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ORIGINAL ARTICLE

Morphological and physicochemical characteristics of three pomegranate cultivars (*Punica granatum* L.) grown in northern Algeria

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Abstract – Introduction. In northern Algeria, various pomegranate cultivars (*Punica granatum* L.) are produced in the region of Mitidja. However, to date, no study has been published on the characteristics of the locally grown cultivars. The objective of the present study was to investigate the morphological and physicochemical characteristics of the fruit of three local pomegranate cultivars. **Materials and methods.** Our study focused on a comparison of the cultivars 'Doux de Koléa', 'Doux de Messaad' and 'Bordj Mira 11', obtained at harvest maturity from the Experimental Station of the ITAFV in the village of Boufarik in the south-west of Algiers, October 2013. A morphological characterization of the fruit, peel and arils was carried out. Some physicochemical characteristics of the juice, including the total soluble solids, pH, acidity, maturity index, total sugar and juice yield, were assessed. **Results and discussion.** Fruit weight ranged from 194 to 297 g and aril weight from 270 to 280 mg. Similarly, the peel thickness of the fruit ranged between 2.50 and 3.00 mm, while the pH recorded was 3.84−4.60. Total soluble solids ranged from 12.87 to 18.64 °Brix and titratable acidity ranged between 0.31 g 100 mL^{-1} and 0.50 g 100 mL^{-1} in pomegranate juices. Vitamin C and total soluble sugar contents were in the range of 9.08−15.74 and 11.33−16.33 g 100 mL^{-1}, respectively. The comparison of our results with other studies reveals that Algerian pomegranate fruit has juice and peel physicochemical characteristics that could play a valuable role in people's diet and health. **Conclusion.** This work provides original data about the composition of pomegranate fruit from Algeria (vitamin C, protein, total sugar content, etc.). It demonstrates that indigenous cultivars can be a good source of different nutrients for the local population.

Keywords: Algeria / pomegranate / *Punica granatum* / indigenous cultivars / morphological characteristics / physicochemical characteristics / fruit juice

Résumé – Caractéristiques morphologiques et physico-chimiques de trois cultivars de grenade *(Punica granatum* L.) du nord de l'Algérie. Introduction. Plusieurs cultivars de grenade (*Punica granatum* L.) sont utilisés en production au nord de l'Algérie et en particulier dans la région de Mitidja. Cependant à ce jour aucune étude n'a été publiée sur les caractéristiques de ces cultivars. L'objectif de cette étude est d'étudier les caractéristiques morphologiques et physico-chimiques des fruits de trois de ces cultivars de grenade cultivés localement. **Matériel et méthodes.** Notre étude a porté sur la comparaison des fruits des cvs 'Doux de Koléa', 'Doux de Messaad' et 'Bordj Mira 11' récoltés au stade de maturité dans la station expérimentale de l'ITAFV, dans le village de Boufarik au sud-ouest d'Alger, en octobre 2013. La caractérisation morphologique des fruits, écorces et arilles, a été réalisée. Les caractéristiques physico-chimiques du jus de ces fruits ont été évaluées : les solides solubles totaux, le pH, l'acidité, l'indice de maturité, les sucres totaux, ainsi que le rendement en jus. **Résultats et discussion.** Une grande variabilité a été observée entre cultivars pour chaque paramètre étudié. Les valeurs enregistrées étaient de 194 à 297 g pour le poids moyen d'un fruit ; de 270 à 280 mg pour le poids moyen des arilles ; de 2,5 à 3,0 mm pour l'épaisseur de la peau du fruit. Les valeurs caractérisant le jus des fruits étaient de 3,84 à 4,60 pour le pH ; de 12,87 à 18,64 °Brix pour les solides solubles totaux ; de 0,31 à 0,50 g 100 mL^{-1} pour l'acidité titrable ; et, de 9,08 à 15,74 g 100 mL^{-1} et de 11,33 à 16,33 g 100 mL^{-1} pour la vitamine C et les sucres totaux, respectivement. **Conclusion.** Ce travail fournit des données originales sur la composition des grenades traditionnelles en Algérie. La comparaison de nos résultats avec d'autres études révèle que le jus et la pelure des fruits de cultivars de grenades algériens ont des caractéristiques physico-chimiques qui pourraient jouer un rôle positif déterminant dans l'alimentation et la santé humaine des populations locales.

Mots clés : Algérie / grenade / *Punica granatum* / cultivars indigènes / caractéristiques morphologiques / caractéristiques physico-chimiques / jus de fruit

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1 Introduction

Pomegranate (*Punica granatum* L.) belongs to the genus *Punica* and family *Punicaceae*. In recent years, this fruit has seen a great expansion in several countries, especially those with a Mediterranean-like climate (Morocco, Spain, Turkey, Tunisia, Egypt and Algeria), where fruit of excellent quality can be obtained [1]. There is growing interest in this fruit because not only is it pleasant to eat, but it is also considered to be a functional product of great benefit in the human diet, as it contains several groups of substances that are useful in disease prevention [1–3]. This temperate species, requiring high temperatures to mature correctly, was once grown in the northern region of Algeria (Mitidja plain), a country characterized by a sub-humid climate. Its successful adaptation to the Mitidja climate has led to its wide dispersion, and the creation of a multitude of cultivars [4].

In Algeria, the cultivation of pomegranate has changed considerably as a result of the aid for agricultural recovery program of 2010−2014 and other programs, including the National Agricultural Development Program (NADP). The production increased from 717.063 t to 790.374 t in 2012 and 2014, respectively, while the yield increased from 7.83 t ha^{-1} to 8.42 t ha^{-1}. However, the genetic materials, especially those for production, issued from the multiplication of plants from a large number of orchards, have no certification that guarantees the trueness-to-type and health quality of the plants. It would be wise to choose the species to grow and ensure the quality of the plants used.

The collection of pomegranate trees in the Experimental Station of the ITAFV also includes other cultivars whose physicochemical identification has not yet been achieved. There are many varieties of pomegranates and they vary in quality. Flavors range from very sweet to very acidic and seeds can be soft, medium or hard. The best-quality pomegranates have a good balance of sugars and acidity and soft seeds, which can be consumed with the pulp. The main variety grown in the area of Mitidja is 'Doux de Messaad', with its large well-colored fruit and good juice [4]. In recent years, despite the short pomegranate production season that lasts two months (September - October), fresh consumption increased from 1.82 kg hab^{-1} in 2009 to 2.07 kg hab^{-1} in 2014. Pomegranate fruit is consumed directly as fresh arils as well as fresh juice [5].

Furthermore, the physicochemical characterization of pomegranate is important because it is closely related to the quality and preservation of products, and the fruit composition is highly dependent on the type of cultivar, growing region, climate, maturity and cultural practices [6–8]. To our knowledge, no information is available for pomegranate cultivars grown in Mitidja. Therefore, this study aimed to characterize three pomegranate fruit cultivars ('Doux de Koléa', 'Doux de Messaad' and 'Bordj Mira 11') grown in the Mitidja area in terms of their morphological and physicochemical properties, and to identify similarities or differences among them.

The results of this study will be useful for the classification of cultivars based on their taste quality with indices of maturity, and for the design of their industrial processing and extraction of their juice. The characteristics identified in this study could be used to establish a catalog of local pomegranate cultivars.

2 Materials and methods

2.1 Plant materials

Three pomegranate cultivars were obtained at harvest maturity from the Experimental Station of the ITAFV in the village of Boufarik in the south-west of Algiers in October 2013. The selected plant materials cvs 'Doux de Koléa' (DK), 'Messaad Doux' (DM) and 'Bordj Mira 11' (BM11) belong to the germplasm collection orchard of the Experimental Station of the ITAFV in Boufarik (Blida). The station is located in Mitidja at 36°34′ N, 2°55′ E, and 63 m altitude. The minimum and maximum average monthly temperatures occur in January (11.5 °C) and August (25.6 °C), respectively. These climatic conditions are considered ideal for the cultivation of high-quality pomegranates. Several local cultivars are grown throughout the Mitidja plains and mountains in northern Algeria, but the sweet type ("doux") occupies the largest cultivated area.

These pomegranate cultivars were selected due to their sweetness and their popularity in Algeria. Their names are mainly based on local geography and they originate from three states in Algeria. 'Doux de Koléa' comes from the village of Koléa located in Tipaza, 'Doux de Messaad' from the village of Messaad in Djelfa, and 'Bordj Mira 11' from the village of Bordj Mira in Bejaia (*table I*). The pomegranate plantation comprised 75 trees on an experimental plot of 1,500 m^2 with a clay loam soil.

The French word "doux" means that the seed tastes sweet and also refers to the softness of the woody part of the seed (the edible portion of the fruit). Its fresh consumption is very popular in its production region. These 3 cultivars were chosen from 38 in the ITAFV germplasm collection; they were selected from the same orchard and grown in homogeneous conditions. Fruits were generally picked when the green color had disappeared from the peel and was replaced by a yellow-pink/red color. Harvest time ranged from mid-September to mid-October.

Between one and two adult trees (~16 years old) were harvested on the same day to obtain a fruit sample of 10 kg for each accession. After harvest, fruits were transported to the ITAFV research laboratory for measurements and analyses. The fruits were stored at 4 °C until analysis. Three replicates were performed for each analysis. All reagents, solvents and standards were of analytical grade

It should be noted that the sampling was done under different variety names and with the features attributed to quality fruit, such as color, aril, peel and fruit taste (*table II*).

2.2 Fruit characteristics

Morphological and physicochemical measurements of fruits [9] were carried out on samples of 10 fruits per cultivar. The following characteristics were studied:

- Fruit weight (Fw) (in g),
- Equatorial diameter (in mm),

Table I. Geographic origin of the studied Algerian pomegranate cultivars.

Cultivars	Origin	Latitude North	Longitude West	Altitude (m)	Rainfall (mm)
Doux de Koléa (DK)	Koléa (Tipaza)	36°38′25″	2°45′53″	130	650
Doux de Messaad (DM)	Messaad (Djelfa)	34°10′00″	3°30′00″	1,010	350
Bordj Mira 11 (DM11)	Bordj Mira (Djelfa)	36°32′51″	5°16′24″	100	660

Table II. Evaluation of peel, aril and seed characteristics by the sensory panel (DK: 'Doux de Koléa'; DM: 'Doux de Messaad'; BM11: 'Bordj Mira11').

Cultivar	Date of maturity	Shape of fruit	Peel color	Aril color	Seeds	Sensorial test
DK	10 October	Roundish	Pale yellow	Pink crystal	Hard	Sweet
DM	Mid-September	Roundish	Greenish yellow	Pale pink	Soft	Sweet
BM11	Mid-October	Roundish	Greenish yellow	Pink	Soft	Sweet

– Calyx diameter (in mm),
– Total length of fruit (in mm),
– Calyx length (in mm),
– Number of carpels in the equatorial section,
– Peel weight (Pw) (in g),
– Carpellary membrane weight (Cmw) (in g),
– Peel thickness (in mm).

Each fruit was weighed individually, then the peel and carpellary membranes were manually removed and weighed. Weights were recorded on an electronic balance (Mettler Toledo, Switzerland) with an accuracy of 0.01 g. The length (fruit polar axis) and diameter (perpendicular to the polar axis) of the fruit and calyx and the peel thickness were measured with a vernier caliper of 0.1 mm accuracy. Measurements were replicated three times for each fruit and peel.

– The aril ratio (Ay) was calculated following the formula:

$$\text{Ay} = (\text{Fw} - (\text{Pw} + \text{Cmw})/\text{Fw}) \times 100 \text{ (in \%)}$$

$$\text{or Ay} = (\text{total aril weight}/\text{fruit weight}) \times 100\ \%\ [9].$$

2.3 Characteristics of the arils

After weighing the fruit, the arils were manually separated from the whole fruits and measured as above. The following aril characteristics were studied:

– Aril width (Aw) and aril length (Al), measured by a digital vernier caliper with 0.01 mm accuracy.

– Aril weight (Aw), determined by a precision weighing device (Mettler Toledo, Switzerland), with an accuracy of 0.001 g.

– Moisture (M) or water content was determined after arils were oven-dried at 40 °C until constant weight. Moisture content was calculated as follows:

$$\%\text{Moisture} = [(M_{(initial)} - M_{(dried)})/M_{(initial)}] \times 100$$

where $M_{initial}$ and M_{dried} are the mass of the sample before and after drying, respectively.

– Juice content was measured by extracting the contents of replicate samples of 100 g arils per fruit using a juice extractor, and squeezing the juice collected in muslin cloth. These juices were used for chemical analysis.

– The juice ratio (Jy in %) was determined using the method described by Martinez *et al.* [9]. The extracted juices were used for chemical analysis. The juice ratio (Jy) was calculated following the formula:

$$\text{Jy} = (\text{total weight juice of 100 arils / fruit weight}) \times 100.$$

– The pH measurements were performed using a digital pH meter (Metrohm 601) at 21 °C.

– Total soluble solids (TSS) were determined with the juice obtained from each subsample using a refractometer and reported as °Brix at 21 °C.

– Total titratable acidity (TA) was determined by titration with 0.1 N NaOH solution to pH 8.1, using phenolphthalein as an indicator, and the results were expressed in mg of citric acid 100 mL^{-1} juice [10].

– The maturity index (MI) was calculated as the ratio of TSS over TA. The following classification has been established for Spanish cultivars: Sweet cultivars, MI = 31–98; Sour-sweet cultivars, MI = 17–24; Sour cultivars, MI = 5–7 [11].

– The quality was established according to the following scale: poor, acceptable, good and excellent [12] (*table II*). For color, three categories were established: pale pink, pink and pink-crystal. Measurements were replicated three times for each aril juice.

2.4 Total sugars, ascorbic acid and protein in the juices

2.4.1 Total sugars

The total sugars were assayed by the phenol sulfuric acid method described by Dubois *et al.* [13]. 0.5 mL of juice was added to 1 mL of phenol (5%) and allowed to stand at room temperature for one hour. Then, 5 mL of concentrated sulfuric acid (0.5 M) were added and the whole mixture was vortexed before being allowed to stand at room temperature for one hour. The absorbance was read at 490 nm wavelength on the UV spectrophotometer. Results are expressed in g 100 mL^{-1} juice. The experiment was repeated three times.

2.4.2 Ascorbic acid

Ascorbic acid was determined using the method described by Arendse *et al.* [14]. A quantity of 5 mL juice was mixed with 15 mL oxalic acid (1%) then allowed to stand at room temperature for one hour and centrifuged.

1 mL supernatant was mixed with 9 mL of DCIP (2,6-dichlorophenolindophenol) 2.5 10^{-3} M. After 5 seconds, the absorbance was read at 515 nm. The ascorbic acid content is expressed as mg 100 mL^{-1} juice, and was determined by referring to a calibration curve obtained by using ascorbic acid.

2.4.3 Proteins

The total protein content was determined by the method of Lowry *et al.* [15], with some modifications by Hmid *et al.* [6]. The juice was diluted with distilled water to 1/100. An alkaline pretreatment solution was prepared by weighing 20 g sodium hydroxide, 100 g sodium carbonate, 2 g potassium and sodium tartrate, and 0.5 g copper II sulfate pentahydrate, then completing with distilled water to 1,000 mL. Next, 4 mL Folin reagent, prepared with 0.5 mL Folin and 4 mL distilled water, was added. The solution was incubated for 5 min at 55 ± 1 °C a nd cooled in cold water for 30 min. The absorbance at 670 nm was measured using a spectrophotometer (UV Mini-1240). The total protein content of the juice was calculated from a calibration curve prepared with human serum albumin. Results are expressed in g 100 mL^{-1} juice.

2.5 Color measurement

The color of pomegranates (peel and juice) was determined using a Minolta portable chromameter (Model CR-300; Minolta® Camera Co., Ltd., Osaka, Japan). Peel color measurements were taken along the equatorial axis of each fruit. Juice color absorbance was measured at 520 nm using a Helios Omega UV-Vis spectrophotometer. Three replicate color measurements were made on peel and juice (per fruit) placed in a colorless glass Petri dish. The chromameter describes color in three coordinates: $L*$, lightness, from 0 (black) to 100 (white); $a*$, from –60 (green) to 60 (red); and b*, from –60 (blue) to 60 (yellow). Chroma values were calculated as chroma $(a^2+b^2)^{1/2}$. The hue angle (H*) was calculated from tan -1 (b* / a*). The C value shows color intensity [5].

2.6 Sensory evaluation

The sensory evaluation was carried out by nine members of the ITAFV laboratory, aged 24-45 years. All panelists had significant experience in sensory evaluation of fruits and fruit juices (*table II*). They were asked to assess the shape, color and taste of the different parts of the fruit. This included fruit quality, fruit shape, peel and aril color, seed hardness, juiciness, and sweet and acid taste. For each characteristic of the juice, the rating was based on a four-point scale: 1: poor; 2: fair; 3: acceptable; 4: excellent, while seeds were described as hard or soft.

2.7 Statistical analyses

Data were analyzed by Statistical Analysis System Version 9.1 using analysis of variance (ANOVA) and differences among means were determined for significance at $P < 0.05$ using Fisher test.

3 Results and discussion

3.1 Fruit morphology

The morphological properties of the three pomegranate fruits are shown in *table III*. The factor "cultivar" significantly ($P < 0.05$) affected all parameters except calyx diameter, number of carpels and peel thickness. The fruit weight ranged from 193.65 to 296.91 g (DK and BM11), respectively (*table III*).

According to the criteria used by Martinez *et al.* [9] for Spanish cultivars, these fruits are classified as medium-sized. The weight is a varietal characteristic that may fluctuate depending on the cultivar and the ecological conditions [16]. Interestingly, the BM11 cultivars had the biggest fruits (296.91 g), although all fruits were collected at the same time in the last week of September 2013. This fact suggests that the weight of fruits during maturity depends on the cultivar, and provides valuable information for farmers and processors [17].

The total fruit length ranged from 80.68 mm (DK) to 82.70 mm (BM11), and the diameter from 72.00 mm (DM) to 81.67 mm (DK). Even these parameters had positive strong correlations ($P < 0.05$) with fruit weight (*table III*).

Calyx diameter was 17.66 mm for DK and 18.0 for DM and BM11, while calyx length was 12.70 mm for DM and 14.33 for DK (*Table III*), thus the shape of the calyx is a specific characteristic of each cultivar studied. Valero and Ruiz-Altisent [18] reported that this knowledge is particularly relevant in the design or selection of appropriate packaging for fruit handling and storage. Our results are generally similar to those of [19] and below those of Tunisian cultivars [20].

Fruit length and diameter increased, while the length/diameter ratio (shape index) decreased during development and maturation, indicating that fruit diameter increases faster than the length.

Other fruit morphological characteristics, such as peel weight, differed significantly among cultivars (*table IV*). The maximum peel weight was recorded in BM11, followed by DM and DK. These values are in agreement with those (36.50-109.54 g) reported by Mansour *et al.* [21], and lower than those reported by Tehranifar *et al.* [22]. Peel thickness was found to be non-significant among all cultivars and its value ranged from 2.50 to 3.00 mm (*table IV*). These are similar to results reported in the literature; between 2.4 and 6.9 mm [5, 12, 23–25].

The results for the morphological characteristics of the pomegranate cultivars in this study show that these cultivars differ for all the measured parameters except calyx diameter, number of carpels and peel thickness. The cultivar 'Bordj Mira 11' seems the most promising, combining the weight of the fruit and the peel, which is a very useful property in the development of cultivars with the greatest agricultural potential.

3.2 Characteristics of the arils

The arils are the edible portion of pomegranate fruit, containing the juice, the pulp and the seeds. Thus, knowing these characteristics enable producers and processors to promote this

Table III. Fruit and calyx morphology of three pomegranate cultivars grown in Northern Algeria. Values are expressed as means ± standard deviation (n = 3). Cultivars: DK: 'Doux de Koléa'; DM: 'Doux de Messaad'; BM11: 'Bordj Mira11'. Physicochemical characteristics of pomegranate fruits : Fw: fruit weight; De: equatorial diameter; Flc: fruit length without calyx; Tlf: total fruit length; Lc: calyx length; Dc: calyx diameter; Lc: calyx length; Nc: Number of carpels.

Cultivars	Fruit characteristics[y]					Calyx characteristics[y]	
	Fw(g)	De (g)	Flc (mm)	Tlf (mm)	Nc (mm)	Dc (g)	Lc (mm)
DK	193.65 ± 1.50 a	72.00 ± 1.00 a	66.66 ± 2.08 a	80.68 ± 5.77 a	6.00 ± 1.53 a	17.66 ± 2.00 a	14.33 ± 0.75 a
DM	206.42 ± 2.21 bc	81.67 ± 3.51 b	78.00 ± 2.00 b	82.68 ± 1.15 a	6.00 ± 1.00 a	18.00 ± 2.65 a	12.70 ± 1.40 ac
BM 11	296.91 ± 7.14 ac	75.67 ± 2.08 c	74.00 ± 2.00 c	82.70 ± 0.00 ab	7.00 ± 1.00 a	18.00 ± 2.00 a	13.20 ± 1.01 bc

[y] Means with different letters in the same column are significantly different ($P < 0.05$).

Table IV. Juice content and physical characteristics of fruit arils of three pomegranate cultivars. Values are expressed as means ± standard deviation (n = 3). Cultivars: DK: 'Doux de Koléa'; DM: 'Doux de Messaad'; BM11: 'Bordj Mira 11'. Morphological characteristics of pomegranate fruits: Pw: peel weight; Pt: peel thickness; Cmw: carpellary membrane weight; Aw: aril weight; An: aril number; Al: aril length; Aw: aril width; Ay: aril ratio; Jy: juice ratio.

Cultivars	Peel[y]				Aril[y]				Juice[y]
	Pw (mm)	Pt (mm)	Cmw (mm)	Aw (mg)	An	Al (mm)	Aw (mm)	Ay (%)	Jy (%)
DK	45.50 ± 0.92 a	3.00 ± 0.30 a	25.18 ± 1.39 a	280 ± 0.4 a	533.33 ± 51.32 b	6.30 ± 0.06 ab	8.00 ± 0.10 ca	66.55 ± 2.60 b	53.33 ± 1.53 a
DM	46.19 ± 5.57 ac	3.00 ± 0.00 a	22.31 ± 2.25 b	270 ± 0.4 a	676.67 ± 37.86 c	4.30 ± 0.06 b	8.00 ± 0.20 a	63.48 ± 0.89 a	45.33 ± 3.06 c
BM 11	55.24 ± 4.70 bc	2.50 ± 0.01 a	43.22 ± 10.75 c	280 ± 0.3 a	432.33 ± 18.61 a	3.70 ± 1.90 ac	9.70 ± 0.60 ab	61.66 ± 8.49 ac	36.67 ± 1.53 b

[y] Means with different letters in the same column are significantly different ($P < 0.05$).

fruit better. Arils have an economic value, and are therefore the most important traits targeted by growers and the food industry [12].

As shown in *table IV*, many physical properties of the arils of the investigated cultivars were found to be statistically different ($P < 0.05$), except for aril weight. The number of arils was significantly highest in DM and lowest in BM11. According to [17], Italian cultivars have a mean aril weight range between 0.3 and 0.6 g, values similar to those found in Spanish and Moroccan cultivars; thus, our cultivars have a lower weight.

On the other hand, the differences among the three cultivars in aril width and length were less significant; DK arils were significantly longer and BM11 arils were wider (*table IV*). This range is similar to those reported by several studies on cultivars grown in other producing countries such as Iran, Oman and South Africa [5, 18, 19].

The aril ratio is a desirable property from a consumer point of view as well as for industrial juice processing [18]; it varies between 61.66 for BM11 and 66.55% for DM. These values are comparable with those (57.86–75.48%) reported by [10], for Iranian cultivars [26] and for Moroccan cultivars [20], ranging from 53.4 to 61.2% [12].

The juice percentage of the studied pomegranate cultivars varied from 36.67% (BM11) to 53.33% (DK); it was highest in the DK and DM cultivars. The corresponding data for Spanish cultivars range from 25.00 to 64.17% [9].

The results of the aril characteristics of the pomegranate cultivars in this research demonstrate that the three cultivars are similar in all measured parameters except for the aril number and aril ratio. The DK cultivar seems the most promising, combining higher aril ratio and aril weight, which is a highly desirable property in the food processing and beverage industry. The other promising cultivar was DM for its larger number of arils per fruit.

Previous studies have confirmed that cultivars with a high juice percentage and aril recovery have great potential for use in the processing and beverage industry and are also preferred for table purposes [25, 26]. However, varieties with thick peel can be incorporated into breeding programs to develop varieties with a longer shelf life and less fruit cracking [27].

3.3 pH, titratable acidity, total soluble solids and maturity index

The results for pH, titratable acidity (TA), total soluble solids (TSS) and the maturity index (MI) of the different pomegranate cultivars revealed significant differences ($P < 0.05$). Their values ranged from 3.84 to 4.60 (pH), 12.87 to 18.64 °Brix (TSS), 0.31 to 0.50 gm L^{-1} (acidity) and 25.87 to 52.58 (MI) (*table V*).

DK showed the highest pH in juice (4.60). Significantly higher acidity (0.50%) was noted in BM11. In this study, titratable acidity increased significantly, while the pH value decreased significantly. Acidity was inversely correlated with pH. The ripe fruit, which had a low acid content, had a correspondingly high pH [28]. Regarding the soluble solid content, the highest value (18.64 °Brix) was found in fruit of the pomegranate DK, and the lowest in the cultivar BM11.

The maturity index (TSS/TA) is an accepted main flavor quality in most fruit species, which some authors have used for classifying pomegranate cultivars [9, 27]. This also varied among the different cultivars and appeared to be a good indicator of fruit maturity. In our cultivars, a comparatively high maturity index was observed in DK, DM and BM11 (*table V*), which can be classified as sweet. The results were higher than those obtained for Iranian cultivars, 5.04 to 46.31 [19], and for the new genotypes in Italy, 7.7 to 35.2 [28]. Previous studies have also reported variable ranges of the maturity index [9, 27, 28].

On the other hand, depending on acidity values, pomegranate cultivars are classified as sweet (< 1%), sour-sweet (1–2%) and sour (> 2%) [29]. A sweet taste is commonly reported among pomegranate genotypes [27, 28].

3.4 Total sugars and ascorbic acid in the juice of

The results regarding the chemical composition (total sugars (TS), ascorbic acid (A), total proteins and moisture) of the juice of the pomegranate cultivars revealed significant differences ($P < 0.05$), except for total proteins (*table VI*).

The concentration of total sugar varied from 11.33 to 16.33 g 100 mL^{-1}, being the highest in the cultivar DK and lowest in BM11. Poyrazoglu *et al.* [30] reported total sugar values of some pomegranate cultivars in Turkey as between 13.90 and 16.06 g 100 mL^{-1}. According to several authors [23,31,32], juice from fully mature pomegranate fruit has 12–16% sugar content, consisting mainly of glucose and fructose. This is in agreement with Al-Maiman and Ahmad [33], who reported that the concentration of glucose was higher than fructose in unripe, half-ripe and fully ripe fruit of the cv. 'Taifi'. Apart from glucose and fructose, Kulkarni and Aradhya [34] found negligible levels of sucrose and maltose in Spanish pomegranate clones during fruit development.

Boutakiout *et al.* [35] reported that the total sugar contents of cvs 'Moro' and 'Sanguinello' orange juice reached 10.3 and 10.9 g 100 mL^{-1}, respectively, and the following values for apple: 9.95 g 100 mL^{-1}, grape: 16.1 g 100 mL^{1}, pineapple: 11.6 g 100 mL^{-1}, and tomato: 3.86 g 100 mL^{-1} [35]. Thus, pomegranate juice contains a large amount of total sugars compared with other juices, and it is as high as the values for grape juice.

Ascorbic acid is abundant and has many biological functions in fruits; for example, controlling many aspects of redox (oxidation-reduction) and antioxidant activity [36]. Our results indicate that the ascorbic acid concentration was significantly highest in the DK and BM11 cultivars and lowest in DM (*table VI*), ranging from 9.08 mg 100 mL^{-1} for DM, 14.92 mg 100 mL^{-1} for DK and 15.74 mg 100 mL^{-1} for BM11. Tehranifar *et al.* [22] reported vitamin C in pomegranate genotypes between 9.9–20.9 mg 100 mL^{-1}. Our results are similar. These studies are also in agreement with Zarei *et al.* [31], who reported a significant decrease from 25.84 g 100 mL^{-1} in 20-day-old fruit to 9.78 g 100 mL^{-1} in 140-day-old fruit.

Higher and lower values have been reported in other juices: orange (38.30 mg 100 mL^{-1}), apple (11 mg 100 mL^{-1}), grape (traces), pineapple (9.5 mg 100 mL^{-1}) and tomato (16.6 mg

Table V. pH, titratable acidity (TA), total soluble solids (TSS) and the maturity index (MI) of three Algerian pomegranate cultivars. Values are expressed as means ± standard deviation (n = 3). Cultivars: DK: 'Doux de Koléa'; DM: 'Doux de Messaad'; BM11: 'Bordj Mira 11'.

Cultivars	Parameters[y]			
	pH	TSS (Brix°)	TA (g 100 mL^{-1})	MI
DK	4.60 ± 0.52 aa	16.17 ± 0.95 a	0.31 ± 0.03 a	52.58 ± 7.39 a
DM	4.09 ± 0.13 ac	18.64 ± 0.53 ba	0.41 ± 0.11 b	38.03 ± 0.84 b
BM 11	3.84 ± 0.09 bd	12.87 ± 0.90 c	0.50 ± 0.06 c	25.87 ± 4.51 c

[y] Means with different letters in the same column are significantly different.

Table VI. Total sugars, ascorbic acid, total proteins and moisture in the juice of three pomegranate cultivars. Values are expressed as means ± standard deviation (n = 3). Cultivars: DK: 'Doux de Koléa'; DM: 'Doux de Messaad'; BM11: 'Bordj Mira 11'.

Cultivars	Parameters[y]			
	Total sugars (g 100 mL^{-1})	Ascorbic acid (mg 100 mL^{-1})	Total proteins (g 100 mL^{-1})	Moisture (%)
DK	16.33 ± 2.31 a	15.74 ± 3.80 a	0.37 ± 0.05 a	73.17 ± 0.18 ac
DM	14.33 ± 2.31 ab	9.08 ± 1.44 ab	0.30 ± 0.07 a	70.80 ± 0.46 ad
BM11	11.33 ± 0.58 ac	14.92 ± 0.02 ac	0.30 ± 0.04 a	71.30 ± 0.93 b

[y] Means with different letters in the same column are significantly different ($P < 0.05$).

Table VII. Color coordinates of pomegranate peel and juice. Values are expressed as means ± standard deviation (n = 3). L* (brightness), a* (+a* = red; -a* = green) and b* (+b* = yellow; -b* = blue).

Cultivars	L*	a*	b*	Chroma	Hue
	Peel color				
DK	47.10 ± 0.10 ac	–4.03 ± 0.06 a	10.970.12 ac	11.63 ± 0.06 ac	110.16 ± 0.50 a
DM	48.07 ± 0.15 a	–3.50 ± 0.10 a	12.33 ± 0.06 a	12.83 ± 0.06 a	106.10 ± 0.28 b
BM11	47.00 ± 0.10 b	–4.37 ± 0.10 a	11.01 ± 0.1 b	11.80 ± 0.10 b	111.47 ± 0.15 c
	Juice color				
DK	39.53 ± 0.21 a	2.10 ± 0.00 ac	8.03 ± 0.06 a	8.33 ± 0.06 a	75.40 ± 0.20 a
DM	40.40 ± 0.10 b	1.27 ± 0.06 a	8.37 ± 0.12 b	8.47 ± 0.06 b	81.40 ± 0.50 b
BM11	40.23 ± 0.06 ab	4.30 ± 0.00 b	3.20 ± 0.00 c	5.37 ± 0.06 c	37.00 ± 0.17 c

Means with different letters in the same column are significantly different ($P < 0.05$)

100 mL^{-1}) [35]. Kulkarni and Aradhya [34] showed that twenty pomegranate juices had higher ascorbic acid values than that from the 'Ganesh' variety (> 10 mg 100 g^{-1}). In addition, ascorbic acid participates in preventing enzymatic browning [37, 38].

These results indicate that the levels of total sugars and ascorbic acid vary between different cultivars of pomegranate and there is a high genetic heterogeneity within the studied cultivars.

3.5 Total protein and moisture of pomegranate juice

The protein content of the pomegranate juices revealed insignificant differences. The highest (0.370 g 100 mL^{-1}) was found in DK and the lowest (0.308 g 100 mL^{-1}) in DM and BM11. These values are similar to those reported by Morales *et al.* [39] and lower than those of Al-Maiman and Ahmad [33] (1.05%). These differences can be explained by the different origins of the pomegranates.

The moisture content varied from 70.80 to 73.17%, for DM and DK, respectively. These differences in moisture content among the cultivars could be due to the different genotypes used [31]. However, the amount of moisture in fruit is an important parameter, as it relates to the juice content of the fruit [40].

The moisture and protein content in fruit juice were previously reported as 71.30–73.17% and 0.30 g 100 mL^{-1}, respectively. The variation in total sugar, vitamin C, moisture and proteins in pomegranate fruits could be due to the different genotypes used, the environmental conditions and the nutritional status of the plantations [31].

3.6 Fruit peel and juice color

Significant differences ($P < 0.05$) were found between the color of the fruit peel and juice, except peel redness (CIE $a*$) (*table VII*). Color is an important factor affecting marketing and consumer fruit preference, which is also true for pomegranates [33, 41]. However, there was no correlation between the outer skin (peel) color and the color of the juice inside the fruit [5, 42]. Fruit peel color varied widely among the cultivars based on the Hunter L, a and b parameters (*table VII*). All cultivars had insignificantly less red color on their peel, while 'Doux de Messaad' had the least red coloration. On the other hand, whiteness (L value) and yellowness (b value) and the chroma value (c) were similar among the cultivars. Juice color varied in all the parameters measured. The red color intensity (a value) of the juice was significantly higher in BM11, which also had significantly less yellowness ($b$value) compared with DK and DM. However, the hue value

Table VIII. Correlation between the nine morphological characteristics of the fruit of pomegranate. Fw: fruit weight; De: equatorial diameter; Dc: calyx diameter; Flc: fruit length without calyx; Pw: peel weight; Cmw: carpellary membrane weight; Pt: peel thickness; TSS: total soluble solids; TA: total titratable acidity; MI: maturity index; Ay: aril ratio; TS: total sugars; A: ascorbic acid; Aw: aril weight.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Fw	**1.000**	***	n.s.	***	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	***	n.s.	n.s.
2. De	0.794	**1.000**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	***	n.s.	n.s.	***	n.s.	n.s.
3. Dc	0.019	0.019	**1.000**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
4. Flc	0.682	0.805	0.095	**1.000**	n.s.	***	n.s.	n.s.	n.s.	***	***	**	n.s.	n.s.	n.s.	n.s.
5. Pw	–0.069	0.016	–0.195	0.015	**1.000**	***	n.s.	**	n.s.	**	n.s.	**	n.s.	n.s.	n.s.	n.s
6. Cmw	–0.382	–0.260	0.295	0.021	.718	**1.000**	*	n.s.	*	n.s.	n.s.	**	n.s.	n.s.	n.s.	n.s.
7. Pt	0.470	–0.071	–0.276	–0.079	–0.333	–0.576	**1.000**	**	***	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
8. pH	–0.173	–0.493	–0.012	–0.519	–0.494	–0.421	0.669	**1.000**	n.s.	***	**	**	n.s.	n.s.	n.s.	n.s.
9. TSS	–0.018	–0.302	–0.030	–0.464	–0.581	–0.572	–0.199	0.874	**1.000**	***	***	**	**	n.s.	n.s.	n.s.
10. TA	0.222	0.262	–0.169	0.506	0.681	0.482	0.444	–0.593	**–0.818**	**1.000**	**	n.s.	n.s.	n.s.	n.s.	n.s.
11. MI	0.465	–0.798	–0.007	–0.762	–0.593	–0.212	0.296	0.776	0.750	–0.700	**1.000**	**	n.s.	**	n.s.	n.s.
12. Ay	–0.449	–0.489	–0.322	–0.681	0.579	–0.555	–0.320	0.690	0.745	–0.801	0.778	**1.000**	n.s.	n.s.	n.s.	n.s.
13. TS	–0.409	–0.367	–0.325	–0.415	0.232	0.406	0.167	–0.373	–0.526	0.386	–0.008	0.336	**1.000**	n.s.	n.s.	n.s.
14. A	–0.636	–0.835	–0.241	–0.389	0.362	0.384	0.023	0.478	0.163	0.017	0.602	0.226	0.428	**1.000**		n.s.
15. Moisture	0.034	0.135	–0.343	–0.389	0.362	–0.120	–0.023	0.061	0.158	–0.191	–0.016	0.226	0.333	0.032	**1.000**	n.s.
16. Aw	0.197	–0.209	0.595	0.030	–0.014	0.282	0.401	0.417	0.209	0.044	0.258	–0.275	–0.269	0.302	–0.283	**1000**

$*P \leqslant 0.05$; $**P \leqslant 0.01$; $***P \leqslant 0.001$; n.s.: not significant.

(*h*) was significantly higher in the cultivars DK and DM, but color intensity (*c*) was lower in BM11. The visible aril color of this cultivar was similar to light pink, while 'Doux de Koléa' and 'Doux de Messaad' had red arils. An attractive red aril color is one of the most important physical characteristics for pomegranate [43].

3.7 Sensory evaluation

The results given by the maturity index of the three cultivars tested classified them as sweet pomegranates. The other pomegranate fruit characteristics, according to the sensory analysis of the three studied cultivars, are given in *table (II)*. In general, they were all evaluated as sweet and acceptable. DK seeds were judged hard, while DM and BM11 seeds were soft.

3.8 Correlation analysis

The correlation matrix relating the different pomegranate fruit characteristics is presented in *table VIII*. It shows a high correlation of the equatorial diameter and fruit weight, fruit length without calyx and fruit weight (r = 794 and r = 805, respectively), carpellary membrane weight and peel weight (r = 0.718), and indicates strong positive relationships (significant at the 0.05 level) indicating that larger fruit are longer and have higher fruit weight. In contrast, the juice yield is poorly correlated with pH (r = 0.690) and strongly correlated with total soluble solids and the maturity index (r = 0.745 and r = 0.778, respectively). As expected, a significant positive correlation was observed between total sugars and total soluble solids (r = 0.597) in all our pomegranate juices (*table VIII*) [37].

This indicates that any one of these characteristics can be used as a measure to assess fruit size or in fruit processing. Fruit maturity can impact juice yield; however, the fruits evaluated in the current study were collected on the same day to ensure that fruits were of identical age.

In terms of farm management practices, the results indicate that methods with the objective of obtaining a greater maturity index may be beneficial. This is in contrast to managing the equatorial diameter of fruit. Fruit weight was poorly correlated with juice yield (r = −0.449) and the maturity index (r = −0.465). An increase in fruit size and equatorial diameter does not appear to be a consequence of improving the production of juice. In pomegranate, fruit size has been highly correlated with the pericarp and membrane weight [44].

4 Conclusion

Pomegranate cultivars grown in the Mitidja area showed significant variations in fruit morphology and physicochemical properties of peels, arils and juice. The results presented in this study reveal great variability among these cultivars according to the fruit and peel weight, number of arils, juice yield, acidity, total soluble solid content and maturity index. This study clearly shows the potential value of the pomegranate germplasm grown in northern Algeria. It highlights the need to assess and preserve local cultivars, not only for consumption and health benefits, but for climatic reasons and consumers' taste adaptation as well. This work provides important data about the composition of the fruit (vitamin C, protein, total sugar, etc.) and demonstrates Algerian pomegranate cultivars to be a good source of various nutrients.

The maturity index and pH values found in the evaluated cultivars are useful in characterizing their taste and flavor. The comparison of these results with other studies reveals that the juice and peel of the Algerian pomegranate fruits have original physicochemical characteristics that can play a valuable role in people's diet and health. Processing fresh fruit into dried fruit is not popular in Algeria, mainly due to the absence of a promoting national policy for such an industry. The results are expected to contribute to guiding the selection of cultivars not just for fresh consumption, but also for the food and health industries. In order to face the numerous challenges within and outside the country, research strategies on pomegranate should to be reoriented toward the development of chemical, biochemical and molecular markers that could confirm the observed intra- and inter-variety variability and assist the necessary breeding and selection work.

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