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Phenological, morphological, and pomological characterizations of three promising plum and apricot natural hybrids

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ABSTRACT: Iran has a rich genetic diversity of *Prunus* spp. This study was conducted to evaluate the phenological, morphological, pomological and sensorial traits on three natural plum and apricot hybrids including *P. armeniaca* × *P. salicina* (Bavanat) and *P. cerasifera* × *P. armeniaca* (Shiraz and Shahriar) during 2018–2020. According to UPOV (International Union for the Protection of New Varieties of Plants) descriptor, all hybrids were characterized by medium growth vigor and a bearing type of spurs and long shoots. Fruit skin color ranged from purple to dark red with the predominant skin color being red. The beginning of the flowering period was affected by year and temperature, however they were classified as very early-flowering genotypes. The highest fruit weight, fruit dimensions and total soluble solids/titratable acidity ratio (TSS/TA) were found in Bavanat. The principal component analysis revealed that the most important fruit characters, including yield, fruit dimensions, fruit flesh fresh weight, fruit weight/stone weight, TSS, TA, TSS/TA and pH were the most effective traits for differentiating the studied genotypes. Shahriar had the highest panel test scores and was more attractive for consumers. Its fruits were sourer and smaller than the two other genotypes while it had the highest yield, fruit number and antioxidant activity. According to genotype-by-trait (GT) biplot analysis, Shiraz was closer to the ideal genotype. However, each of these three genotypes, due to their fruit-bearing capacity and specific traits, are interesting as valuable genetic resources for breeding programs to improve plum or apricot pomological traits coordinated to yield performance.

KEY WORDS: Fruit quality, GT-biplot, panel test, phenology, pomology, *Prunus*, *P. armeniaca*, *P. cerasifera, P. salicina*.

INTRODUCTION

The genus *Prunus* (from the family Rosaceae), known as stone fruits, has about 430 species (Burgos *et al*., 2007; Vicente *et al*., 2011). According to classification of *Prunus* by Rehder (1940), which is widely accepted, it consists of five subgenera including *Amygdalus* (almonds and peaches), *Prunus* (plums and apricots), *Cerasus* (sweet and sour cherries), *Laurocerasus* (bay-cherries) and *Padus* (bird cherries) (Gharaghani *et al*., 2017). The most important commercial species including peach and nectarine (*P. persica* L.), plum (*P. domestica* L., *P. salicina* Lindl., *P. cerasifera* Ehrh.), cherry (*P. avium* L., *P. cerasus* L.), apricot (*P. armeniaca* L.) and almond (*P. dulcis* (Miller) D. A. Webb.) have originated in Europe, western and central Asia and China, and have spread naturally across temperate regions (Burgos *et al*., 2007; Faust *et al*., 2011; Vicente *et al*., 2011). Iran is also one of the centers of the origin and diversity of *Prunus* spp. and one of the largest producers of plums and apricots in the world (Burgos *et al*., 2007; Gharaghani *et al*., 2017). *P. domestica* L., *P. spinosa* L., *P. divaricate* Ledeb., *P. cerasifera* Ehrh., *P. bilireina* Andre., *P. dasycarpa* Ehrh., *P. armeniaca* L., and *P. mandshurica* Koehne are the most important species and hybrids of *Prunus* subgenus in Iran (Gharaghani *et al*., 2017). Many wild species, cultivars, and genotypes of stone fruits are important genetic resources in Iran so that there are about 75 cultivars of plum and prune native to Iran, and a considerable genetic diversity can be found for these species to breed new varieties or rootstocks as the requirements of market demands or growers (Gharaghani *et al*., 2017; Martínez-Gómez *et al*., 2003).

Breeding research in plums and apricots has focused mainly on searching for highly productive cultivars adapted to diverse biotic and/or abiotic stresses (such as resistance to pests and diseases, tolerance to poor soils, cold hardiness and torelarnce to spring frost), reduced tree size for high-density orchards, or improved fruit quality and storage capability (Burgos *et al*., 2007; Ham, 2009; Milošević and Milošević, 2018). Despite over 6000 plum cultivars from 19-40 species that were used for fresh market and processing, there is still a need to produce new cultivars (Milošević and Milošević, 2018). The ability to use germplasm from related *Prunus* species has enhanced the options for improving the commercial *Prunus* trees (Cici and Van Acker, 2010). Hybridization is considered an important evolutionary process or breeding method that can increase plant diversity and contribute to achieving genotypes with new traits (Baek *et al*., 2018;

Soltis and Soltis, 2009; Szymajda *et al*., 2015). Interspecific hybrids are important in *Prunus* breeding (Hartmann and Neumüller, 2009; Szymajda *et al*., 2015; Yaman and Uzun, 2020). Interspecific hybridization of the genus *Prunus*- such as Marianna, an interspecific hybrid of *P. cerasifera* × *P. munsoniana*- are commonly used for the breeding of rootstocks, while it is relatively little for scion improvement (Hartmann and Neumüller, 2009). Interspecific hybridisations allow the transfer of desired traits in one *Prunus* species to another one. For example, the cold hardiness of *P. cerasifera* and *P. americana* could be incorporated to *P. salicina* and *P. domestica*, or high content of anthocyanins and phenolic compounds of *P. cerasifera* and *P. salicina* seems to be promising in improving the nutritional value of other *Prunus* species (Fanning *et al*., 2014; Hartmann and Neumüller, 2009; Wang *et al*., 2012). Due to many morphological, anatomical, and physiological barriers, such as genetic incompatibility or the different number of chromosomes that prevent fertilization and embryo formation, it is difficult to obtain *Prunus* interspecific hybrids (Burgos *et al*., 2007; Okie and Hancock, 2008; Szymajda *et al*., 2015). However, several natural and artificial *Prunus* interspecific hybrids, such as plumcot (apricot × European plum), aprium (plumcot × apricot), pluot (plumcot × plum), and tanasgol (apricot × plum), have been reported many of which have been introduced as new fruits or a parent in breeding programs (Das *et al*., 2011; Gharaghani *et al*., 2017; Okie and Hancock, 2008).

This research aimed to investigate some genotypes belonging to the natural hybrids of Japanese or cherry plums (*P. salicina* and *P. cerasifera*, respectively) and apricot (*P. armeniaca*) based on phenological, morphological, and pomological characteristics to introduce superior genotypes and determine the best traits for the discrimination and selection of genotypes in breeding programs.

MATERIALS AND METHODS

Experimental site and plant materials

In this study, the phenological, morphological, pomological and sensorial characteristics of three promising natural hybrids of *Prunus armeniaca* × *P. salicina* (Bavanat) and *P. cerasifera* × *P. armeniaca* (Shiraz and Shahriar) (Khakzad *et al*., 2013; Zarifi and Gharehsheikh Bayat, 2018) preserved in the collection of Horticultural Science Research Institute (N35°51′27″, E50°51′46″ and altitude 1235 m), Karaj, Iran, were evaluted. The examined genotypes were 7 years old collected from different geographical regions of Iran including Bavanat (N30°27′14″; E53°39′01″), Shiraz (N 29°39′13″; E 52°28′53″) and Shahriar (N35°39′35″; E51° 03′33″). Standard cultural practices were performed on the trees of the studied hybrids.

Analysis of phenological, pomological, and morphological traits

This research examined phenology, 54 qualitative morphology, and 23 quantitative pomology characteristics during three growing seasons (2018 to 2020). The phenological stages were determined according to Chapman and Catlin (1976) for three years. The growth stage 5 (white bud) was considered as the beginning of flowering, and the ending of flowering was marked by petal fall (stage 7). The mean temperatures during the phenological observations in 2018-2020 were 11.5, 8.6 and 9.4 °C, respectively.

The qualitative morphological characteristics were measured based on rating and coding by Japanese plum descriptor (UPOV, 2010). Total soluble solids (TSS) and titratable acidity (TA) were determined according to Latimer (2016). Antioxidant activity was calculated by DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity according to Nisar *et al*. (2015).

Sensory attributes (Panel test)

To measure the fruit attractivity and flavor, ten panelists (5 males and 5 females, between 27 and 63 years old) evaluated two typical fruits of each genotype by filling a questionnaire with the following parameters: fruit size, fruit shape, skin color, aroma, flavor, sweetness, acidity, juiciness, and texture. The score ranged from 1 to 9 for each parameter in which 1 indicated the minimum score and 9 represented the maximum rate for each trait (Butac *et al*., 2015).

Statistical analysis

The pomological studies were performed on ten random samples at the fruit maturity stage, which were replicated in six trees for each genotype. Coefficient of variation (CV) of qualitative and quantitative traits was calculated following the formula as described by Mellidou *et al*. (2020), and reported in Khadivi-Khub and Barazandeh (2015) and Mirheidari *et al*. (2020):

$$CV\ (\%) = (SD/\bar{x}) \times 100$$

where SD is the standard deviation and $\bar{x}$ is the mean values. Mean values and standard deviation were calculated on the basis of six individual samples (qualitative traits) or of sixty fruits (quantitative traits) for each genotype. Combined ANOVA was conducted using SPSS 22.0 software and means were separated using Duncan's multiple range test at $p< 0.05$. Principal component analysis (PCA) was performed to identify the most variable characteristics among the genotypes. The data of the sensorial attributes were subjected to normal scores by Tukey's formula prior to performing ANOVA. The following equation is used to normalize the sensorial data:

$$\left(r - \tfrac{1}{3}\right) \Big/ \left(n + \tfrac{1}{3}\right)$$

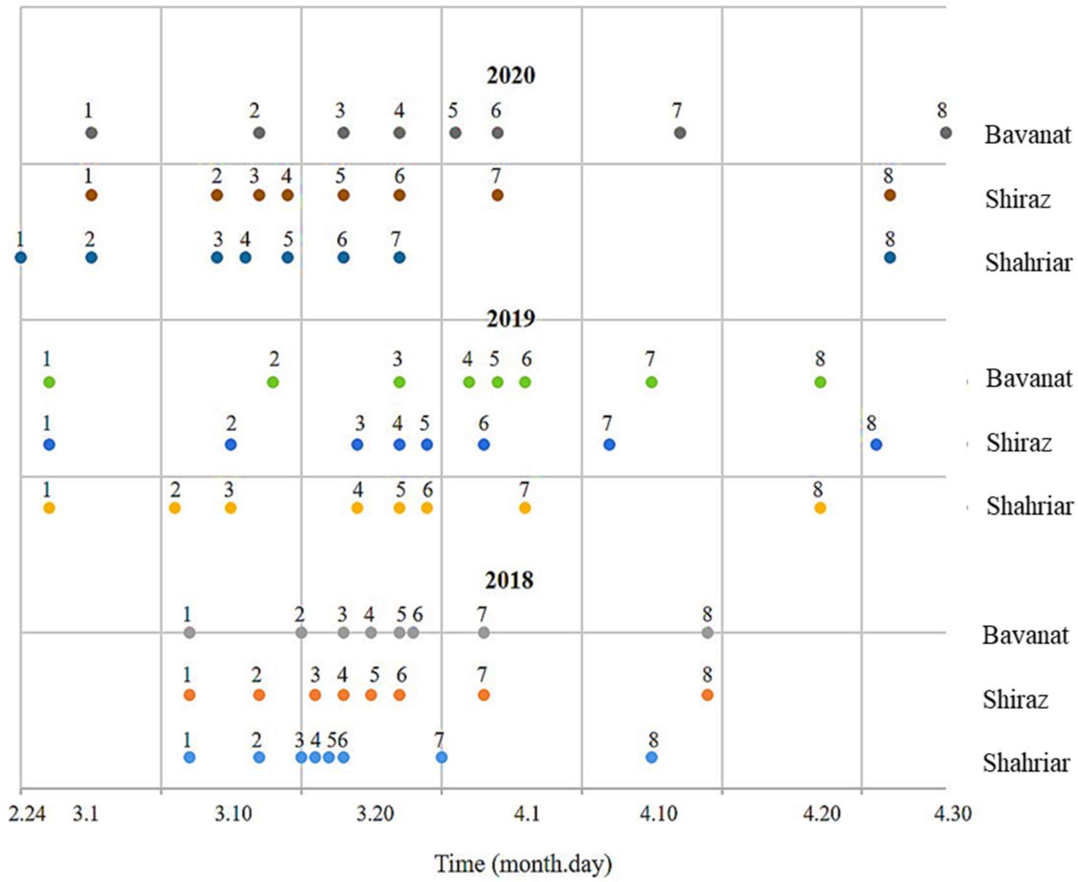

Fig. 1. The phenogram of bud growth stages from dormant to fruit set according to Chapman and Catlin (1976) in three plum and apricot hybrids during 2018-2020. 1: Dormant, 2: Swollen bud, 3: Bud burst, 4: Green cluster, 5: White bud, 6: Bloom, 7: Petal fall, 8: Fruit set.

where r is the rank of score value, ranging from 1 to n (Solomon and Sawilowsky, 2009). The correlations between sensorial attributes were calculated based on Pearson's bivariate correlation coefficient by using SPSS 22.0 software. The *GGEBiplotGUI* package in R 4.0.2 was used for genotype-by-trait (GT) biplot analysis. The model for the GT-biplot is given as:

$$\frac{\alpha_{ij-\beta_j}}{\sigma_j} = \sum \lambda_i \varepsilon_{ij} \eta_{ij} + \varepsilon_{ij} = \sum \varepsilon_{ij} \eta_{ij} + \varepsilon_{ij}$$

where α_{ij} is the mean value of genotype i for trait j, β_j is the mean value of all genotypes for trait j, σ_j is the standard deviation of trait j among genotypes means, λ_i is the singular value for principal component n (PCn), ε_{ij} and η_{ij} are scores for treatment i and trait j on PCn, respectively, and ε_{ij} is the residual associated with treatment i in trait j (Yan and Rajcan, 2002).

RESULTS

Phenological characteristics

The time of flowering beginning was from March 14 (Bavanat, 2020) to March 29 (Shahriar, 2019), and bloom was March 22 (Bavanat, 2020) to April 11 (Shahriar, 2020) (Fig. 1). Although the beginning of flowering varied between genotypes, all these genotypes were classified as very early flowering (Table 1). The flowering of Shahriar began 5-12 and 2-8 days later than Bavanat and Shiraz, respectively, and ended 3-20 and 0-13 days later than Bavanat and Shiraz, respectively. Generally, the flowering period in the genotypes was in the order of Bavanat > Shiraz > Shahriar.

Morphological and pomological characteristics

The results of qualitative attributes showed the variations in many of the studied traits. The coefficient of variations (CV%) varied from 0 to 56% (Table 1). The highest was recorded in the leaf blade shape and the beginning of the fruit ripening. Out of the 54 traits, 22 traits did not show any variation. The genotypes showed different tree habits including spreading, upright, and semi-upright in Bavanat, Shiraz, and Shahriar, respectively, while tree growth vigor and bearing type were the same in all three genotypes. Leaf traits including leaf blade shape, leaf blade angle, and leaf blade incision were quite different between the three genotypes. The genotypes showed two leaf blade shapes, i.e., obovate (Shahriar) and ovate (Bavanat and Shiraz). The color of the leaf blade was medium green in all genotypes (Table 1 and Fig. 2).

Table 1. Qualitative morphological and pomological characters based on International Union for the Protection of New Varieties of Plants (UPOV, 2010) among three natural hybrids of plum and apricot.

Trait	Genotype			CV (%)
	Bavanat	Shiraz	Shahriar	
Type of bearing	spurs and long shoots	spurs and long shoots	spurs and long shoots	0
Tree vigor	medium	medium	medium	0
Tree habit	spreading	upright	semi-upright	25
One year old shoot color	greyish brown	greyish brown	greyish brown	0
One year old shoot position	markedly held out	markedly held out	markedly held out	0
Spur length	medium	medium	medium	0
Bud: size	medium	medium	medium	0
Bud: shape	acute	acute	acute	0
Leaf blade: length/width ratio	slightly elongated	slightly elongated	moderately elongated	35.3
Leaf blade: shape	ovate	ovate	obovate	56.5
Leaf blade: color	medium green	medium green	medium green	0
Leaf blade: angle	obtuse	right angled	acute	41.2
Leaf: blade: glossiness	weak	weak	weak	0
Leaf blade: density of pubescence	sparse	sparse	sparse	0
Leaf blade: incision of margin	bi-crenate	bi-crenate	serrate	20.2
Petiole length	long	long	long	0
Pedicel	short	short	short	0
Flower diameter	large	large	large	0
Flower arrangement	touching	touching	touching	0
Sepal shape	medium ovate	medium elliptic	broad ovate	37.4
Petal shape	circular	obovate	circular	35.3
Petal undulation margin	weak	weak	medium	35.3
Stigma position	above	above	below	40.4
Fruit: length stalk	short	short	short	0
Fruit: size	medium	medium	medium	0
Fruit: height	medium	medium	medium	0
Fruit: width	medium	medium	medium	0
Fruit: shape	oblate	circular	circular	14.1
Fruit: symmetry	moderately asymmetric	moderately asymmetric	strongly asymmetric	40.8
Fruit: shape base	truncate	depressed	truncate	20.2
Fruit: shape apex	rounded	rounded	rounded	0
Fruit: depth of stalk cavity	medium	medium	medium	0
Fruit: depth of width cavity	medium	medium	medium	0
Fruit: depth of suture	shallow	medium	shallow	20.2
Fruit: bloom of skin	absent or very weak	weak	medium	54.4
Fruit: ground color of skin	yellow	not visible	yellow	46.6
Fruit: relative area of over color	medium	very large	large	23.3
Fruit: color of skin	medium red	dark red	purple	20
Fruit: pattern of over color	mottled	solid flush only	mottled	20.2
Fruit: color of flesh	yellowish green	orange	orange	21.7
Fruit: firmness	soft	soft	medium	25.7
Fruit: juiciness	high	high	low	40.4
Fruit: acidity	low	low	medium	35.4
Fruit: sweetness	medium	high	low	40.8
Fruit: adherent	non-adherent	adherent	adherent	40.4
Fruit: fiber	low	low	medium	35.3
Stone shape: lateral view	narrow elliptic	broad ovate	circular	46.7
Stone shape: ventral view	medium elliptic	medium elliptic	broad elliptic	20.2
Stone shape: basal view	narrow elliptic	medium elliptic	broad elliptic	40.8
Stone symmetry: lateral view	strongly asymmetric	strongly asymmetric	symmetric	40.4
Stone texture: lateral surface	granular	rough	granular	20.2
Stone: width of stalk-end	medium	narrow	broad	40.8
Time of beginning flowering	very early	very early	very early	0
Time of fruit ripening	very early	very early	early	56.5

CV: coefficient of variation

Fig. 2. Tree habit and characteristic of leaf, fruit and stone in the three natural hybrids of plum and apricot.

Fruit shape, skin color and pattern, fruit symmetry, and fruit base shape varied among the studied genotypes. The predominant shape of the fruits was circular. Fruit skin color ranged from purple (Shahriar) to dark red (Shiraz), with red being the predominant color (two out of three genotypes). Fruit flesh color was predominantly orange (Shiraz and Shahriar), while Bavanat was yellowish-green (Table 1 and Fig. 2). Fruit flesh firmness was soft in Bavanat and Shiraz (1.9 and 2.1 kg/cm^2, respectively) and medium in Shahriar (2.5 kg/cm^2) (Tables 1 and 2). The stone shape in the lateral view was narrow elliptic (Bavanat), broad ovate (Shiraz), and circular (Shahriar) (Table 1 and Fig. 2). The basal shape of the stone differed from narrow elliptic to broad elliptic.

Table 2. The combined ANOVA of the qualitative pomological traits in the three natural hybrids of plum and apricot.

Source of variation (SOV)	Year (Y)	Replication (Year)	Genotype (G)	G × Y	Error	CV (%)
Degree of freedom (df)	2	15	2	4	30	
Yield (Yi)	22.17^{ns}	245.49	6743.17**	16.58^{ns}	43.03	30.5
Fruit number (FN)	53104.8^{ns}	160699.5	19169225.7**	34574.96^{ns}	49227.53	21.3
Fruit weight (FW)	0.130^{ns}	70.61	159.19**	0.324^{ns}	1.456	5.5
fruit volume (FV)	530.32**	0.342	158.14**	8.5**	0.484	3.4
Fruit length (FL)	101.21**	0.489	61.25**	2.1*	0.549	2.4
Lateral width (LW)	139.5**	0.369	5.59^{ns}	8.14**	0.631	2.6
Ventral width (VW)	249.8**	18.83	20.20^{ns}	13.66^{ns}	20.7	13.5
Fruit firmness (FF)	0.027^{ns}	0.15	7.63*	0.025^{ns}	0.14	7.7
Depth of stalk cavity (DSC)	30.6^{ns}	30.76	36.3^{ns}	28.33^{ns}	31.4	10
Fruit length/ Ventral width (FL/VW)	0.006**	0.0003	0.036*	0.004**	0.0003	1.7
Fruit length/ Lateral width (FL/LW)	0.014^{ns}	0.009	0.059^{ns}	0.009^{ns}	0.01	10.4
Fruit flesh wet weight (FFW)	476.26**	0.366	171.20**	9.7**	0.462	3.4
Fruit flesh dry weight (FFD)	34.16**	0.029	24.43**	1.2*	0.37	11.3
Fruit flesh wet weight/ Fruit flesh dry weight	0.021^{ns}	0.031	42.37**	0.005^{ns}	0.014	3
Stone weight (SW)	0.978**	0.016	0.144^{ns}	0.065 ^{ns}	0.019	7.1
Kernel weight (KW)	3.42*	0.82	3.15ns	2.05ns	0.12	33.6
Fruit weight/ Stone weight (FW/SW)	38.23**	0.519	74.99**	5.62**	0.569	6.6
Kernel weight/ Stone weight (KW/SW)	1.56^{ns}	0.48	1.87^{ns}	1.15^{ns}	0.06	48.4
Total soluble solids (TSS)	1.81*	0.249	52.66**	3.77**	0.453	3.7
Titratable acidity (TA)	0.11*	0.22	23.20**	0.023^{ns}	0.19	13.2
Total soluble solids/ Titratable acidity	0.414^{ns}	0.125	91.09**	3.09*	0.15	6.3
Acidity (pH)	0.09**	0.13	6.36**	0.021^{ns}	0.12	8.5
Radical scavenging activity (DPPH)	0.31^{ns}	169.46	829.15**	0.77^{ns}	25.8	28.1

*, **, ns: significant difference at P< 0.05, P<0.01 and non-significant, respectively

Table 3. The quantitative pomological traits in the three hybrids of plum and apricot (mean of 2018–2020)

Genotype	Bavanat	Shiraz	Shahriar
Yi[a] (kg/tree)	18.3b	3.8c	42.2a
FN	763.1b	174.8c	2182.2a
FW (g)	24.5a	22.3b	18.6c
FV (cm^3)	23.0a	20.7b	17.2c
FL (mm)	32.9a	31.9b	29.3c
LW (mm)	30.9	30.5	29.8
VW (mm)	34.5	32.5	34
FF (kg/cm^2)	1.9b	2.1b	2.5a
DSC (mm)	4.4c	4.9 b	5.7a
FL/VW	1.07a	1.05b	0.98c
FL/LW	1.02	0.96	0.91
FFW (g)	22.7a	20.3b	16.6c
FFD (g)	4.0b	5.9a	6.1a
FFW/FFD	5.7a	3.4b	2.7c
SW (g)	1.8	1.9	2.3
KW (g)	0.87	1.17	1.04
FW/SW	13.4a	11.4b	9.3c
KW/SW	0.45	0.58	0.49
TSS	17.9b	20.2a	16.8c
TA	2.6b	2.6b	4.6a
TSS/TA	6.8 b	8.1 a	3.7 c
pH	4.4a	4.4a	3.4b
DPPH (%)	42.4c	55.4b	60.0a

1. Means with at least one common letter do not differ significantly according to DMRT (p< 0.05).
2. [a]: Abbreviations as in Table 2

The results of combined ANOVA revealed a significant difference between genotypes for most quantitative pomological traits (Table 2). The yield of genotypes was significantly different, ranging from 3.8 (Shiraz) to 42.2 kg/tree (Shahriar). The interaction between genotype and year for fruit yield was not significant (Table 3). The results showed that fruit weight differed among genotypes, and higher fruit weight was produced in Bavanat, Shiraz, and Shahriar, respectively. Fruit number varied among the genotypes, but it was constant in three years. Shahriar showed the highest number of fruits (2182.2 fruit/tree) and the least number was recorded in Shiraz (174.8 fruit/tree). Length, weight and volume of fruits showed a significant difference among genotypes and were affected by environmental conditions during the three experimental years. Fruit length ranged from 29.3 to 32.9 mm. The highest of these traits were recorded in Bavanat followed by Shiraz and Shahriar (Table 3). Fruits in all three genotypes were medium-sized (Table 1), and their weight ranged from 18.6 g (Shahriar) to 24.6 g (Bavanat) (Table 3).

The genotypes did not have significant differences in fruit stone weight and also kernel weight/stone weight. Besides, the interaction of genotype and year was not significant. One of the most important characteristics of fresh fruits, such as plums and plumcots, is the fruit weight/fruit stone ratio. This trait is affected by the environment. The means comparison showed that

Bavanat had the highest value (13.4) while Shahriar had the lowest (9.3) (Table 3).

The genotypic effect on TSS was significant and varied from 16.8 (Shahriar) to 20.2 Brix (Shiraz). TA ranged from 2.6 (Bavanat and Shiraz) to 4.6 (Shahriar). The pH of fruit juice significantly differed among the genotypes. The highest pH was 4.4 in Bavanat and Shiraz, which was significantly higher than that of Shahriar (3.4). TSS/TA ratio was 6.8, 8.1, and 3.7 for Bavanat, Shiraz, and Shahriar, respectively. Differences were also found in DPPH radical scavenging activity among genotypes. Shahriar had the highest antioxidant activity (60.0%) followed by Shiraz (55.4%) and Bavanat (42.4%) (Table 3).

Principal component analysis

The results revealed that the first six components could represent 90.03% of the total variability in PCA. Eigenvalues of > 1.0 were considered to be significant for the studied traits (Table 4). PC1 explained 47.2% of the total variance and comprised the most important traits including yield, fruit number, fruit weight, fruit volume, fruit length, fruit firmness, fruit length/ventral width, fruit flesh fresh weight, fruit weight/stone weight, TSS, TA, TSS/TA, pH and DPPH. PC2, which comprised fruit ventral width, lateral width, fruit flesh dry weight, and stone weight explained 23.7% of the total variance. PC3 correlated with kernel weight and kernel weight/stone weight and accounted for 10.6% of the total variance.

Sensorial analysis

The total score was calculated for each questionnaire, and then a general mark was calculated by an average of 10 panelists. The mean comparison of normalized data showed a significant difference in all sensorial attributes except for fruit shape (Table 5). The highest values (general score) based on the panelists' evaluation for Bavanat, Shiraz, and Shahriar were 59, 58, and 60.1, respectively. There were positive and negative correlations between fruit size with aroma and taste, respectively. Texture also showed a strong negative correlation with sweetness and a positive correlation with acidity and juiciness (Table 6).

GT-biplot analysis

The genotypes vs. traits biplot (GT-biplot) analysis showed that all of the total variation was explained through the first two PCs (69.09 and 31.91% for PC1 and PC2, respectively). The 23 pomological studied traits were divided into three sectors (Fig. 3A). The first sector comprised yield, fruit number, fruit firmness, TA, DPPH, stone weight (SW), and fruit flesh dry weight. Shahriar was the most responsive to these traits. The second sector consisted of ventral width (VW), fruit volume, fruit lateral width (LW), fruit flesh fresh weight, fruit weight (FW), fruit length (FL), FW/SW, pH, and FL/VW. Bavanat was the most responsive to the second group of traits. Finally, Shiraz was the winning genotype in the third sector containing the depth of stalk cavity, kernel weight (KW), TSS, KW/SW, FL/LW, and TSS/TA. Positive correlations were found among yield, fruit number, fruit firmness and TA. On the other hand, yield negatively correlated with fruit weight, fruit volume, fruit length, fruit flesh wet weight, fruit weight/stone weight, TSS, TSS/TA and pH. Fig. 3B shows the representativeness and discriminating capacity of each genotype towards the studied traits. The performance of genotypes according to the mean of traits is depicted by the average traits coordination (ATC) method. The small circle on the line passing through the coordinate axis represents the mean of the traits. The projection (dashed line) length, i.e., the distance between the genotype and the coordinate axis, is a measure of its discriminating ability: the longer vector is the more discriminating genotype. The angle of the projection from a genotype onto the coordinate axis represents the genotype's representativeness (Yan, 2001; Yan and Rajcan 2002). Therefore, Shahriar showed good representativeness of the traits, while Bavanat showed good discrimination. The ideal genotype is the one presenting high means in all traits. Based on the pomological studied traits, none of the genotypes can be considered the ideal genotype (Fig. 3C).

Table 4. Correlation between original variables and the first three principle components (PCs).

Trait	PC1	PC2	PC3
Yield	-0.743	0.374	-0.309
Fruit number	-0.846	0.406	-0.220
Fruit weight	0.394	-0.153	-0.347
Fruit volume	0.745	0.637	-0.144
Fruit length	0.833	0.489	-0.120
Lateral width	0.529	0.806	-0.031
Ventral width	0.186	0.640	-0.202
Fruit firmness	-0.932	0.306	0.190
Depth of stalk cavity	0.053	0.019	0.181
FL/VW	0.563	-0.651	-0.182
FL/LW	0.313	-0.301	0.236
Fruit flesh wet weight	0.766	0.609	-0.158
Fruit flesh dry weight	0.002	0.748	0.514
FFW/FFD	0.612	-0.199	-0.661
Stone weight	0.061	0.744	0.178
Kernel weight	0.289	0.307	0.630
Fruit weight/Stone weight	0.829	0.263	-0.298
Kernel weight/Stone weight	0.293	0.280	0.630
TSS	0.565	-0.455	0.483
TA	-0.927	0.333	0.031
TSS/TA	0.858	-0.415	0.186
pH	0.938	-0.279	-0.064
DPPH	0.671	0.384	0.255
Variance (%)	47.2	23.7	10.6
Cumulative variance (%)	47.2	70.9	81.5

Abbreviations as in Table 2

Table 5. Sensorial attributes in three plum and apricot hybrids.

Genotype	Exterior (commercial) aspect of fruits			Pulp traits (sensory traits)					
	Size	Shape	Skin color	Odor intensity	Flavor	Sweetness	Acidity	Juiciness	Texture
Bavanat	5.26* a	8.46 a	8.16 b	2.26 a	5.56 b	5.36 b	4.96 b	8.06 a	2.26 b
Shiraz	3.06 c	8.76 a	8.76 a	1.26 b	7.56 a	8.46 a	1.36 c	8.26 a	1.86 b
Shahriar	3.76 b	8.86 a	8.86 a	1.36 b	7.86 a	3.46 c	6.56 a	4.86 b	5.66 a

Means with at least one common letter do not differ significantly according to DMRT ($p< 0.05$)
*: 1 indicated the minimum score and 9 represented the maximum rate for each trait.

Table 6. Pearson's correlation coefficients between sensorial attributes in three natural plum and apricot hybrids.

Traits	Size	Shape	Skin color	Odor intensity	Flavor	Sweetness	Acidity	Juiciness
Shape	-0.23							
Skin color	-0.26	0.13						
Odor intensity	0.47**	-0.23	0.09					
Flavor	-0.48**	0.36	0.19	-0.32				
Sweetness	-0.27	0.01	0.07	0.02	0.11			
Acidity	0.36	-0.04	0.15	0.14	0.02	-0.88**		
Juiciness	0.19	-0.09	0.24	0.09	-0.26	0.72**	-0.67**	
Texture	-0.1	0.17	0.24	-0.04	0.31	-0.67**	0.67**	0.93**

**: significant difference at p<0.01.

DISCUSSION

Phenological characteristics revealed that the blossoming period varied among genotypes, although they were all very early flowering and under the risk of spring frost damage. Ganji Moghaddam *et al*. (2011) and Khadivi-Khub and Barazandeh (2015) reported genotypic dependence in flowering time between plum cultivars. Moreover, Głowacka *et al*. (2021) demonstrated the time and length of flowering period in Japanese plums depended on the year and cultivar. Blooming and consequently harvesting time may change every year depending on the environmental conditions, however the flowering time was not affected by the interaction of year × genotype and the order of the flowering starting time among the genotypes was stable during the three years of the present investigation. In contrary, Koskela et al. (2010), Liverani et al. (2010) and Khadivi-Khub and Barazandeh (2015) believe that these traits are affected by the interaction of genotype with the environment. Variation in flowering time of genotypes in similar geographical conditions might be a result of different heat requirements (Asma and Ozturk, 2005). Variation in flowering time of genotypes in similar geographical conditions may be the result of different heat requirements. The flowering period is affected by year (environment), so that flowering period was shorter in 2018 than the other two years as it had a higher mean temperature.

Natural hybrids of plum and apricot were evaluated for 54 qualitative morphological attributes based on the Japanese plum descriptor. Of these, 32 qualitative traits showed diversity for coefficient of variation. The CV value can be an indicator to genetic diversity, as the traits with no variations (CV = 0%) are homogeneous and cannot be used to distinguish the genotypes. Accordingly, the investigated genotypes were different concerning tree habit, most leaf and fruit traits, all stone characteristics and fruit ripening time. Similarly, Kumar *et al*. (2015) found high CV values in fruit and kernel characteristics of Indian apricot genotypes. The vegetative growth behavior of plum depends on the varietal characteristics and environmental conditions of the region (Sosna, 2002; Vitanova *et al*., 2004). Aazami and Jalili (2011) and Khadivi-Khub and Barazandeh (2015) reported that leaf-related criteria had significant morphological diversity among Iranian plums and plumcots. In addition, the characteristics of the stone in *Prunus* are almost stable, so the fruit stone shape is useful for genotype identification (Bilgin *et al*., 2020; Khadivi-Khub and Barazandeh, 2015; Woldring, 2000). Kumar *et al*. (2015) reported that apricot stones can be used to determine genotypes and its kernel oil has great value in food and medicine.

The fruit yield is a very important characteristic due to its economic importance. The yield of three genotypes was not affected by variable factors such as temperature, humidity, and rainfall during the three crop seasons and showed yield stability across the three years. However, yield was inversely related to fruit weight, So that Shariar had a high yield that had an adverse effect on the fruit weight and size, which was also reported by Głowacka *et al*. (2021) on Japanes plum cultivars.

The dominant shape of the fruits, stones, and leaves of Shiraz and Shahriar were the plum type, while Bavanat was apricot type. Zhivondov (2010) conducted pomological studies on plum-apricot hybrids and reported that the plum type dominated in the shape of the fruits, stones and leaves. Variation among parameters as fruit weight, fruit color, and firmness are very important in breeding studies (Khadivi-Khub and Khalili, 2017;

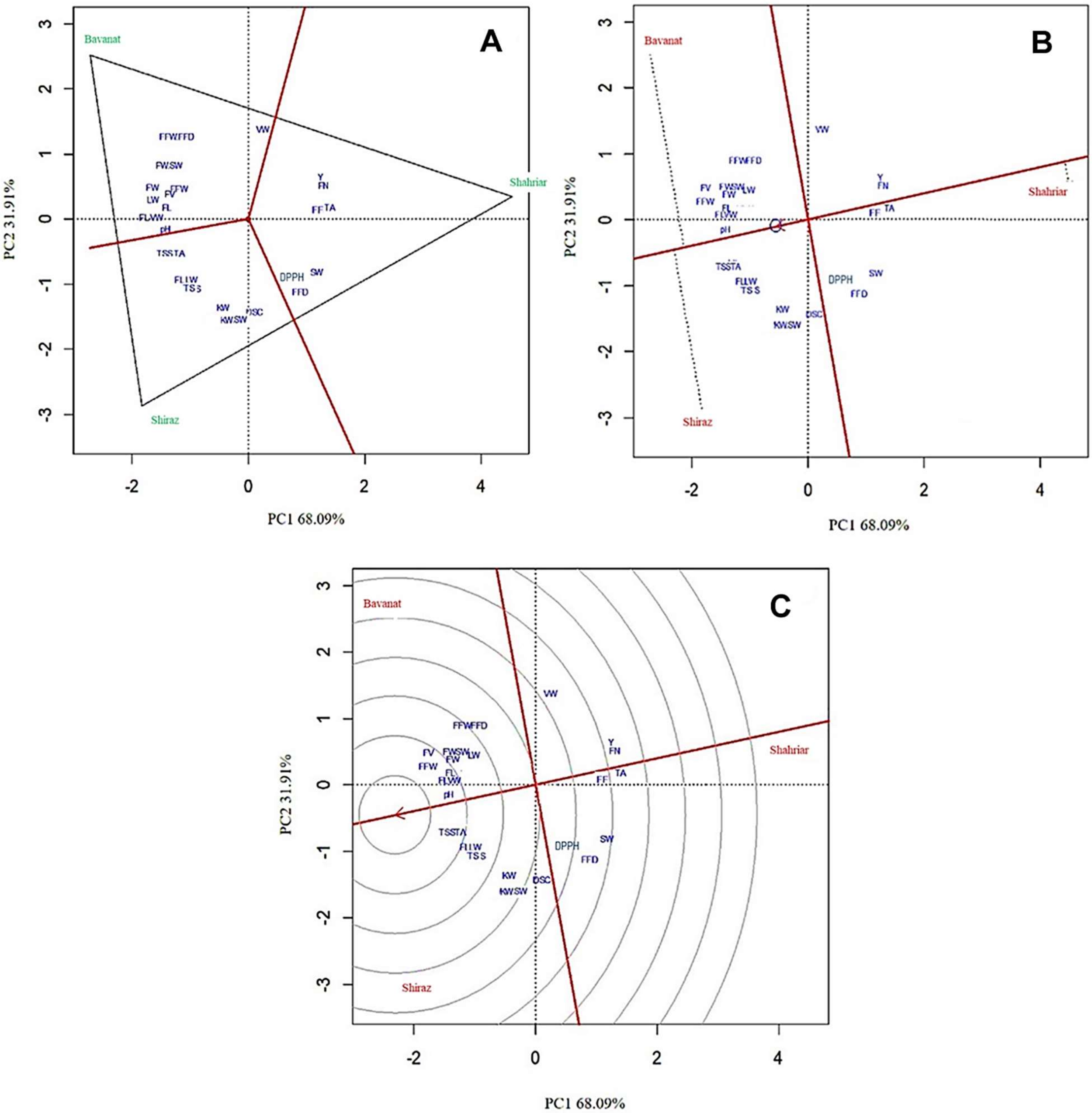

Fig. 3. GT biplot representing: **A**. the "which-won-where" graph, **B.** means x stabilities, indicating the ranking of three plum and apricot hybrids according to the traits, and **C**. an estimate of the ideal genotype. Abbreviations as in Table 3

Wani *et al*., 2017). The predominant shape, skin color, flesh color and flesh firmness of the fruits were circular, red, orange and soft-medium, respectively. These traits are very important quality factors that have a significant impact on consumer perception due to the fruit attractiveness (Ruiz and Egea, 2008). In plum and plumcot, round shapes without protruding tip and dark-red fruits are preferred by consumers (Crisosto *et al*., 2007; Ruiz and Egea, 2008). Anthocyanins, carotenoids, flavonols, proanthocyanidins and hydroxycinnamic acid derivatives are the major phytochemicals and pigments in plum fruits, but anthocyanins are predominantly responsible for the colors in red peel and flesh plums (Fanning *et al*., 2014; Wang *et al*., 2012). However, fruit skin color is dependent on tree location, temperature, tree growth habit, the microclimate of the canopy, light distribution, and genetics (Ionica *et al*., 2013; Mirheidari *et al*., 2020). Fruit flesh color also is strongly affected by environmental conditions and may depend on the maturity stage of the fruit (Ionica *et al*., 2013). Our results are in accordance with the results of Khadivi-Khub and Barazandeh (2015) and Milošević and Milošević (2012), who have reported that fruit color and fruit shape may be the most important characteristics for differentiating plum cultivars. Higher quality fruits have firmer flesh, which affects the fruit's shelf life and consumer acceptance. Morphological and pomological variations were reported in genotypes of apricot (Bilgin *et al*., 2020; Ruiz and Egea, 2008), plum and prune (Ganji Moghaddam *et al*., 2011; Sedaghathoor *et al*., 2009).

In addition, fruit size, dry matter, and soluble solid content are the most important marketability traits that determine fruit quality. Smaller fruits are typically sweeter and more suitable for processing, especially for the production of dried fruits, such as prunes (Maghlakelidze *et al*., 2017; Wolf *et al*., 2020). Although in our experiment, the fruit weight was not affected by the year, however, Głowacka *et al*. (2021) found that the fruit weight of the *P. salicina* cultivars varies from year to year and mainly depends on the climatic conditions and yield/plant. Milošević and Milošević (2012) reported that the fruit weight of Serbian plum cultivars was in the range of 6.2-28.0 g, while Khadivi-Khub and Barazandeh (2015) observed a range of 16.3-31.0 g. Our results are consistent with these reports (18.6-24.5 g). On the other hand, Yaman and Uzun (2020) found average fruit mass in apricot × plum hybrid combinations was 30.7 g. The fruit characteristics provide important groups of traits relative to the characterization of plum, and certain traits such as fruit size, fruit diameter, and skin color have been used to distinguish plum cultivars and genotypes (Božović *et al*., 2017; Maghlakelidze *et al*., 2017; Šebek *et al*., 2016).

TSS and TA content are analyses commonly used to indicate quality and to account for consumer acceptability of fruits (Crisosto *et al*., 2004). Genetic variations in the TSS content of plum and apricot were reported by several authors (Khadivi-Khub and Barazandeh, 2015; Mirheidari *et al*., 2020). The TSS content of three natural hybrids in this research was consistent with the reports of Kumar *et al*. (2015), Milošević and Milošević (2012), and Khadivi-Khub and Barazandeh (2015), and higher than the findings of Yaman and Uzun (2020). According to results of TA and pH, Shahriar was sourer than the other two genotypes. Consumers prefer low-acid fruits, and fruits are perceived as sweet if the TA value is less than 0.6% and the TSS content varies between 10 and 12 °Brix. The plum fruits with TSS content of at least 12 °Brix were acceptable for the market (Crisosto *et al*., 2004; Kitzberger *et al*., 2017; Wolf *et al*., 2020). However, if the TA value was greater than 1%, the consumers would perceive the sweetness of the fruit provided that the TSS values were above 15% (Kitzberger *et al*., 2017). The value of TSS in the three genotypes was almost high. The TSS/TA ratio, which indicates the taste and acceptance index by the consumer, showed moderate and low values in these genotypes due to the high TA content. On the other hand, Głowacka *et al*. (2021) reported a negative correlation between the yield of trees and quality of Japanese plum fruit. Our results confirm this relationship, and the acceptance index of Shiraz (with the lowest yield) was the highest, followed by Bavanat and Shahriar (with the highest yield).

DPPH assay was used to evaluate antioxidant activity among genotypes. In Shahriar and Shiraz, whose flesh color was orange, a higher antioxidant activity based on DPPH assay was observed than Bavanat with yellowish green flesh color. Byrne *et al*. (2004) found that anthocyanin, phenolic contents and antioxidant activity were higher in red/purple-flesh peach and plum varieties than in light colored flesh varieties. They suggested that red/purple-flesh peaches and plums have a greater potential health benefit based on antioxidant content and activity. A positive correlation has also been observed between vitamin C, anthocyanin and phenolic contents with antioxidant activity in fruits of the plum genotypes (Nisar *et al*., 2015).

Principal component analysis (PCA) was used to identify the most significant traits in the dataset. All the components of the quantitative data had an eigenvalue of over 1. The first component was strongly correlated with yield, fruit number, fruit dimensions, and fruit quality traits. Kumar *et al*. (2015) found the first PC was positively related to fruit number, yield and physical properties of fruit, stone and kernel of apricot genotypes. These attributes were the most effective ones for separating and identifying the studied accessions. These results in some cases were in agreement with the results reported by other plum studies (Crisosto *et al*., 2007; Milošević and Milošević, 2012). Yilmaz *et al*. (2012) used 57 morphological traits to characterize diversity in Turkish apricot germplasm. They revealed that 21 components might be sufficient to divid apricot accessions instead of using 57 morphological criteria.

Based on the results of sensory attributes, the consumer's top preference was Shahriar followed by Bavanat and Shiraz, while based on pomological evaluations, Bavanat had acceptable specifications. Indeed, there was less agreement between the chemical and sensorial analyses. Crizosto *et al*. (2004) and Kitzberger *et al*. (2017) showed that fruits with higher TSS were more acceptable by consumers. However, despite this, Shahriar with low TSS had the highest general marks. In contrary to our results, Madalina *et al*. (2015) reported that large fruits and excellent taste were considered the best characteristics for fresh consumption of plum cultivars based on panel test. There are traits related to the mouth feeling like crispness, fibrousnesses, juiciness, toughness, etc. (Piagnani *et al*., 2013). Probably, our panelists paid more attention to the other traits, such as skin color, acidity, and texture than the size and sweetness of the fruits.

GT-biplot analysis was conducted to assess genotypes based on multiple traits and identifies those that are superior in the desired variables. GT-biplot accounted 100% of the total variation indicating the accuracy of associations among the measured traits by the biplot method (Yan and Kang, 2003). It was found that each genotype was superior in some important traits. For instance, two hybrids (i.e., Shiraz and Shahriar) had marketable dark-red colored fruits. The attractive and large-sized fruits of the Bavanat hybrid gave it an advantage on marketability. In spite of the small size of the Shahriar fruits, it showed the highest yield and overall score of the panel test. Nevertheless, Shiraz is closer to the ideal genotype than Bavanat and Shahriar. To achieve cultivars with high fruit yield and quality, crosses could be performed between genotypes with high yield, fruit number, antioxidant activity (Shariar), large fruit size, high fruit weight/stone weight ratio (Bavanat) and high TSS (Shiraz). Therefore, each genotype can be considered as important germplasm resources to develop new cultivars in plum and apricot breeding programs.

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