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AN OVERVIEW OF APRICOT BREEDING PROGRAMS FOCUSED ON PRODUCTION IMPROVEMENT, FIELD RESISTANCE AND HIGH-QUALITY FRUITS

Imad Al-SUWAID[1]*, Florin STĂNICĂ[1], Ana BUTCARU[1]*, Cosmin MIHAI[1], Nazar AL GHASHEEM[2]

[1]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Mărăști Blvd, District 1, Bucharest, Romania
[2]College of Agricultural and Marshlands, University of Thi-Qar, Iraq

*Corresponding author emails: ana.butcaru@qlab.usamv.ro, nizar.shihan.post.am@utq.edu.iq

Abstract

Scientific knowledge through studies with fundamental and applied research has revolutionized plant breeding over the past decades. Given the importance of the fruits for their nutritional, health, and industrial value, the apricot breeding programs evolved continuously. The integrated use of actual gene banks, multiple crossings, selection, and the use of genetic engineering programs lead to improve apricot trees performance. Meanwhile, the production of resistant cultivars to harsh environmental conditions and climate changes, especially to hard winter temperatures and late frosts, disease-resistant, with early maturity, high-quality fruits, and large production is the main objective. This article aims to provide an overview of achievements in the breeding and improving the production of apricot fruits in the world, highlighting the modern challenges in apricot orchards. Recently, digitalization and mechanization can be involved as useful tools in breeding studies and orchard monitoring and management.

Key words*: core collection, crossing, early selection, disease-resistant, digitalization.*

1. Origin and distribution

The scientific name of the apricot is *Prunus armeniaca* L., being part of the Rosaceae family, and one of the most valuable fruit trees in the world (Zhang & Zhang, 2003). The word apricot chosen by the roman, is derived from the combination of the word "praecocia" meaning early matured, and "albarquq" meaning short ripening period (Guclu et al., 2009).

According to the available documents, the origin of apricots dates back to 5,000 years ago in China (Zhang & Zhang, 2003). Some sources consider this plant to be native to northern China. Wild species of this plant have been seen from Japan to Afghanistan. The Romans called this plant “the Armenian apple”, and based on this issue, some researchers believe that this fruit originates from Armenia (Punia, 2007).

The apricot has been planted at the beginning of the first century AD in this country. This plant was transferred to Anatolia in the fourth century BC due to Alexander the Great's travels to Iran. During the Roman-Iranian wars in the first century BC, the apricot plant was first transported to Italy and then to Greece. Finally, the apricot plant was transported to Spain and England in the thirteenth century and to France and the United States in the seventeenth century (Buttner, 2001). There are about 3,000 apricot cultivars in the world, 2,000 of which are found in China (Wang & Liu, 1998).

2. Nutritional value and production of apricots

Apricot is a fruit with high nutritional quality that is cultivated in the temperate climate of the world (Bhat et al., 2013). This fruit is highly valued among consumers due to its early ripening, beautiful colors, and high-nutritional-quality (Zhang & Zhang, 2003). Apricot fruit contains sufficient amounts of glucose, sucrose, fructose, antioxidant compounds such as lycopene, β-carotene, and vitamins A and E, and also minerals such as potassium, phosphorus, and magnesium (Muradoğlu et al., 2011).

Apricot is an important food source and its consumption was recommended in the presence of vitamin A deficiency, in case of depression, mental disorder, stress, anaemia, physical and mental fatigue (Iordanescu & Micu, 2012). In addition, the consumption of apricots strengthens the body's nervous system and increases the body's immune responses. Due to its alkaline properties, its consumption helps maintain the balance of acidity of blood and body tissues (Drogoudi et al., 2008).

Apricot fruit can be eaten fresh, industrial, dryed and deep freezing (Milošević & Milošević, 2019b). In recent years, in Henei Provence, as the second-largest area under cultivation of apricot in China, there has been a significant increase in the area cultivation and plant performance (Wu et al., 2018b).

According to FAO statistics (2022), in the last twenty years, the average apricot production in the world was 3,719,974 million tons., the highest percentage (57.5%) being of Asia mainly due to the large farms established (Turkey, Iran, Uzbekistan, Pakistan) and Africa (Algeria, Morocco, Egypt). It is followed with 25.4% by the European production, that increased at a lower rate, while in North America and Oceania production has decreased. Turkey ranks first in the world in production with an average of 624,256 tons among the ten apricot-producing countries in the past twenty years (FAOSTAT, 2022).

3. The purpose and research conducted to enhance apricots crop quality

Today, apricot research has been done in various fields, such as: evaluation and improvement of fruit quality characteristics (Ilhan et al., 2020; Wang et al., 2018), the effect on the apricot based on morphological and physiological characteristics of the scion (Yordanov et al., 2018), identification, management and resistance to various types of diseases (Lambert et al., 2020; Suran et al., 2020), investigation of physiological characteristics of the plant and environmental conditions affecting it (Kwon et al., 2020), identification of genomes of different apricot cultivars and study on native and wild cultivars (Ruiz et al., 2020; Li, 2018), introduction of new cultivars (Milatović et al., 2018), fruit postharvest studies (Ledbetter, 2012).

4. Breeding methods

Plant breeding is done by two groups including farmers and specialized breeders (Breseghello & Coelho, 2013). The goal of apricot breeding programs was to develop cultivars for fresh and processed use, starting with the ability to adapt to different ecological conditions and the ability to cultivate in different areas. The first controlled apricot pollination took place in the Soviet Union. Kostina's collection of apricot cultivars at the Nikiski Botanic Garden prompted her to work as a breeding researcher.

More than 150 years ago, apricot breeding programs began in the United States, Canada, and Romania, followed by Hungary, Yugoslavia, France, Italy, Greece, and Yugoslavia (Layne et al., 1996). Hybridization techniques such as pollination, seed collection, and check seedling were first used in the apricot breeding process (Layne et al., 1996).

In traditional plant breeding, the selection is based on the appearance of the plant. However, plant breeding is controlled by specialists through controlled fertilization and sequential checks of new compounds using molecular markers (Breseghello & Coelho, 2013; Batnini et al., 2016).

In the early years of breeding activities, apricot breeding focused on the collection and exploitation of germplasm resources from all geographical areas of China. From the 1980s, hybridization programs began at several pomology institutes. However, new cultivars with acceptable features emerged through controlled interbreeding. Since the 1990s, biotechnology, marker-assisted selection (MAS) and molecular breeding have been widely used in fruit tree breeding programs (Wang et al., 2014b; Liu et al., 2015).

4.1. Hybridization

In apricot breeding, standard breeding techniques are used such as: cross-breeding by emasculation, manual pollination, self-pollination, open pollination (Krška & Vachun, 2016). Hybridization is one of the important methods in apricot breeding. By selecting the optimal parent, the obtained hybrids that have their own unique feature can be used in subsequent breeding programs and also in cultivation for commercialization (Nesheva et al., 2020). In a study conducted in Bulgaria at The Fruit Growing Institute, the use of the hybridization method was able to produce hybrids with better quality fruits. Parents 'Lito' and 'Silistrenskaranna', 'Modesto' and 'Harcot' and 'Harlayne' and 'Harcot' were used in this study, and at the end of the experiment, it was found that the hybrids from the parents of 'Modesto', 'Harcot' and 'Harlayne'×'Harcot' had larger fruits and its TSS content was more than 15° Brix. In addition, the highest inheritance of PPV-resistant alleles was observed in hybrids derived from 'Harlayne'×'Harcot' parents. Interspecific hybrids between *Prunus salicina* Lindl and *Prunus armeniaca* L. are called 'Pulmcot'. This hybrid produces high-quality fruit for sale, and some of them are resistant to the PPV virus and do not show any incompatibility (Bassi & Audergon, 2006). In the Czech Republic, hybridization programs have been used to select suitable parents to produce hybrids that are resistant to disease, cold, and frost and have a long dormancy period and also high-quality fruit (Nečas et al., 2020).

After phenological, pomological studies, and performance analysis in 3718 hybrids from 42 crosses with the aim of producing late cultivars, it was found that 12 genotypes had promising results (Cross et al., 2018). In Turkey, the hybridization method in 'Hacıhaliloğlu' cultivar and cultivars resistant to monilinia disease has been used to produce monilinia resistant cultivars; according to phenological observations and characteristics of fruits and plants, promising results have been obtained (Bilgin et al., 2020a). In a study conducted in the Samara region, after interspecific and interstitial hybridization, 9 cultivars of apricot were produced, and finally, 4 cultivars were registered in the Russian Federation. The flower buds of these cultivars and their wood had a high resistance to low temperature during dormancy. The 'Samarskij', 'Vnuchok', and 'Elita no.1' cultivars had high performance. Ripening time, weight, and taste of fruit varied according to cultivar, air temperature, and rainfall. The best fruit flavor was observed in 'Andryushka', 'Bojcovyj', 'Seyanec Voenkomovskij', 'Trofej' cultivars, and the largest fruits were observed in new 'Avdeevskij', 'Andryushka', 'Bojcovyj', 'Seyanec Voenkomovskij' cultivars (Mini et al., 2020). 16 plants were obtained from hybridization of native plum and black apricot (*Prunus domestica* L. x *Armeniaca dasycarpa* Ehrh), and finally, 12 plants were introduced as hybrids. In the resulting hybrids, a wide range of dominance of morphological characteristics of native plums was observed. Black apricot-related traits in hybrids were poorly displayed in seven hybrids. However, some of the most important characteristics such as resistance to biological and abiotic stresses, growth inhibition, performance, maturity, and high fruit quality were combined in these hybrids. The aim of obtaining the hybrids from this study was to select and modify new cultivars of local plum, to produce tetraploid and hybrid cultivars of black apricot, and to modify and select ordinary apricots with some valuable traits of plum (Soldatov & Salaš, 2007).

Interspecific cross-breeding is one of the most common methods in breeding fruit trees (Arbeloa et al., 2006). The intraspecific hybridization method is also used to produce scions in apricots and the interspecific crossing method between *Prunus* species is used to improve the rootstock and the features of the scion (Bassi & Audergon, 2006). At interspecific cross-breeding, the number of fruits formed is generally lower than the pollinated flowers (Szymajda et al., 2015).

In interspecific hybridization in *P. armenia* L., *P. salicina* Lindl, *P. cerasifera* Ehrh, and *P. salicina* × *P. cerasifera* hybrids it was found that the percentage of fruit formed was directly related to the pollination of crossed species. Most fruits were observed in the cross between *P. salicina* × *P. armeniaca* and *P. salicina* × *P. cerasifera*. According to the results, adaptation and efficacy in crossbreeding were more affected by the mother's parent genotype of *P. salicina* compared to the paternal parent genotypes of *P. armeniaca* and *P. cerasifera* (Szymajda et al., 2015). In a study that aimed to investigate pomological factors and fruit formation, the effect of intra-species hybridization in some apricot cultivars (*Prunus armeniaca* L.) and interspecific hybridization in apricot and paternal parent plum cultivars (*Prunus salicina* L.) was studied and it was found that crossbreeding combinations of 'Black Amber' plum cultivar provided better results. In crossbreed hybrids, 'Palstein' group hybrids showed better performance index (Yaman & Uzun, 2020).

According to breeding principles, apricot breeding by hybridization is very slow due to the long seedling period and high heterozygosity.

Some research was done to introduce suitable cultivars. 'Darina', 'Dobrzyńska', 'Harostar', 'KijewskijKrasen', 'Krojczynka', 'Apricot from Ukraine', 'Pietropawłowskij', 'Poleskij Krupnopłodnyj', 'Veharda', 'Hungarian Early' cultivars are capable of growing in Polish climates and are suitable for cultivation in these climatic conditions (Sitarek, 2020). In order to produce late-maturing cultivars, the following cultivars can be used: 'Da-Huang-Hou' (from China); 'Geogdzhanabad' and 'Voski' (Iranian-Caucasian group); 'ManduleRogni', 'Morava', 'Hersonsky 23', '16-15-9a', 'Original', 'Saratovsky Rubin' (European group); 'Luchak Sumbarsky', 'KokPshar', 'Khurmai', 'Zard' (Central Asian group) (Gorina et al., 2020). 'Ananasny Avgustovsky', 'Bagration', 'Zapozdaly', 'Kazachok', 'Stepnyak Orangevy', 'Professor Smykov', 'Altair', 'Pasynok', 'Jupiter', 'Krasny Krym', 'Iskorka Tavridy', 'Vynoslivy', 'Ozornik' cultivars can also be used in variable climates, but it should be noted that these cultivars are late or medium flowering (Gorina et al., 2020).

4.2. Molecular markers

Molecular markers have made possible to study genetic diversity and association in plants and improves the use of different genotypes in breeding programs and ultimately facilitates the design of new crosses (Sánchez-Pérez, 2005). The use of isozymes was first introduced by Byrne & Littleto (1989) (cited by Zhebentyayeva et al., 2012). In a short time, the use of molecular markers replaced the use of isozymes (Zhebentyayeva et al., 2012; Ruiz et al., 2011).

Apricot genomic sequencing is also one of the strategies that lead to shorter stages of breeding and production of new cultivars (Teber et al., 2020). Today, molecular markers can be used in apricot breeeding. RLFP (Restriction Fragment Length Polymorphisms), AFLP (Amplified Fragment Length Polymorphisms) and SSRs (Simple Sequence Repeats), AFLP-RGAs (AFLP markers targeting the Resistance Gene Analogs), AFLP-cDNA are molecular markers used for this purpose (Zhebentyayeva et al., 2012).

The use of SNP (single nucleotide polymorphisms) marker is one of the ways that can be used in apricot breeding programs with the aim of selecting PPV resistant seedlings and the result is a faster selection of cultivars (Lambert et al., 2020). Nowadays, selection using molecular markers in the breeding programs has made significant progress and is one of the efficient ways in experiments to improve the quality of apricot fruit in new cultivars (Ruiz et al., 2020).

The use of SSR molecular markers in different apricot cultivars from different regions showed that the use of this method made it possible to molecularly identify all apricot genotypes. According to this method, apricot genotypes were divided into seven main groups according to origin and pedigree (Sánchez-Pérez, 2005). Examination of 14 apricot hybrids and 6 of their parents based on morphological and molecular indices revealed that Ay × P3 cross was a promising genotype related to early maturity and fruit indices. Finally, 224 bands could be scored with 8 combinations of SRAP primers (25 bands), 8 DAMP primers (81 bands) and 18 ISSR bands (118 bands); which showed a great variety between hybrids and cultivars. In addition, a total of 4 S-RNase alleles (SC, S2, S3, S6) were identified that Sc and S3 alleles were more widely present than other alleles (Pinar et al., 2017). Another efficient molecular method in apricot breeding programs is Marker-Assisted Selection (MAS) (Ruiz et al., 2011; Zhebentyayeva et al., 2012). This method can be used in traditional hybridization techniques, especially in interspecific crosses (Zhebentyayeva et al., 2012). The MAS method is very efficient and practical for fruit trees with long seedlings such as apricots. The MAS method has been used to identify PPV-sensitive cultivars in some studies (Auvinet et al., 2020).

Gene mapping in some apricot hybrids is another breeding method in this plant. In this method, two characteristics of PPV resistance and self-incompatibility have been investigated (Zhebentyayeva et al., 2012). Preserving plant genetic resources and using them in research should be a priority for agricultural research. In research on apricots, DNA extraction from older cultivars and the use of SSR polymorphisms make it possible to preserve and identify these cultivars and prevent genetic erosion in the plant. This method is also effective in identifying cultivars that have only seeds (Martín et al., 2011).

Genetic analysis of a group of 202 apricot plants using 13 microsatellite markers or SSRs, which included introduced breeding cultivars and native cultivars in several countries and it was found that the diversity of parameters in modified plants was higher compared to native plants. However, a decrease in genetic diversity was seen in recent breeding programs. Using phylogenetic analysis based on Nei genetic distance, two main groups were created. The first group consisted mainly of traditional American and European cultivars, and the second group included commercial species created by breeding programs. Population distribution in each group was close to each other, which confirmed the results of molecular phylogenetic analysis. Finally, it should be noted that genetic diversity in apricots is currently declining and one of the most important solutions is to preserve traditional cultivars and local germplasms as genetic resources in breeding programs (Herrera et al., 2021).

In the apricot plant, microsatellites have been used to study the evolutionary history of the plant, to describe and study traditional cultivars, and to study local cultivars in Spain, Turkey, Tunisia, and Iran (Bourguiba et al., 2020; Liu et al., 2019; Hormaza., 2002; Murathan et al., 2017; Bourguiba et al., 2013; Batnini et al., 2016; Raji et al., 2014).

The study of genetic diversity in apricots is performed by SSR (Sheikh et al., 2021a).

In a study, sexual incompatibility and S allele diversity were studied using PCR (polymerase chain reaction) and sequencing techniques in 24 cultivars of Turkish apricot, Paviot and Sakit-1 as parents and 127 F1 breeds. The results showed that most Turkish cultivars were self-incompatible. The Sc allele, indicating self-compatibility in the plant was observed in only three cultivars. In 124 F1 breeds, 2 S alleles of Paviot were inherited by half of the breeds; 76% of the breeds inherited the S52 allele from Sakit-1 and less than 24% from the S20. Amplifying was successful with all 18 SSR primers (Murathan et al., 2017).

The SSR molecular marker was effective in differentiating 48 apricot genotypes and finally UPGMA cluster analysis grouped the genotypes based on pedigree information and their origin (Hormaza, 2002). Molecular markers make it possible to describe the germplasm in apricots. In a study, 890 apricot genotypes with different origins were used. Finally, 5 different genetic clusters were obtained based on the Bayesian model. Accessions from China and Central Asia are in the same cluster and show the highest diversity resulting from a region and origin. In general, the results showed that apricots originated and expanded from China and Central Asia. Identification of specific alleles outside the centre of origin confirms the existence of secondary variability.

The existing database provides the conservation of apricot genetic resources and is also used in its breeding programs (Bourguiba et al., 2020). In a study of 27 Iranian apricot cultivars, based on morphological indices and molecular markers, it was found that there is a high diversity in relation to fruit weight, total soluble solids (TSS) and titratable acidity (TA). High correlations were observed between fruit size, pit and kernel, TSS and TA. In the molecular study, 53 alleles were identified and UPGMA cluster analysis divided the studied apricots into seven groups (Raji et al., 2014). Molecular markers have been used in the study of domestication of wild apricot cultivars and it has been found that apricot is a suitable model for the study of speciation and domestication in perennial fruit trees with long life (Liu et al., 2019).

In a study using SNP markers, a total of 267 allelic compounds were identified in 37 studied apricots. The use of SNP markers is effective in studying genetic diversity in apricots and in determining the relationship between their accessions, which is due to pedigree relationships (Salazar et al., 2015). In the study of genetic diversity and determining the relationship between different apricot cultivars using SRAP (Sequence related amplified polymorphism) it was found that the similarity between Turkish apricot cultivars and foreign cultivars was between 0.77 to 0.97%.

Significant genetic diversity was identified in Turkish cultivars and between Turkish and foreign apricot cultivars. The four cultivars with high cold requirements originated in eastern Turkey and were placed in separate clusters. No clear grouping was observed between European, South African, North American, and other Turkish cultivars. Finally, it can be concluded that these cultivars have similar genetic backgrounds due to their different geographical origins (Uzun et al., 2010).

The AFLP molecular marker has been successful in identifying the apricot gene mapping in some of the studied traits, such as disease resistance (Hurtado et al., 2002). Evaluation of genetic diversity in older Spanish cultivars was performed using microsatellite molecular markers and the results showed that the samples were derived from four closely related genotypes and one of them includes 89% of the samples (Martínez-Mora et al., 2009). Molecular markers in the apricot plant play an important role in the study of molecular properties and genetic linkage mapping (Ruiz et al., 2011). Apricot breeding programs focus primarily on several specific purposes for the production of commercial cultivars: Self-compatibility, PPV resistance, fruit quality and development of fruit ripening period (Herrera et al., 2021).

4.3. Transgenic plants and *in vitro* culture

Other breeding methods in apricot include transgenic (Zhebentyayeva et al., 2012). Biotechnological techniques are used in the analysis of gene function or the introduction of new agronomic traits in apricots that are not introduced by hybridization or selection (Pérez-Casellaes et al., 2021). Transgenic plants are generally produced through *Agrobacterium*-mediated transmission (Pérez-Casellaes et al., 2021) and direct gene transfer (Ruiz et al., 2011). Genetic engineering allows plants to grow and develop faster, also vegetative propagation of these plants allows them to grow in wider areas. The first plant produced by genetic engineering was introduced to the market in 1994 (Lobato-Gómez et al., 2021). The first transfer in apricot was done by Petri in leaf explants (Petri et al., 2008). Cultivation *in vitro* plant allows the researcher to produce disease-free and virus-free plants. Soma clonal diversity is another method of producing plants with a new phenotype (Ruiz et al., 2011).

Micropropagation is also commonly used in the production of rootstocks (Burgos & Ledbetter, 1993) and virus-free plants in apricots (Mitrofanova et al., 2020). *In vitro* embryo culture can be successfully used as a tool in apricot growing program for large-scale plant production (Burgos & Ledbetter, 1993). By comparing traditional breeding methods with modern breeding methods, it was found that in modern breeding methods, fruit size was increased using controlled fertilization, while self-compatibility and firmness were acceptable. Cluster and structural analysis of SSR data, identified and distinguished different genotypes based on their geographical origin and pedigree. Finally, some alleles related to fruit weight, firmness, and fruit ripening were also identified using SSR molecular markers (Batnini et al., 2016).

5. Breeding programs in apricot plant

One of the important breeding goals in apricot breeding programs includes: improving apricot cultivation, resistance to biological stresses, increasing fruit harvest time, improving fruit quality for fresh eating and processing, and productivity, resistance to bacterial diseases caused by *Pseudomonas* spp., or *Xanthomonas arboricola* pv. *pruni* Smith, biological stresses (Sharka virus, root Brown caused by *Monilinia* spp.), Chlorotic Leaf Roll Phytoplasma, and Apricot Decline Syndrome, and adaptation to different environmental conditions (Zhebentyayeva et al., 2012; Bassi & Audergon, 2006).

5.1. Evaluation and improvement of fruit quality characteristics

Numerous studies have been performed to improve fruit quality in apricots and their focus is on improving fruit quality in the market, improving skin color, fruit flavor, TSS, TA, fruit size, fruit firmness, fruit scent and fruit ripening time and after fruit harvest time. In most studies, the hybrid fruits produced fruit weight, flesh firmness, skin color and marketability are considered (Oprita et al., 2020). Fruit quality is one of the most important goals in breeding program in apricot.

Fruit size and firmness are two influential factors in the performance, marketability, and value of the product (Roussos et al., 2011).
In fresh eating cultivars, breeding goals have been changed from increasing performance to improving fruit quality such as taste, attractiveness, firmness, and aromatic compounds. Using China's unique resources, kernel-yielding apricots are an option used in recent breeding programs. The goal of these breeding programs is to increase performance, sweet kernel, large kernel, and hardness. Also increasing the fruit harvest season and attractive appearance have been other goals of breeding in recent programs in China (Sun et al., 2018). In China, from 2006 to 2013, 46 new cultivars with new features were introduced (Sun et al., 2018). The features of these cultivars were precocity, disease resistance, dwarfism, resistance to various environmental conditions, attractive appearance, long life after fruit harvest, improved fruit quality features, and increased fruit size (Sun et al., 2018).
The goal of apricot breeding programs in Spain is to produce and introduce early maturing and Sharka resistant cultivars (Egea et al., 2012). Many studies have provided satisfactory results in improving the quality of fruits, it was found that spraying the tree with 1 mmol/l salicylic acid is effective in delaying fruit ripening and increasing its shelf life by reducing fruit maturity index (Elsabagh et al., 2020). Also, pre-treatment of apricots using oxalic acid seven days before harvest improved fruit quality traits compared to the control and the concentration of 1 mM oxalic acid had the greatest effect on fruit quality (SevinçÜzümcü et al., 2020).
The use of benzyl adenine (BA) as a foliar spray in the pit hardening stage, improves the quality of the fruit. Fruits treated with 100 ppm benzyl adenine were larger in size and firmer (Canli et al., 2014). Foliar spray of the apricot tree at a concentration of 0.1 mMmelatonin, improves fruit quality and maintains the quality characteristics of the fruit during its storage life and maintenance period (Medina-Santamarina et al., 2021). In a study conducted by Ilhan et al. (2020) in Turkey, the physiochemical properties of wild apricots were investigated and it was found that apricots have considerable antioxidant properties and phenolic compounds, and vitamin C (Ilhan et al., 2020).
Today, the use of molecular markers in improving fruit quality is an effective tool. In addition, molecular methods have been effective in post harvesting apricots and determining genes associated with firmness and softness of fruit tissue (Wei et al., 2018). In a study conducted in the CEBAS-CSIC breeding program to identify genes related to fruit quality in apricots, a combined genetic, genomic and transcriptomic approach was performed. This process had two stages; the first step involved making genetic linkage maps and identifying quantitative trait loci and the second step was RNA sequencing to identify the genes involved. Finally, in this study, the genes responsible for fruit white / orange color, anthocyanin content and carbohydrate metabolism were identified (Ruiz et al., 2020). Hybridization is also an efficient method of producing high quality fruit hybrids.
In 'Hacıhaliloğlu' × 'Boccucia hybrids', high diversity of fruit zone, fruit color, fruit firmness and fruit harvest time were observed. Two factors, fruit color and harvest time, were distinct parameters in genotype selection. Finally, cluster analysis placed 20 genotypes in the same group and other genotypes in different groups (Bilgin et al., 2020b). Hybrid production was produced from the parents of 'Lito' and 'Silistrenska ranna', 'Modesto' and 'Harcot', and 'Harlayne' and 'Harcot' with the aim of investigating PPV resistance and pomological traits. 'Harlayne' × 'Harcot' was the hybrid with the highest frequency of inheritance of PPV-resistant alleles. Full flowering time, fruit ripening time, fruit weight, fruit shape, fruit color and TSS were examined in the resulting hybrids. The results showed that the hybrid fruits of the crosses 'Modesto' × 'Harcot' and 'Harlayne' × 'Harcot' had the largest size (more than 45 g). In addition, the TSS level in these fruits was higher than 15 °Brix (Nesheva et al., 2020).
In another study found that fruit ripening in 'Ariel®', 'Leda®' and 'Alissa®' apricots occurred 95, 89 and 102 days after full bloom, respectively. Also, all of these cultivars are self-fertile. The fruits produced in all three apricots had 30-40% bright red color and orange background, firm but juicy and also had

good taste and smell (Bassi & Foschi, 2020). The selection of early apricot cultivar as the maternal rootstock is effective in transmitting this trait to the breeds (Wu et al., 2018a). 'Jinyu' and 'Jinhe' cultivars are new early cultivars derived from the early maternal rootstock in the Plum and Apricot Laboratory of SFRIHAAFS. 'Jinyu' cultivar has high freshness, sweet taste and high content of vitamin C. This cultivar is derived from the intersection of 'Yuzhouhong' cultivar as the maternal rootstock and 'Sungold' cultivar as the paternal rootstock. 'Jinhe' cultivar has a large size fruit, good appearance and high flesh quality and this cultivar is derived from the intersection of 'Zihe' cultivar as maternal parent and 'Xinshiji' cultivar as paternal parent (Wu et al., 2021).

In the study of hybrids obtained from Irano-Caucasian and European groups and some important cultivars of the Eastern Mediterranean, it was found that 'Çağataybey' hybrid cultivar had the highest TSS, phenolic content and the highest levels of antioxidant capacity. In addition, more than 50% of the fruit skin was red (Caliskan et al., 2012). In a research program in Spain, three cultivars 'Mirlo Blanco', 'Mirlo Naranja', and 'Mirlo Rojo' due to their high fruit quality, ripeness and resistance to Sharka were introduced. These cultivars were obtained from a cross between cultivars with moderate cold requirements and early cultivars with low cooling requirements and good quality (Egea et al., 2012).

5.2. Genetic erosion and reduction of genetic diversity in apricots

One of the ways to increase the quality of apricots in the market is to improve the cultivars and select seedlings with high quality. Another way is to introduce cultivars from all over the world in order to select useful and suitable genotypes for cultivation (Krska & Vachun, 2016). In recent years, the introduction of new cultivars has become necessary in most breeding programs. New cultivars are needed to produce apricots that improve performance and profitability (Krska & Vachun, 2016). Research by Herrera et al. (2021) has shown that genetic erosion and reduction of genetic diversity in apricots are currently occurring, and the best method for solving this problem is to pay more attention to existing traditional cultivars and local germplasm as future genetic resources in apricot breeding (Herrera et al., 2021). Decreased diversity in modernization products is defined as genetic erosion. The two main reasons for genetic erosion are the replacement of traditional cultivars with modern cultivars and functions related to breeding programs. Genetic erosion occurs at three levels of product, cultivar and allele (Wouw et al., 2009). Rich genetic diversity is an important resource for breeding programs in plants. However, it should be noted that the reduction of genetic resources and artificial selection in plants, reduces the genetic diversity and potential of plant germplasm (Laido et al., 2013). Consequently, evaluation of the genetic diversity of plant germplasm is necessary to select superior genotypes and conserve endangered resources (Sheikh et al., 2021b; Martín et al., 2011). Preservation of traditional fruit cultivars is essential due to genetic erosion. The use of molecular methods plays a significant role in identifying, retrieving and preserving traditional cultivars (Martín et al., 2010). SSR molecular markers were used to analyze the genetic diversity of the structural population of 120 apricot genotypes in India. Molecular analysis of variance showed that the rate of change within individuals, between individuals and between populations was 73, 25 and 2%, respectively (Wani et al., 2021). ISSR markers were able to separate native genotypes from foreign genotypes and divided the modern apricot genotypes studied in India into two completely separate groups. Determining genetic divergence between native and non-native genotypes plays a significant role in apricot breeding programs (Sheikh et al., 2021). Kashmir Valley and Ladakh region in India is one of the rich germplasms in apricots. Some important apricot genotypes in this region include: Afghani, Raktsey-Karpo, Halman, Australian Sweet, and Charmagz (Wani et al., 2020).

Domestication is one of the reasons for the decrease in genetic diversity due to genetic drift and extinction of wild ancestors (Bourguiba et al., 2012; Li et al., 2020). In a study by Bourguiba et al (2012), it was found that genetic diversity in the Iranocaucasian gene pool as one of the secondary centres of diversity is declining (Bourguiba et al., 2012). In the study of apricot genetic diversity using single-nucleotide polymorphisms (SNPs), it was found that Dzhungar-Ili ecological group had the highest genetic diversity related to the number of private alleles, heterozygosity and nucleotide diversity. The researchers said that the Central Asian ecological group originated from the Dzhungar Ili ecological group and became native. In addition, it has been suggested that the population structure and gene flow of the North China and European ecological genetic group have *P. sibirica* background. *P. armeniaca* originated in Northwest China and later expanded to Central Asia and then to Europe (Li et al., 2020).

Germplasm genetic diversity is necessary to search phenotypic and genetic resources and plays an important role in the sustainability and improvement of crop breeding. It seems that the genetic diversity of ordinary apricot germplasm grown in China is greater than the Western countries. Research studies showed that 27% of the studied genome was identified as introgressed. These introgressed regions have created a high diversity in the germplasm of common apricots grown in China through the introduction of different genes associated with distinct phenotypes from other cultivated groups. Introgressed regions can be said to be an important source of genetic resources and can be used in breeding programs (Zhang et al., 2021).

A study of Siberian apricots in China from 22 populations using molecular markers showed that the number of alleles per loci varied from 5 to 33 (mean 19,323 alleles). Structural analysis showed that all populations are divided into 4 genetic clusters. Based on hierarchical analysis of molecular variance, 94% variation was observed within populations. There was no significant difference between wild and semi-wild groups, which is probably due to the current cultivation conditions of Siberian apricots. In addition, according to Mantel test, genetic distance between populations was not significantly correlated with geographical distance (Wang et al., 2014a). It should be noted that breeding programs with specific pomological aim and the production of new cultivars have reduced genetic diversity in apricots (Corrado et al., 2021).

5.3. Precocious maturity

Precocity is another breeding goal in this plant. According to the consumer market, precocity apricots have more commercial value among consumers (Wu et al., 2021). In fact, many programs focus on improving very precocity apricots. 'Zaojinyan' homologated by Zhengzhou Fruit Research Institute or 'Chunhua' from the Shandong Institute of Pomology in China are results of these programs (Yuan et al., 2019; Huang et al., 2019). 'Chunhua' cultivar is obtained from the intersection of 'Jintaiyang' × 'Honghebao' and the fruit ripens in mid-May. The duration of fruit ripening in this cultivar is about 55 days (Yuan et al., 2019). Two new and early cultivars of 'Jinyu' and 'Jinhe' have been produced at Plum and Apricot Laboratory of SFRIHAAFS. 'Jinyu' cultivar is derived from the cross between 'Yuzhouhong' cultivar as maternal parent and 'Sungold' cultivar as paternal parent. 'Jinhe' cultivar is derived from the cross between 'Zihe' cultivar as maternal parent and 'Xinshiji' cultivar as paternal parent (Wu et al., 2021).

5.4. Disease resistant

Production of disease-resistant cultivars is also one of the important goals of breeding in this plant (Ruiz et al., 2011). Resistance to Sharka (plum pox virus) was studied. Sharka viral disease caused by Plum pox virus (PPV); is one of the significant cases in apricot production in Central European regions that should be considered (Krska & Vachun, 2016). Sharka is one of the most important viral diseases in apricots. The disease was first introduced in Bulgaria in 1917 and then it was seen in some other parts of the world. Undoubtedly, one of the effective ways to control this disease is to create resistant varieties. Recent research has shown that 'Stark Early Orange' and 'Stella' cultivars do not show signs of viral infection after two years of graft (Syrgiannidis et al., 1991). Recently, resistant cultivars such as 'Rojo Pasión' and 'Murciana' have also introduced in Spain. Based on field farm, and artificial experiments, 'Harcot' and 'Bebecou' cultivars were introduced as cultivars resistant to this viral disease (Karayiannis et al., 2008). Three cultivars resistant to PPV were introduced in Spanish breeding programs, including: 'RojoPasión', 'Selene', 'Murciana' (Zhebentyayeva et al., 2012). In Italy, resistant cultivars include: 'Antonio Errani', 'Cafona', 'Fracasso', 'Noumo', 'Paviot', 'Pelese di Giovanillo', 'Portici', 'Stark Early Orange', 'Stella', and 'Veecot' were also introduced using the artificial inoculation-chip budding method on woody indicator GF-305 (Faggioli et al., 2009). 'Goldrich', 'Henderson', 'Harlayne', 'Stark Early Orange' (SEO), 'Stella', and 'LE-3276' are cultivars that are naturally resistant to PPV and can be used in other research (Gorina et al., 2020).

One reliable way to detect viral infection in apricot trees is to use the High-throughput sequencing (HTS) method for sequence analysis (Canbulat et al., 2020). Screening is one of the methods used to find disease-resistant cultivars in apricots (Karayiannis et al., 2008).

Finding resistant cultivars was done based on biological tests described by Audergon & Morvan (1990). In this method, peach seedling 'GF-305', which is very sensitive to this disease and shows the symptoms of the disease quickly, is selected as an indicator of the disease. The studied apricots are grafted on peach seedlings and after inoculation of the virus, the symptoms in apricots and peaches are examined. Finally, the presence of the virus is analyzed by ELISADASI and RT-PCR. At least two growth cycles are required for the final conclusion (Badenes & Lláce, 2006).

Screening of apricot seedlings using molecular markers is one of the best solutions to increase the efficiency of breeding programs (Rubio et al., 2014).

5.5. Apricot rootstock

Scion adaptation, resistance to pests and diseases, adaptation to a wide range of different soil types, and climatic conditions are good plant rootstock characteristics (Cinelli & Loreti., 2004). One of the important things in apricot cultivation is the selection of the rootstock in this plant (Milošević & Milošević, 2019b).

The primary goals of rootstock selection in apricots include scion growth strength, fruit size, function, tree longevity, precocity, rootstock growth strength, graft adaptation, disease and pest resistance, tolerance to specific biological conditions (Zhebentyayeva et al., 2012).

In addition, in arid regions, such as the Mediterranean region, it is necessary to select the appropriate rootstock with the ability to withstand various types of environmental stresses to prevent further problems in the gardens and reduce cost management (Jiménez et al., 2008; Moreno et al., 2008). Suitable rootstock not only affects graft quality but also affects the long-term performance of trees, scion function, fruit size, fruit quality, tree growth, performance efficiency, nutritional characteristics, water, and nutrient absorption (Milošević & Milošević., 2019b; Milošević et al., 2012). The use of cherry plum *(Prunus cerasifera*) rootstock, apricot seedling, and 52 and 38 St. Julien rootstock, prevents grafted trees from being infected with *Phytoplasma* (Suran et al., 2020).

Choosing the suitable rootstock for each cultivar and each climatic condition is an important issue for breeders. Apricot seedlings' rootstocks are mainly used as rootstocks all over the world. However, these foundations are not suitable for heavy soils and waterlogged land (Milošević & Milošević, 2019b). Apricots, peach, and plum seedlings are also used as rootstocks in apricots (Zhebentyayeva et al., 2012). One of the cheapest apricot rootstocks is seedlings, which have acceptable physiological compatibility with scion and are resistant to sulphate and chloride salts. In addition, these rootstocks can tolerate nematodes in the soil. These factors have led to the use of this rootstock in Asia and Europe, but due to the sensitivity of these rootstocks to *Verticillium* wilt and fungal infection (Oak root fungus), mainly plum rootstocks are used commercially for this plant (Kaya et al., 2018).

In acid soils, mainly Myrobalan seedling rootstocks (*P. cerasifera* Ehrh.) and other local plum cultivars derived from *P. domestica* L. and *P. insititia* L. such as 'Belošljiva', 'Petrovača', 'Cerovačkipiskavac' are used. These rootstocks show good compatibility in grafting and have the ability to grow in these soils but they are susceptible to PPV disease (Milosevic & Milosevic, 2010). 'Marianna' (*P. cerasifera* × *P. munsoniana*), 'Myrobalan' (*P. cerasifera*), and 'Pollizo' (*P. insititia*) plum rootstocks grow in different soil conditions but show signs of incompatibility (Moreno, 2008). In some regions of Spain, the rootstocks that are used are apricot seedling rootstocks 'Real Fino' and 'Canino' cultivars and plum rootstocks 'Pollizos de Murcia' (*P. insititia*) (Hernández et al., 2010).

In the Czech Republic, apricot seedling rootstocks can also be used as rootstocks (Vachůn, 2001). In Poland, seedlings of *Prunus divaricata* Ledeb. are mainly used as rootstock (Sosna & Licznar-Małańczuk, 2012; Licznar-Małańczuk & Sosna, 2013).

One of the most important apricot rootstocks in Serbia is the suckers of local (autochthonous) plum called 'Belošljiva'. High compatibility on these rootstocks has been confirmed especially in Hungarian Best compared to 'Myrobalan' (Milošević et al., 2019a). But it should be considered that both rootstocks are not suitable for medium and high-density gardens due to vigorous growth (Milošević et al., 2015).

5.6. The impact of digitalization and mechanization equipment in modern orchards

Currently, one of the important factors in the economic growth and development of agricultural products is digital technologies and their application in the agricultural industry. Today, mechanization of fieldwork, mechanization, and use of mechanical equipment in the production process is part of it (Kovács & Husti, 2018). The use of automatic and robotic machines is associated with labor shortages and increased labor costs and is necessary to increase fruit quality with minimal dependence on manpower. Mechanized orchard management includes: pruning, thinning, spraying, and harvesting (Zhang et al., 2019). Mechanical harvesting of apricots has been introduced by various researchers since the 1960s (Erdoğan et al., 2003).

Mechanization is seen in different parts of apricot cultivation. Mechanical thinning in apricot showed satisfactory results and in addition to increasing the efficiency of thinning, reduced damage to fruits and branches (Assirelli et al., 2021). In another study, mechanical thinning removed 20.8% of flowers and 43.6% of fruits but saved 48% of the time compared to hand-thinning (Assirelli et al., 2018). Mechanical thinning of flowers in stone fruits such as apricots using tractor-mounted string thinners drastically reduces costs and saves time (Lewis, 2015).

The spraying system developed by Xiao et al. (2017) determines the rate of pesticide application using the RGB-D camera, based on leaf area density and distance-to-canopy. This issue increases the efficiency and productivity of the pesticide and reduces the waste in the pesticide spray on apricots, grapes, and peaches (Xiao et al., 2017).

CONCLUSIONS

Apricot is one of the most important stone fruits that can be eaten fresh or processed. Most research on this fruit is associated with improving the quality of the fruit, such as taste, skin color, firmness of the fruit, the amount of TSS, acidity of the fruit, and the shelf life of the fruit.

Selecting the suitable rootstock is another issue studied in most research, which is due to the climatic and soil conditions of the region. In most cases, the research has tried to select the best rootstock according to the climatic conditions of the region to improve tree growth conditions and fruit quality, resistance to diseases and biological stresses in each region, and also early and late ripening of fruit. In addition, other research on this plant has included genomic studies on commercial and local cultivars to select suitable parents to produce new hybrids.

Inbreeding of this plant, it has been tried to produce cultivars that have the best features, according to the breeding goals in each region, through hybridization and molecular markers.

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