rvi6*) and Minister Kiselev ($2n = 3\times$) are characterized by a high sugar content - 13.0 and 13.1%, respectively, while the widely known varieties of folk selection are significantly inferior to them (Antonovka obyknovennaya 9.1%, Osennee polosatoe 9.2%, Moscow Grushovka 9.3%). The varieties Ivanovskoye (*Rvi6*), Veteran, Nizkorosloe and Pepin Orlovsky are characterized by an increased content of ascorbic acid in fruits (19.5; 19.4; 18.0 and 15.3 mg/100 g, respectively vs. 11.8 mg/100 g in the variety Antonovka obyknovennaya and 6.0 mg/100 g in varieties Osennee polosatoe and Grushovka Moskovskaya). The content of P-active substances was increased in the varieties Kandil Orlovsky (*Rvi6*) (558 mg/100 g), Orlovsky Pioneer (*Rvi5*) (514 mg/100 g), Pamyati Khitrovo (*Rvi6*) (480 mg/100 g) and Radost' Nadezhdy (474 mg/100 g) compared to previously widespread varieties Antonovka obyknovennaya (263 mg/100 g), Osennee polosatoe (415 mg/100 g), Korichnoe polosatoe (129 mg/100 g) (67). Apple breeding for a high content of ascorbic acid and P-active substances in fruits has great prospects, since the introduction of vitamin varieties into production will increase the nutritional and therapeutic value of fruits.

The presented data show that a feature of our breeding program since its inception in 1965 has been the priority of high biochemical value, quality and yield of fruits in combination with resistance and other economically and technologically significant traits. In continuation of these studies, we have already obtained elite triploid apple seedlings that combine quality and yield indicators with scab immunity and columnar appearance. Such hybrid forms of apple trees have not yet existed among varieties and have not been identified among wild forms.

It is important to note that under the conditions of climate change, the improvement of varieties in terms of yield size and quality, stability and adaptability, resistance to abiotic and biotic stresses becomes even more relevant and requires an in-depth and comprehensive study of the physiological, genetic, cytoebriological characteristics of crops [6, 12, 60, 68]. Breeders around the world continue to develop new varieties with improved characteristics. Their arsenal has been replenished with modern methods — whole genome sequencing [8, 29], molecular labeling [10, 21, 29], QTL mapping [10], marker-assisted selection (MAS) and genomic (GS) selection [10, 30], genomic editing technologies (10). However, there is still a significant gap between genomics and breeding [29]. While facilitating and in some cases speeding up the process, modern methods do not reduce the value of classical selection.

Thus, the result of the 65-year breeding program was 56 state-registered apple varieties, including 38 varieties based on a fundamentally new genetic basis. For the first time in Russia and in the world, 12 triploid varieties were obtained from intervalent crossings of diploids and tetraploids, for the first time in Russia, 15 varieties immune to scab were created, as well as six triploid varieties with immunity to scab, and five columnar varieties, of which four are immune to scab. A series of varieties with improved biochemical composition of fruits has been created. To address breeding problems, a technique was developed for intervalent crossings of diploids and tetraploids using cytoembryological analysis. The issues of identifying spontaneous and creating (through hybridization) new tetraploid initial forms, the donors of diploid gametes, as well as obtaining unreduced pollen when meiosis is affected by physical and chemical agents remain topical. The next task is to create new columnar triploid varieties of apple trees, as well as triploid varieties combining columnar and scab immunity (elite seedlings with such qualities have already been obtained). Such hybrid forms of apple trees have not yet existed either among varieties or among wild-growing forms.

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