

Genetic resources of the genus *Malus* as the basis for the accelerated creation of domestic adaptive apple tree varieties

*Elena Ulianovskaya**, and *Evgeniya Belenko*

Federal State Budgetary Scientific Institution "North Caucasus Federal Scientific Center of Horticulture, Viticulture, Winemaking", 40-letiya Pobedy Str., 39, 350901 Krasnodar, Krasnodar Krai

Abstract. Innovations in the apple tree breeding process are associated with the study of the gene pool, the use of valuable samples for accelerated production of commercially popular domestic varieties. The purpose of the study is to identify the most valuable genotypes of the genus *Malus* of various origins and ploidy for the accelerated creation of domestic adaptive varieties. Modern programs and methods of breeding and variety study were used. The results of the study (2010-2020) of collection of apple trees samples growing in the conditions of the Prikuban zone of the North Caucasus region are presented. It was found that a significant decrease in yield in 2017 and 2020 in the apple tree crop as a whole (11.69-12.48 t/ha) is due to an increase in the negative complex impact of spring-summer and winter stressors on the plant. Promising samples for industrial research and breeding are identified: Gin, 12/1-21-46, 12/2-20-53, immune to scab (*Venturia inaequalis* (Cook) G. Winter), with increased adaptability to the complex effects of abiotic stressors in the region, high productivity potential (average yield 26.15-30.05 t/ha, total - 287.65-330.55 t/ha). Selected by large-fruit: Orpheus, Gin, 12/1-21-6, 12/2-20-53, 12/1-21-24 (average fruit weight is 200.3-225.5 g) for further use in breeding research and creation of high-quality southern varieties.

1 Introduction

The method of remote hybridization, especially interspecific hybridization, which is currently most frequently used in the breeding of the most important agricultural perennial plants, including apple trees, is aimed at improving the created sample according to the characteristics of stability and adaptability to abio- and biotic stressors of the environment, which are closely related to the manifestation of increased and stable productivity of the genotype under stressful conditions, as well as at strengthening the qualitative and biochemical composition of fruits [1-4]. Active use of the induced polyploidy and remote hybridization methods in fruit plant breeding, including their combination or sequential application, helps to enhance the diversity of qualitative and quantitative significant traits of hybrid progeny, increase the number of combinations and variations of the most important

* Corresponding author: ulyanovskaya_e@mail.ru

economic traits in new genotypes, increasing the probability of creating the most valuable ones for breeding and production use [2, 5-7]. In order to speed up obtaining the most important results for the priority goals of a long and time-consuming breeding process, most of the world's scientists successfully use the entire genetic potential of cultural biodiversity to create the latest improved genotypes of leading fruit plants, including apple trees [1, 3, 8-10]. The breeding use of only a small number of initial forms leads to a serious decrease in the resulting biodiversity, hindering the successful solution of breeding problems [8]. Especially for the "breakthrough" areas of fruit plant breeding, including the creation of new valuable forms with high resistance to abiotic stressors, biotic stressors of the growing region environment and their complex, the use of the entire genetic potential of the crop is most valuable and does not lose its relevance over time, becoming increasingly important. Often, the role of valuable genetic sources of inherited variability within a crop belongs to species, native, local varieties, half-culture forms, polyploids, interspecific hybrids, which show a degree of variation in traits that are significant for breeding to a greater extent, as well as new genotypes created on their basis in the cultivation region [11-13]. In conditions of a serious increase in the negative impact of the environment on the fruit plant, the involvement in the breeding of new material with increased adaptability to abiotic and biotic stressors of the environment, stable fruiting, obtained on the basis of the gene pool of half-culture, wild-growing, local varieties and forms is a significant biological resource for the successful solution of modern breeding priorities in the future [1, 14-17]. The purpose of the study is to identify the most valuable genotypes of the genus *Malus* of various origins and ploidy for the accelerated creation of domestic adaptive varieties.

2 Materials and methods

Objects of study are genotypes of apple trees (*Malus × domestica* Borkh.) of different ploidy and genetic origin of the collection of the FSBSI SKFNTSSVV. Apple tree plantings are located in the North Caucasus horticulture region of Russia, the Prikuban zone, and the Central subarea. Gardens of the 2000-2004 year of planting on the rootstock M9, schemes: 5×1.5 m; 5×2 m, EPF "Centralnoye" (city of Krasnodar). To assess the dynamics of yield on the apple tree crop as a whole for the period 2010-2020, data on 246 samples of the collection being in the heavy bearing season are summarized. The study was carried out with the financial support of the Kuban Science Foundation in the framework of the scientific project No. IFR – 20.1/92. Research work was carried out according to breeding programs and methods: "Program of the North Caucasus Center for the selection of fruit, berry, flower and ornamental crops and grapes for the period up to 2030"; "Modern methodological aspects of the breeding process organization in horticulture and viticulture"; "Program and methodology of variety studies of fruit, berry and nut crops".

3 Results and discussion

Knowledge of the limits of both varieties and apple tree crops reaction to uncontrolled stress factors in the region is necessary to ensure the maximum possible productivity of the agroecosystem. In the conditions of southern gardening, the main stress factors of the winter period are early frosts (in late autumn and early winter, the third decade of November - I-II decade of December), critical winter frosts in mid-winter, frosts during the thaw (the second decade of February), return frosts (late February, March) and spring frosts. Nevertheless, their impact on the productivity of apple tree crops in the south of Russia is not the same. Comparing the frequency of each abiotic stressor repetition in the winter period in the conditions of the Central subarea of the Prikuban zone of the North Caucasus region over the last twenty

years (2001-2020) and the preceding twenty years (1981-2000), we note a number of changes (Table 1).

Table 1. Winter stressors of the North Caucasus Horticultural Region

Winter stress factors	T min, °C (year)	Repetition rate, %
1981-2000		
Early frosts	-15.9 °C (1993); -11.6 °C (1999); -15.9 °C (1989) -16.2 °C (1993); -19.4 °C (1997)	46
Winter frosts	-26.5 °C (1987/88)	9
Frosts during thaw	-21.2 °C (1986); -20.5 °C (1994)	18
Return frosts	-26.5 °C (1985); -25.6 °C (1986)	18
Spring frosts	-2.8 °C (1999)	9
2001–2020		
Early frosts	-16.7 °C (2002); -11.5 °C (2011); -17.0 °C (2016)	25
Winter frosts	-24.6 °C (2001/02); -27.7 °C (2005/06); -20.5 °C (2009/10); -22.1 °C (2014/15)	33
Frosts during thaw	-20.8 °C (2012)	9
Return frosts	–	0
Spring frosts	-5.6 °C (2004); -2.3 °C (2005); -1.8 °C (2009); -2.7 °C (2020)	33

If earlier (1981-2000) early frosts were most frequent, then in recent years - these are frosts in the middle of winter and spring frosts, the frequency of repetition of each increased from 9 to 33 % or 3.7 times; in general, it was 66 %. Nevertheless, apple trees, in contrast to stone crops, are more adaptive to the negative effects of low-temperature stressors in winter and early spring. During the period of deep dormancy the crown, vegetative and generative buds of most apple tree varieties can withstand a drop in temperature to -25-27 °C, with the exception of a number of Western European and New Zealand varieties that were seriously affected by the January frosts in the winter of 2005/06. In recent years (2001-2020), milder winters have been observed in terms of severity (Table 2).

Table 2. Comparison of the severity of winters (North Caucasus horticulture region)

Absolute annual T min, °C	Year	Winter characteristics	Frequency of occurrence
Above -10 °C	1991/92 1998/99	Very mild	2/20 (10 %)
	2003/04; 2017/18; 2018/19;		3/20 (15 %)
From -10 °C to -20 °C	1982/83; 1983/84; 1988/89; 1989/90; 1990/91; 1992/93; 1994/95; 1995/96; 1996/97; 1997/98; 1999/2000	Mild	11/20 (55 %)
	2000/01; 2002/03; 2004/05; 2006/07; 2007/08; 2008/09; 2010/11; 2012/13; 2013/14; 2015/16; 2016/17; 2019/20		12/20 (60 %)
From -20 °C to -25 °C	1981/82; 1986/87; 1993/94	Moderately mild	3/20 (15 %)
	2001/02; 2009/10; 2011/12; 2014/15;		4/20 (20 %)
Below -25 °C	1984/85; 1985/86; 1987/88	Moderately cold	3/20 (15 %)
	2005/06		1/20 (5 %)

In the 21st century, only one winter (2005/06) can be considered moderately cold, which is 3 times lower compared to the previous period. In the last decade, there were no moderately cold winters, most of them were mild and very mild, which is due to the general trend of climate warming in the world [18, 19]. An increase in the number of very mild and mild winters often provokes an early exit from the dormant period of apple tree plants, especially early summer and summer varieties. The role of varieties resistant to spring frosts, as well as genotypes with high regenerative abilities, is increasing. The winter of 2019/20 in the central zone was quite warm and mild, with a minimum temperature in February (-13.7 °C), frosts up to -5.0 °C in the second decade of March, which, according to laboratory and field studies, did not significantly affect the development of generative buds of most of the studied

varieties, with the exception of insufficiently frost-resistant early-summer varieties: Kirmizak Krasny, Sukhskaya Krasavitsa, Piros (Figure 1).

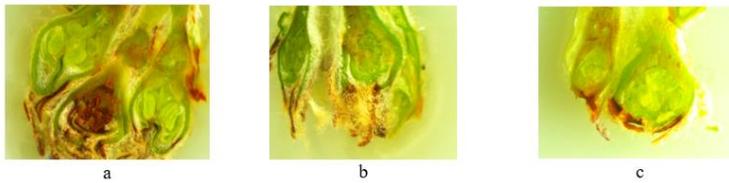


Fig. 1. Microphoto of a longitudinal section of a generative apple tree bud at the end of March 2020 (magnification $10\times 10\times 1.5$, without dye): a - early summer variety Piros; b - winter variety Renet Platona; c - autumn variety Honey Crisp

Nevertheless, further frosts to $-2.7\text{ }^{\circ}\text{C}$ in April caused the death of flowers (especially central) and inflorescences of apple tree varieties, especially early summer (Rassvet, Kirmizak Krasny, Sukhskaya Krasavitsa, Plamy Kubani, Piros – death up to 70-95 %, Feya – up to 45-60 %) and summer (Soyuz – 65-75 %, Dayton – 55-65 %, Early Mac – 40-50 %, Fortuna – 20-35 %, Zolotoye Letneye – 20-25 %), as well as insufficiently stable to freeze winter varieties: Red Jonagold, Cameo, Eliza (80-85 %), Red Delicious, Starkrimson, Red Chief (85-100 %). The death of flower buds was in autumn, winter and late winter varieties: Azimut, Spartak, Ketni, Nikita – 10-15 %, Margo – 10-25 %, Gin, Nocturne, Vasilisa – 20-35 %, Nika, Zolotaya Korona – 30-35 %, Lyubimoye Dutovoy, Liberty, Rumyanii Alpinist, Persikovoye, Gala, Gala Schniga, Renet Platona – 30-40 %, Renet Simirenko, Renet Kubanskiy, Orphej, Prikubanskoe – 40-60 %, Enterprise, Malinovi Delicious, Moldavskoye Krasnoye, Kubanskoye Bagryanoye, Bagryanets Kubani – 65-80 %. As a result of the negative impact of the stressor – in varieties that are unstable to spring frosts: Red Chief, Red Delicious, Plamy Kubani, Piros, Kirmizak Krasny, Sukhskaya Krasavitsa the harvest was completely absent or was low (Rassvet, Cameo, Pink Lady, Jonagold Prince, Red Jonagold - 0.7-9.5 t/ha).

An adaptive reaction of a number of varieties to the stressor action: a longer flowering period in comparison with the average long-term; flowering at a later date; high ability to regenerate by awakening adventive buds near the dead; the presence of "second and third waves of flowering". This allowed the most adaptive varieties to the abiostressor complex to form a yield of 22-38 t/ha or more. Basically, these are varieties that have specific and complex interspecific forms in their breeding record, varieties of national and local breeding, as well as new varieties of regional breeding obtained on their basis.

For the successful realization of the biological potential of apple tree productivity in the south of Russia, resistance to the complex effects of stressors is of great importance. In recent years (2010-2020), there has been a significant increase in the average air temperature in comparison with long-term data, including in May-September - the most important period of fruits growth, development and ripening (Figure 2).

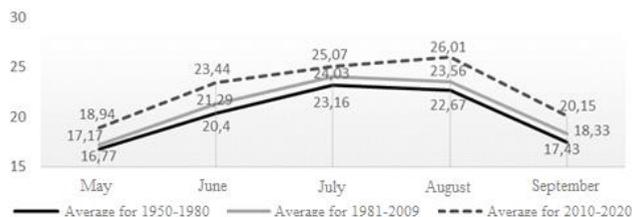


Fig. 2. Average monthly air temperature ($^{\circ}\text{C}$) from May to September in the period 2010-2020 in comparison with long-term data (city of Krasnodar)

An increase in the maximum air temperature (T_{max}) has also been noted in recent years. In 2017, from May to October inclusive, T_{max} exceeded the value of $30\text{ }^{\circ}\text{C}$; and in 2017 and in 2020, in the period from June to September inclusive, T_{max} varied in the range of $34.7\text{--}38.7\text{ }^{\circ}\text{C}$ and $35.0\text{--}38.4\text{ }^{\circ}\text{C}$, respectively, which, in general, combined with a lack of precipitation, instability of the moisture regime, negatively affects the quality and quantity of the yield. The analysis of the dynamics of the average yield for the apple tree crop as a whole allowed to establish that in the years of the most severe impact of the abiotic stressor complex on the apple tree plant, a significant decrease in crop yield was noted (Figure 3).

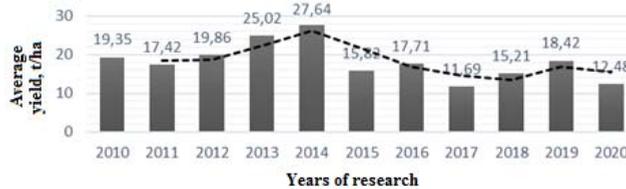


Fig. 3. Dynamics of average yield (t/ha) for apple tree crop, 2010-2020

A significant decrease in yield in the apple tree crop was noted in 2017 and 2020 (11.69 and 12.48 t/ha), respectively, which is caused by an increase in the negative impact of the abiotic stressor complex on plants. The negative impact of stressors on the plant at the beginning of winter (early frosts in December 2016 to $-17.0\text{ }^{\circ}\text{C}$) or in spring (frosts in April to $-2.7\text{ }^{\circ}\text{C}$ in 2020) was enhanced by the further negative impact of both biotic stressors (the development of epiphytotic scab, powdery mildew and other fungal pathogens during the growing season) and abiotic stressors in the summer-autumn period – a combination of abnormally high temperature stresses, instability of the moisture regime, uneven supply of moisture to the plant and often severe and long-term precipitation deficits. According to the data of long-term variety testing, varieties and forms of apple trees of domestic breeding were identified (FSBSI SKFNTSSVV together with FSBSI VNIISPK): Azimut (Delishes \times Balcgard 0247E); Lyubimoye Dutovoy (Royal Red Delicious \times 13-83-88 (Antonovka ploskaya \times Nesravnennoye)); Gin, 12/2-20-53, 12/1-21-24, 12/1-21-46 (Idared \times Balcgard 0247E), Nika (Golden Delishes 4X \times 2034 (F2 *M. floribunda* \times Golden Delishes)); Orpheus (Golden Delishes 4X \times OR18T13 (Wolf River \times (Wolf River \times *M. atrosanguinea* 804/240-57)); 12/2-20-24, 12/2-20-48 (Korei \times Prima); 12/1-21-6 (Stark John Grayms \times Prima), resistant and immune to scab, with increased adaptability to the abiotic stressor complex of the region (Table 3). Their increased adaptive potential is probably due to the fact that most of them have wild species and forms, polyploids, old and local varieties, and complex interspecific hybrids in their breeding record.

Table 3. Assessment of yield and fruit weight of apple tree varieties and forms, 2010-2020

grade, form	ploidy	fruit weight, g		yield (2010-2020)			
		m av.	m max	average		total	
				kg/tree	t/ha	kg/tree	t/ha
Azimut*	2n=2x	174.2	249.6	17.18	22.90	188.98	251.90
Gin*	2n=3x	207.8	292.5	19.62	26.15	215.82	287.65
Nika*	2n=2x	175.3	209.5	17.67	23.55	194.37	259.05
Lyubimoye Dutovoy	2n=2x	174.3	218.9	18.58	24.77	204.38	272.47
Orpheus*	2n=2x	204.5	278.8	18.25	24.32	200.75	267.52
12/2-20-24*	2n=2x	183.3	220.8	18.41	24.54	202.51	269.94
12/2-20-48*	2n=2x	155.6	190.8	16.38	21.83	180.18	240.13
12/2-20-53*	2n=3x	207.5	301.6	20.15	26.86	221.65	295.46
12/1-21-24*	2n=3x	225.5	286.3	14.48	19.30	159.28	212.30

12/1-21-46*	2n=2x	179.2	191.8	22.54	30.05	247.94	330.55
12/1-21-6*	2n=2x	200.3	229.2	15.25	20.33	167.75	223.63
Margo* (k)	2n=2x	194.5	281.6	18.43	24.56	202.73	270.16
LSD ₀₅		2.81	4.11	0.95	1.09	3.14	3.62

Note: * - variety, form have the *Rvi-6 (Vf)* gene of immunity to scab according to the DNA analysis performed in the breeding and biotechnological laboratory of the FSBSI SKFNTSSVV

Varieties with high elite productivity potential 12/1-21-46, 12/2-20-53 and the Gin variety (average yield of 26.15-30.05 t/ha, total - 287.65-330.55 t/ha) were identified. At the control level, the yield of the following varieties was noted: Orpheus, Lyubimoye Dutovoy, elite 12/2-20-24 (24.32-24.77 t/ha). According to large-fruitness varieties were allocated as diploids: Orpheus and 12/1-21-6 (with an average fruit weight of 200.3-204.5 g), and triploid varieties and elite forms: Gin, 12/2-20-53, 12/1-21-24 (the average weight of the fruit is 207.5-225.5 g).

4 Conclusions

For the successful realization of the biological productivity potential of apple tree varieties, the presence of high adaptability parameters to bio- and abiotic stressors of the environment and their complex effects on the plant is becoming increasingly important. According to the long-term data (2010-2020) of the yield assessment for 246 samples of the collection, it was found that a significant decrease in yield in 2017 and 2020 in the apple tree crop as a whole (11.69-12.48 t/ha) is due to the increased negative impact of the complex of abiotic stressors of the winter, early spring and summer periods on the plant. The increase in the frequency and strength of the negative impact of the entire complex of environmental stressors on the apple tree plant in recent years makes it possible to conduct accelerated mass and individual selection of samples of the gene pool for high adaptability in the conditions of the region, identifying the most valuable varieties and forms for breeding and production. Based on the results of variety testing in the conditions of the North Caucasus region, promising for industrial study and selection were identified: Gin, 12/1-21-46, 12/2-20-53, immune to scab, with increased adaptability to the complex effects of abiotic stressors in the region, with high productivity potential (average yield – 26.15-30.05 t/ha, total - 287.65-330.55 t/ha). Varieties were selected based on large-fruited trait: 12/1-21-6, 12/2-20-53, 12/1-21-24, Orpheus, Gin (average fruit weight 200.3-225.5 g) for further creation of high-quality southern varieties.

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