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Multidimensional scaling analysis of sensory characteristics and quantitative traits in wild apricots

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Abstract: The Cappadocia Region in Central Anatolia, Turkey is rich in wild apricot genetic resources. In this study, a multivariate analysis method of metric and nonmetric multidimensional scaling analysis (MDS) was used to classify 43 wild apricot genotypes and 5 standard cultivars by using Euclidean distance. MDS was applied, based on dissimilarities, to quantitative traits of weight, height, width and thickness of fruit, stone and kernel weight, flesh/stone ratio, total soluble solids content, titratable acidity and pH in fruit juice, and sensory attributes of fruit size and shape, cavity depth, suture (cheek line), fruit apex, fruit attractiveness, skin pubescence, ground and over color (blush), eating quality, aroma, firmness and juiciness of flesh, uniformity of ripening of fruit, flesh color and texture, skin cracking and pit burn susceptibility, separation of stone, stone size and shape (lateral view), stone surface and kernel taste. The results showed that most of the wild apricots (91.66%) had small sized fruits ranging from 10.5 g (type #53) to 79.3 g (type #68) with an average of 25.27 ± 2.44 g. The genotypes had fair or good eating quality and aroma, good fruit attractiveness and light bitter or sweet kernel taste in general. The harvest date showed quite a wide range between late June and early September among the genotypes. The sufficient number of dimensions was determined by stress value and pseudo-R^2 statistics, then relative positions of genotypes were displayed on graphics. The Aprikoz was the most distinct cultivated apricot from the wild genotypes. Both MDS analyses revealed that most of the wild genotypes had similar fruit characteristics while genotypes of #13, #20, #39, #60, #64, #68 differed the most. The wild apricot individuals with interesting features could be used as a parent in apricot breeding programs for the development of commercial cultivars.

Key words: *Prunus*, genetic diversity, classification, stress value, pseudo-R^2

1. Introduction

Apricot is a tree fruit species (*Prunus armeniaca* L.) which can be consumed as fresh and dried or processed and/or as additive products in the food industry, are rich in minerals of K, Fe, Mg, P and Se, vitamins of A, C and E, and have anticancer, antiaging, antiatherosclerosan, antianginal, cardio/hepato/renoprotective and antioxidant effects (Yılmaz, 2018). However, plants of this species bloom early that flowers or young fruits often get damaged extensively by late spring frosts. Thus, the development of late flowering and/or frost-resistant genotypes is of prime importance. Also, the development of late-maturing cultivars would be another goal since fresh fruits have very short storage life in this species. The selection technique is one of the oldest breeding methods where superior genotypes within a natural fruit tree population are identified and selected (Akçalı and Uzun, 2016). The source of the genetic variation in such population, in general, is natural pollination which results in plants with the seedling origin that selected each plant is considered as a distinct genotype. Once selected, these genotypes are subjected to detailed pomological studies to determine their potential use in fresh or dried fruit consumption or various processed food products (Asma and Ozturk, 2005; Mratinic et al., 2011). Fruit quality was defined as the conjunction of physical and chemical characteristics which give a good appearance and acceptability to the consumable product (Kramer and Twigg, 1966). Quality includes sensory properties (appearance, texture, taste and aroma), nutritional values, chemical compounds, mechanical properties and functional properties (Abbot, 1999). Investigations on selections are also extended to physiological and molecular studies to explore their possible further use as a parent in breeding programs (He et al., 2007; Bakır et al., 2019).

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Turkey, the leader in world apricot production, alone meets 20.7% of 4 million tons of apricots produced in the world (FAO, 2019). Apricot is grown in many parts of Anatolia in Turkey. In addition, Anatolia being in the secondary origin of the center (Layne et al., 1996; Ercişli 2004; Zhebentyayeva et al., 2012) has plenty of apricot genetic resources with seedling origin. Although there are several selection breeding studies carried out in different parts of Anatolia (Bostan et al., 1995; Akça and Asma, 1999; Akça and Sen, 1999; Bolat, 1999; Önal, 1999; Balta et al., 2002; Kazankaya, 2002; Asma et al., 2007; İmrak et al., 2017; Yurtkulu et al., 2019) the rich wild apricot genetic resources of the Cappadocia Region in Central Anatolia were investigated for the first time in detail by the authors for late flowering, resistance to late spring frosts, large fruit size and/or late maturity, and a large number of genotypes were selected (Dumanoglu et al., 2019). On the other hand, some fruit-related traits such as size, weight, taste and aroma may suggest that some of the seedlings may not be true wild accessions but they may be derived from escaped cultivated germplasm.

Multidimensional scaling (MDS) is a versatile technique for understanding and displaying the structure of multivariate data that is generally used to reduce dimensions and classify individuals/variables according to their dissimilarities. MDS analysis does not need any assumption. It intends to build the structure of the data more understandable and easily interpreted by a graphical representation which is obtained by considering the differences and similarities between observation values, individuals, variables and even events (Jaworska and Anastasova, 2009). Metric-MDS is used for interval and ratio data while nonmetric MDS is used for nominal and ordinal data. In practice, nonmetric MDS is largely preferred over metric one since the assumptions are much more flexible and less dimensional results could be obtained. MDS analysis has found a wide range of use in practice such as in market and public research, psychology, medicine, law, communication and biology since nonlinear relationships between variables can be modeled, and nominal or ordered data can be evaluated (Torgerson, 1952; Kruskal, 1964a; Young, 1987; Başpınar et al., 2000; Daşdemir and Güngör, 2002; Wickelmaier, 2003; Bülbül and Köse, 2010). MDS method was also used in horticultural crops to establish associations among measured traits and identify trait and cultivar groupings such as in apple (Dumanoglu et al., 2018), banana (Hasan et al., 2013), Brazil nut (Pacheco et al., 2021), cucumber (Mliki et al., 2003), mulberry (Lo Bianco and Mirabella, 2018), olive (Pehlivan and Yılmaz, 2010), ornamental pepper (Costa et al., 2020), peach and nectarine (Farina et al., 2019), persimmon (Parfitt et al., 2015), pomegranate (Mansour et al., 2015), strawberry (Yamamoto et al., 2015) and tomato (Van der Knaap and Tanksley, 2003).

In this study, the MDS analysis technique was used for the first time to evaluate the fruit quality by quantitative traits and sensory attributes of wild and cultivated apricots. The objective of the research was to perform MDS analysis to identify the similarities/dissimilarities among the 43 promising wild apricot genotypes selected for the various breeding goals (Dumanoglu et al., 2019) and 5 standard apricot cultivars in terms of investigated traits, and to obtain prior knowledge before further breeding activities since the method enables breeders to interpret the results much easier with visual expression than many statistical methods.

2. Materials and methods

In this study, 43 wild apricot genotypes selected for late flowering, resistance to late spring frosts, large fruit size or late maturity from Cappadocia region, Nevşehir, Turkey between 2014 and 2017 were used. The cultivated standard cultivars of Aprikoz, Kabaaşı, Hasanbey, Hacıhaliloğlu and Levent were used as controls. The fruits were harvested at optimum maturity. Field codes were used for the genotypes in the analyses.

Fruit quality was determined by sensory and quantitative traits. Sensory characteristics of fruit size and shape, cavity depth, suture (cheek line), fruit apex, fruit attractiveness, skin pubescence, ground and over color (blush), eating quality, aroma, firmness and juiciness of flesh, uniformity of ripening of fruit, flesh color and texture, skin cracking and pit burn susceptibility, separation of stone, stone size and shape (lateral view), stone surface and kernel taste were determined (Table 1) based on Apricot Descriptor (Guerriero and Watkins, 1984). Quantitative characters of fruit weight (g), height (mm), width (mm) and thickness (mm) of fruit, stone weight (g), kernel weight (g), flesh/stone ratio, total soluble solids content (TSS, %), titratable acidity (TA, %) and pH in fruit juice were determined as described by Guerriero and Watkins (1984), Asma et al. (2007) and Yılmaz et al. (2012). A total of 50 fruits were used in analyses for each genotype. Data of two years were averaged, and used in the statistical analyses.

The data of sensory and quantitative characteristics were analyzed by MSA, a multivariate analysis method, with the use of Euclidean distance using software package (NCSS 2007, NCSS LLC. Kaysville, Utah, USA). Initially, each of the sensory characters was classified and coded (Table 1) by considering the data structure following the Apricot Descriptor (Guerriero and Watkins, 1984).

The Euclidean distances were calculated for both encoded sensory and quantitative characters. Nonmetric-MDS analysis for sensory characters and metric-MDS analysis for quantitative characters were performed. The nonmetric MDS analysis results were interpreted by

Table 1. The classifications and codes of sensory characteristics used in MDS analysis in wild apricot genotypes.

Sensory characteristics	Classifications and codes
Fruit size	(1) Extremely small (<20 g), (2) Very small (20–30 g), (3) Small (31–40 g), (4) Small-medium (41–45 g), (5) Medium (46–55 g), (6) Medium-large (56–60 g), (7) Large (61–70 g), (8) Very large (71–85 g)
Fruit shape	(1) Triangle, (2) Elliptic, (3) Ovate, (4) Round, (5) Round-flat, (6) Rectangular
Cavity depth	(1) Shallow, (2) Intermediate, (3) Deep
Suture (cheek line)	(1) Shallow, (2) Intermediate, (3) Deep
Fruit apex	(1) Depressed, (2) Flat, (3) Round, (4) Pointed
Fruit attractiveness	(1) Poor, (2) Fair, (3) Good, (4) Extremely good
Skin pubescence	(0) Absent, (1) Present
Ground color	(1) Cream, (2) Greenish yellow, (3) Yellow, (4) Light orange, (5) Orange
Over color (blush)	(0) None, (1) Trace, (2) Slight, (3) Mottled, (4) Intermediate red
Eating quality	(1) Poor, (2) Fair, (3) Good, (4) Excellent
Aroma	(1) Little, (2) Intermediate, (3) Rich
Firmness of flesh	(1) Firm, (2) Medium, (3) Soft
Flesh juiciness	(1) Dry, (2) Intermediate, (3) Juicy
Uniformity of ripening of fruit	(1) Nonuniform, (2) Uniform
Flesh color	(1) Whitish green, (2) Cream, (3) Yellow, (4) Light orange, (5) Orange, (6) Deep orange
Texture of flesh	(1) Fine, (2) Intermediate, (3) Coarse
Skin cracking susceptibility	(1) Intermediate, (2) Low, (3) Very low
Pit burn susceptibility	(1) Intermediate, (2) Low, (3) Very low
Separation of stone	(1) Cling, (2) Semicling, (3) Free
Stone size	(1) Small, (2) Medium, (3) Large
Stone shape (lateral view)	(1) Elongated, (2) Ovate, (3) Elliptic, (4) Round, (5) Oblong
Stone surface	(1) Pitted, (2) Smooth
Kernel taste (bitterness)	(1) Strong, (2) Light, (3) Sweet

considering the stress value, and the metric-MDS analysis results by considering both the stress value and the pseudo-R^2 statistic. Kruskal's stress value (Stress-1), which is frequently used in practice was used in the analysis. The stress value formula is given below in Equation (1) (Torgerson, 1952; Shepard, 1962a, 1962b; Kruskal, 1964a, 1964b; Young, 1987; Borg et al., 2013). The stress values were interpreted according to the stress value classification table developed by Kruskal (Table 2) which were used to determine the minimum (sufficient) number of dimensions that would provide the desired goodness of fit (Kruskal, 1964b; Borg et al., 2013).

$$\text{Stress-1} = \sqrt{\frac{\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}(d_{ij}-\delta_{ij})^2}{\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} d_{ij}^2}} = \sqrt{\frac{\sum (d_{ij}-\delta_{ij})^2}{\sum_{i<j} d_{ij}^2}} \quad (1)$$

d_{ij}: observed distances between ith and jth points,
δ_{ij}: configuration distances between th and j^{th} points, as a result of the c. iteration.

Sufficient number/s of dimensions were determined by evaluation of stress value together with pseudo-R^2 statistic which was obtained from MDS analysis. The computation of pseudo-R^2 statistic is given below in Equation (2) (Cox and Cox, 2001; Alpar, 2013). The results of the MDS analysis yielded by the determined dimensions were denoted visually.

$$\text{Pseudo}-R^2 = 1 - \frac{\sum_{i=1}^{n}\left(d_{ij}-\delta_{ij}\right)^2}{\sum_{i=1}^{n}\left(d_{ij}-\bar{d}\right)^2} \quad (2)$$

d_{ij}: observed distances between i^{th} and j^{th} points,
δ_{ij}: configuration distances between ith and jth points, as a result of the c. iteration,
$\bar{d}$: average of observed distances.

3. Results and discussion

The average harvest date and some of the fruit characteristics of 43 wild apricot genotypes and 5 standard cultivars are given in Table 3 while the frequency of sensory

Table 2. Kruskal's stress value classification showing critical intervals and goodness of fit.

Stress	Goodness of fit
0.20 ≤ stress	Poor
0.10 ≤ stress < 0.20	Fair
0.05 ≤ stress < 0.10	Good
0.025 ≤ stress < 0.05	Excellent
Stress < 0.025	Perfect

characteristics and descriptive statistics of quantitative characteristics are given in Tables 4 and 5, respectively. The harvest date showed quite a range between late June and late August in the wild apricots. Morphological characteristics are among the most significant quality attributes affecting consumers' preferences in apricots (Ercişli, 2009). The eating quality and aroma were mostly fair or good, fruit attractiveness was good while the kernel taste was light bitter or sweet in the wild apricots. Fruit weight is an important fruit quality parameter. The average fruit weight of all of the genotypes studied was 26.23 ± 2.27 g. It was 25.27 ± 2.44 g and 34.54 ± 5.32 g in wild and cultivated apricots, respectively (Table 4). The wild apricots showed a large variation in fruit weight between 10.5 g (type #53) and 79.3 g (type #68). İmrak et al., (2017) and Yurtkulu et al., (2019) reported similar findings for promising wild apricots selected in Nevşehir region that fruit weight was between 30.31 g (type #N95) and 55.19 g (type #N82), and between 21.02 g (type #50-K-96) and 84.02 g (type #50-K-17), respectively. Fruit weight of the wild apricot genotypes ranged from 10.0 g to 61.1 g in Erzincan plain, East Anatolia (Güleryüz, 1995) and from 14.6 g to 42.1 g in Southeast Anatolia region (Önal, 1999). The seedling population of 73 late flowering apricot genotypes in Iran had fruit weight between 33.01 g and 66.01 g (Khadivi-Khub and Khalili, 2017).

Most of the wild apricots (29) were in semicling, 4 types were in cling and 10 types were in free classes for separation of stone from the fruit flesh (Table 5). Önal (1999) reported 19 freestone and only 3 semicling native apricots selected from Southeast Anatolia region. Stone and kernel weights were between 0.7 g (type #13) and 4.7 g (type #68), and between 0.3 g (types #13, #48) and 1.3 g (type #39), respectively. Kernel taste was sweet in 18 genotypes, light bitter in 10 genotypes and strong bitter in 15 genotypes. The ratio of flesh to stone was between 6.5 (type #47) and 24.8 (type #64). The chemical constituents of TSS were between 10% (types #38, #39) and 22.8% (type #4), TA was between 0.52% (type #64) and 3.91% (type #42), and pH was between 2.85 (type #42) and 4.04 (type #64). Similar results were reported for selected promising apricot genotypes by Güleryüz (1995) for seed weight (1.74–2.41 g), TSS (14.8%–21.0%) and TA (0.60%–1.32%) in Malatya region, and by İmrak et al. (2017) for stone weight (2.00–2.80 g), flesh to stone ratio (12.29%–19.23%), TSS (27%–31%), TA (0.53%–1.47%) and pH (4.27–5.26) in Nevşehir region. Other researchers also reported comparable results on wild apricots from different regions of Anatolia (Bostan et al., 1995; Akça and Asma, 1999; Akça and Sen, 1999; Bolat, 1999; Önal, 1999; Balta et al., 2002; Kazankaya, 2002; Asma et al., 2007; Yurtkulu et al., 2019). In Serbia, Milosevic et al. (2010) determined TSS and TA between 8.88% and 15.72%, and between 0.77% and 1.08%, respectively in selected 14 apricot genotypes. It is clear that, the results of previous studies fall in the range of the variation determined in this study probably due to a more detailed evaluation of the genotypes made and larger selection criteria applied for various breeding objectives in this study. Large variation also indicates high genetic variability in the wild apricot population in the Cappadocia region. The data showed that standard apricot cultivars differentiated relatively from wild genotypes. In general, most of the genotypes (91.66%) had small-sized fruits. The frequency of the genotypes with an average fruit weight of extremely small (< 20 g), very small (20–30 g) and small (31–55 g) were 39.58%, 33.33% and 18.75%, respectively while the that of genotypes with larger fruit weights of medium-large (56–60 g), large (61–70 g) and very large (71g <) were 2.08%, 4.17%, and 2.08%, respectively (Table 3).

3.1. Metric-MDS analysis results for quantitative characters

Descriptive statistics of quantitative characteristics of the wild apricots are given in Table 4. The results of metric-MDS analysis showed that the calculated stress value for 2-dimensions was 0.0364 which indicates "excellent" concordance based on Kruskal's classification (Table 2) between the observed distances and the configuration distances. Thus, 2-dimensions were found sufficient for the classification of 48 wild and cultivated apricots. The metric-MDS analysis also showed that the calculated pseudo-R^2 statistic for 2-dimensions was 99.68% which indicates that 99.68% of the variation in observed distances could be explained by the configuration distances. Both stress value and pseudo-R^2 statistic indicated that the configuration distances from the metric-MDS analysis were in perfect harmony with the observed distances, and 2-dimensions were enough to make a satisfactory classification for the apricots.

The scatter plot of the 2-dimensions, displaying the positions of the genotypes concerning each other, is presented in Figure 1. Among the wild apricots #13, #64 and #68 were differentiated from the other wild genotypes

Table 3. Average harvest dates and some of the fruit characteristics of wild apricot genotypes and standard cultivars.

Genotype code	Harvest date	Fruit weight (g)	Separation of stone	Kernel taste (bitterness)	Flesh/ stone ratio	Fruit attractiveness	Eating quality	Ground color	Over color	Aroma	TSS (%)	TA (%)	pH
3	Mid July-Early Aug.	18.4	Semicling	Strong	10.5	Good	Fair	Orange	Inter. red	Little	12.0	1.55	3.08
4	Mid-late Aug.	45.8	Free	Sweet	14.8	Good	Excellent	Yellow	None	Little	22.8	0.93	3.80
6	Mid-late July	29.7	Free	Sweet	9.6	Good	Good	Light orange	Inter. red	Intermediate	15.0	2.05	3.69
7	Late July-Early Aug.	20.1	Semicling	Strong	11.6	Good	Good	Light orange	None	Intermediate	16.2	1.86	3.15
13	Early Aug.	16.2	Cling	Light	22.1	Good	Fair	Greenish yellow	None	Little	15.5	1.59	3.92
14	Late July-Early Aug.	23.1	Semicling	Light	10.0	Good	Fair	Light orange	None	Little	13.8	1.74	3.23
15	Late July	22.6	Semicling	Strong	12.3	Good	Good	Light orange	None	Intermediate	13.8	2.02	3.10
16	Late July	20.3	Semicling	Strong	11.7	Good	Good	Yellow	Inter. red	Rich	15.5	2.67	2.95
17	Early Aug.	19.4	Semicling	Light	10.4	Good	Good	Orange	None	Intermediate	19.8	2.12	3.43
18	Late July-Early Aug.	13.2	Semicling	Sweet	9.1	Fair	Fair	Light orange	None	Little	14.9	2.58	2.99
19	Late July	20.3	Semicling	Strong	10.9	Fair	Fair	Orange	Inter. red	Little	13.2	3.17	2.86
20	Late July	43.0	Semicling	Sweet	10.6	Ext. good	Good	Light orange	Inter. red	Intermediate	15.5	1.97	3.29
22	Early Aug.	16.5	Semicling	Sweet	11.7	Fair	Good	Greenish yellow	None	Intermediate	19.2	0.87	3.63
23	Early Aug.	19.9	Semicling	Strong	11.4	Good	Fair	Light orange	Slight	Intermediate	17.0	1.81	2.95
24	Early Aug.	17.1	Semicling	Light	7.1	Good	Fair	Greenish yellow	None	Little	15.9	3.16	3.0
26	Early Aug.	14.5	Cling	Light	11.1	Fair	Good	Orange	None	Rich	13.7	1.38	3.39
27	Early Aug.	12.4	Semicling	Strong	10.3	Good	Good	Yellow	None	Little	14.8	1.36	3.31
28	Late Aug.	15.8	Semicling	Sweet	6.9	Good	Fair	Light orange	None	Little	12.2	1.33	3.31
29	Late Aug.	16.9	Semicling	Sweet	6.7	Good	Good	Light orange	None	Little	14.8	1.65	3.37
31	Early Aug.	21.3	Semicling	Strong	9.1	Good	Poor	Orange	None	Little	14.6	2.74	2.96
32	Early Aug.	25.5	Semicling	Strong	11.5	Good	Good	Orange	Inter. red	Little	14.0	1.57	3.35
33	Early Aug.	16.7	Free	Sweet	10.9	Good	Fair	Light orange	Mottled	Little	13.0	2.13	3.06
34	Early Aug.	22.6	Semicling	Strong	9.3	Good	Good	Light orange	Mottled	Intermediate	15.0	2.41	2.98
35	Early Aug.	18.3	Semicling	Light	10.4	Good	Fair	Orange	Inter. red	Little	15.2	2.47	3.03
38	Late June	27.3	Cling	Light	12.0	Good	Fair	Light orange	Inter. red	Little	10.0	1.41	3.14
39	Late June-Early July	56.2	Semicling	Sweet	13.0	Ext. good	Good	Orange	Inter. red	Intermediate	10.0	1.71	2.98
41	Late July	15.9	Semicling	Light	10.4	Good	Fair	Cream	None	Intermediate	16.5	2.41	3.23
42	Late July-Early Aug.	22.7	Semicling	Sweet	11.6	Good	Fair	Orange	Mottled	Little	17.6	3.91	2.85
43	Late July-Early Aug.	21.1	Semicling	Strong	8.6	Good	Poor	Light orange	Inter. red	Little	14.7	1.06	3.20
45	Early Aug.	15.9	Cling	Sweet	8.3	Good	Good	Yellow	None	Intermediate	14.4	0.92	3.66

Table 3. (Continued).

46	Early Aug.	27.1	Semicling	Strong	13.3	Good	Good	Orange	Inter. red	Intermediate	15.6	1.64	3.24
47	Late July	12.8	Semicling	Strong	6.5	Good	Fair	Yellow	None	Little	16.6	2.37	2.99
48	Late Aug.	11.7	Semicling	Strong	9.6	Good	Fair	Yellow	None	Intermediate	10.1	1.75	2.99
49	Mid-Aug.	14.5	Semicling	Strong	8.1	Good	Fair	Orange	Mottled	Intermediate	14.5	1.02	3.57
50	Mid-Aug.	20.4	Semicling	Sweet	9.7	Good	Good	Light orange	None	Little	15.5	2.36	3.12
53	Late July-Early Aug.	10.5	Free	Sweet	7.7	Fair	Fair	Light orange	None	Intermediate	13.5	0.99	3.78
54	Early Aug.	13.5	Free	Light	7.4	Poor	Fair	Orange	None	Intermediate	16.2	1.50	3.61
59	Late Aug.	12.5	Semicling	Sweet	7.9	Good	Fair	Yellow	None	Little	15.1	1.35	3.74
60	Late June-Early July	61.7	Free	Light	14.8	Good	Good	Greenish yellow	Inter. red	Intermediate	13.7	1.02	3.42
61	Late June-Early July	43.6	Free	Sweet	13.5	Good	Good	Orange	Inter. red	Intermediate	12.8	1.63	3.15
64	Late June-Mid July	67.1	Free	Sweet	24.8	Ext. good	Excellent	Yellow	Mottled	Rich	13.5	0.52	4.04
68	Late June	79.3	Free	Sweet	15.9	Ext. good	Good	Light orange	Inter. red	Intermediate	12.6	1.39	3.10
76	Late Aug.	43.0	Free	Sweet	13.8	Good	Good	Orange	Inter. red	Intermediate	22.6	0.75	3.61
Control cultivars													
Aprikoz	Late June-Mid July	52.9	Free	Sweet	22.0	Good	Good	Yellow	Trace	Intermediate	13.8	0.37	4.33
Kabaaşı	Late July	32.0	Free	Sweet	14.2	Good	Good	Yellow	Mottled	Intermediate	17.9	0.26	4.52
Hasanbey	Late June-Ealy July	35.8	Free	Sweet	13.3	Good	Good	Light orange	None	Intermediate	15.1	0.27	4.78
Hacı-haliloğlu	Late July	32.1	Free	Sweet	15.0	Good	Good	Yellow	Mottled	Rich	22.7	0.28	4.86
Levent	Early Sept.	19.9	Semicling	Sweet	8.9	Good	Good	Yellow	Mottled	Intermediate	17.4	1.09	3.60

Table 4. Descriptive statistics for quantitative fruit characteristics of wild apricot genotypes and standard cultivars.

Genotype	Quantitative characters	n	Mean	Std. error of mean	Min.	Max.
Wild genotypes	Fruit weight (g)	43	25.27	2.44	10.50	79.30
	Fruit height (mm)	43	35.86	1.05	27.50	55.00
	Fruit width (mm)	43	33.69	0.91	24.60	51.70
	Fruit thickness (mm)	43	32.48	0.90	25.80	52.00
	Stone weight (g)	43	2.03	0.13	0.70	4.70
	Kernel weight	43	0.61	0.04	0.30	1.30
	Flesh/stone ratio	43	11.09	0.55	6.50	24.80
	TSS (%)*	43	0.15	0.00	0.10	0.23
	TA (%)**	43	0.02	0.00	0.01	0.04
	pH	43	3.29	0.05	2.85	4.04
Standard cultivars	Fruit weight (g)	5	34.54	5.32	19.90	52.90
	Fruit height (mm)	5	42.00	3.44	31.30	51.90
	Fruit width (mm)	5	36.60	1.61	34.00	42.90
	Fruit thickness (mm)	5	37.24	1.53	33.20	42.40
	Stone weight (g)	5	2.18	0.10	2.00	2.50
	Kernel weight	5	0.76	0.05	0.60	0.90
	Flesh/stone ratio	5	14.68	2.11	8.90	22.00
	TSS (%)	5	0.17	0.02	0.14	0.23
	TA (%)	5	0.01	0.00	0.00	0.01
	pH	5	4.42	0.23	3.60	4.86
Overall	Fruit weight (g)	48	26.23	2.27	10.50	79.30
	Fruit height (mm)	48	36.50	1.03	27.50	55.00
	Fruit width (mm)	48	33.99	0.84	24.60	51.70
	Fruit thickness (mm)	48	32.98	0.84	25.80	52.00
	Stone weight (g)	48	2.04	0.12	0.70	4.70
	Kernel weight	48	0.63	0.03	0.30	1.30
	Flesh/stone ratio	48	11.47	0.55	6.50	24.80
	TSS (%)	48	0.15	0.00	0.10	0.23
	TA (%)	48	0.02	0.00	0.00	0.04
	pH	48	3.40	0.07	2.85	4.86

*TSS: Total soluble solid content; **TA: Titratable acidity.

as scatter plot displays. Earlier, genotype #13 was selected for late flowering, and genotypes #64 and #68 for large fruit size (Dumanoglu et al., 2019). Among the cultivated cultivars, the Aprikoz (#81) was distantly located from other standard cultivars and most of the wild genotypes, except genotype #64. Aprikoz is known as Şalak locally and is largely grown in Iğdır region in the east of Turkey. The fruits having distinct shape, color and taste are easily separated from other cultivars and the wild genotypes. Thus, its distant location from the majority of the genotypes is not unexpected. On the other hand, Kabaaşı (#82), Hasanbey (#83) and Hacıhaliloğlu (#84) are relatively similar cultivars in terms of fruit characteristics. They share the same area of origin, in around Malatya province in the east of Turkey. Their close position to each other on the scatter plot was expected. The majority of the wild genotypes were located close to these cultivars indicating their similarities. Among them, the most similar one was #46 located near Kabaaşı (#82). Wild apricots encoded by #6, #20, #39 and #60 were located distantly from each

Table 5. Frequency (%) of sensory characteristics for wild apricot genotypes (W) and standard cultivars (S) by corresponding classification codes.

Sensory characteristics		Classification code								
		0	1	2	3	4	5	6	7	8
Fruit size	W		19 (44.19%)	15 (34.88%)	1 (2.33%)	2 (4.65%)	2 (4.65%)	1 (2.33%)	2 (4.65%)	1 (2.33%)
	S		-	1 (20.00%)	2 (40.00%)	1 (20.00%)	1 (20.00%)	-	-	-
Fruit shape	W		2 (4.17%)	2 (4.65%)	2 (4.65%)	20 (46.51%)	3 (6.98%)	14 (32.56%)		
	S		-	1 (20.00%)	2 (40.00%)	2 (40.00%)	-	-		
Cavity depth	W		1 (2.33%)	19 (44.19%)	23 (53.49%)					
	S		-	2 (40.00%)	3 (60.00%)					
Suture (cheek line)	W		15 (34.88%)	21 (48.84%)	7 (16.28%)					
	S		1 (20.00%)	4 (80.00%)	-					
Fruit apex	W		14 (32.56%)	21 (48.84%)	1 (2.33%)	7 (16.28%)				
	S		1 (20.00%)	1 (20.00%)	1 (20.00%)	2 (40.00%)				
Fruit attractiveness	W		1 (2.33%)	5 (11.63%)	33 (76.74%)	4 (9.30%)				
	S		-	-	5 (100.00%)	-				
Skin pubescence	W	37 (86.05%)	6 (13.95%)							
	S	4 (80.00%)	1 (20.00%)							
Ground color	W		1 (2.33%)	4 (9.30%)	8 (18.60%)	16 (37.21%)	14 (32.56%)			
	S		-	-	4 (80.00%)	1 (20.00%)	-			
Over color (blush)	W	22 (51.16%)	-	1 (2.33%)	5 (11.63%)	15 (34.88%)				
	S	1 (20.00%)	1 (20.00%)	-	3 (60.00%)	-				
Eating quality	W	2 (4.65%)	19 (44.19%)	20 (46.51%)	2 (4.65%)					
	S	-	-	5 (100.00%)	-					
Aroma	W		20 (46.51%)	20 (46.51%)	3 (6.98%)					
	S		-	4 (80.00%)	1 (20.00%)					
Firmness of flesh	W		9 (20.93%)	20 (46.51%)	14 (32.56%)					
	S		4 (80.00%)	1 (20.00%)	-					
Flesh juiciness	W		12 (27.91%)	16 (37.21%)	15 (34.88%)					
	S		-	4 (80.00%)	1 (20.00%)					
Uniformity of ripening of fruit	W		6 (13.95%)	37 (86.05%)						
	S		1 (20.00%)	4 (80.00%)						

Table 5. (Continued).

Flesh color	W		2 (4.65%)	3 (6.98%)	3 (6.98%)	12 (27.91%)	21 (48.84%)	2 (4.65%)		
	S		-	-	-	5 (100.00%)	-	-		
Texture of flesh	W		13 (30.23%)	27 (62.79%)	3 (6.98%)					
	S		-	5 (100.00%)	-					
Skin cracking susceptibility	W		1 (2.33%)	1 (2.33%)	41 (95.35%)					
	S		-	-	5 (100.00%)					
Pit burn susceptibility	W		9 (20.93%)	18 (41.86%)	16 (37.21%)					
	S		-	4 (80.00%)	1 (20.00%)					
Stone size	W		9 (20.93%)	26 (60.47%)	8 (18.60%)					
	S		-	2 (40.00%)	3 (60.00%)					
Stone shape	W		1 (2.33%)	13 (30.23%)	4 (9.30%)	13 (30.23%)	12 (27.91%)			
	S		1 (20.00%)	2 (40.00%)	2 (40.00%)	-	-			
Stone surface	W		1 (2.33%)	42 (97.67%)						
	S		-	5 (100.00%)						
Separation of stone	W		4 (9.30%)	29 (67.44%)	10 (23.26%)					
	S		-	1 (20.00%)	4 (80.00%)					
Kernel taste	W		15 (34.88%)	10 (23.26%)	18 (41.86%)					
	S		-	-	5 (100.00%)					

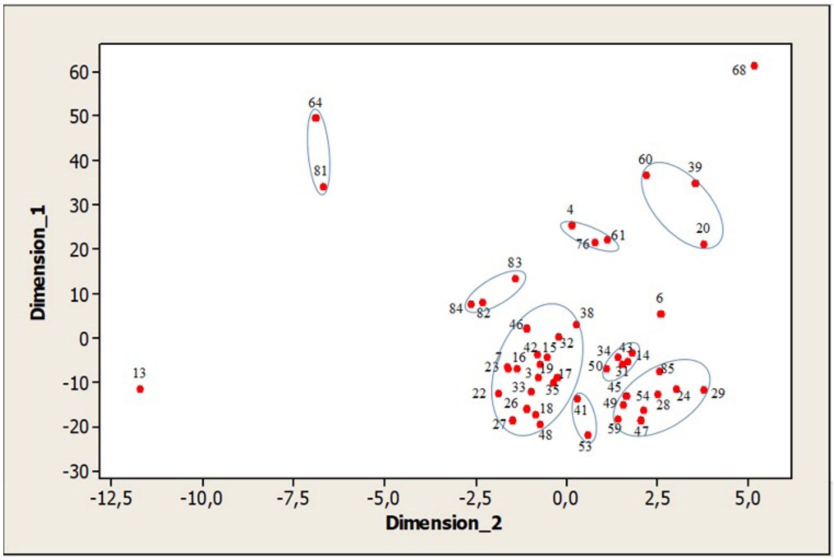

Figure 1. Scatter plot of the 2-dimensions in terms of quantitative characteristics of wild apricot genotypes and standard cultivars (#81-Aprikoz, #82-Kabaaşı, #83-Hasanbey, #84-Hacıhaliloğlu, #85-Levent).

other as well as from the other genotypes. The scatter plot implies that wild genotypes coded #4, #61 and #76 form a small group and exhibit relatively similar characteristics. Genotype #4 was selected for late flowering and #61 and #76 for large fruit size (Dumanoglu et al., 2019).

In the scatter plot, genotypes #14, #31, #34, #43 and #50 formed a small group and exhibited similar fruit characteristics to the cultivar Levent (#85). Likewise, the genotypes #24, #28, #29, #45, #47, #49, #54 and #59 also located close to the cultivar Levent (#85) and formed another cluster. These similarities could be due to open-pollinated seedling origin of Levent, around Malatya region. It is a self-incompatible cultivar and was released in 2017 for its very late maturity in about mid-September (Çöçen et al., 2019). Wild genotypes encoded by #3, #7, #15, #16, #17, #18, #19, #22, #23, #26, #27, #32, #33, #35, #38, #42, #46 and #48 constituted one large cluster. Genotypes of #41 and #53 were identified as a transitional form between the latter two clusters (Figure 1).

3.2. Nonmetric MDS analysis results for sensory characters

The stress value was calculated as 0.0997 for 4-dimensions based on the nonmetric MDS analysis of sensory characteristics. Since the stress value showed “good” fit based on the Kruskal’s classification in Table 2, 4-dimensions were found sufficient for the classification of apricot genotypes. Figure 2 presents the scatter plots of binary combinations of all of the 4-dimensions. In pomegranates, a similar stress value of 0.071 was reported for the nonmetric multidimensional scaling plot which reflected the large number of data points for the analysis of 13 morphological and chemical traits (Mansour et al., 2015).

Evaluation of all of the graphics showed that the standard cultivars of Kabaaşı (#82), Hacıhaliloğlu (#84) and Levent (#85) were relatively similar to each other (Figure 2) for the sensory characteristics. Although cultivar Hasanbey (#83) was more similar to this group than Aprikoz cultivar (#81), it is located slightly distant from them on the map. Aprikoz cultivar (#81) was the most dissimilar one. For the wild genotypes, the majority of them were located near, thus similar to Kabaaşı (#82), Hacıhaliloğlu (#84) and Levent (#85) cultivars on the MDS-map for the sensory characteristics. The wild genotypes similar to cultivar of Hasanbey (#83) were #22, #38, #46, #59 and #61, and the ones similar to cultivar of Aprikoz (#81) were #20, #54, #64 and #76. Evaluations of all of the scatter plots indicated that wild apricot genotypes of #3, #4, #13, #16, #19, #20, #22, #32, #39, #54, #60, #61, #64 and #68 were clearly distinct from the rest of the genotypes, while only genotypes of #68 and #39 were relatively close to each other (Figure 2).

In tree fruits, the MDS method has been useful to identify trait and cultivar groupings. Eight olive oil samples produced from the same olive type by different production systems were grouped into three distinct groups based on their physicochemical properties (Pehlivan and Yılmaz, 2010). Banana cultivars of different genomic groups (AAA, AAB, ABB, BBB and BB) were screened for tolerance/resistance to pests and diseases, and the stress value of 0.103 and R^2 value of 97% were reported (Hasan et al., 2013). Pomegranate accessions from South Eastern Tunisia were classified into three groups as the genotypes

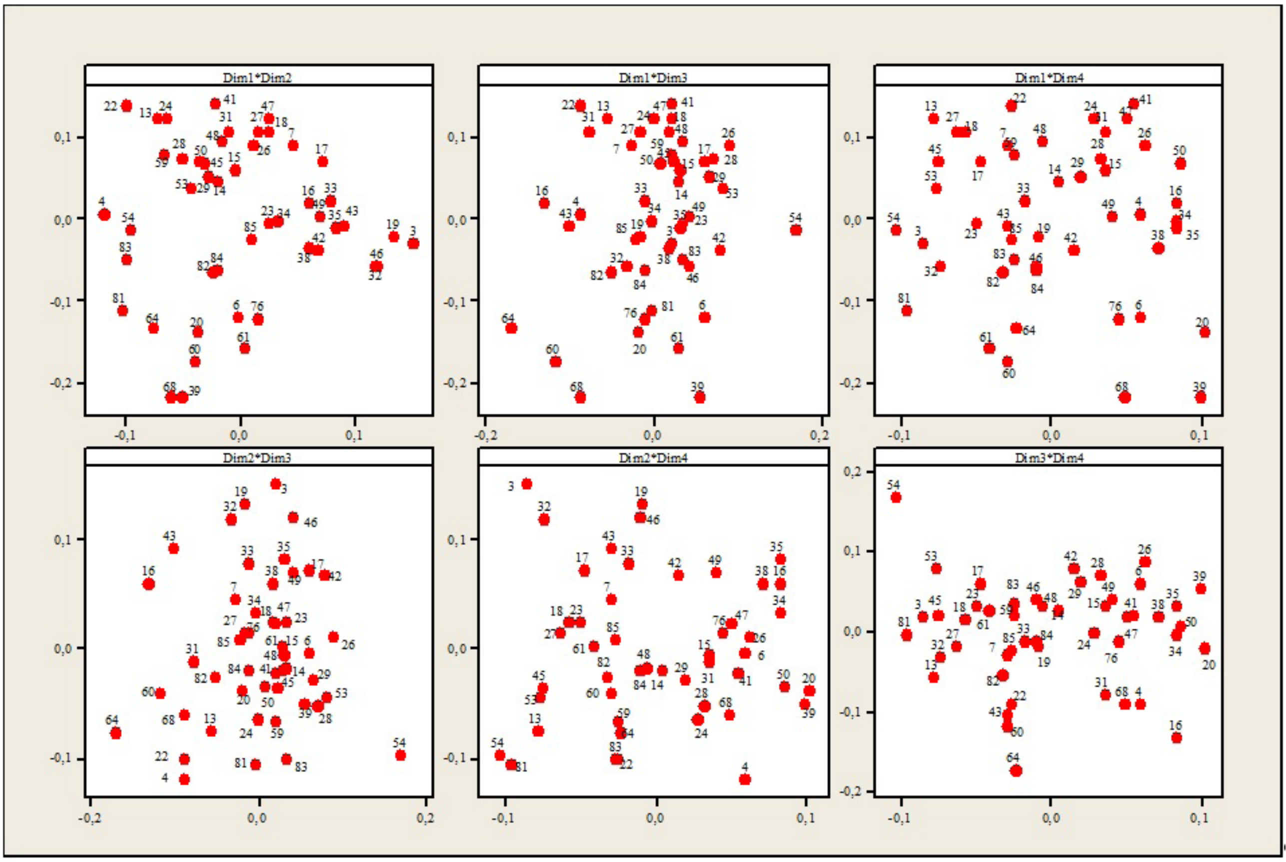

Figure 2. Scatter plots of binary combinations of all of the dimensions in terms of sensory characteristics of wild apricot genotypes and standard cultivars (#81-Aprikoz, #82-Kabaaşı, #83-Hasanbey, #84-Hacıhaliloğlu, #85-Levent).

with soft seeds and red peel, with semihard seeds or with close geographical origin (Mansour et al., 2015). In Asian persimmons, two distinct clusters were reported based on their amplified fragment length polymorphism profile that Chinese and Korean cultivars clustered together but formed two subpopulations by country of origin, and all of the Japanese cultivars formed a separate group (Parfitt et al., 2015). In strawberries, small differences in the appearance of the fruits were visualized based on multiple characteristics on a two-dimensional surface that significant correlations were found between the first dimensional score and surface L* value and fruit size, and between the second dimensional score and the a* and b* values and fruit size (Yamamoto et al., 2015).

Fruit attributes such as size, shape, color, attractiveness, aroma, stone size and late-ripening are important features in the fresh fruit market. Metric and nonmetric MDS analysis of 43 wild apricot genotypes selected in the Cappadocia region showed substantial variability in terms of tested fruit features. The results indicate that valuable individuals with interesting features within the seedling population of wild apricots might contribute to the apricot breeding programs for the development of commercial cultivars.

Conflicts of interest

The authors declare no conflicts of interest.

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