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# Genetic Apricot Resources and their Utilisation in Breeding

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## Abstract

This chapter outlines the evolution of apricot which took place not only in its original gene centers but also after its domestication in new, secondary areas. During this process, Ice Age, migration of nations as well as the influence of mountains played a significant role in the diversity of this fruit species where many clones of genetically similar cultivars and ecological groups of apricots were formed. The chapter presents the list of donors of main biological and economic properties which are important in breeding to increase the adaptability of the species. The chapter summarizes some of the breeding results and inheritance of characters related to frost hardiness of blossom buds, fruits and plum pox virus (PPV).

**Keywords:** apricot, *Prunus armeniaca* L., germplasm, inheritance, breeding

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## 1. Introduction

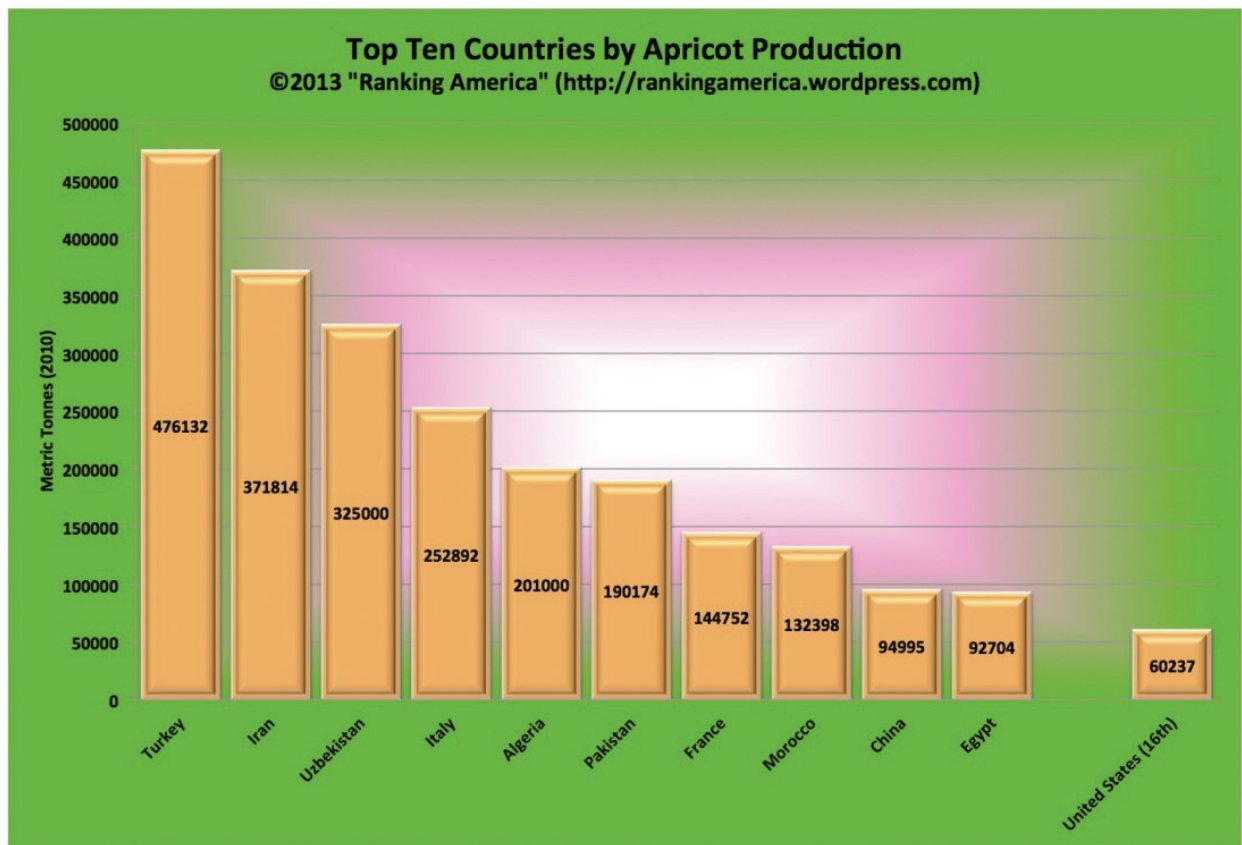
Man has participated in the evolution of cultivated plants by selection as well as by controlled evolution, that is, crossing. In the past, most or all wild fruit trees possessed certain properties that were beneficial and tempting for humans. Plants were also known for their changeability due to the influence of external conditions but also to breeding with related varieties. As a result, even in their wild form, hybrids with complex genetic bases were created. Their seeds gave rise to many distinct types which were preserved and in fruit trees this initiated either accidental or intentionally developed bud mutations which also led to a greater diversification of species. This method of propagation is being used in some areas of Central Asia and China to this day, and, as a result, even within the European group of apricots, we have been

able to select some interesting varieties with higher adaptability to the environment (Sucre de Bohutice, Rosa Early, Holubova, Pourtáleská, Kecskemete Rozsa, Kamenickyi and so on).

In all countries where apricots can be grown, apricots enjoy great attention. With the change of economic factors and growing influence of globalization, further development of apricot-growing activities is determined mainly by the three following factors:

- 1. Costs are on the increase, mainly the cost of labor which is not offset with corresponding yield per hectare and price, particularly where traditional varieties of apricots are grown.
- 2. Due to the spread of plum pox virus (PPV)—Sharka and European stone fruit yellows (ESFY) phytoplasma into previously unaffected areas—the yields here are lower and so is the quality of fruits.
- 3. An unresolved problem in apricot growing persists which causes early death and therefore results in significant economic losses.

The overall trend of world apricot production is rising, currently at approximately 2.2 million tons of apricots a year. From 1950 to 2000 the worldwide production of apricots increased four times. Some major European countries growing apricots include Spain, Italy, France, Greece, Ukraine, Moldova and others. In addition to these main producers, there are also other world producers such as Turkey, Iran, Uzbekistan, Algeria, Pakistan, and Morocco, as shown in **Figure 1** [1].



**Figure 1.** Top ten counties by apricot production.

## 2. Domestication and selection of apricots

### 2.1. Domestication and genetic diversity of apricots

The origin of all eco-geographic groups of apricot dates to the beginning of the Tertiary Period and is associated with the Northern and Middle China centers, which gave origin to more than 100 species of stone fruit, particularly to cherry, peach and apricot. In the Tertiary Period, apricot trees were found abundantly in extensive mountainous parts of Northern and Middle China, where, because of changing conditions, a process of forming and creation of new ecotypes was developed through natural selection best adapted to the changeability of the environment.

Ice Age, as stated by Kostina [2], played a significant part in the formation of individual apricot varieties mainly on the edges of apricot-growing areas. In the North, frost-resistant varieties were formed with shortest vegetation period, that is, the xerophytic dwarf variety of *Armeniaca sibirica* and its related variety of *A. Davidiana* and a forest tree, *A. mandshurica*. Kostina further suggests that the greatest diversity of varieties and forms can be found from the middle to northern area of the overall species region of China which is represented by *A. vulgaris*, *A. Davidiana*, *A. mandshurica* as well as *A. ansu* and *A. mume* varieties. The connection of different areas of several varieties with easy breeding potential facilitates great diversity among both domesticated and wild apricot trees.

In relation to the presence of the only variety *A. vulgaris* in the western part of China (Tian Shan), and, with regard to comparable unity of these apricot forms, we can deduce that this area is of secondary and later origin as a result of migration of Common Apricot from the primary Chinese area westward. At the time, when the climate in these mountains was not so arid and the mountains were covered in woody vegetation, they could provide a sort of bridge between woody flora of China and the eastern part of Tian Shan.

The formation and movement of apricot was probably a lengthy one and commenced with the beginning of human agricultural activities. It was then when humans started to plant first orchards in the mountains by cutting the trees around their settlements, leaving only those who provided edible fruits. This activity had a considerable influence on the diversity of wild apricot trees with juicy and sweet flesh. The earlier natural biodiversity of more abundant varieties represents even today's abundance of apricot varieties in the mountainous parts of Tian Shan and Northeastern China. Subsequent introduction of apricots as a domesticated species means a new era of apricot tree evolution influenced by artificial selection.

Man has influenced the growth of the apricot for a significant period of time. Historical records prove that as early as 4000 B.C., apricot trees accounted for widespread cultivated fruit trees in China. Later, via Central Asia, the apricot spread to Western Asia. It was only at the beginning of our century that the apricot made its way from Armenia to ancient Rome and was called the Armenian apple at the time. Simultaneously, the apricot made its way from China to Central Asia where it was possible for it to be formed autonomously by domestication of local wild apricot trees from Tian Shan. This process of transmittal into areas of wild growing apricots can be observed in many regions of Eastern Kazakhstan and Kyrgyzstan where "mountain" apricots are regarded as the most frost-resistant types and less sensitive than cultivated species [2].

Cultivated types of the basic *A. vulgaris* variety went through significant changes and took on various characters when moving west and south from China to Central Asia. This happened because of many evolutionary factors (external conditions, environment, changeability of inheritance and natural or artificial selection). As the role of artificial selection was of most important significance, these changes were reflected mainly in the quality of fruits (size and taste) but also in some economic traits such as frost resistance, immunity to main fungal diseases and biology of propagation.

The simplicity of generative propagation and a commonly known method of vegetative apricot propagation have played a key role in the intensity of selection and vegetative propagation of most economically valuable differences. The comparison of the current cultivated range of apricot with wild varieties in Western and Central Tian Shan provides evidence of gradually acquired biodiversity of traits in apricots. Primary differences between these two groups are based on the size of the fruit. Wild grown apricots in Tian Shan weigh from 3.0 to 35 g (an average of 8–12 g), domesticated varieties of Central Asia from 5.5 to 55 g (an average of 15–30 g) and Irano-Caucasian and European domesticated varieties weigh from 10 to 165 g (an average of 30–55 g). Other traits include sugar and acidity contents, taste, kernel taste, skin pubescence and stone size [2].

The evolution of cultivated apricots in Europe took on a slightly different direction because of its shorter history in this region. The apricot first arrived from Iran to Ancient Greece and Rome and to southern Europe. A more or less substantial spread of the apricot in Europe was not achieved until the seventeenth century. At the same time, a brief period of growing and limited original material domination of vegetative propagation and a very low degree of seed propagation in the apricot have all led to a lot more limited diversity in European apricots. Direct consumption of apricot fruits initiated the selection and vegetative propagation of those varieties which had been formed as random seedlings in orchards and nurseries. Basic characteristics that presented value in introducing apricots as fruits used in their fresh form were the size of fruits, a comparable low stone-to-flesh ratio, excellent taste, harmonious constitution of sugars and acids, aroma and flesh firmness.

Vavilov highlights the importance of mountains when clarifying the variety of cultivated plants [3, 4]. Vavilov states that apricots are grown in their three centers of origin. Key areas of these centers are Central China (Gansu Province, mountain areas of Northeastern and Central China and Northeastern Tibet) and Central Asia (mountain areas stretching from Northwestern Iran, the Caucasus Region to Central Turkey). Vavilov found that the center of Near East is a secondary center for apricots in terms of originally grown varieties. As these findings on the origin and evolution of growing apricots outline, the importance of mountains when clarifying biodiversity of apricot species and varieties is unquestionable. The connection of wild species and forms, old and formerly grown varieties with mountains is also confirmed when studying the terrain of regions in Central Asia [3] (**Picture 1**).

The apricot spread to Europe from Central Asia, through Iran and into the trans-Caucasus Region and then further West. This movement was conditional to war campaigns and economic and cultural exchange during the arrival of Alexander the Great in the area from Turkistan to the Fergana Valley in the fourth century BC. Another shift of the apricot westward





**Picture 1.** The mountains and valleys of Western Pamir (photo by Saodatkadamova T.M.).

took place in two stages. Apricots were known in Italy and Greece as a result of the Roman-Persian wars in the first century BC. The species of *Armeniaca* suggests that apricots were first brought to Italy and Greece by Armenian traders. This happened much later when the apricot was already grown in other parts of Southern Europe [5].

Because of lack of biological material, the specification of local varieties in North Africa and Spain is not highlighted. Here, apricots were brought mainly by the Arabs from Syria and they kept their Syrian names (mesh mesh and mush mush). For the character of its fruits and biological properties, this group can be assigned to the Irano-Caucasian ecological geographic group. However, these were classified as a North African group adapted to warmer climate [6].

The process of domestication in Mediterranean species results in a loss of diversity which is far greater in fruit species introduced into Mediterranean areas compared to the species native to this region (olive and grape). By comparing genetic diversity among regional apricot gene pools in several Mediterranean areas, the loss of genetic diversity associated with apricot selection and diffusion into the Mediterranean Basin was investigated [7]. Microsatellite markers were able to detect a marked domestication bottleneck in the Mediterranean apricot material. This led to the depiction of a global image of two diffusion routes from the “Irano-Caucasian” gene pool: North Mediterranean and Southwest Mediterranean. It also assessed a significant loss of genetic diversity from the “Irano-Caucasian” gene pool, considered as a secondary center of diversification, to the Northern and Southwestern Mediterranean Basin. A substantial proportion of shared alleles were specifically detected when comparing gene pools from the “North Mediterranean Basin” and “South Mediterranean Basin” to the secondary center of diversification. Based on the three main identified gene pools, we observed a significant and substantial loss of apricot genetic diversity, ranging from about 37 to 49%

from the secondary apricot diversification zone (“Irano-Caucasian”) to the Southwestern Mediterranean Basin, depicting a genetic signature of apricot domestication and diffusion into the Mediterranean Basin. Unlike Kostina’s assumptions, we proposed an evolutionary scenario in favor of two diffusion routes in Southern Europe and North Africa as revealed by a substantial proportion of shared alleles that were specifically detected along each of the two diffusion routes [8]. This study generated genetic insight that will be useful for management and conservation of Mediterranean apricot germ-plasm as well as genetic selection and breeding programs related to adaptive traits [7].

## 2.2. Selection of donors of characters related to breeding aims

Breeding programs of all countries with economically significant apricot production are based on the effort of obtaining varieties with wide or varied ecological adaptability regarding their production areas. The efforts are to create varieties that are adaptable to low temperatures, mainly to sudden temperature changes during the post-dormancy period, but also to meet requirements for a small number of chilling units in winter. Since the apricot requires specified eco-climatic conditions as outlined by its phylogenesis, it lacks the ability for wide environmental adaptability as opposed to, for example, the apple variety Golden Delicious or the peach variety Redhaven. The change in the traditional range of apricots is also caused by globalization, methods of sale, requirements of vendors and the fact that in the European market apricots are of increasingly higher importance as a fresh commodity.

Successful introduction of new apricot varieties should focus on main targets which are similar in most growing periods. Generally, it is possible to summarize breeding aims into several objectives:

- Adaptability to both cold and warm areas: To achieve an appropriate level of adaptability, it is important to assure a good degree of frost resistance. Furthermore, it is a requirement for a small or large number of chilling units, long or short dormancy periods, slow development of pollen microsporogenesis during the post-dormancy period, late blooming period, frost hardiness and autogamy.
- Ideotype of fruits: For their utilization, it is important fruits comply with certain criteria, that is, the size and firmness of fruits, attractive appearance, taste, aroma, sugar and acid contents.
- Resistance to diseases and early death: In Europe, for example, the main objective is breeding apricots resistant to Sharka—PPV, European stone fruit yellows (ESFY), brown rot, *Cytospora* and bacteria such as *Pseudomonas* spp. and *Xanthomonas* spp. and early decline as a result of pathological factors and environment.

It is possible to say that all the aforementioned breeding aims are of fundamental importance and are pursued by a majority of breeders worldwide. Complimentary breeding objectives include growth control, so called dwarfism or semi-dwarfism, the compatibility of varieties with diverse rootstock, crown habitat and its suitability for different modern breeding shapes and resistance to drought.

Michurin used the seedlings of Mongolian, Siberian and Manchurian apricots as donors for frost hardiness and increased adaptability. Abrikos No. 84, No. 86, No 241, No 246, Mongol, Sacer were utilized as Mongolian apricot seedlings and Lučšij Mičurinskiy and Tovarišč as the seedlings of *P. sibirica*. To increase frost hardiness, it is recommended to breed apricot varieties with varieties that are native to countries further away from the center of cultivated varieties, such as those of Asia Minor, Palestine and Persia [9].

To increase the frost hardiness of flower buds, breeding apricots with *P. salicina* L. while creating several fertile types with transitional traits called “Plumcot” have been suggested. It has been highlighted that the Royal variety can be grown in many regions where other apricot varieties do not bear fruit and may prove to be a valuable material for further selection [10].

Hummel created a list of *Prunus* varieties which are known as frost hardy or grown with minimal damage in zones classified according to frost hardiness from 4b (from  $-30$  to  $-20^{\circ}\text{F}$ , which is  $-34.4$  to  $-28.9^{\circ}\text{C}$ ) to zone 1 (below  $-50^{\circ}\text{F}$ , below  $-45.6^{\circ}\text{C}$ ). For zone 4a varieties such as Anda, Harbin and Labin—all seedlings of *P. mandshurica* L.— and then Manchu and Moongold, Morden 604, Morden 601 and Scout and others have been chosen [11].

The basic requirement for breeding, selection and further introduction of new varieties is knowledge of a wide collection of genotypes, varieties, clones and landraces of all ecological groups of *P. armeniaca* L. This enables breeders to select donors of individual properties which they expect to appear in the progeny’s genotype. At Horticulture Faculty in Lednice, studies have been carried out since 1985 on several apricot collections of genotypes, and several years of observations have helped in choosing the most important characters connected with adaptability to environment [12]. The analysis of these characters enables breeders to choose parents—donors of characters and conservation of genetic characters. Genetic improvement of apricots as a species is possible in all characters relating to increase in adaptability. However, it usually takes a longer period of time. The following donors of characters have been chosen.

### 2.2.1. Frost hardiness of flower buds

In different years and in different collections, the frequency of genotypes having a high level of frost hardiness of flower buds varied from 8.6% to almost 18% of all observed apricot progeny. Genotypes having fruits presenting a good market value and a high frost hardiness had a frequency of occurrence varying from 2 to 48% (**Table 1**). Some of the frost-hardy cultivars are Harlayne, Harval, Leala, Lejuna, Leronda, Leskora, Lenova, Lejara, LE-498, LE-806, NJA 1, Vivagold, Volschebnyi, Vynoslivi, Yulskyi, Strepet, Harrow Star, NJA 35, NJA 62, NJA 77, NJA 44, Veharda, Vegama, Harcot, Saldcot, Vyndrop, Alfred, Reliable, apricot seedlings of the serious M-LE-1, M-VA-3, M-VA-2, M-VA-1, Dzhankojskiy rannyi, Arzami, Henderson, Morden, Senetate, VS 023/187, Riland, Veecot, Vestar, Lunnik, Harglow, Stark Early Orange, Orange Red, Scout and Lel.

### 2.2.2. Late termination of dormancy

A higher frequency of phenotypes (16%) was observed with late ending of dormancy character, globally. From the breeding and practical points of view, genotypes presenting a combination



Characters	Categories	No. of individuals	Frequency
<b>Frost hardiness of flower buds</b>		<b>346</b>	<b>1</b>
	High hardiness	182	0.135
	Hardiness + market value of fruits	56	0.042
<b>Termination of bud dormancy</b>		<b>82</b>	<b>1</b>
	Late	13	0.159
	Late + market value of fruits	6	0.073
<b>Frost tolerance of juvenile fruits more tolerant</b>		<b>209</b>	<b>1</b>
	Than control	37	0.177
	More tolerant + market value of fruits	14	0.066
<b>Blooming time</b>		<b>489</b>	<b>1</b>
	Late	29	0.059
	Late + market-value of fruits	13	0.030
<b>Self-fertility</b>		<b>124</b>	<b>1</b>
	Self-fertile	44	0.354
	Self-fertile + market value of fruits	31	0.250

**Table 1.** Frequency of the most important characters of apricots connected to their adaptability [12].

of both characteristics (late dormancy time and fruit quality) are very interesting, but this was the case for only 7% of analyzed progeny (Vestar × Stark Early Orange). Henderson, ChuanZhi Hong, Lebela, LE-498, Oranzevo-krasnyi, Stark Early Orange, Vegama, Veharda, Zard, Vynoslivi, Reliable, NJA2 and Curtis are varieties exhibiting late termination of dormancy.

### 2.2.3. Frost tolerance of juvenile fruits

Almost 18% of observed genotypes showed a higher frost hardiness in young fruits than the control clone Velkopavlovická LE 12/2 /type Hungarian Best. Other genotypes having pomological characters answering market requirements were altogether 6.7% in the whole collection. For example, cultivars such as Leala, Lemira, Ledana, Leskora, Lejuna, Lefrosta, Neptun, Re Umberto, Henderson, Early Gold, Zard, Oranzevo-krasnyi, Marculești 17/2, Horáková raná, Fara, Rakovskyi, Bergeron, Reumberto, Marlen, Detskyi, M 146, Neptun, Triumf severa, Patriarca temprano, M 90B, Baneasa 16/3, Kamenickýi, Selenia, Mari de Cenad, NJA 33, Morden 604, Sephora, Bergeval, Big Red, Orange Rubis, Anegat, Primaya and Orangered had juvenile fruits with frost tolerance.

#### 2.2.4. Late blooming

On the contrary, the character of late blooming was observed in the lowest number of phenotypes (0.061). The frequency of individuals presenting both a late blooming and a good market value of fruit appeared to be very rare, only about 0.8% of all evaluated genotypes of apricots (Early Gold, Machova, Marculesti, *P. brigantiaca* L. xOlymp, Re Umberto, Sulmona, Stella, Pozdněkvětoucí, Frostina, Farclo, Fardao, Dolgocvetna, Polyus yuznyi, Zard, Oranzevo-krasnyi, Venus, Tilton, Selena, Badami, Kamenický, Rosa Late, Yulskyi, Ambrosia, Farbaly and Harglow).

#### 2.2.5. High level of self-fertility

High frequency of the requested values of characters was achieved on self-fertility. Of the overall number of self-fertile genotypes, 25% showed significant pomological traits. Examples of such cultivars are Bergeron, Minaret, Vestar, Kostinskyi, Leala, Marlen, Pisana, Kioto and Gergana.

#### 2.2.6. Climatic adaptation

Bergeron, Goldrich, Marculesti, Tilton, Kecskemet Rose, Leala, Lejuna, Leskora, Re Umberto, Rose Early, Vynoslivi, Bergarouge, Harrow Star, Harlayne, Tomcot, Bronzoviy and Kostinskyi show climatic adaptation. Harglow, NS-4 and Strepét also had a higher level of adaptability in the European eco-geographical groups of apricots. It includes some types bearing small fruits which come from a European subgroup as well as species from the groups Rosa Early, Holubova, Pourtal abricose, Sucre de Bohutice, Kecskemet Rozsa, Bergeron, Kamenickiy and other types of natural population.

#### 2.2.7. Field tolerance to European stone fruit yellows (ESFY)

Vestar and Royer were the only two cultivars which were tolerant to European stone fruit yellows.

#### 2.2.8. Tolerance or resistance to plum pox virus (PPV)

Stark Early Orange, Harlayne, Henderson, Orangered, Betinka, Adriana, Candela, Sophia, Veecot, Leronda, Harval, Sundrop and Harcot are some of the varieties resistant to PPV.

#### 2.2.9. Attractiveness of fruits

Harrow Joy, Bergarouge, Betinka, Orangered, Rubista, Pincot, Chuan Zhi Hong, Laycot, Bobcot, Roxana, Neptun, Gergana, Veselka, Gama, Robada, Big Red, Tsunami, Carmen Top, Harrow Star, Flavor Cot, Kioto, Harrow Blush, Harogem, Magic Cot, Cegledi Piroška, Sophia, Bergeval, Sephora, Orange Rubis, Pricia, Bergeval, Swired, Gilgat, Rougemont and Montier are some of the attractive varieties.

#### 2.2.10. *Big fruit size*

Gergana, Roxana, China, Hargrand, Senetate, Goldrich, Olymp, Gama, Velikiy, Exnerova, Agat, Jumbo Cot, Goldstrike are some of the varieties that have big fruit sizes.

#### 2.2.11. *High sugar content*

Shalach, Sekerpare, Forum, Lakaniy, Strepet, Nadezda, Olymp, Kabaasi, Hacıhaliloglu, Bronzoviy, Abutalibi, Vynosliviyy, Hasanbey, Suphani and Isfarah are some of the varieties that have high sugar content.

#### 2.2.12. *Excellent taste and apricot aroma*

Velkopavlovická, Sucre de Bohutice, Sabinovská, Hungarian Best, Klosterneuburg, Krasnoscokiy, Bronzoviy, Vynosliviyy, Bobcot, Harrow Joy, Bergarouge, Hargrand, Skopljanska krupnoplodna, Royer, Paviot, Sucre de Holub, Nancy apricot, Luizet, Polonais, Betinka, Bergeval, Breda and Paviot are some of the varieties that have an excellent taste and aroma.

#### 2.2.13. *Extension of the ripening time*

In relation to late ripening, many potentially interesting parents are also available. Pisana Bergeron, Tardif de Bordaneil, Tardicot, Anegat, Farbaly, Farclo, Fardao, Kechpsar, Vynosliviyy, Helena de Roussilon, Rosa Late, Kecskemetr rozsa and Borsi-félekései rózsa are some of them.

In relation to early ripening, many potentially interesting parents are also available such as Tomcot, Magic Cot, Wonder Cot, Pricia, Spring Blush, Big Red, Bukuriya, Early Samarkand, Tsunami and Banzai [11].

All the evaluated traits exhibited a different value of variability and frequency enabling the breeders and geneticists to make more informed choices on the selection of donors for a particular character. This variability allows the integration and combination of each single character in the breeding process which will lead to the production of hybrids with a higher level of adaptability and fruit market value [12].

Increased adaptability to environment is also essential for the selection of genotypes with frost-tolerant fruits. Late spring frost which damages small developing fruits after the blooming period is more common in the Mediterranean, but from time to time it can also occur in the Central European climate. As the climate changes (milder winters, early onset of spring), spring frost after the blooming period is more frequent.

A degree of hardiness in fruits of individual varieties is of the greatest difference as conditioned by the development phase and the length and time of the critical period.

Different authors suggest that the temperatures from  $-0.5$  to  $-1.6^{\circ}\text{C}$  are dangerous for apricots after the blooming period. Djurič found no relation between the development (size) of fruits and their frost hardiness. He found that varieties with the smallest percentage of frozen fruits (Hindukush, Overnskyi, Zimostojki and Novosadski clone BC-1) had fruits of lower weight than 1 gram; however, varieties Blenril, Nugget, Royal, SEO, Kostjuženskij and NJ 27, NJ 26

and hybrid 252 had heavier fruits than 1 gram and the percentage of frozen fruits were from 69 to 100%. This means that the size of fruits is of lesser significance to sensitivity or hardness than genetic foundation of a variety character.

Among hardy varieties, Djurič further included Sacharijstyj. Melitopol early, Keč-pšar, RuchiDžuvanon and Zemljaničnij (frost damage to fruits varied from 40.1 to 60%) were categorized as semi-sensitive varieties [13].

In Italy, Bassi et al. [14] evaluated a collection of apricots at a temperature of  $-5.8^{\circ}\text{C}$  when in full bloom and for the next four consecutive nights. In 1993, when apricots were losing petals, frost occurred 6 times (from  $0.0$  to  $-4.8^{\circ}\text{C}$ ). What the team in Italy found in 1990 was that some most productive varieties had more than 80% of brown pistils and the relation between the detected percentage of brown pistils and crop yield ( $r = 0.04$ ) was not therefore confirmed.

Varieties that had fruits mostly in the upper part of the crown were Alfred, Bella di Casale, Farmingdale and Harlayne. Other varieties such as Bergeron, Precoce di Cesena, Bulida, Canino, Goldcot and Ivonne Liverani a Mandorlou showed a relatively uniform location of fruits. Very late blooming varieties from Hungary and Romania showed a very low count of buds during all the years as well as a high percentage of brown pistils even though they had bloomed after a period of frost. This defect is caused by bad adaptability of varieties from Central to Eastern Europe which demands cooler conditions [14].

Concerning the damage to the apricot fruits during spring frost at Mendel University in Brno, Horticulture Faculty in Lednice, from 1989 to 1996, the following was observed:

- i. The genotypes Leala, Lemira, Ledana, Leskora, Lejuna, Lefrosta, Henderson, Early Gold, Zard, Oranžovokrasnij, Marculešti 17/2, Horáková raná, Fara, Rakovského, Reumberto, Lednická, Detskij, Neptun, Triumf severa, Patriarca temprano, Baneasa 16/3, Kamenický, Selená, Mari de Cenad and NJA 33 conclusively or highly conclusively increased tolerance of fruits to frost than the control variety (Velkopavlovická LE-19/2,) in 2, possibly 3 years.
- ii. The genotypes Orange Red, Legolda, Shalah, Nugget, Kecskemetr rozsa, Leronda, Skaha and Lerosa showed lower resistance of fruits to frost.

It was possible to detect a highly conclusive impact of genotype, year and blooming period during these years of observation when the conditions differed each time either because of vegetation development or because of critical temperatures. The impact of blooming period was recorded as highly conclusive in relation to the percentage of frozen fruits ( $r = 0.41++$ ). In all years, the fruits of late blooming varieties sustained less damage (Reumberto, Venus, Zard, Marculesti 17/2, Neptun and Leala). However, there were certain genotypes which, despite their early or mid-early blooming period, were not significantly damaged (Bukurija, Junskej, Senetate and Henderson) [15].

Breeders also face another challenge, which is to single out the most harmful diseases and pests relevant to a particular area, recognize their biology and inheritance and explore the mechanism of resistance. They would then be able to, based on such selection, use disease-resistance donors in breeding programs with quality donors. When growing plants, resistance breeding is the most efficient, natural and widespread method of protection against pathogens [16].



Greek colleagues have worked very hard studying apricot varieties mainly in a stage after a strong natural infection. Syrgiannidis was first to describe the Stark Early Orange and Stella cultivars as resistant against *plum pox virus* based on his fieldwork between the years of 1967–1970. He then sorted the varieties into very sensitive (ProimoTyrinthos, Rouge de Sernhac), quite sensitive (Blenril, Canino, Docteur Mascle, Bergeron, Moorpark, Nugget, Rouge de Fournes, Sungold and Tilton a Stavropoulos) and less sensitive (Blenheim Royal, Ricordo di Amic and Grossa del Giardino) [17].

Murg et al. [18] recorded the results of observing 64 apricot species infected with PPV in the region of Oradea and found that Stark Early Orange, Manitoba, Farmingdale, Bolšoj Rozovoj, Blenril, King, Doty, Arzami, Pize, Smyrna, Sophie, Tarzii de Bucuresti, Selenia, Favorit, Timpurii de Chisinau, Rozova Scora, Rosii de Banesa, Magyar Kayszi and Borozi Rozsa varieties were not infected. Varieties which had no symptoms in fruits and weak symptoms on leaves were Venus, Tuzla, Saturn, Calatis, Dalia, Neptun, Sulina, Excelsior, Čačak, Raske Carpo, Joubert, Toulon and Precoce de Italia [18].

### 2.3. Achieved findings in apricot breeding

Clone selection can be regarded as an evolution of varieties when clones with higher adaptability are selected during a long-term growing period in a relatively vast area, whereas clones with lower adaptability to the environment cease to exist or are only relevant to a smaller section of areas. This is called the plasticity of a given cultivar which, influenced by its environment and length of growing, provides an array of clones with various adaptabilities. This plasticity is conditioned by the age of varieties. Hence, clone selection provides one of the solutions for increased adaptability for varieties such as Velkopavlovická, Hungarian best and Sabinovská. Clone selection can increase environmental adaptability as can the selection of additional properties other than just fertility. In the scope of several cycles of clone selection of apricots which Professor Vachůn initiated in the 60s, variability of the blooming period was also detected (a 1–2-day delay of full bloom can in some years positively influence the harvest), as was the number of blossoms with two pistils making the clones with higher number of pistils more efficient. Of other variable properties, clone selection can be used to improve the health of trees (early death or economically significant viral diseases) when even in these traits conclusive differences were found [19].

In Hungary, Nyujtó chose large fruits of local cultivars and saw the European group of apricots as being suitable enough to achieve a faster and significant improvement in cultivar adaptability using clone selection as opposed to the creation of new cultivars through crossing. His program saw the creation of varieties such as Cegledi Biborkajzi C.244, Keczkei rozsa barack C.171, Cegledi oriás and Mandula kajzi C.712. When selecting 532 items of apricot, it was discovered that the size of fruits and excellent taste are rarely related to high productivity and even less to frost hardiness and drought tolerance [20]. Later, Szabó showed that Keczkei rozsa and Mandula kajzi varieties introduced frost hardiness into its progeny dominantly and irrespective of them being used as female or male parents [21].

The degree of apricot adaptability is, to a certain extent, conditioned by the level of frost hardiness in buds, blossoms and juvenile fruits. Therefore, the period of vegetative dormancy

(its intensity and length) ensures less dependence on external environmental conditions and is a crucial factor for frost hardiness. Based on its origin, the apricot is a mountainous plant and as such is typical for its adaptability to cold winter without fluctuating temperatures. Results of many authors have shown that buds of stone fruit experience important stages of micro- and macrosporogenesis at the time of autumn, winter and spring [22].

Development of blossom buds at the time of dormancy is assured by individual changes and intensity of metabolism. Jablonskij and Elmanova found a relation between accumulated hydrocarbons and the pace of morphogenesis as well as a relation between morphological and anatomical changes and the dynamics of phenol contents in buds ( $r = 0,83$ ). This occurrence relates to the fact that most phenols inhibit the growing process. They found that the highest contents of phenols in blossom buds were present (as detected in the beginning of April) in the following varieties: Narjadniy, Vynosliviyy and Orfyand Amur [23].

Kostina et al. compared the inheritance of dormancy length in reciprocal crossing of varieties Zard and Shalah, which belong to two different eco-geographical groups with different dormancy lengths. In this cross, 34.8% of progeny inherited the character of slow development of Zard and 21.9% of progeny inherited the character of its father variety Zard [24].

The study on two progenies, where the late terminating dormancy variety Stark Early Orange (SEO) was the male variety for both of them and female varieties from early to mid-early-breaking dormancy of Vestar and Velkopavlovická LE-19/2 were utilized, observed that in both the combinations 82.1% of hybrids terminated their deep vegetative dormancy after their parents and intermediates. New traits appeared in 17.9% of progeny, of which being positive (late dormancy termination) appeared in 9.4% [25].

In her breeding work, Kostina established a dominant inheritance character in apricots from Central Asia regarding several biological traits including late blooming and increased frost hardiness if apricots in this group had been crossed with apricots in the Irano-Caucasian group or European group [8]. Crossa-Raynaud (when crossing Canino and Amerleuch showed the intermediate inheritance character of development rhythm in flower buds of blooming period [26]. Zagrodnaya also found that more than a half of observed progeny possessed frost-hardiness properties of blossom buds among parents and quite a considerable number of progeny were drawing nearer to their frost-hardy parent, particularly if this parent was used as a mother cultivar [27].

Oranževokrasniy is also recommended as a frost-hardy donor for crossing by Kostina together with Churmai variety (long dormancy period and late blooming) [24]. Hough also recommended (written statement, 1989) the crossing of Oranževokrasnyi × Orange Red with the aim of obtaining frost-hardy individuals with firm fruits and early ripening [28].

*Plum pox virus* (PPV) resistance presents one of the most discussed topics in European breeding programs. This topic has been reviewed by Zhebentyayeva et al. [29]. All apricot cultivars of European origin are susceptible to PPV. Currently, most apricot breeding programs in Europe use the PPV-resistant North American cultivars to introduce this trait into European germplasm. Resistance among apricots has been found only in some North American cultivars such as "Goldrich," "Harlayne," "Stark Early Orange," (SEO) "Stella" and "Harcot" [30, 31].

Therefore, most conventional breeding programs very often use one of these as a source of resistance in the development of new varieties. Badenes et al. were the first to suggest the role of Eastern Asiatic species, particularly *P. mandshurica*, as a potential source of PPV resistance into North American germ-plasm [32]. The results from Karayiannis et al. [31, 33] gave more support to this idea, even if not all the progenies of *P. mandshurica* were PPV resistant [34]. North American selections derived from *P. mandshurica* were introduced for their cold hardiness in midwinter and spring, late blooming and the ability to set fruit under adverse conditions for pollination [35]. Besides *P. mandshurica*, other East Asian species such as *P. sibirica* var. *daurica* and *P. mume* may also have been involved in the pedigree of PPV-resistant North American apricots. A likely scenario for introgression of resistance into North American germ-plasm might include hybridization of European apricots with Northern Chinese varieties cultivated in overlapping areas of *P. armeniaca* and East Asian apricot species [28]. The histories of apricot domestication and of its resistance to Sharka are however still poorly understood. In another piece of work, Decroocq et al. used 18 microsatellite markers to genotype a collection of 230 wild trees from Central Asia and 142 cultivated apricots as representatives of the worldwide cultivated apricot germ-plasm. The genetic markers confirmed highest levels of diversity in both wild and cultivated apricots in their original areas (Central Asia, China). Furthermore, high frequency of resistance to Sharka was detected in apricots native to Central Asia [36].

The PPV resistance trait in apricots was first mentioned by Dosba et al. [37]. In the population of Stark Early Orange × Scream, 64 inoculated (by both methods, chip budding and aphids) hybrids were tested for PPV and a polygynous character of heredity for PPV was found. Dosba et al. mentioned 30% resistant hybrids in the same hybrid combination [37]. Moustafa et al. agreed with Dosba [37]. A ratio of 3:1 sensitive/resistant genotypes in hybrid populations of North American PPV resistant varieties and local Spanish sensitive cultivars corresponds with the hypothesis of heredity to PPV resistance by two independent dominant genes. Resistance donors who used incrossing could be heterozygous for both loci. Only those heterozygous seedlings in both loci as the parental donors could be resistant [38].

On the contrary, Dicenta et al. established the ratio of 1:1 in 291 of seedlings of 20 different crossing activities between resistant and sensitive parents. Based on these results, the authors conclude that PPV resistance in apricots is controlled by one dominant gene and that resistant parents could be heterozygous even in this trait [39].

Faculty of Horticulture in Lednice has got a long tradition of apricot breeding which started in 1990 and focuses on resistant breeding against Sharka (PPV). One of the parents used in the breeding program in Lednice (Harlayne) was assessed as resistant by Martínez-Gómez et al. [40], while both Dosba et al. [37] and Fuchs et al. [41] classified it as immune.

When crossing the parents of resistant to susceptible, using Harlayne species, a hypothesis was reached on heredity of three dominant genes which are responsible for PPV resistance [42]. In the progeny derived from the four apricot crosses (resistant to susceptible), the segregation ratios were compatible with the hypothesis of three dominant genes being responsible for PPV resistance, with “Harlayne” being heterozygous for all three genes [43]. Four quantitative trait loci (QTLs) were identified of which three mapped on linkage group 1 (LG1) which explained between 5 and 39% of the phenotypic variance. This happened when analyzing quantitative

resistance of Harlayne cultivar in a large F1 population [44]. Dondini et al. established that a major QTL for resistance to both PPV-M and PPV-D strains was found in the top half of “Lito” LG1 (just like in “Stark Early Orange”) and when the resistant, tolerant and recovered seedlings were pooled together, the ratio of these to susceptible plants was fixed as 1:1, explaining why such a large part of the phenotypic variability is accounted for by a single QTL in the LG1 [45].

A first determinant was mapped on linkage group 1 (LG1) by using an F1 progeny of Goldrich 9 Valenciano [46]. These studies were also verified by a quantitative trait locus (QTL). Goldrich is known to be tolerant to the pathogen while Valenciano was highlighted as susceptible [39, 47]. This preliminary result was recently confirmed by a quantitative trait locus (QTL) analysis carried out on another F1 progeny, Goldrich 9 Currot [47]. A major QTL was also found in LG1 by the analysis of F1 and F2 progenies of Stark Early Orange (SEO) [48] and its progeny Lito [46, 49]. Minor QTL were discovered in the Polonais 9 SEO progeny in LG3 and LG5 of both SEO and Polonais [50]. The main QTL on LG1 was upheld by Sicard et al. [51] establishing new microsatellite (SSR) markers flanking the QTL and by Lalli et al. [52] in a backcross population of SEO 9 Vestar and was again confirmed by Soriano et al. [46] in the extended F2 Lito selfed progeny. Most of the resistance determinants shown above were characterized using the PPV-D strain as a source of inoculum and, at present, the only resistances specific to the PPV-M strain are those endorsed in the BC1 SEO xVestar [52] and in *P. davidiana* [44]. Dodini et al. [45] introduced a potentially different QTL which either explained a very small part of the variance or was below the LOD threshold. The markers closer to the QTL peaks would already be suitable for marker-assisted breeding. Those plants that recovered should be subjected to another observation to evaluate their tolerance or resistance.

Krška et al. studied the inheritance of resistance to PPV in F1 progeny of cross “Harlayne” × “Betinka” obtained within gene pyramiding. The observed segregation ratio (153,30,16) for the progeny of “Harlayne” × “Betinka” was not significantly different from the predicted 12:3:1 segregation ratio ( $\chi^2 = 2.551$ ,  $P = 27.9\%$ ). These findings showed that PPV resistance in apricot is controlled by two independent dominant genes with epistatic interaction, where resistance would be a dominant trait and the resistant parents (“Harlayne” and “Betinka”) would be heterozygous for both loci. Tolerant plants would be heterozygous for the hypostatic (masked) locus, and susceptible plants would be homozygous recessive for both loci. They established that it is possible to pyramidize genes for resistance to PPV in apricot and gain a cultivar with durable resistance to PPV. This principle was upheld in the apricot breeding program at the Mendel University in Brno, Czech Republic [53].

### 3. Conclusion

1. The apricot is a species with lower adaptability to the environment, which has, in the scope of its species, many genotypes—donors that can be used in breeding against biotic factors.
2. At present, there are substantial gene resources for apricot breeding and scientific activity relating to this species. These are used intensively to achieve mainly higher quality of fruits and resistance to Sharka.



3. In chosen and traditionally most significant apricot cultivars, it is essential to carry out clone selection and it is important to maintain this process so that the biological quality of clones is maintained. The use of local genotypes and clones of genetically similar cultivars should not just be the nostalgia of “good old days” but the reality of economically justified growing and agri-tourist utilization.
4. The study of apricot germ-plasm so far has enabled not only the selection of suitable genotypes to be tested in growing practice but also the selection of suitable genotypes for targeted breeding while aiming to use gene variability. Results obtained using the analysis of polymorphic markers have enabled breeders to carry out their work. It was possible to use them in the context of evaluated collection of apricot genotypes to identify the difference to assess the genetic similarity and more detailed characteristics of varieties, genetic resources and breeding material as well as for methods of early selection of progenies with chosen traits. Developed molecular markers for selection in breeding programs (MAS) represent almost a routine method today, particularly in the area of resistant breeding.
5. New methods of selection (MAS) have so far aided in early selection of traits of PPV resistance and determination of self-compatibility.
6. Currently, newly created cultivars present the opportunity of genotype selection with appropriately combined traits of resistance to abiotic or biotic pathogens but also in terms of requirement for an ideotype of fruits with increased adaptability, so that the apricot could again, as stated by Hough and Bailey, descend from the mountains.

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