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Characterization of Algerian apricots (Prunus armeniaca) using morphological and pomological markers

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Keywords

Prunus armeniaca, Principal component analysis, Algerian accessions, morphology, pomology

Cover Page Footnote

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RESEARCH PAPER

Characterization of Algerian apricots (*Prunus armeniaca*) using Morphological and Pomological Markers

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Abstract

The aim of this study was to evaluate the diversity of an Algerian apricot germplasm. This Algerian apricot was characterized by a green-yellow skin, a red ground color, and a light orange flesh color in general. Besides, highly positive and negative significant correlations were revealed between the studied characters. Whereby, the principal component analysis explained 81% of the variability. Fruit, stone and leaves dimensions were the main features that explained evidentially the majority of variability. Moreover, the cluster analysis divided the accessions into two major groups. Thus, Algerian accessions selected in this study may have the potential to be used in apricot breeding programs in the future.

Keywords: Prunus armeniaca, Principal component analysis, Algerian accessions, Morphology, Pomology

1. Introduction

Prunus armeniaca, also known as *Armeniaca vulgaris* [1], is a common rosaceae drupe with eight pairs of chromosomes [2,3], and it is native to China and Central Asia [4]. Despite the presence of six other species (*Prunus sibirica, Prunus mume, Prunus brigantiaca, Prunus holosericea, Prunus mandshurica, Prunus dasycarpa*) [2], *P. armeniaca* is the most cultivated fruit tree in the world [5], its fruits has a worldwide commercial worth as well as a high nutritional value (protein, fats, water, fiber, minerals, vitamins, and polyphenols), and its seeds, which, in addition to being a source of natural protein, have a number of medicinal benefits [3]. It is mostly cultivated in Mediterranean countries [6]. With a total output of 4.083.861 million tons in 2019, Turkey, Iran, Uzbekistan, Italy, France, Pakistan, Algeria, Spain, and Japan were the most productive countries [7].

Algeria cultivates many genotypes of *P. armeniaca* in various locales where they excel, including coastal regions, lowlands, the Tellian Atlas, high plateaus, pre-desert environments, and Saharan oasis [8]. Knowing that the climatic requirements of this fruit tree are quite limited [9], each cultivar is produced in a more suited area. Khenchela, Batna (N'gaous), M'sila, Biskra, and Tiaret are the primary traditional apricot growing and producing locations in Algeria [10]. The production of apricots in Algeria is 209.204 tons in 2019 [7]. New apricot cultivars or genotypes must be distinguished by excellent fruit quality features that please customers. The effective conservation and use of plant genetic resources requires an accurate assessment (measurement and characterization) of the genetic variation that they contain at the inter- or intra-species level. The evaluation aimed at describing genetic diversity based on an understanding of its structure and its evolution often uses morphological, biochemical, chromosomal or

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molecular (DNA markers) markers. Traditionally, genetic diversity was assessed by measuring variation in phenotypic traits which focuses on morphological ones. These characteristics define the shape and appearance of a set of individuals. Genetic resources are the basis for the creation of new fruit varieties. The investigation of the diversity of morphological traits of varieties growing in various eco-geographical zones is interesting, and it is also the first step in varietal selection. As a result, germplasm is collected and characterized by specifying phenological, pomological, and morphological qualities (tree vigor, fruit quality features, leaf, stone, flower, and harvest time). Morphological markers are used to study genetic variation in various fields and horticultural crops, characterization of interspecific hybrids of many *Prunus* species and, they are found to be key markers in germplasm management [5].

The breeding program was established to select promising apricots for better fruit quality, resistance to late spring frost, late flowering, a longer ripening season, as well as fruit quality, flavor, resilience to biotic and abiotic challenges. Because numerous criterias cannot be conveyed, these features are the most crucial. To preserve and use local genotypes, germplasm collection and characterization for morphological, phenological, and pomological features may be required [3]. Several studies have been undertaken to assess the variability of apricot through morphological indicators. They investigated germplasm's morphological diversity to identify any promising characteristics for breeding programs [5,11−18]. The work that has been done on Algerian apricot was that of [19] who studied diversity through molecular markers.

The characterization of plant genetic resources is the first step towards improving their use. Moreover, there is no reliable data regarding genetic diversity evaluation, using morphological and pomological descriptors of Algerian Apricot cultivars. Thus, the present study aimed to characterize the apricot accessions present in the current major growing areas in Algeria. The specific objectives were to evaluate phenotypic diversity for different morphological descriptors and pomological traits, to reveal the importance of these traits in addition to their relationship, and to assess the diversity in apricots for accession identification.

2. Materials and methods

2.1. Morphological studies

During the 2019−2020 season, 54 accessions were gathered from 26 distinct private orchards located in five states in Northern Algeria: Biskra, Constantine, Batna, M'sila, and Bordj Bou Arreridj (Fig. 1). This study was based on the analysis of morphological features of 54 *P. armeniaca* accessions according to [20,21]. 56 morphological and pomological parameters were evaluated using a ruler and a 0−200 mm caliper with an accuracy of 0.02 mm to assess diversity. The qualitative characteristics were evaluated based on rating and coding. The measurement of different parts of the plant (2650 leaves, 619 flowers, and 2602 fruits and seeds) was based on 50 replicates (On-line Suppl. Table 1, On-line Suppl. Table 2 https://kijoms.uokerbala.edu.iq/cgi/editor.cgi?article=3263&window=additional_files&context=home).

2.2. Data analysis

To discover significant differences between the measured characteristics, non-parametric one-way ANOVA (Kruskal−Wallis test) was assessed, and the coefficients of variation (CV%) were also determined. Pearson correlation coefficients and principal component analysis (PCA) were calculated to find correlations between the features and the genotypes. The distance matrix of morphological data was utilized as input data for cluster analysis to better understand the patterns of variation across genotypes. Missing data were replaced by the mean value.

3. Results

3.1. Cultivar's characteristics

Fifty-six morphological and pomological features were investigated for the 54 accessions, and the studied apricot accession matched the majority of the UPOV and IBPGR units of the observed description. Based on the assessed quantitative and qualitative characteristics, there were significant differences between the examined genotypes (Kruskal−Wallis test, $P < 0.001$) (On-line Suppl. Table 3 https://kijoms.uokerbala.edu.iq/cgi/editor.cgi?article=3263&window=additional_files&context=home).

26 of 56 examined characters indicated a variability index higher than 20%, showing variability between accessions. The majority of them were fruit and leaf characters (On-line Suppl. Table 3 https://kijoms.uokerbala.edu.iq/cgi/editor.cgi?article=3263&window=additional_files&context=home). The flowers' diameters extended from 3.1 cm (VR-3-15) to 3.96 cm (VR-6-2). The petals were mostly white (22), and light pink (11). Flowering time was in mid-

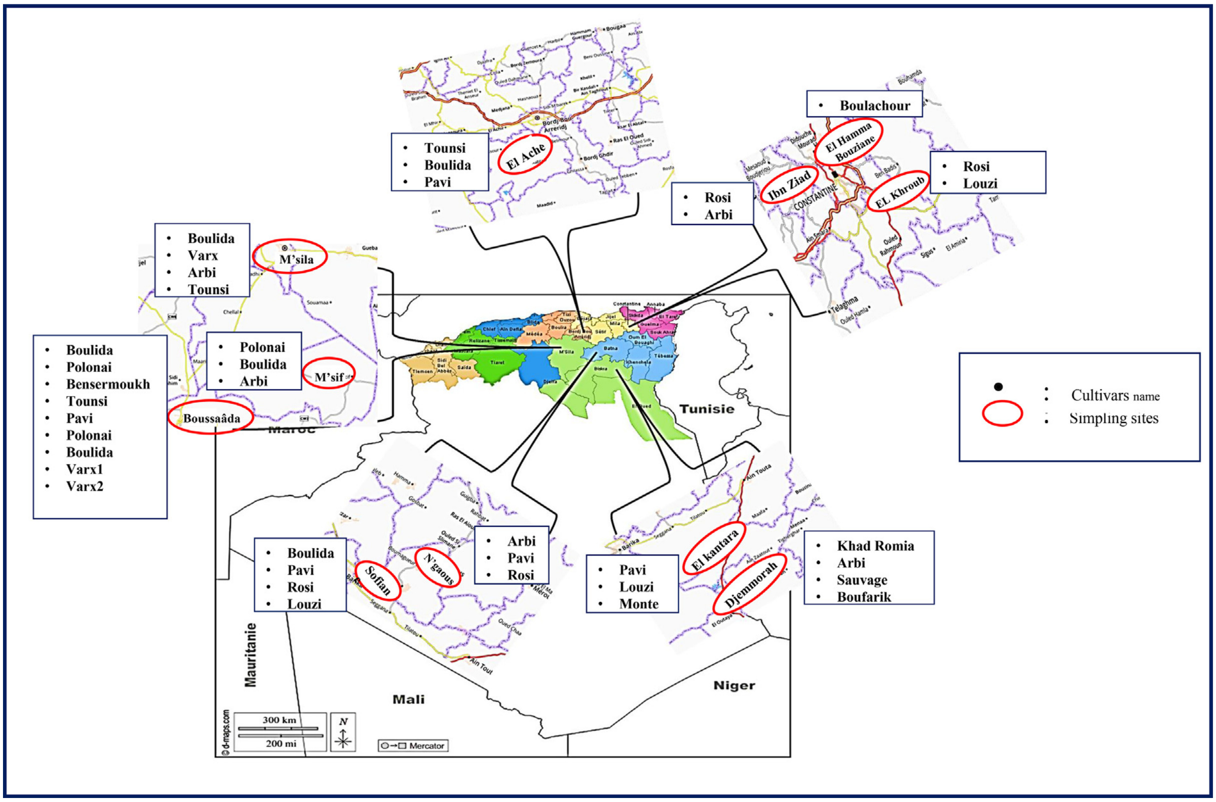

Fig. 1. Sampling site after prospection, and accessions name located in each site (online only).

February (3), late-February (13), early-March (19), mid-March (7), and twelve in late March (On-line Suppl. Table 2 https://kijoms.uokerbala.edu.iq/cgi/editor.cgi?article=3263&window=additional_files&context=home).

The fruits of the studied Algerian accessions studied were characterized by a red over color and a yellowish or light orange flesh. The patterns of over color were either solid flushes or isolated spots (Fig. 2). Fruits' length ranged from 2.38 cm (VR-11) to 4.96 cm (VR-5-3). The lateral form of the fruits was round or oblate, and the fruits were oval or oblate in ventral view. Fruit lateral widths varied from 2.18 cm (VR-11) to 4.84 cm (VR-5-3) and ventral widths ranged from 2.17 cm (VR-11) to 4.47 cm (VR-5-3). It was characterized by a small area of over color that adheres to the flesh, and a total absent of stone. Furthermore, the ground color of the fruit skin was mostly yellowish green, in which the fruit flesh's firmness was soft. The majority of fruits had smooth or slightly bumpy surfaces, where the ratio of fruit lateral width to fruit ventral width ranged from 0.98 (VR-1-5) to 2.27 (VR-1-5, VR-16-1). Additionally, the variation was found in repining time: early May (3), mid-May (9), late May (28), early June (6), mid-June (6), and late June (2). Most genotypes had an elliptical stone shape. The dimensions of the kernel, the stone, and the seeds showed a low coefficient of variability (On-line Suppl. Table 2 https://kijoms.uokerbala.edu.iq/cgi/editor.cgi?article=3263&window=additional_files&context=home).

The length of the leaf blade varied from 7.12 cm (VR-5-5) to 9.99 cm (VR-15), while the width varied from 5.64 cm (VR-3-4) to 10.06 cm (VR-5).

The majority of accessions had a medium green color on the upper side of the leaf blade and an obtuse leaf blade shape at the base. The blade length of the tip varied from 0.8 cm (VR-3-1) to 1.54 cm (VR-15) with a serrated leaf blade incision of the margin. However, the length of the petiole ranged from 2.02 cm (VR-12) to 5.93 cm (VR-13-4) with a medium intensity of its anthocyanin coloration on the upper side (23) containing two or three nectaries, with small size.

3.2. Correlation analysis

Positive and negative correlations between characters were shown through Pearson correlation analysis. The correlation was significant at the 0.05 (*) and 0.01 (**) levels (On-line Suppl. Table 4 https://kijoms.uokerbala.edu.iq/cgi/editor.cgi?article=3263&window=additional_files&context=home).

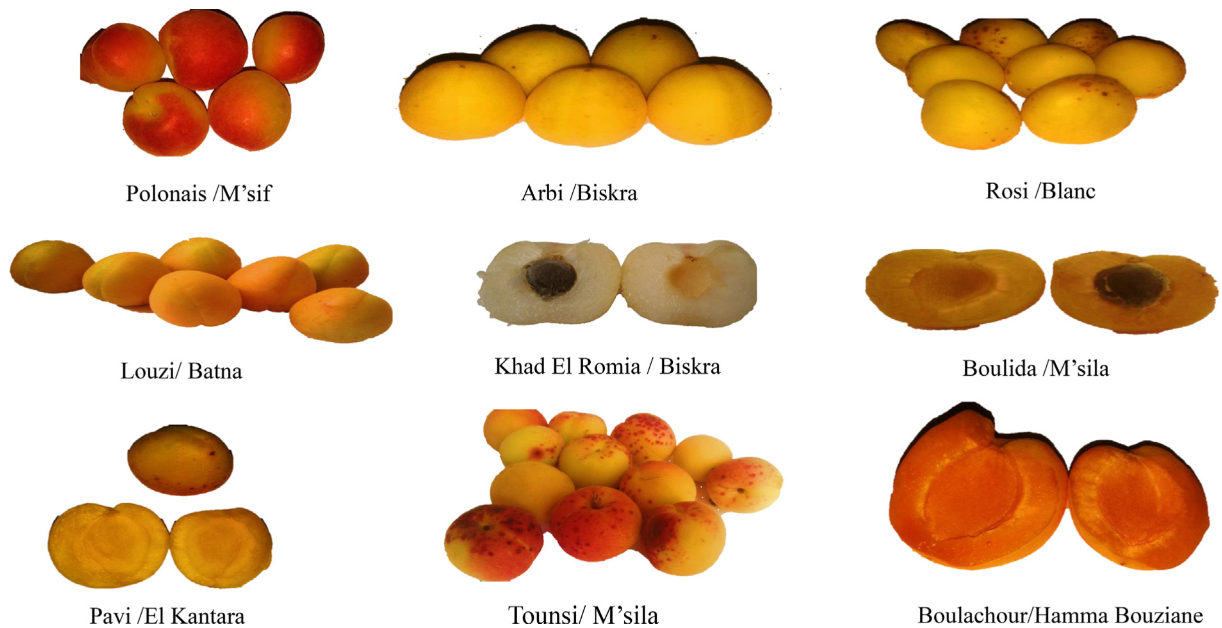

Fig. 2. Fruits of several cultivars/and collecting regions (online only).

Flower diameter was correlated significantly and positively with petal width (r = 0.581). Besides, petal color was positively correlated with the number of petals (r = 0.384) and the fruit pattern of over color (r = 0.354), but negatively with leaf blade width (r = −0.385). Flowering time was also correlated negatively with the intensity of fruit overcolor (r = −0.505), the lateral form of the fruits (r = −0.450), stone adhesion to flesh (r = −0.504), fruit flesh firmness (r = −0.373), but positively with kernel length (r = 0.596).

Hue of over color was positively and significantly correlated with the intensity of fruit over color (r = 0.489) and negatively with stone width in ventral view (r = −0.363). Moreover, the color of the fruit flesh was significantly correlated with the fruit firmness (r = 0.564). The patterns of over color were highly correlated with the relative area of over color (r = 0.743). Fruit length was positively and significantly correlated with fruit width in both lateral and ventral view (r = 0.891 and r = 0.838) respectively, stone length (r = 0.777), stone width in lateral and ventral view (r = 0.675 and r = 0.711) consecutively, kernel width in lateral view (r = 0.790), leaf blade length and width (r = 0.705 and r = 0.512) respectively, and petiole length (r = 0.591). The lateral form of the fruits was significantly and negatively correlated with leaf blade length (r = −0.415) and positively correlated with fruit shape at the apex (r = 0.358). Besides, fruit form in ventral view showed extremely positive correlations with fruit width in ventral view (r = 0.941), stone length (r = 0.570), stone width in lateral and ventral views (r = 0.817 and 0.767) respectively, kernel length (r = 0.644), stone width in lateral view (r = 0.781), and leaf blade length (r = 0.564). The intensity of over color was significantly correlated with the relative area of over color on the fruit (r = 0.383). The ground color of the fruit skin was correlated with stone length (r = 0.426). Fruit flesh firmness was also positively correlated with fruit surface (r = 0.369) and stone adhesion to flesh (r = 0.464).

3.3. PCA analysis

The PCA results demonstrated that 9 components explained 80.876% of the observed variations (Online Suppl. Table 5 https://kijoms.uokerbala.edu.iq/cgi/editor.cgi?article=3263&window=additional_files&context=home). 32.99% of the total variance was explained by the two first Eigen values (PC), PC1 (18.852%) and PC2 (14.147%). PC1 was correlated significantly and positively with fruit height, fruit width in both lateral and ventral view, stone length, stone width in lateral view, kernel length, kernel width in ventral view, leaf blade length, leaf blade width, petiole length, leaf blade length/petiole length ratio, and negatively correlated with fruit intensity of over color, fruit shape in lateral view, fruit adherence of stone to flesh, leaf blade incision of margin, flowering time, and repining time, while PC2 was correlated with pistil length,

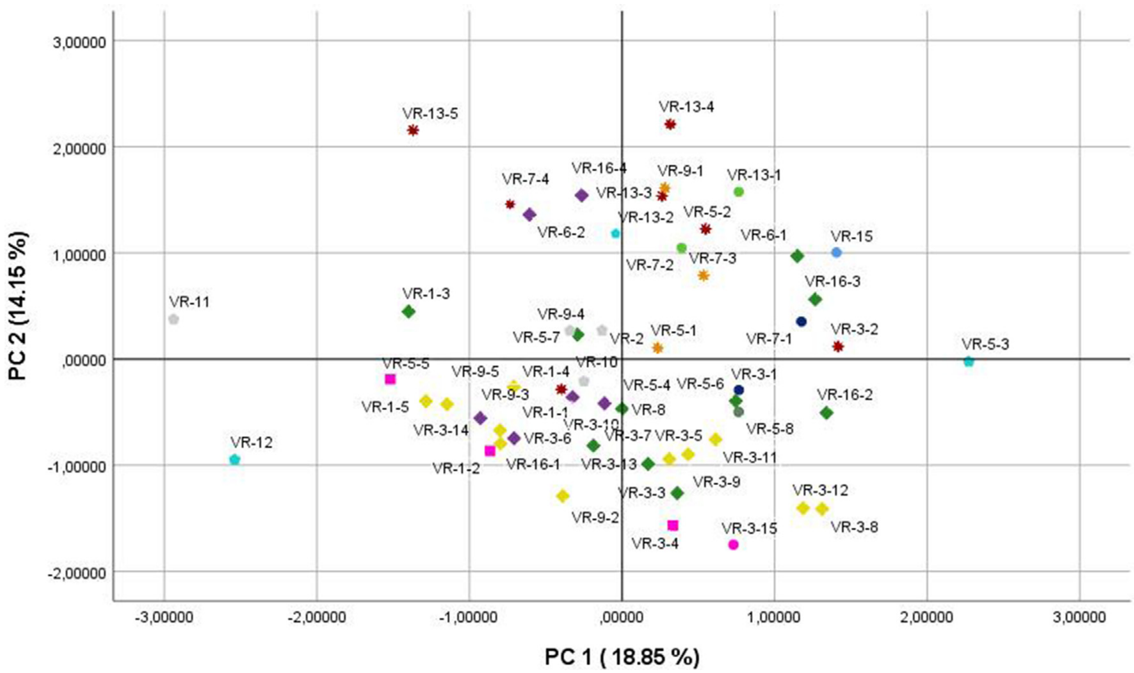

Fig. 3 Factor ratings for 54 apricot accessions for the first two principal components (PCs): Constantine (● El Khroub, ● Hamma Bouziane, ● Ibn Ziad), Bordj Bou Arreridj (■ El Mdjaz), M'sila (◆ Bousaâda, ◆ M'sif, ◆ M'sila), Biskra (⬟ El Kantara, ⬟ Djemorah), Batna (✱ Sofiane, ✱ N'gaous) (online only).

leaf blade length/lead (On-line Suppl. Table 6 https://kijoms.uokerbala.edu.iq/cgi/editor.cgi?article=3263&window=additional_files&context=home). When the Scatter plot was set up, using only the two first Eigen values to represent and show variability among the 54 cultivars, we could observe the cultivars scattered all over the four sides of the plot (Fig. 3).

3.4. Cluster analysis

4. Hierarchical clustering was performed using Ward's technique and Euclidean distance. It categorized the 54 accessions into two primary groups, which were further subdivided based on their morphological and pomological data (Fig. 4). Cluster I classified 26 accessions and cluster II included the remaining accessions (28), this later was divided into two sub-clusters (II-1, II-2). Sub-cluster II-1 contained only 8 accessions compared to cluster II-2. The clustering was mostly based on morphological and pomological features. The dissimilarity level ranged between 3.490 and 179.093, indicating a high distance between accessions.

4. Discussion

Due to ideal climatic and eco-geographical conditions, the Algerian regions contain a wide diversity of apricot cultivars. The investigation of significant pomological and morphological variations is a necessary prerequisite for breeding and categorization purposes [16,22].

According to certain researches, Algerian cultivars presented a high degree of morphological and pomological diversity [19,23], which support our findings. A high variability was also shown in Tunisian cultivars regarding relative areas of over color adherence of stone to flesh and fruit shape in lateral view [14]. A low variability index was noted in flower diameters; it was contradictory to other studies. The results were similar to [15] regarding petal color. Flower diameters were between 3.10 and 3.96 cm in our study and 1.78–3.76 cm in the study of [17]. The studied accessions had all larger flower diameters compared to the Afghan apricot.

Flowering time is an important criterion in breeding programs (On-line Suppl. Table 7 https://kijoms.uokerbala.edu.iq/cgi/editor.cgi?article=3263&window=additional_files&context=home). The findings disclosed a high variability in this study. There was a difference in blooming date between the same cultivars grown in different regions. Thus, flowering time of the same cultivars were less different, when sampling sites were closed. The difference in flowering time between the same cultivars from different regions may be due to the difference in altitude; the blossoming season was

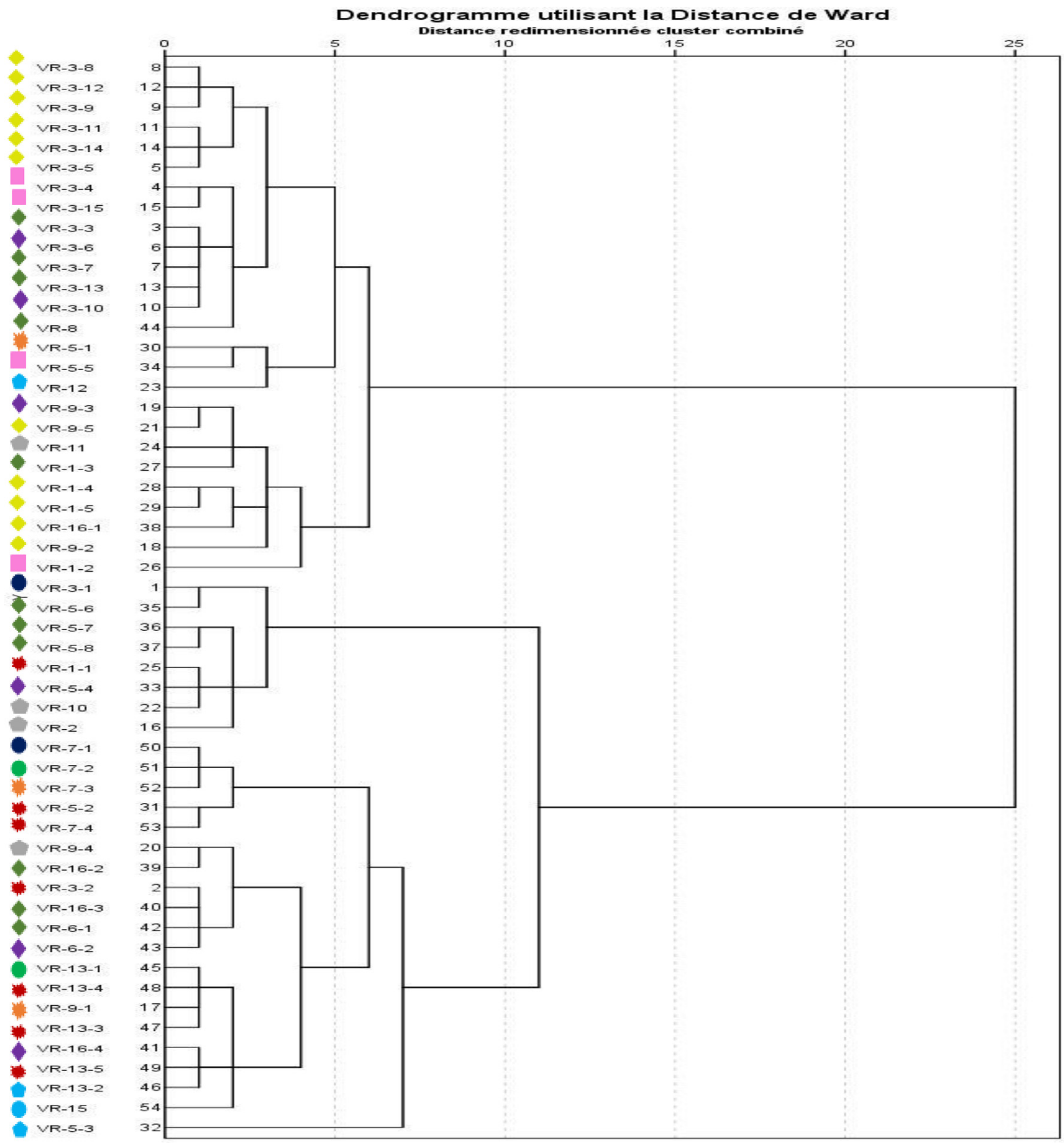

Fig. 4 Dendrogram of 54 apricot accessions (wards method, and Euclidian distance): Constantine (● El Khroub, ● Hamma Bouziane, ● Ibn Ziad), Bordj Bou Arreridj (■ El Mdjaz), M'sila (◆ Bousaâda, ◆ M'sif, ◆ M'sila), Biskra (⬟ El Kantara, ⬟ Djemorah), Batna (✸ Sofiane, ✸ N'gaous) (online only).

delayed when the trees were at a high altitude. To prevent mistakes in comparison between variables, it is critical to identify the timing of blooming of cultivars growing in the same environment. Apricot cultivated in Algeria starts to flourish in mid-February and finishes in late-March. The flowering time between different cultivars was 7 days under the same conditions. According to researchers, the blooming date ranges between 2 and 4 days under ideal conditions and 6–8 days under less ideal conditions [3]. Furthermore, the variation in flowering under the same geographical circumstances is related to various climate exposure [22,24]. Finding late-flowering trees is one of the main aims of the apricot breeding program, because late blooming is a significant element in protecting against spring frost damage [3] which include lower yield. The varieties that bloomed after the frost period are considered as target varieties, which were Pavi, Louzi rouge and Rosi. The ones which bloomed in the frost period were all vulnerable to spring frost damage. Flowering time was early for VR-1 and late for VR-7.

Fruit size, shape, and color influence market value and are essential characteristics in fruit grading, sorting, packaging, transportation, and aesthetic appeal [16,25]. For that, the selection must be directed toward the marketable product [3,26]. According to various sources, the fruit with the highest customer approval is the fruit with gorgeous color, a broad and graceful shape [27] (On-line Suppl. Table 8 https://kijoms.uokerbala.edu.iq/cgi/editor.cgi?article=3263&window=additional_files&context=home). There were similarities between Algerian, Tunisian and Turkish cultivars. A round shape has also been identified in Turkish, Tunisian, and Kashmirian cultivars [13,16,22]. Through genetic analysis [23], also found a relationship between Algerian, Tunisian, and Moroccan cultivars.

The results for the fruit dimensions were also similar to those demonstrated by [15,28]. Siberian apricots showed a larger dimension in fruit than Algerian cultivars [29]. The green color of the skin was similar to that of Afghan apricots [17]. Fruit dimension in the present investigation was a little higher compared with that of the Tunisian cultivars [14]. Thus, the more the fruit was large, the more it was demanded in the marketplace. VR-5-3, VR-15, and VR-3-2 had the desired fruit size. The studied genotypes studied had high fruit morphological features, and they may be expected to produce larger fruits with enhanced cultural methods [30].

The color of the fruit is an essential criterion not only for commercial value but also because it shows the carotenoids content. The presence of orange color, according to the literature, indicates the presence of carotenoids [3,31] and the accessions with orange color were VR-3-2, VR-3-4, VR-9-1, VR-12, VR-5-1, VR-5-5, VR-16-4, VR-13-1 and VR-13-2. Fruits' color is also a significant indicator of maturity and harvest date [3,31]. Aside from their great economic value, apricot stones have also been utilized to assess diversity. In this study, apricot stone and kernel features didn't show a high diversity index among cultivars for the studied characters.

Harvest time varies considerably among Algerian apricot accessions; the majority of them were harvested from early May to early June. A two-month harvesting season was a significant factor in improving apricot marketability. It was longer than the declared periods of [15,22], but shorter than the declared periods of Hungarian cultivars (11 June−10 September) [32], Iranian cultivars (early May−mid August) [33], and comparable to the findings of [34]. The earliest genotype for harvest was VR-1. Late harvest time is an important criterion in the breeding program. Late-maturing cultivars among the collected Algerian accessions were VR-7 and VR-13. The period of harvest and flowering time was different among cultivars depending on the cultivars and the growing area.

VR-9, VR-10 and VR-11 were the most commonly used in the manufacture of Fermesse (dried apricots) (local information), it should be widely cultivated, because dried apricots are higher in antioxidants [35].

Morphological similarities were noticed between cultivars that have different names, and there was a morphological difference between cultivars grown in different regions but have the same name. Those remarks were also reported by [19]. VR-1 is known as Fali in M'sila and Boulila in Batna, VR-3 is known as Bedai in Biskra and Boulida in Batna, and VR-7 is known as Louzi Blanc in Batna and Rosi in Bou Saâda (local information). He also confirmed that Louzi Blanc is Rosi through genetic analysis.

Leaf morphology also showed variability among cultivars. The highest leaf blade length was 9.99 cm for (VR-15) and the largest width was 10.06 cm for (VR-5-6). The majority of the accessions had green color on the upper side of the leaf blade and an obtuse leaf blade shape at the base, with the leaf blade angle at the apex being moderately obtuse in half of the accessions and strongly obtuse in the other half, and the leaf blade incisions at the margin being serrated in half of the accessions and bi-separated in the other half. Kashmirian cultivars have also been reported to have moderately obtuse base and apex shapes, as well as bi-separated margin incisions [15].

There was a significant correlation between the phenological variable repining time and flowering date. It was similar to the finding of [24] and contradictory to previous work on apricots realized by [3,15,22]. Leaf blade length was positively correlated with leaf blade width and petiole length. Fruit length correlated positively with fruit width in lateral and ventral view, leaf blade length and width, as well as petiole length. Those results were similar to the findings of [3,15]. Fruit firmness was correlated with fruit surface, which is similar to the finding of [3].

Fruit intensity of over color and firmness were negatively and significantly correlated with flowering time. It could be justified by early cultivars being firm and with an intense over color. Fruit length and width in lateral and ventral view are significantly correlated positively with stone length, width, kernel length and width. This could be justified by a large fruit carrying bigger stones. Those results were similar to those obtained by [22]. The size of the fruit has been taken as a distinguishing feature between different varieties [3].

The comparison of genotypes was challenging because it relied on so many variables, including geographical location, climate, altitude, and longitude [4,22,24].

PCA analysis may help in the selection of a collection of genotypes because it is a way to reveal similarities and differences between cultivars [36,37]. It also simplified the categorization of apricot genotypes for collection and breeding. PC (1) was the most important component (18.85%) and it is correlated with the fruit stone kernel and leaf size characteristics. This circumstance validates the utility of using pomological characteristics to identify superior genotypes. Fruit size characteristics have been shown to be critical for differentiating apricot genotypes [3,4,15,28,31]. Instead of using 53 characters, the morphological characteristics utilized in PCA analysis may be adequate to characterize genotypes [12].

PC (1) classified cultivars with large fruit, stone, kernel, petiol, leaf blade dimensions, flowering and harvest time, as positively. Likewise, cultivars with a high leaf blade/petiole length ratio (>2), a biserrate incision of margins, and a weak to absent adherence of stone to flesh, as negatively. While PC (2) was commended for having a high leaf blade length-to-width ratio (>1) and a long pistil, PC (3) was criticized for having a short pistil.

Cluster analysis was able to show variability between the 54 studied Algerian cultivars studied. A large interval of dissimilarity was observed, unlike the outcomes of [38,39] morphologic classifications, which reflected a relationship between those accessions.

5. Conclusion

This study was carried out to determine the genetic diversity of Algerian apricot germplasm. The findings might be useful for comparing genetic resources, characterizing apricot genotypes, and selecting the best cultivar with the most diversity in apricot breeding programs. The Algerian collection showed a high variability in the most important characters, among them flowering and ripening dates. It was also found that morphological traits such as fruit, leaf, stone, and kernel size (length and width) can be used to reliably explaining the difference between genotypes. The apricot breeding program prioritizes producing new cultivars with a long hibernation period that require a large number of chilling units, as well as late blooming behavior that reduces the risk of frost occurrence during bloom. Two genotypes exhibited later flowering periods and harvesting times (Rosi, Louzi rouge).

Conflicts of interest

The authors declare that they have no conflit of interest.

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