ACTA Acta Sci. Pol. Hortorum Cultus, 22(2) 2023, 119–132

https://czasopisma.up.lublin.pl/index.php/asphc ISSN 1644-0692 e-ISSN 2545-1405 https://doi.org/10.24326/asphc.2023.4734

ORIGINAL PAPER

Accepted: 19.10.2022
Issue published: 28.04.2023

Pomological evaluation and GT-biplot analysis of promising open-pollinated genotypes of apricot (*Prunus armeniaca* L.)

Katayoon Oroji Salmasi [1], Seied Mehdi Miri [1] ✉, Rahim Gharesheikhbayat [2], Mohiedin Pirkhezri [2], Daryoush Davoodi [3]

[1] Department of Horticulture, Karaj Branch, Islamic Azad University, Karaj, Iran

[2] Temperate Fruits Research Center, Horticultural Science Research Institute, Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran

[3] Department of Nanotechnology, Agricultural Biotechnology Research Institute of Iran (ABRII), Karaj, Iran

ABSTRACT

Apricot is an important stone fruit species with different cultivars cultivated worldwide. Therefore, breeding programs are necessary for developing new varieties with various fruit quality and sensory traits. The present study evaluated morphological and fruit-quality attributes of thirty-seven apricot genotypes selected from several Iranian and Italian open-pollinated cultivars together with Shahroudi cultivar (control) during two growing seasons (2019–2020) using the UPOV descriptor and GT-biplot analysis. The results showed great variability in fruit size among all apricot genotypes studied. Most genotypes showed medium-sized fruits while large and small fruits were observed in eight and four genotypes, respectively. The highest yield was recorded in G-464, G-432, G-588, Shahroudi and G-571. Genotypes G-432, G-464, G-571, G-573, and G-576 had higher fruit weight than Shahroudi. In addition, G-450 and G-553 had the highest TSS (18.2°Brix) and TSS/TA (25.4), respectively. The GT-biplot analysis revealed that fruit weight and dimensions along with pH and TSS could be indicators for selecting superior genotypes. According to the present study, G-464, G-571 and G-450 can be introduced as superior genotypes and it is expected that the inter-crossing of these three have the potential to produce cultivars with sweet fruit, high yield and large fruit size.

Key words: genotype by trait interaction, fruit quality, stone fruit, UPOV, yield

INTRODUCTION

Apricots (*Prunus armeniaca* L.) from the Rosaceae family are regular diploids (2n = 2x = 16) that can be intercrossed with each other [Zhebentyayeva et al. 2012]. They have extensive genetic diversity due to sexual reproduction and growth in different geographical areas [Kumar et al. 2015]. The first diversity centers include Armenia, Georgia, Azerbaijan, Dagestan, Iran, Iraq, Syria, Turkey, North Africa, Spain, and Italy where apricots are usually self-incompatible and generally produce bigger fruits and higher yields and flower earlier than the central Asian group apricots with less chilling requirements. The Iranian-Caucasian group is the second center of the apricot gene pool [Zhebentyayeva et al. 2012], which includes Iranian and Turkish cultivars and has high phenotypic diversity. However, European apricots, which are cultivated

✉ smmiri@kiau.ac.ir

CC BY

in Europe, North America, Australia, and South Africa, have the lowest genetic diversity [Halász et al. 2006].

The fundamental sources of genetic variability of *Prunus* germplasm include landraces, introductions, and wild genotypes originating from natural hybridization and seed-based reproduction [Zhebentyayeva et al. 2012, Shamsolshoara et al. 2021]. Although a large number of apricot cultivars exist, it is of great importance for breeding new apricot cultivars, mostly for developing cultivars with the most desirable characteristics [Hagidimitriou et al. 2010]. Extensive studies are conducted to obtain new varieties to meet the desired apricot growing goals. For this aim, studies using the hybridization breeding improvement method to combine various desired traits have been accelerated. By hybridization of two selected parents, populations are created with high variations, and individuals with desired characteristics could be chosen [Khadivi-Khub and Khalili 2017, Wani et al. 2017]. However, the fruit quality characteristics of the hybrid population should be determined in addition to the overall goal. The parent that reflects these characteristics in the phenotype has a higher probability of producing offspring that have an attractive fruit [Bilgin et al. 2020].

Iran is one of the largest producers of apricots all around the world. Hence, it is crucial to develop and introduce new varieties that meet market demands [Shamsolshoara et al. 2021]. As such, the present study evaluatedthe pomological properties of apricot genotypes obtained from hybridization breeding. The overall objective of this study was to introduce superior genotypes.

MATERIAL AND METHODS

Experimental site and plant materials. The study was carried out at an experimental orchard of Horticultural Science Research Institute located in Karaj, Iran (35°74'58"N and 50°95'11"E) at an altitude of 1235 m above sea level. The mean maximum and minimum temperature recorded daily during the cropping season (March–June) was 28.1 ±6.5°C and 13.6 ±4.6°C, respectively, while the mean maximum and minimum relative humidity was 62.1 ±3.7% and 33.8 ±4.8%, respectively. The average rainfall was 460 mm. Thirty-seven promissing apricot genotypes obtained from the open pollination of Iranian (Shahroudi and Shams as maternal parents) and Italian (San Casterese, Vitillo, Cafona and Palumella) apricot cultivars and the commercial cultivar of Shahroudi with high yield as control were investigated. The examined genotypes were 5 year-old and spaced 5 × 4 m.

Pomological traits. In this research, 9 qualitative characteristics based on rating and coding according to apricot UPOV guidelines (UPOV Apricot Guideline TG/70/4 – 06.04.2011) and 11 quantitative traits were examined during the two growing seasons (2019 and 2020). Fruits of each tree were harvested at maturity stage and yield per tree was calculated. Fruit and stone weight was measured with an electronic balance to an accuracy of 0.01 g. Dimensional properties were measured with a digital caliper to an accuracy of 0.01 mm. Total soluble solids (TSS) were measured with a refractometer (ATAGO, Tokyo) and values were corrected at 20°C. Titratable acidity (TA) was determined by titration using 0.1 N NaOH and values expressed as % malic acid.

Statistical analysis. The pomological study was performed on 12 random samples at the fruit maturity stage, which replicated in three trees for each genotype. The analysis of variance and mean comparisons by Duncan's Multiple Range Test were performed using SAS 9.1 software. The GGE Biplot GUI package in R 4.0.2 [Frutos et al. 2014] was used for genotype-by--trait (GT) biplot analysis to determine which genotype was the best in what trait.

RESULTS AND DISCUSSION

Descriptive pomological attributes. A high variation was observed in descriptive pomological characters of genotypes examined. The coefficient of variation (CV%) varied from 8.1% in stone adherent to 44.9% in over color of skin. Traits with a lower CV are less diverse and therefore not suitable for differentiation between genotypes (Tab. 1). Fruit size, ground color of fruit skin, stone adherent, and kernel bitterness could not apply to distinguish genotypes. These characteristics are among the observable pomological traits that are of great commercial importance, and therefore, they are likely to be retained as breeding objects. In contrast, the fruit shape, over color of fruit skin and stone shape showed high variations among genotypes and could be criteria for as certaining the genotypes. Among the apricot genotypes, variation has been reported in morphological and pomological characters [Ruiz and Egea 2008, Bilgin et al. 2020].

There were variations in fruit size among all 38 studied apricot genotypes. Most genotypes produced medium-size fruits. Large fruit size was observed in eight genotypes (G-432, G-462, G-463, G-464, G-509, G-571, G-573 and G-576), and four genotypes had small-size fruits (Tab. 1).

The fruit shape of the genotypes was obliquerhombic, triangular, circular, oblong, obovate, or ovate. Oblong and ovate shapes were predominant among genotypes (10 and 9 genotypes, respectively), while only 2 genotypes were triangular in shape (Tab. 1). Ebrahimi et al. [2015] stated that the Iranian apricot landraces have a high genetic diversity in fruit shape, size, stone and kernel, phenolic compounds and physiological attributes.

As presented in Table 1, the skin ground color was widely varied. The skin color was yellowish, yellow-green and white in 17, 7 and 14 genotypes, respectively. The fruit over color was different among genotypes so pink, purple, red, and orange-red were recorded. The skin and flesh color of G-417, G-432, G-451, and G-585 were white. Furthermore, unlike the rest, the skin ground color of the G-450 apricots was yellow-green and the color of its flesh was cream (Fig. 1). The flesh color of G-526, G-544, and G-546 was light orange, whereas their skin color was yellow-green. Additionally, the yellow-green skin was observed in G-552, G-579, and G-592, while the flesh color of these genotypes was whitish green, medium orange, and cream, respectively. Although Yilmaz et al. [2012] found fruit ground color and flesh color of Turkish apricot accessions were generally yellow, Asma et al. [2007] reported that fruits from different apricot accessions exhibited a wide range of colors for skin and flesh. Milošević et al. [2010] found yellow, orange, and deep orange for flesh color,and yellow, light orange, orange, and deep orange skin color among 14 apricot genotypes in Serbia.

Twenty-five genotypes had soft fruit flesh, suitable for ready-to-eat, whereas the firm fruit flesh was present only in four genotypes (G-509, G-565, G-575 and G-588) (Tab. 1).

Low variation was observed for the stone adherent so that all genotypes (except G-432, G451 and G-578) did not have stone adhesion or were very weak (Tab. 1). Corrado et al. [2021] similarly found very little variability for the adherence of stone to flesh in 28 apricot landraces. On the other hand, there was a high variability in the stone shape, so that the 5 possible categories listed in the apricot UPOV guidline were scored for the studied genotypes. The shape lateral view of the stone was elliptical in 13 genotypes (Tab. 1). The characteristics of apricot stones have been used in genotype identification [Wani et al. 2017].

In this study, the kernels of 35 out of the 38 genotypes were sweet and the remaining (G-463, G-500, and G-588) were bitter. Irano-Caucasian group apricots had mostly sweet kernels, which is among the desirable traits in apricots, while most European apricot cultivars have a bitter kernel taste [Asma et al. 2007, Karayiannis 2010]. Gecer et al. [2020] demonstrated that sweet kernel taste was dominant in the seeds of wild apricot genotypes. Sweet kernels have a less overpowering taste, are better for snacking, and have less amygdalin; but the bitter kernel is renowned for its therapeutic values. Bitter kernels are also used in Russian and American medicine to treat cancer, as well as being used in traditional Chinese medicine [Ercisli 2009].

Physico-chemical attributes of fruits. Genotypes and the interaction of genotype × year were significant for all quantitative traits (Tab. 2). During the two growing seasons, the response of these traits differed among genotypes, which indicates the existence of genotype-environment interactions. The highest and the lowest values of CV were identified by yield (30.7%) and fruit length (5.7%), respectively.

The highest yield over two years was amounted in G-464, G-432, G-588, Shahroudi and G-571 (9.5 to 11.5 kg/tree). The range of fruit weight among genotypes was 13.6 to 55.8 g during the two-year experiment (Tab. 3). The high coefficient of variations and standard deviation of this trait showed that there was a significant variation among the studied genotypes. The highest mean fruit weight was recorded in G-571 (42.4 g), while 579 and 548 showed the lowest fruit weight (20.4 g) (Tab. 3). The fruit weight of 9 genotypes was over 30 g, but only genotypes G-432, G-463, G-464, G-571, G-573, and G-576 had higher fruit weight than cv. Shahroudi (control). On the other hand, G-432, G-571 and Shahroudi showed the highest

Table 1. Descriptive pomological characters based on UPOV among 38 apricot genotypes

Genotypes	Fruit: size	Fruit: shape	Fruit: ground/over color of skin	Fruit: color of flesh	Fruit: firmness of flesh	Stone: adherent	Stone: shape	Kernel: bitterness
Shahroudi	large	oblique rhombic	yellowish/pink	white	soft	absent or very weak	elliptic	absent or weak
G-393	medium	circular	white/red	cream	medium	absent or very weak	elliptic	absent or weak
G-406	small	oblong	yellowish/orange-red	cream	soft	absent or very weak	elliptic	absent or weak
G-417	medium	circular	white/orange-red	white	soft	absent or very weak	elliptic	absent or weak
G-431	medium	circular	yellowish/red	cream	soft	absent or very weak	elliptic	absent or weak
G-432	large	obovate	white/orange-red	white	soft	medium	elliptic	absent or weak
G-450	medium	ovate	yellow-green/pink	cream	soft	absent or very weak	oblong	absent or weak
G-451	medium	circular	white/pink	white	soft	medium	elliptic	absent or weak
G-457	medium	oblique rhombic	white/orange-red	medium orange	soft	absent or very weak	elliptic	absent or weak
G-462	large	ovate	yellowish/pink	white	soft	absent or very weak	elliptic	absent or weak
G-463	large	obovate	white/pink	light orange	soft	absent or very weak	oblong	medium
G-464	large	triangular	yellowish/orange-red	whitish green	soft	absent or very weak	elliptic	absent or weak
G-484	medium	ovate	yellowish/none	cream	soft	absent or very weak	circular	absent or weak
G-496	medium	circular	yellowish/pink	white	soft	absent or very weak	elliptic	absent or weak
G-499	medium	oblong	yellowish/orange-red	light orange	medium	absent or very weak	ovate	absent or weak
G-500	medium	obovate	yellowish/pink	white	medium	absent or very weak	oblong	medium
G-509	large	oblique rhombic	yellowish/purple	light orange	Firm	absent or very weak	ovate	absent or weak
G-525	medium	circular	yellowish/orange-red	cream	soft	absent or very weak	elliptic	absent or weak
G-526	small	oblong	yellow-green/orange-red	light orange	medium	absent or very weak	circular	absent or weak
G-533	medium	ovate	white/pink	cream	medium	absent or very weak	oblong	absent or weak

G-534	medium	circular	white/red	light orange	soft	absent or very weak	oblong	absent or weak
G-544	medium	ovate	yellow-green/purple	light orange	soft	absent or very weak	circular	absent or weak
G-546	medium	oblong	yellow-green/pink	light orange	soft	absent or very weak	ovate	absent or weak
G-548	medium	ovate	yellowish/red	white	medium	absent or very weak	ovate	absent or weak
G-552	medium	obovate	yellow-green/orange-red	whitish green	medium	absent or very weak	oblong	absent or weak
G-553	medium	oblong	yellowish/orange-red	cream	medium	absent or very weak	circular	absent or weak
G-555	medium	oblong	yellowish/purple	light orange	soft	absent or very weak	circular	absent or weak
G-565	medium	ovate	white/purple	cream	firm	absent or very weak	ovate	absent or weak
G-571	large	ovate	white/pink	light orange	soft	absent or very weak	ovate	absent or weak
G-573	large	oblong	white/pink	cream	soft	absent or very weak	obovate	absent or weak
G-575	medium	oblong	white/pink	cream	firm	absent or very weak	circular	absent or weak
G-576	large	obovate	white/none	light orange	soft	absent or very weak	ovate	absent or weak
G-578	medium	oblong	yellowish/orange-red	white	soft	medium	oblong	absent or weak
G-579	small	ovate	yellow-green/purple	medium orange	soft	absent or very weak	circular	absent or weak
G-581	medium	obovate	yellowish/orange-red	cream	medium	absent or very weak	ovate	absent or weak
G-585	medium	triangular	white/purple	white	soft	absent or very weak	oblong	absent or weak
G-588	medium	oblique rhombic	yellowish/pink	white	Firm	absent or very weak	elliptic	medium
G-592	small	oblong	yellow-green/pink	cream	soft	absent or very weak	circular	absent or weak
CV (%)	26.4	49.9	25.8/44.9	33.9	34.7	8.1	41.9	24.7

CV – coefficient of variation

Table 2. Combined ANOVA for pomological traits of 38 apricot genotypes

SOV	Df	MS										
		Y	FW	FL	LW	VW	SW	FW/SW	TSS	TA	TSS/TA	pH
Year (Y)	1	53.078**	869.40**	100.172**	194.40**	317.66**	0.03ns	229.10**	53.95**	0.05ns	477/68**	0.62*
Error 1	4	5.157	33.49	8.10	7.02	3.93	0.24	30.14	2.11	0.03	0.59	0.03
Genotype (G)	37	35.382**	534.62**	279.76**	97.92**	118.92**	6.84**	96.17**	59.29**	18.75**	854.70**	5.78**
G × Y	37	13.478**	74.67**	25.10**	15.28**	14.11**	0.50**	22.75**	7.92**	1.39**	88.64**	0.61**
Error 2	148	3.438	18.34	5.09	5.24	4.34	0.17	3.19	1.49	0.02	1.11	0.10
CV (%)		30.7	15.4	5.7	6.4	6.1	16.1	15.8	8.5	8.6	9.9	9.0

*, **, ns – significant difference at $p < 0.05$, $p < 0.01$ and non-significant, respectively

Y – yield, FW – fruit weight, FL – fruit length, LW – lateral width, VW – ventral width, SW – stone weight, FW/SW – fruit weight/stone weight, TSS – total soluble solids, TA – titratable acidity, pH – acidity, CV – coefficient of variation value in fruit length (45.6–46.4 mm). G-571 also showed the highest value of lateral and ventral width (42.1 and 40.9 mm, respectively) (Tab. 3). Fruit yield is one of the most important parameters for selection of cultivars and objectives of apricot breeding [Rezaei et al. 2020, Shamsolshoara et al. 2021]. Although the Shahroudi cultivar along with four other genotypes had the highest tree yield, but its value is lower than that of Ebadi et al. [2020] (38.3 kg/tree), which is due to the trees not reaching the economic bearing ages. Milatovic et al. [2017] found that the initial bearing of apricot cultivars has a direct relationship with their full bearing. Therefore, it can be stated that four genotypes G-464, G-432, G-588 and G-571 have high potential yield. Fruit weight and dimensions are the main quantitative hereditary traits that determine yield and consumer acceptance [Mratinić et al. 2011]. Previous studies on apricot have shown high variability in fruit weight of apricot cultivars/hybrids, ranging from 19.8 [Krichen et al. 2014] to 105.3 g [Drogoudi et al. 2008]. Asma et al. [2007] and Gecer et al. [2020] reported small size fruits in Irano-Caucasian group apricots. These differences could be related to the different eco-geographical situation of apricot cultivars studied.

Stone weight varied in a range of 0.9 to 5.6 g, which is similar to the results reported by Asma and Ozturk [2005] and Angmo et al. [2017] for apricot genotypes in Turkey and India, respectively. However, the mean value (2.5 g) is lower as compared to 3.0–5.0 g reported by Milošević et al. [2010] for promising apricot genetic resources in Central Serbia. The maximum stone weight was recorded in genotypes G-464 and G-571 (3.7 g), followed by G-576 (3.6 g), while the lowest stone weight was observed in G-500 and G-526 (1.6 and 1.7 g, respectively). Apricot stones can be used to identify genotypes and its kernel oil has a high value in food and medicine [Mandal et al. 2007].

The ratio of fruit weight to stone weight varied from 6.0 to 32.1. It seems that there was an extremely high diversity in this trait among different apricot genotypes. G-500 showed the highest value of fruit to stone weight ratio, while the lowest was recorded in G-534 (Tab. 3). Karaat and Serçe [2019] and Gecer et al. [2020] reported that the fruit weight to stone weight ratio ranged from 12.7 to 19.3 and 8.4 to 12.2 in some Turkish apricot cultivars, respectively. Consumers prefer high fruit to stone weight ratio, so its higher value is a desired economical characteristic for both fresh and dried apricots [Mratinić et al. 2011].

The total soluble solids ranged from 8.0 to 24.0°Brix (Tab. 3). Sixteen genotypes had higher TSS contents than the control (cv. Shahroudi). Among the genotypes, based on the mean of two years, the maximum TSS was measured in genotype G-450 (18.2 °Brix) followed by G-592 (16.6°Brix). The lowest was exhibited by G-576 (10.7°Brix). TSS content is a very important quality property [Mratinić et al. 2011]. Fruits with at least 12°Brix are acceptable for the market [Mratinić et al. 2011]. Therefore, G-576 was classified as undesirable, and G-575 and G-565 were less admissible, while G-450, and G-592 were more acceptable. Genetic variation in the TSS content of apricots has been reported by Mirheidari et al. [2020]. The reports of Asma and Ozturk [2005] for Turkish apricot, Milošević et al. [2010] for genotypes grown in Central Serbia, and Ruiz and Egea [2008] for genotypes grown in Spain supported our results, while Angmo et al. [2017] reported higher TSS content (31.1°Brix) in Indian apricots. Genetic and dry environmental conditions (humidity 21–28%) probably caused higher TSS content [Angmo et al. 2017]. The average humidity in the Karaj region was 32% to 63%, so, in addition to genotypic influence, humidity also affected TSS content.

Titratable acidity varied from 0.5% to 4.5%. It was less than 1% in nine genotypes. The genotypes G-417 and G-585 showed the highest TA content (3.7%), while G-553, G-555 and G-578 recorded the lowest one (0.6%) among studied genotypes (Tab. 3). According to Karaat and Serçe [2019], the TA content often Turkish apricot cultivars grown in Malatya was 0.55–2.10%.

There are criteria for considering a fruit acceptable by the consumer among which TSS and TA are the most important [Gecer et al. 2020]. Fruits are perceived as sweet if their TA value is less than 0.6% and their TSS content is more than 12%. However, if the TA value is greater than 1%, the consumer will be able to perceive the sweetness of the fruit provided that the TSS values is more than 15%. More acceptable fruits contain lower TA and higher TSS. The TSS/TA ratio is a commonly used quality index in many types of fruits. A higher ratio is indicative of higher and more acceptable fruit quality [Shamsolshoara et al. 2021].

Table 3. Quantitative fruit traits in 38 apricot genotypes (mean of two years: 2019–2020)

Genotype	Y* (kg/tree)	FW (g)	FL (mm)	VW (mm)	LW (mm)	SW (g)	FW/SW	TSS	TA	TSS/TA	pH
Shahroudi	10.1^{ab}	31.0^{cd}	45.8^{a}	36.4^{f-i}	33.6^{h-l}	2.1^{kl}	15.0^{bc}	14.7^{g-j}	0.8^{r}	19.5^{d}	3.7^{h}
G-393	7.3^{c-f}	23.4^{k-m}	37.9^{k-m}	34.4^{k-m}	31.5^{n-o}	2.3^{h-j}	10.1^{l-q}	15.5^{d-g}	1.5^{k}	10.1^{i}	3.5^{ij}
G-406	5.1^{f-l}	22.7^{l-o}	38.9^{h-l}	34.5^{k-m}	31.4^{o}	2.2^{jk}	10.2^{k-q}	13.4^{l-o}	1.1^{o}	12.4^{g}	3.8^{gh}
G-417	3.5^{j-m}	25.7^{h-k}	39.9^{g-i}	34.7^{j-m}	32.6^{k-o}	2.3^{h-j}	11.0^{h-m}	16.4^{bc}	3.7^{a}	4.5^{rs}	4.2^{bc}
G-431	3.4^{j-m}	26.5^{f-j}	40.9^{e-g}	35.0^{i-m}	31.8^{m-o}	2.4^{g-i}	10.9^{i-n}	14.3^{h-k}	1.9^{i}	7.6^{kl}	3.9^{e-g}
G-432	10.9^{a}	33.8^{b}	46.4^{a}	38.2^{b-e}	35.5^{d-g}	3.4^{b}	10.0^{m-q}	13.7^{k-n}	2.0^{h}	6.9^{mn}	3.3^{kl}
G-450	4.7^{g-m}	25.2^{i-l}	37.6^{l-n}	35.1^{i-m}	33.7^{h-k}	2.2^{jk}	11.6^{g-j}	18.2^{a}	1.6^{j}	11.2^{h}	4.3^{ab}
G-451	6.6^{d-i}	28.2^{d-h}	42.5^{b-d}	35.3^{h-m}	32.9^{i-m}	3.0^{d}	9.5^{p-r}	16.2^{b-d}	2.1^{g}	7.5^{kl}	3.7^{h}
G-457	7.3^{c-f}	27.6^{e-i}	39.2^{h-k}	36.4^{f-i}	32.9^{i-m}	2.3^{h-j}	12.1^{f-h}	16.0^{b-e}	0.9^{q}	18.0^{e}	4.4^{a}
G-462	7.7^{b-e}	30.5^{cd}	43.8^{b}	37.6^{d-g}	33.8^{h-k}	2.1^{kl}	14.3^{cd}	13.7^{k-n}	1.6^{j}	8.4^{j}	3.4^{jk}
G-463	6.4^{d-i}	32.9^{bc}	42.5^{b-d}	38.5^{b-d}	36.2^{c-d}	2.5^{gh}	13.4^{de}	12.1^{rs}	2.3^{f}	5.2^{qr}	2.9^{op}
G-464	11.5^{a}	35.6^{b}	43.3^{bc}	38.2^{b-e}	36.0^{c-e}	3.7^{a}	9.6^{p-r}	13.4^{l-o}	2.0^{h}	6.5^{no}	3.8^{gh}
G-484	2.9^{lm}	23.8^{j-l}	38.6^{i-l}	34.4^{k-m}	31.3^{o}	2.6^{fg}	9.2^{qr}	14.0^{i-l}	1.0^{p}	14.6^{f}	2.9^{op}
G-496	4.3^{h-m}	28.7^{d-g}	42.1^{c-e}	36.0^{h-k}	34.2^{f-j}	2.1^{kl}	14.3^{cd}	15.7^{c-f}	3.0^{c}	5.2^{qr}	4.1^{cd}
G-499	5.9^{d-k}	27.2^{f-i}	36.4^{n-p}	36.0^{h-k}	36.2^{cd}	2.3^{h-j}	11.5^{g-j}	15.3^{e-g}	0.8^{r}	15.0^{d}	3.8^{gh}
G-500	3.0^{k-m}	27.5^{e-i}	39.8^{g-i}	36.1^{g-j}	33.8^{h-k}	1.6^{o}	17.6^{a}	13.0^{n-q}	2.1^{g}	6.1^{op}	3.5^{ij}
G-509	6.0^{d-j}	30.5^{cd}	39.5^{g-j}	36.9^{e-h}	34.2^{f-j}	3.1^{cd}	9.7^{n-r}	14.3^{h-k}	0.8^{r}	18.5^{e}	3.5^{ij}
G-525	3.7^{j-m}	27.1^{f-i}	41.0^{e-g}	35.3^{h-m}	31.8^{m-o}	2.8^{ef}	9.7^{n-r}	14.8^{g-i}	2.1^{g}	6.9^{mn}	3.2^{lm}
G-526	4.4^{g-m}	21.0^{m-o}	30.7^{s}	32.2^{n}	32.8^{j-n}	1.7^{o}	12.6^{e-g}	13.0^{n-q}	2.7^{e}	4.7^{rs}	3.3^{kl}
G-533	4.8^{g-m}	23.3^{k-n}	35.8^{op}	33.9^{m}	32.6^{k-o}	2.5^{gh}	9.4^{p-r}	13.1^{m-p}	0.9^{q}	14.8^{f}	3.0^{no}

G-534	7.0d–g	26.4f–j	40.2f–h	35.6h–l	32.5k–o	3.0d	8.6r	14.1i–l	1.4l	9.9i	4.1cd
G-544	5.6e–k	28.9d–f	39.0h–l	36.4f–i	34.3f–i	2.6fg	10.8j–o	12.9o–r	3.6b	3.6t	3.0no
G-546	4.9^{f-l}	27.1^{f-i}	36.6^{m-p}	35.7^{h-l}	34.2^{f-j}	2.3^{h-j}	11.4^{h-k}	14.9^{f-h}	1.2^{n}	12.4^{g}	4.4^{a}
G-548	3.4^{j-m}	20.4^{o}	35.2^{p-q}	31.5^{n}	29.4^{p}	2.0^{lm}	10.1^{l-q}	14.0^{i-l}	1.9^{i}	7.5^{kl}	3.3^{kl}
G-552	4.6^{g-m}	26.6^{f-j}	35.9^{op}	35.5^{h-l}	34.1^{g-j}	2.1^{kl}	12.8^{ef}	16.2^{b-d}	2.1^{g}	7.6^{kl}	3.1^{l-n}
G-553	4.9^{f-l}	25.9^{g-k}	36.4^{n-p}	35.8^{h-l}	35.5^{d-g}	2.5^{gh}	10.1^{l-q}	14.8^{g-i}	0.6^{s}	25.4^{a}	4.3^{ab}
G-555	4.6^{g-m}	20.6^{no}	33.3^{r}	34.5^{j-m}	31.6^{m-o}	2.2^{jk}	9.5^{p-r}	12.6^{p-r}	0.6^{s}	21.7^{b}	3.4^{jk}
G-565	8.3^{b-d}	29.2^{d-f}	39.3^{h-k}	36.0^{h-k}	34.8^{e-h}	2.4^{g-i}	12.0^{f-i}	11.8^{s}	1.5^{k}	8.0^{jk}	2.6^{q}
G-571	9.5^{a-c}	42.4^{a}	45.6^{a}	42.1^{a}	40.9^{a}	3.7^{a}	11.3^{h-l}	13.3^{l-p}	2.3^{f}	5.8^{pq}	3.8^{gh}
G-573	7.9^{b-e}	35.2^{b}	41.5^{d-f}	39.1^{bc}	37.1^{bc}	3.3^{bc}	10.5^{j-p}	13.9^{k-m}	2.7^{c}	5.1^{r}	4.3^{ab}
G-575	3.3^{k-m}	24.7^{i-l}	37.7^{l-n}	35.2^{i-m}	33.6^{h-l}	2.3^{h-j}	10.6^{j-p}	11.6^{s}	1.6^{j}	7.3^{lm}	3.1^{l-n}
G-576	8.0^{b-e}	34.7^{b}	39.7^{g-j}	39.5^{b}	38.2^{b}	3.6^{ab}	9.7^{n-r}	10.7^{t}	2.9^{d}	3.7^{t}	2.9^{op}
G-578	7.0^{d-h}	30.2^{de}	39.6^{g-j}	35.9^{h-l}	35.6^{d-f}	2.9^{de}	10.3^{k-q}	12.3^{q-s}	0.6^{s}	20.1^{d}	4.0^{d-f}
G-579	2.3^{m}	20.4^{o}	34.0^{q-r}	32.5^{n}	30.0^{p}	1.9^{mn}	10.6^{j-p}	15.2^{e-g}	1.3^{m}	11.4^{h}	4.5^{a}
G-581	8.3^{b-d}	28.9^{d-f}	40.1^{f-i}	37.8^{c-f}	34.2^{f-j}	2.4^{g-i}	12.1^{f-h}	14.7^{g-j}	1.3^{m}	11.4^{h}	3.5^{ij}
G-585	4.3^{i-m}	22.9^{l-o}	38.3^{j-l}	34.6^{j-m}	32.3^{l-o}	2.4^{g-i}	9.5^{p-r}	15.7^{c-f}	3.7^{a}	4.2^{st}	3.4^{jk}
G-588	10.7^{a}	29.0^{d-f}	41.5^{d-f}	36.4^{f-i}	33.8^{h-k}	1.8^{no}	15.8^{b}	15.0^{f-h}	2.3^{f}	6.5^{no}	3.5^{ij}
G-592	4.4^{g-m}	25.3^{h-l}	36.7^{m-o}	34.8^{j-m}	32.6^{k-o}	2.4^{g-i}	10.2^{k-q}	16.6^{b}	0.8^{r}	21.0^{c}	3.9^{e-g}
Min	1.9	13.6	26.6	25.7	23.2	0.9	6.0	8.0	0.5	2.8	2.2
Max	15.9	55.8	51.3	47.6	43.5	5.6	32.1	24.0	4.5	34.0	5.1
Mean ±SD	6.0 ± 2.9	27.7 ± 6.5	39.3 ± 4.1	35.9 ± 3.1	33.8 ± 3.1	2.5 ± 0.6	11.2 ± 2.8	14.3 ± 2.0	1.8 ± 0.9	10.5 ± 6.3	3.6 ± 0.6

* – symbols as in Table 2; SD – standard deviation

Fig. 1. Appearance of fruits in G-571 with large fruit, G-450 with good taste and control cultivar (Shahroudi)

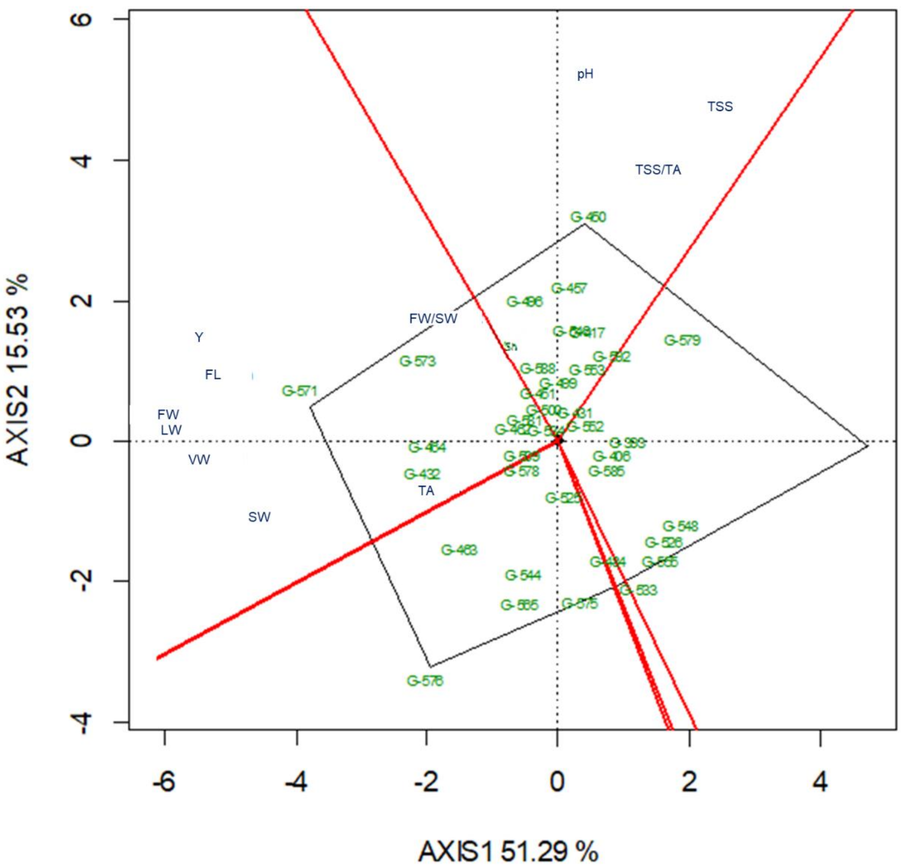

Fig. 2. GT-biplot for 38 apricot genotypes based on mean of 2019-2020, "which-won-where" pattern for genotype and traits. Sh – Shahroudi, other symbols as in Table 2

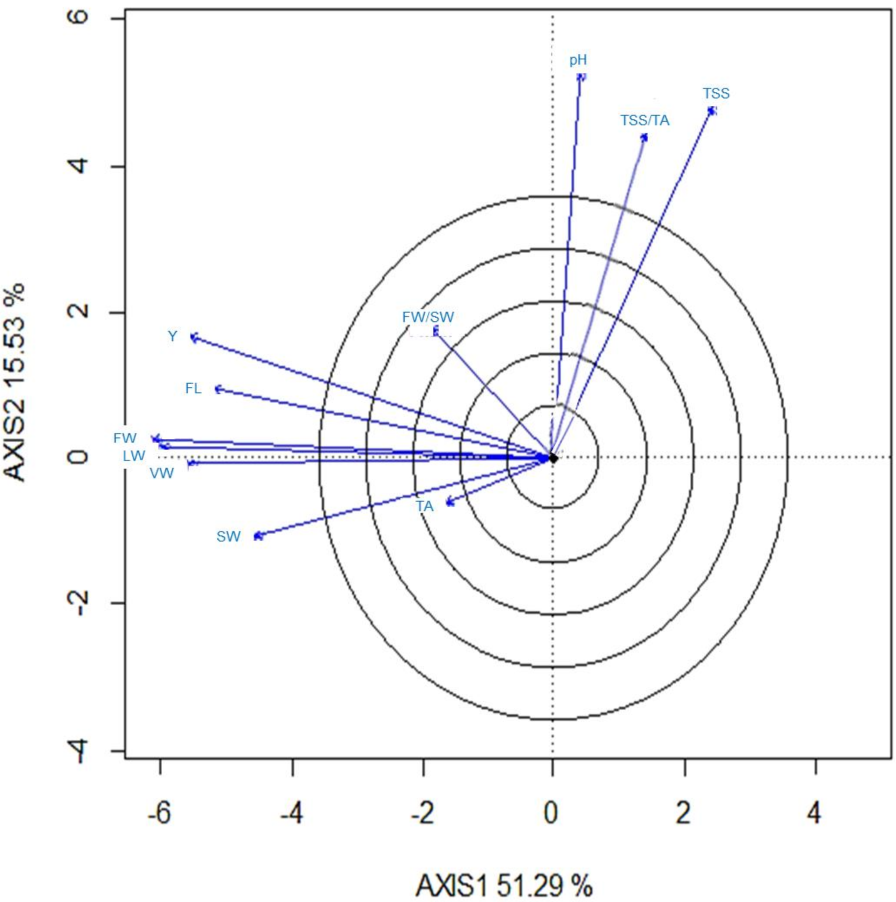

Fig. 3. Biplot vector diagram in 38 apricot genotypes, the cosine of the angle between the vectors shows a correlation between the measured traits. Symbols as in Table 2

The maximum, minimum and mean values of TSS/TA were 34.0, 2.8 and 10.5 ±6.3 (Tab. 3). Leccese et al. [2012] reported a TSS/TA ratio of 6 to 29 in 18 Italian genotypes, which is similar to our results. However, these 38 apricots were less sweet than those reported by Angmo et al. [2017]. In this experiment, the studied genotypes had a suitable amount of TSS for consumer acceptance. Accordingly, G-553 was the most acceptable genotype followed by G-555, and G-592.

The juice acidity level (pH) significantly differed among the genotypes. The highest pH was 4.5 in G-579, followed by 4.4 in G-546 and G-457, and 4.3 in G-553, G-573 and G-450 (Tab. 3). Central Asian and Iranian-Caucasian apricots have less acidity in comparison to European and Japanese apricots [Zaurov et al. 2013].

In general, our results are supported by Asma et al. [2007] and Kumar et al. [2015], who have reported that genetic diversity among morpho-physicochemical attributes is probably due to several factors such as geographical distribution, origin, genotype, climate, and their interactions. Variations among significant quality parameters including fruit weight, color, and firmness in apricots are very important in breeding studies [Khadivi-Khub and Khalili 2017, Wani et al. 2017].

Relationships of genotypes by trait. Genotype × trait biplot analysis (GT-biplot) is highlighted among the multivariate methodologies because it assesses genotypes based on multiple traits and identifies those that are superior in the desired variables. They can then be used as parents in breeding programs or even as possible commercial cultivars. A quick and practical visualization of the genetic correlation between traits is also provided by this analysis [Yan and Tinker 2006]. The relationships among traits are visualized by genotype profiles (Fig. 2). A biplot illustrated as a graph can be bi-directionally interpreted in different ways [Yan and Kang 2002]. The GT-biplot analysis identified that the first two components explained 66.86% of the total variance of the standardized data (the first component accounted for 51.29% and the second component for 15.53%). Figure 2 is a GT-biplot with a polygon view and presents the data of the 38 apricot genotypes with 11 traits averaged over the 2 years. Using the GT-biplot polygons, valuable genotypes were determined for one or more traits. The genotypes G-533, G-578, G-571, and G-460 were away from the biplot origin and were at the vertices of the polygon. These genotypes are the best or worst in terms of the quantity-measured traits. Four sectors can be identified based on the trait's vector in the biplot polygon. The first sector was composed of pH, TSS and TSS/TA. The ratio of fruit weight to stone weight, yield, fruit length, fruit weight, lateral width, ventral width, TA, and stone weight were placed in the second sector. The other sectors included no traits. Therefore, the genotypes G-571, G-573, G-464, and G-432 had the high values of fruit weight to stone weight, yield, fruit length, fruit weight, lateral width, ventral width, and stone weight (Fig. 2). Table 3 confirms the GT-biplot, and there is high conformity with the mean comparisons results.

The correlation coefficient between any two traits is approximated by the cosine of the angle between the vectors. An acute angle indicates a positive relationship whereas an obtuse angle indicates a negative relationship. A 90-degree angle between the two attributes indicates the absence of correlation between the two traits; in other words, the two vectors showing an angle of 90 degrees are independent of each other [Yan and Kang 2002]. Based on Figur 3, the most positive correlation was observed between yield and fruit length, and also among fruit weight and fruit dimensions (fruit length, lateral, and ventral width). A positive and high correlation was recorded between fruit weight with stone weight. The same relationship was observed between fruit weight and fruit weight/stone weight ratio and TA. This can be attributed to the fact that fruits that are larger in size will have larger stones and a higher fruit weight/stone weight ratio. There was no direct relationship between fruit weight and TSS, TSS/TA and pH. This finding was also reported in different studies on apricots [Asma and Ozturk 2005, Khadivi-Khub and Khalili 2017, Bilgin et al. 2020]. There was no correlation between TSS and TA, which supports the study by Ruiz and Egea [2008] and Bilgin et al. [2020]. In this study, pH and TSS correlated positively, while Asma et al. [2007], Ruiz and Egea [2008], and Bilgin et al. [2020] have reported the independence of these traits. It seems that the relationship between traits in apricots in different research differs with genetic diversity, geographical groups, and evaluated germplasm size.

The angles of fruit weight, fruit lateral, and ventral width vectors with PC1 were very low, which shows the high and negative correlation of these traits with PC1 (Fig. 3). Therefore, this component can be considered an element of fruit weight and fruit dimensions. Genotypes that have higher values of the first component will have lower fruit weight and size. According to Table 3 and Figure 1, G-526, G-548 and G-555 with a higher values of PC1 showed the least value of fruit weight and fruit dimensions. Genotypes located on the left side of the biplot origin have higher yield, fruit weight and fruit dimensions compared to the genotypes located on the right side of the biplot origin (Fig. 2). The PC2 showed a high and positive correlation with the pH, TSS and TSS/TA. Therefore, genotypes with higher values of PC2 will be more acceptable to consumers. Accordingly, the G-450, G-553 and G-579 genotypes had the highest pH, TSS and TSS/TA (Tab. 3). In contrast, G-544, G-576 and G-576, which is located at the farthest point below the biplot origin, showed the lowest pH, TSS and TSS/TA.

Another main feature of the GT-biplot is the vector length of each trait, which approximates the standard deviation within each trait. These vectors are an indicator of the ability to distinguish between attributes. Long vectors have a high standard deviation and thus have more potential for differentiating. They also indicate greater diversity in the measured characters [Yan and Kang 2002, Yan and Tinker 2006]. In the study of the relationships between genotypes and traits, longer vectors indicate the stronger relationship compared to the shorter ones. The fruit weight had a longer vector than the other traits (Fig. 3), so the genetic diversity of this trait was high among apricot genotypes. In contrast, genetic variation in TA and fruit weight/stone weight ratio was lower than that in other traits.

CONCLUSION

The selected apricot genotypes obtained from the cross between Iranian and Italian cultivars showed significant genetic diversity in pomological attributes. Among the studied genotypes, G-450 and G-553 had the sweetest fruits and the best taste index from the consumer point of view. The highest yield was obtained by G-464, G-432, G-588 and G-571. In addition, G-571 had the highest fruit weight and a considerable fruit size, followed by genotypes G-576, G-432 and G-464. Since there was no correlation between fruit weight and TSS and TSS/TA, the genetic control of these traits is independent of each other and can be used to have tasty fruits in a larger size. Therefore, we suggest pyramiding these traits by inter-crossing of G-464 and G-571 with G-450. According to GT-biplot analysis, due to the high correlation of fruit size with fruit weight, these two traits can be used as indicators, along with the pH and TSS, for selecting superior genotypes.

ACKNOWLEDGEMENTS

This study was supported by the Horticultural Science Research Institute.

SOURCE OF FUNDING

This research received no external funding.

REFERENCES

Angmo, P., Angmo, S., Upadhyay, S.S., Targais, K., Kumar, B., Stobdan, T. (2017). Apricots (Prunus armeniaca L.) of trans-Himalayan Ladakh: Potential candidate for fruit quality breeding programs. Sci. Hortic., 218, 187–192. https://doi.org/10.1016/j.scienta.2017.02.032

Asma, B.M., Kan, T., Birhanlı, O. (2007). Characterization of promising apricot (Prunus armeniaca L.) genetic resources in Malatya, Turkey. Genet. Resour. Crop Evol., 54(1), 205–212. https://doi.org/10.1007/s10722-005-3809-9

Asma, B.M., Ozturk, K. (2005). Analysis of morphological, pomological and yield characteristics of some apricot germplasm in Turkey. Genet. Resour. Crop Evol., 52(3), 305–313. https://doi.org/10.1007/s10722-003-1384-5

Bilgin, N.A., Evrenosoğlu, Y., Mısırlı, A., Kokargül, R. (2020). Analysis of fruit properties of 'Hacıhaliloğlu' × 'Boccucia' hybrid population. Erwerbs-Obstbau, 62(2), 231–239. https://doi.org/10.1007/s10341-020-00476-z

Corrado, G., Forlani, M., Rao, R., Basile, B. (2021). Diversity and relationships among neglected apricot (Prunus armeniaca L.) landraces using morphological traits and SSR markers: implications for agro-biodiversity conservation. Plants, 10(7), 1341. https://doi.org/10.3390/plants10071341

Drogoudi, P.D., Vemmos, S., Pantelidis, G., Petri, E., Tzoutzoukou, C., Karayiannis, I. (2008). Physical characters and antioxidant, sugar, and mineral nutrient contents in fruit from 29 apricot (Prunus armeniaca L.) cultivars and hybrids. J. Agric. Food Chem., 56(22), 10754–10760. https://doi.org/10.1021/jf801995x

Ebadi, M., Fatahi Moghaddam, M.R., Zamani, Z. 2020. Study of bearing status and fruit quantity and quality traits in some apricot cultivars in Karaj condition. Iran. J. Hortic. Sci. Technol., 21(4), 471–482.

Ebrahimi, S., Rezaei Nejad, A., Ismaili, A., Karami, F. (2015). Physiological and phenological variability and heritability of some apricot (Prunus armeniaca L.) cultivars and genotypes. J. Plant Genet. Res., 1(2), 55–70. http://dx.doi.org/10.29252/pgr.1.2.55

Ercisli, S. (2009). Apricot culture in Turkey. Sci. Res. Essays, 4(8), 715–719.

Frutos, E., Galindo, M.P., Leiva, V. (2014). An interactive biplot implementation in R for modeling genotype-by-environment interaction. Stoch. Environ. Res. Risk Assess., 28(7), 1629–1641. https://doi.org/10.1007/s00477-013-0821-z

Geçer, M.K., Kan, T., Gundogdu, M., Ercisli, S., Ilhan, G., Sağbaş, H.I. (2020). Physicochemical characteristics of wild and cultivated apricots (Prunus armeniaca L.) from Aras valley in Turkey. Genet. Resour. Crop Evol., 67(4), 935–945. https://doi.org/10.1007/s10722-020-00893-9

Hagidimitriou, M., Rousakis, E., Tripolitsiotis, K., Linos, A., Karayiannis, I. (2010). Genetic diversity of a collection of Greek and foreign apricot cultivars and hybrids using molecular markers. Acta Hortic., 862, 39–43. https://doi.org/10.17660/ActaHortic.2010.862.3

Halász, J., Hegedűs, A., Pedryc, A. (2006). Review of the molecular background of self-incompatibility in rosaceous fruit trees. Int. J. Hortic. Sci., 12(2), 7–18. http://dx.doi.org/10.31421/IJHS/12/2/630

Karaat, F.E., Serçe, S. (2019). Total phenolics, antioxidant capacities and pomological characteristics of 12 apricot cultivars grown in Turkey. ADYUTA YAM Dergisi, 7, 46–60.

Karayiannis, I. (2010). Inheritance of sweet kernel taste in apricot. Acta Hortic., 862, 73–76. https://doi.org/10.17660/ActaHortic.2010.862.9

Khadivi-Khub, A., Khalili, Z. (2017). A breeding project: The selection of promising apricot (Prunus armeniaca L.) genotypes with late blooming time and high fruit quality. Sci. Hortic., 216, 93–102. https://doi.org/10.1016/j.scienta.2016.12.027

Krichen, L., Audergon, J-M., Trifi-Farah, N. (2014). Variability of morphological characters among Tunisian apricot germplasm. Sci. Hortic., 179, 328–339. https://doi.org/10.1016/j.scienta.2014.09.054

Kumar, D., Lal, S., Ahmed, N. (2015). Morphological and pomological diversity among apricot (Prunus armeniaca) genotypes grown in India. Indian J. Agric, Sci., 85(10), 1349–1355.

Leccese, A., Bartolini, S., Viti, R. (2012). From genotype to apricot fruit quality: the antioxidant properties contribution. Plant Foods Hum. Nutr., 67(4), 317–325. https://doi.org/10.1007/s11130-012-0314-0

Mandal, S., Suneja, P., Malik, S., Mishra, S. (2007). Variability in kernel oil, its fatty acid and protein contents of different apricot (Prunus armeniaca) genotypes. Indian J. Agric, Sci., 77(7), 464–466.

Milošević, T., Milošević, N., Glišić, I., Krška, B. (2010). Characteristics of promising apricot (Prunus armeniaca L.) genetic resources in Central Serbia based on blossoming period and fruit quality. Hortic Sci. (Prague), 37(2), 46–55. https://doi.org/10.17221/67/2009-HORTSCI.

Milatovic, D., Đurović, D., Zec, G. (2017). Productivity of early and medium early apricot cultivars in the Belgrade area. J. Agric. Food Environ. Sci., 71(2), 131–136.

Mirheidari, F., Khadivi, A., Moradi, Y., Paryan, S. (2020). The selection of superior plum (Prunus domestica L.) accessions based on morphological and pomological characterizations. Euphytica, 216(6). https://doi.org/10.1007/s10681-020-02617-7

Mratinić, E., Popovski, B., Milošević T., Popovska, M. (2011). Evaluation of apricot fruit quality and correlations between physical and chemical attributes. Czech J. Food Sci., 29(2), 161–170. https://doi.org/10.17221/203/2010-CJFS

Rezaei, M., Heidari, P., Khadivi, A. (2020). Identification of superior apricot (Prunus armeniaca L.) genotypes among seedling origin trees. Sci. Hortic., 262, 109062. https://doi.org/10.1016/j.scienta.2019.109062

Ruiz, D., Egea, J. (2008). Analysis of the variability and correlations of floral biology factors affecting fruit set in apricot in a Mediterranean climate. Sci. Hortic., 115(2), 154–163. https://doi.org/10.1016/j.scienta.2007.08.016

Shamsolshoara, Y., Miri, S.M., Gharesheikhbayat, R., Pirkhezri, M., Davoodi, D. (2021). Phenological, morphological, and pomological characterizations of three promising plum and apricot natural hybrids. Taiwania, 66(4), 466–478. https://doi.org/10.6165/tai.2021.66.466

Wani, A.A., Zargar, S.A., Malik, A.H., Kashtwari, M., Nazir, M., Khuroo, A.A., Ahmad, F., Dar, T.A. (2017). Assessment of variability in morphological characters of apricot germplasm of Kashmir, India. Sci. Hortic., 225, 630–637. https://doi.org/10.1016/j.scienta.2017.07.029

Yan, W., Kang, M.S. (2002). GGE biplot analysis: A graphical tool for breeders, geneticists, and agronomists. CRC Press, Boca Raton, FL.

Yan, W., Tinker, N.A. (2006). Biplot analysis of multi-environment trial data: principles and applications. Can. J. Plant Sci., 86(3), 623–645. https://doi.org/10.4141/P05-169

Yilmaz, K.U., Paydaş Kargi, S., Kafkas, S. (2012). Morphological diversity of the Turkish apricot (Prunus armeniaca L.) germplasm in the Irano-Caucasian ecogeographical group. Turk. J. Agric. For., 36(6), 688–694. http://dx.doi.org/10.3906/tar-1111-14

Zaurov, D.E., Molnar, T.J., Eisenman, S.W., Ford, T.M., Mavlyanova, R.F., Capik, J.M., Funk, C.R., Goffreda, J.C. (2013). Genetic resources of apricots (Prunus armeniaca L.) in Central Asia. Hortic. Sci., 48(6), 681–691. https://doi.org/10.21273/HORTSCI.48.6.681

Zhebentyayeva, T., Ledbetter, C., Burgos, L., Llácer, G. (2012). Apricot. In: Fruit breeding. Vol. 8. Badenes, M.L., Byrne, D.H. (eds). Springer, Boston, MA, 415–458.