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Original article

Physicochemical criteria, bioactive compounds, antioxidant activity and sensory attributes of ten Moroccan pomegranate cultivars

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Summary

The attractiveness of pomegranate (*Punica granatum* L.) is increasing worldwide among producers and consumers. Depending on its characteristics, the pomegranate may be intended for fresh consumption, for medical purposes or for industrial processing. This study aims to evaluate and compare the characteristics of ten pomegranate cultivars that have been grown in six production regions of central Morocco. Morphological, physicochemical and sensory parameters related to fruit quality, bioactive compound content and antioxidant activity were determined in pomegranate fruits. Results showed significant differences between cultivars. With the exception of the cultivar 'Lhamdha', which has a sour taste and hard seeds and can be used as a functional food in the medical or cosmetic industry, all cultivars are intended for fresh consumption. The cultivars 'Sefri 6' cultivated in Beni Meskine, 'Lahmer' and 'Marrakchia' were more appreciated by the sensory panel for their intense red colour, flavour and sweetness. The cultivars 'Sefri 1' cultivated in Lalla Takerkoust, 'Sefri 2' cultivated in Sour Laaz, 'Sefri 3' cultivated in Tmassine, 'Sefri 4' cultivated in Sidi Abdellah and 'Sefri 5' cultivated in Ouled Abdellah were characterized by their large, heavy fruit with high arils yield. The cultivar 'Bzeq Tir' could be a source of agri-food by-products (peel and seeds) rich in beneficial molecules to human health. Cluster analysis revealed the criteria divergence for cultivars with the same 'Sefri' appellation. The cultivars studied showed promising nutritional, technological and sensory characteristics for fresh consumption and processing.

Keywords

Morocco, *Punica granatum*, diversity, antioxidant activity, bioactive compounds, morphological parameters, physicochemical criteria, sensory attributes

Significance of this study

What is already known on this subject?

- The pomegranate fruit is less valued in Morocco compared with other countries. The cultivar 'Sefri' cultivated in Ouled Abdellah (Beni-Mellal region) is a labeled pomegranate cultivar as protected geographical indication.

What are the new findings?

- Cultivars 'Lahmer' and 'Marrakchia', cultivated in Ain Lahrar (Essaouira region) and 'Sefri 6', cultivated in Beni Meskine (Settat region), showed interesting organoleptic and nutritional properties for fresh consumption and processing.

What is the expected impact on horticulture?

- This study will provide significant advice on the exploitation of the studied cultivars for fresh consumption and processing.

Introduction

The pomegranate (*Punica granatum* L.) is one of the ancient fruit trees of the *Punicaceae* family that has been cultivated for centuries and was highly valued for its delicious fruit flavour (Legua et al., 2012). Its wide distribution was facilitated by its great capacity to adapt easily to the environmental conditions (Haddioui, 2012). Pomegranate is consumed fresh or in other processed forms such as jam, juice and jelly (Melgarejo and Valero, 2012; Vazquez-Araujo et al., 2014) or used as a source of nutraceutical substances (Tapia-Campos et al., 2016). The pomegranate world production has increased from 3,000 thousand tons in 2011 to 5,954 thousand tons in 2017 (Melgarejo et al., 2020). The world's largest producers are Iran, India, China, United States of America (U.S.A.), Turkey and Spain (Moghaddam et al., 2019). The main exporters to the world market are Spain, Iran, India and Turkey (Melgarejo and Valero, 2012). Pomegranate consumption has gradually increased due to its nutritional value and bioactive compound content. This fruit is rich in polysaccharides, sugars, proteins, minerals and organic acids (Al-Maiman and Ahmad, 2002) and contains significant amount of vitamin C and phenolic compounds with high antioxidant activity (Pérez-Vicente et al., 2002). Pomegranate showed higher polyphenol content and antioxidant activity compared with other fruits (Alahyane et al., 2019; Mastello et al., 2012). Accordingly, its consumption has several medical benefits such as the treatment of cardiovascular diseases, cancer, Alzheimer's disease, diabetes, arthritis and colitis (Li et al., 2015). In Morocco, despite the evolution of its production, from 65.0 thousand tons in 2008–09 to 121.7 thousand tons in 2013–14 (MAPMDREF, 2018), the pomegranate is less valued compared to other producing coun-

Table 1. Geographic origins and environmental conditions of pomegranate fruits of ten Moroccan cultivars harvested in 2018 and 2019.

Cultivar	Geographic origin	Latitude North	Longitude West	Altitude (m)	Minimum temperature (°C)	Maximum temperature (°C)	Precipitation (mm)	Insolation (h)
Sefri 1	Lalla Takerkoust, Amizmiz	31°21'26"N	8°8'7"W	619	15.32	31.14	70.53	2,444.33
Sefri 2	Sour Laaz, El Kelâa Des Sraghna	31°49'47"N	7°1'52"W	674	15.70	31.03	81.86	2,444.33
Sefri 3	Tmassine, Settat	32°43'23"N	7°41'30"W	357	16.22	31.25	71.46	2,457.31
Sefri 4	Sidi Abdellah, Skhour Rhamna	32°35'13"N	7°49'7"W	286	16.22	31.25	71.46	2,457.31
Sefri 5	Ouled Abdellah, Beni-Mellal	32°29'42"N	6°26'57"W	463	14.76	29.44	69.4	2,451.28
Sefri 6	Beni Meskine, El Borouj, Settat	32°38'37"N	7°23'18"W	543	16.36	32.14	76.94	2,457.31
Lahmar	Ain Lahjar, Essaouira	31°39'14"N	9°35'32"W	98	17.86	23.56	31.21	2,443.31
Marrakchia	Ain Lahjar, Essaouira	31°39'14"N	9°35'32"W	97	17.86	23.56	31.21	2,443.31
Lhamdha	Ain Lahjar, Essaouira	31°39'14"N	9°35'32"W	96	17.86	23.56	31.21	2,443.31
BzeqTir	Machraa Ben Abou, Settat	32°38'47"N	7°48'1"W	201	16.22	31.25	71.46	2,457.31

tries. The exports do not exceed 0.5% of the total production rate (Haddioui, 2012). The main products are locally marketed with little processing and valorisation of the by-products (Haddioui, 2012). To this end, many efforts are being made to promote this fruit through industrialization and export. In the Beni-Mellal/Khenifra region, the 'Sefri' cultivated in Ouled Abdellah variety has been labeled as "Protected Geographical Indication: IGP" within the Green Morocco Plan (MAPMDREF, 2015). Another four cultivars have been conceived as leading products of the regions. The geographical origins of these cultivars were Ain Lahjar, Tmassine, Skhour Rhamna and Sour Laaz (MAPM, 2014). In this context and with the aim of identifying promising new cultivars that can be exported or used in food or pharmaceutical industries (juice extraction, nutraceutical products, etc.), it was important to identify the physicochemical, sensory, and functional properties of the main cultivars in these regions. Therefore, this study assesses the physical parameters of fruits, arils and seeds, and the physicochemical parameters of the juice of ten selected pomegranate cultivars. It also evaluates the polyphenols content and antioxidant activity of pomegranate juice, as well as the sensory attributes of the arils and the seeds. The information generated will be useful in selecting new pomegranate cultivars and deciding on their suitability for fresh consumption, industrialization or export.

Materials and methods

Plant material

Ten pomegranate cultivars named 'Sefri 1' for 'Sefri' cultivated in Lalla Takerkoust (Amizmiz region), 'Sefri 2' for 'Sefri' cultivated in Sour Laaz (El Kelâa Des Sraghna region), 'Sefri 3' for 'Sefri' cultivated in Tmassine (Settat region), 'Sefri 4' for 'Sefri' cultivated in Sidi Abdellah (Skhour Rhamna region), 'Sefri 5' for 'Sefri' cultivated in Ouled Abdellah (Beni-Mellal region), 'Sefri 6' for 'Sefri' cultivated in Beni Meskine (Settat region), 'Lahmar', 'Marrakchia' and 'Lhamdha' cultivated in Ain Lahjar (Essaouira region), and 'Bzeq Tir' cultivated in Machraa Ben Abou (Settat region) (Table 1) were collected in six important production regions in central Morocco, which account for about 62% of total Moroccan production (Hmid, 2014). 32 fruits per cultivar and per year (2018 and 2019) were harvested, which made a total of 64 fruits. Indeed, for each year, 4 fruits were randomly collected from the four geographic orientations in the middle of 8 sampled trees during the period of 12 and 15 October. The fruits were stored at 4°C and 85% of relative humidity until analysis. From the annual aggregate sample of each cultivar, 20 fruits were used for physical, physicochemical and biochemical analyses and 12 fruits were used for sensory analyses. The same examinations were made each season, and the results were the average of the data obtained over the two years. Meteorological data (Table 1) were downloaded from Worldclim dataset (Moukrim et al., 2019). They included precipitation (millimeter), insolation (hours), maximum and minimum temperature (°C) from the pomegranate fruit bloom at the middle of April (Oukabli, 2004) to pomegranate harvest at the middle of October. The environmental information was the average of the data obtained over two years (2018 and 2019).

Physical parameters of pomegranate fruits

Twenty fruits per cultivar were analyzed individually. Each pomegranate fruit was delicately cut in the equatorial zone, peeled and the arils removed manually. The following

parameters were evaluated to assess the quality attributes of the fruits (Hernández et al., 2014; Hmid et al., 2018; Radunić et al., 2015; Tapia-Campos et al., 2016). Fruit weight (FW, g), arils weight (AsW, g), total fruit length (L1, mm), length of the fruit without calyx (L2, mm), calyx length (L3, m), fruit diameter (DF, mm), rind thickness (Rt, mm), number of arils counted in 100 g to estimate the total number of arils in each fruit (Nar). The fruit, rind and carpellary membranes were weighed with a balance (Radwag PS 8000/C/1, Poland) with an accuracy of 10^{-2} g. The length and diameter of the fruit and calyx, as well as the thickness of the rind were measured with a digital electronic calliper (OTMT Stainless Hardned, Taiwan) with an accuracy of 10^{-2} mm. The aril yield (Ay, %) was determined as follows: Ay = [AsW/FW] × 100 (Martínez et al., 2012). The juice was obtained by pressing the arils with a manual press, which keeps the seeds intact. The juice yield was calculated as the ratio between the milliliters of juice acquired per 100 g arils sample, the juice yield per fruit (Jyf, mL 100 g^{-1} fruit) was deducted. The fruit form index (If, %), calyx index (Ic, %) and rind thickness index (Irt, %) were calculated as follows: If = (Df/L2) × 100, Ic = (L3/L1) × 100, Irt = (Rt/DF) × 100 (Martínez et al., 2012).

Physical parameters of arils, seeds and juice

1. Physical parameters of individual arils and seeds. After extracting the arils manually, twenty-five units of each cultivar were randomly selected from a homogeneous sample where the following parameters were measured (Alcaraz-Mármol et al., 2017; Hmid et al., 2018): weight of aril (Aw, g), maximum length (La, mm) and width (Wa, mm) of aril. The fleshy part of the arils was then removed and seed weight (Sw, g), maximum seed length (Ls, mm) and width (Ws, mm) were measured on the woody part. The arils and seeds were weighed using a balance (Radwag AS 220/C/2, Poland) with an accuracy of 10^{-4} g. Aril and seed dimensions were measured with a digital electronic calliper (OTMT Stainless Hardned, Taiwan) with an accuracy of 10^{-2} mm. The proportion of the woody part was calculated as follows: seed index, Si = Sw/Aw × 100 (Martínez et al., 2012).

2. Colour parameters of pomegranate juice. The colour of the homogenised filtered juice was measured and expressed in CIELAB coordinates ($L^*a^*b^*$) using the Lovibond PFX195 tintometer (Salisbury, U.K.). The coordinates a^* and b^* fluctuate from -100 (green) to +100 (red) and -100 (blue) to +100 (yellow), respectively, and L^* represents the dimension of luminosity fluctuating from 0 (pure black) to 100 (white). The chroma (C*) has been calculated as follows: $(a^{*2} + b^{*2})^{½}$ (Melgarejo-Sánchez et al., 2015). Data were obtained in triplicate.

Physicochemical parameters of pomegranate juices

After pressing the arils, the juice obtained was filtered and the total soluble solids (TSS, %), and total titratable acidity (TTA, g citric acid L^{-1}) were measured (Alcaraz-Mármol et al., 2017; Caliskan and Bayazit, 2013; Ferrara et al., 2014; Martínez et al., 2012). TSS was measured with a digital refractometer (RFM 830, U.K.). The TTA was determined by titration with 0.1 N NaOH to pH 8.1 according to AOAC (1990) using Consort C861 (The Netherlands). The ratio between TSS and TTA, also known as the Maturity Index (MI), was then calculated (Martínez et al., 2012). The classification of the cultivars studied was carried out according to Martínez et al. (2012): MI = 31–98 for sweet cultivars, MI = 17–24 for sour-sweet cultivars, and MI = 5–7 for sour cultivars. The moisture content (moisture, %) was determined after drying the juices in an oven under atmospheric pressure at (103 ± 2°C) (Function Line, Germany) until they reached a constant weight (AOAC, 1990). The measurements were repeated three times for each cultivar.

Total polyphenols content (TP)

TP was measured by the Folin-Ciocalteu method (Akhavan et al., 2015; Legua et al., 2012; Melgarejo-Sánchez et al., 2015), based on the condition optimized by Georgé et al. (2005). The absorbance was measured with an UV visible Spectrophotometer (Varian Cary 50 Conc, The Netherlands). TP was expressed as mg gallic acid equivalent (GAE) per kg pomegranate juice. Calibration curves at concentrations between 0 and 500 g GAE L^{-1} showed good linearity ($R^2 \geq 0.997$) were used to quantify TP.

Antioxidant activity (AA)

AA was measured in terms of radical scavenging ability using the stable free radical 2,2-diphenyl-1-picrylhydrazyl (DPPH) (Akhavan et al., 2015; Li et al., 2015; Mphahlele et al., 2014) according to the procedure described by Moktan et al. (2008). Calibration curves at concentrations between 0 and 500 g ascorbic acid equivalent (AAE), which showed good linearity ($R^2 \geq 0.999$), were used to quantify antioxidant activity. The absorbance was measured at 517 nm with an UV visible spectrophotometer (Varian Cary 50 Conc, The Netherlands). The AA was expressed in mg of AAE kg^{-1} of fresh juice.

Sensory attributes of pomegranate arils and seeds

A panel of eight experts from the Regional Agricultural Research Centre of Marrakech (INRA-Marrakech) with extensive experience in sensory analysis of food participated in this study. Each panel member assessed, independently, the visual colour of the arils, as well as the flavour and mouthfeel attributes, and gave their assessment of the overall quality of the sample. The taste and odour neutralization were provided with water. A consensus profile method using a digital scale with 0 representing zero and 10 extremely strong with an increment of 0.5 was used for flavour, mouthfeel attributes and sensory score (Vazquez-Araujo et al., 2014). For the evaluation of colour, six categories were established: white, light pink, pink, pink-red, red and dark red (Martínez et al., 2012; Radunić et al., 2015). The sensory rating was established according to the following scale: poor, acceptable, good and excellent (Martínez et al., 2012). The panel worked with the attributes and definitions mentioned by Vazquez-Araujo et al. (2014). The analyses were carried out in the sensory analysis room of the Food Technology and Quality Laboratory of INRA in Marrakesh, established in accordance with the general guidelines for sensory evaluation rooms: ISO 8589-2007.

Statistical analyses

The obtained data was statistically analysed using IBM SPSS 22.0 statistical database for Windows. The analysis of variance (ANOVA) for the comparison of means was performed after a basic descriptive statistical analysis. Correlation coefficients (r) were determined using the Pearson Correlation Matrix method to reveal possible relationships between traits. The XLSTAT Addinsoft TM software (XLSTAT, 2016) was used to perform the principal component analysis (PCA) and the cluster analysis (CA).

Table 2. Mean values of the principal physical parameters of pomegranate fruits of ten Moroccan cultivars* harvested in 2018 and 2019.

Cultivars	L1 (mm)	DF (mm)	Rt (mm)	FW (g)	If (%)	Ic (%)	Irt (%)	AsW (g)	Nar**	Ay (%) (g 100 g^{-1} fruit)	Jyf** (mL 100 g^{-1} fruit)
Sefri 1	101.28±5.61^{d}	97.88±5.83^{ef}	3.68±0.88^{ab}	466.11±83.98^{de}	115.00±5.09^{ab}	16.10±3.48^{ab}	3.78±0.98^{a}	276.25±66.67^{cd}	664.64±85.94^{c}	58.73±6.14^{abc}	42.52±3.00^{bc}
Sefri 2	102.21±5.61^{d}	96.30±5.28^{de}	3.85±0.65^{ab}	460.66±72.51^{de}	112.57±5.00^{ab}	14.94±3.39^{a}	4.01±0.70^{a}	271.92±65.68^{cd}	619.94±13.55^{bc}	58.47±7.53^{abc}	43.08±3.25^{bc}
Sefri 3	98.64±7.60^{cd}	95.58 ±7.20^{cde}	3.14±0.69^{a}	430.89±97.29^{cd}	114.89±5.65^{ab}	15.78±2.62^{ab}	3.29±0.68^{a}	276.21±65.38^{cd}	692.59±27.31^{c}	64.29±7.14^{c}	46.40±3.67^{c}
Sefri 4	103.44±6.74^{de}	100.69±7.81^{ef}	3.87±1.32^{ab}	513.67±137.62^{e}	117.25±10.43^{bc}	17.16±3.6^{abc}	3.89±1.02^{a}	335.35±127.23^{e}	730.85±136.31^{c}	64.00±9.13^{c}	48.09±4.92^{c}
Sefri 5	108.21±5.11^{e}	102.60±4.74^{f}	3.91±0.73^{ab}	526.09±67.38^{e}	113.54±4.75^{ab}	18.18±1.46^{bc}	3.81±0.85^{a}	310.63±54.90^{de}	667.35±21.90^{c}	58.83±5.62^{bc}	44.39±3.12^{c}
Sefri 6	89.73±5.31^{a}	87.57±5.60^{ab}	3.13±0.73^{a}	325.20±72.09^{ab}	117.68±5.43^{bc}	18.76±3.80^{c}	3.58±0.83^{a}	198.04±50.73^{ab}	464.48±67.93^{ab}	60.47±6.55^{bc}	45.44±0.91^{c}
Lahmer	95.81±5.69^{bc}	90.91±8.51^{bc}	3.51±0.74^{ab}	382.45±81.63^{bc}	114.72±7.23^{ab}	17.35±2.24^{abc}	3.90±0.94^{a}	232.44±58.08^{bc}	599.42±68.78^{bc}	60.47±6.55^{bc}	44.43±3.56^{c}
Marrakchia	92.22±5.54^{ab}	88.80±6.96^{b}	3.65±0.99^{ab}	342.11±70.11^{ab}	109.73±12.50^{a}	18.69±2.92^{c}	4.13±1.03^{ab}	204.54±54.72^{ab}	614.96±52.62^{bc}	59.44±8.33^{bc}	44.62±2.13^{c}
Lhamdha	90.76±5.44^{a}	82.75±5.71^{a}	4.20±1.44^{b}	283.07±60.68^{a}	118.60±13.61^{bc}	19.07±3.72^{c}	5.14±1.13^{b}	159.14±50.71^{a}	606.59±14.60^{bc}	55.37±7.28^{abc}	36.96±4.77^{ab}
Bzeq Tir	92.87±8.01^{ab}	91.60±6.36^{bcd}	5.05±1.05^{c}	332.47±66.00^{ab}	123.86±8.77^{c}	23.75±3.09^{d}	5.55±1.25^{b}	154.21±40.26^{a}	326.34±15.34^{a}	46.22±12.63^{a}	32.51±0.96^{a}

L1: Total fruit length; DF: Fruit diameter; Rt: Rind thickness; FW: Fruit weight; If: Form index; Ic: Calyx index; Irt: Rind thickness index; AsW: Arils weight; Nar: Total number of arils per fruit; Ay: Aril yield per fruit; Jyf: Juice yield per fruit.
* Values followed by the same letter show no statistically significant differences ($P < 0.01$, $n = 40$, **: $n = 6$).

Results and discussion

Physical parameters of pomegranate fruit

1. Physical parameters of the fruits. The morphometric variables measured on pomegranate fruit are of economic interest. In addition, they affect consumer acceptance, some of them have an influence upon industrial manipulation (Martínez et al., 2012). The physical parameters of the pomegranate fruits of the ten cultivars studied are presented in Table 2. Statistical analysis showed significant differences ($p < 0.01$) and high variability among the ten cultivars. Mean FW was between 283.07 g and 526.09 g. The largest fruits were found for 'Sefri 5' with 526.09 g and 102.60 mm diameter, followed by 'Sefri 4', while 'Lhamdha' had the smallest fruits with 283.07 g and 82.75 mm diameter. The results found for the weight of the studied cultivars concurred with those presented by other cultivars from Morocco (between 430.8 g for 'Rouge Marrakech' and 535.1 g for 'Sefri') (Martínez et al., 2012), Tunisia (between 101.3 g for 'Garsi 1' and 549.7 g for 'Chelefi 8-2') (Zaouay et al., 2012), and Italy (192.6 g for 'Mod Tri, 622.3 g for 'Wond') (Ferrara et al., 2014). FW, FD and L1 are related variables and varietal characteristics which can fluctuate according to climatic and agricultural conditions (Caliskan and Bayazit, 2013; Ferrara et al., 2014; Shulman et al., 1984; Tapia-Campos et al., 2016). In fact, Pearson correlation was used to examine the dependence among the studied variables at $P < 0.01$ (Supplemental Table S2). FW was highly correlated with L1, DF, AsW and Nar ($r = 0.841$, $r = 0.906$, $r = 0.933$ and $r = 0.497$, respectively) which indicates that pomegranate with high FW presented high dimensions and high arils weight and number. These results agreed with those of Martínez et al. (2012) who found also high correlation between pomegranate FW and size, and with Melgarejo-Sánchez et al. (2015) who reported that pomegranate with higher FW showed higher weight of arils. The correlation between the studied variables and environmental conditions showed that low minimum temperatures favor the production of heavy and large fruits. Negative correlation was noted between the minimum temperature and the DF ($r = -0.622$), the FW ($r = -0.562$) and the AsW ($r = -0.451$), which explains why the cultivars cultivated in the center of the country, where the minimum temperatures are low, showed heavy and large fruits compared with cultivars cultivated near coastal areas.

All cultivars studied had If larger than 100, indicating that their equatorial diameter was greater than their length without a calyx (between 9.73% and 23.86%). The Irt ranged, respectively, from 3.29% for the cultivar 'Sefri 3' to 5.55% for 'Bzeq Tir'. The reported results were consistent with results from Spanish cultivars (Hernández et al., 2014) and Moroccan cultivars (Martínez et al., 2012). Consumers generally prefer thin-skinned pomegranates, in order to be able to peel the fruit and reduce fruit waste (Radunić et al., 2015).

2. The edible fruit yield. The edible fruit yield of pomegranates of the ten Moroccan cultivars is shown in Table 2. Cultivars 'Sefri 3' and 'Sefri 4' contained the largest proportion of the edible part, with 64.29%, 64.00% of the Ay and 46.40%, 48.09% of the Jyf, respectively. While cultivar 'Bzeq Tir' had the smallest fraction of the edible portion, with 46.22% of the Ay and 32.51% of the Jyf. The results obtained for the Ay and Jyf of the cultivars studied were similar to those reported by Spanish cultivars (from 52.67% for 'ME14' to 65.87% for 'PTO7' of Ay, and from 46.00% for 'ME16' to

Table 3. Mean values of morphological parameters of arils and seeds and colour coordinates of pomegranate juice of ten Moroccan pomegranate cultivars harvested in 2018 and 2019*.

Cultivars	Pomegranate aril				Pomegranate seed			Pomegranate juice			
	La (mm)	Wa (mm)	Aw (g)	Ls (mm)	Ws (mm)	Sw (g)	Si (%)	L^*	a^*	b^*	C^*
Sefri 1	11.66±0.83^{cd}	7.70±0.89^{bcd}	0.463±0.066^{cde}	7.58±0.58^{d}	2.98±0.38^{cde}	0.046±0.008^{de}	9.94±1.95^{bc}	78.11±4.05^{e}	23.81±3.77^{ab}	8.59±1.51^{a}	25.31±3.06^{a}
Sefri 2	11.53±1.01^{bcd}	7.86±0,92^{bcd}	0.468±0.088^{de}	7.76±1.06^{d}	2.88±0.43^{abcd}	0.043±0.008^{d}	9.28±1.61^{abc}	71.12±4.56^{cde}	31.45±2.06^{bc}	9.20±2.29^{a}	32.87±1.35^{ab}
Sefri 3	11.48±0.84^{bcd}	7.66±0.79^{bcd}	0.428±0.057^{cd}	7.36±0.66^{cd}	2.67±0.38^{abc}	0.036±0.007^{abc}	8.49±1.39^{abc}	54.24±1.54^{a}	11.82±1.49^{a}	26.79±2.25^{b}	29.36±1.46^{ab}
Sefri 4	11.49±1.08^{bcd}	7.89±1.18^{cd}	0.489±0.081^{ef}	7.53±0.80^{d}	3.01±0.39^{de}	0.043±0.009^{de}	9.05±2.36^{abc}	69.78±5.45^{bcde}	20.72±3.80^{ab}	11.99±0.34^{a}	24.19±3.82^{a}
Sefri 5	11.75±1.43^{d}	8.00±0. 93^{d}	0.488±0.060^{e}	7.34±0.68^{bcd}	2.68±0.34^{abc}	0.040±0.008^{bcd}	8.21±1.74^{ab}	72.17±5.15^{de}	31.84±4.40^{bc}	10.96±2.29^{a}	33.69± 4.16^{abc}
Sefri 6	10.98±1.08^{bc}	7.21±1.07^{ab}	0.4229±0.061^{cd}	6.77±0.88^{ab}	2.61±0.40^{a}	0.032±0.009^{a}	7.65±2.00^{a}	61.37±5.85^{ab}	27.29±2.62^{b}	11.06±1.97^{a}	29.56±1.69^{ab}
Lahmer	10.78±1.05^{b}	7.33±0.79^{abc}	0.417±0.059^{c}	6.82±0.67^{abc}	2.86±0.39^{abcd}	0.041±0.010^{cd}	9.94±2.16^{bc}	62.04±2.18^{abc}	43.89±3.61^{c}	13.57±2.14^{a}	45.94±5.40^{c}
Marrakchia	9.80±0.96^{a}	6.82±0.75^{a}	0.348±0.044^{b}	6.49±0.67^{a}	2.65±0.45^{ab}	0.029±0.005^{ab}	10.08±2.03^{c}	66.03±2.42^{bcd}	40.18±2.92^{c}	9.84±1.46^{a}	41.45±3.40^{bc}
Lhamdha	9.48±0.83^{a}	6.85±0.94^{a}	0.264±0.069^{a}	6.52±0.86^{a}	2.93±0.43^{bcde}	0.035±0.006^{ab}	14.27±5.11^{d}	63.83±2.40^{bcd}	59.16±0.65^{d}	25.83±3.32^{b}	64.69±0.26^{d}
Bzeq Tir	11.64±0.95^{cd}	8.09±0.70^{d}	0.538±0.100^{f}	7.51±0.76^{d}	3.23±0.59^{e}	0.049±0.006^{e}	9.25±1.27^{abc}	72.05±2.46^{de}	24.44±1.85^{b}	13.50±1.51^{a}	27.91±1.87^{a}

La: Aril length; Wa: Maximum aril width; Aw: Aril weight; Ls: Seed length; Ws: Maximum seed width; Sw: Seed weight; Si: Seed index Si = (Sw/Aw) × 100.
* Values followed by the same letters within the same column are not significantly different ($P<0.01$, $n=50$ for morphological parameters, $n=6$ for colour coordinates).

60.33% for 'CRO2' of Jyf) (Hernández et al., 2014), and Mexican cultivars (from 46.6% for 'Manzanita' to 66.8% for 'ToroD' of Ay, and from 32.00% for 'Manzanita' to 48.2% for 'El Tio Criolla' of the Jyf) (Tapia-Campos et al., 2016). Differences in Ay and Jyf are influenced by cultivar and agro-climatic conditions within regions (Melgarejo-Sánchez et al., 2015). Jyf is also influenced by the method of juice extraction. Mechanical pressing generally provides lower pressing yields than extraction by blender (Rajasekar et al., 2012). Generally, the cultivars 'Sefri' presented high fruit weight and size compared with other cultivars, the 'Sefri 3 and 'Sefri 4' were more characterized by their high Nar, Ay and Jyf.

Physical parameters of arils, seeds and juice

1. Physical parameters of individual arils and seeds. Pomegranate arils contain pulp, juice and seeds that are rich in nutrient constituents. The size and weight of the arils and seeds are major factors to be taken into account when the fruit is to be consumed fresh (Tapia-Campos et al., 2016). The morphological characteristics of the arils and seeds of the ten pomegranate cultivars studied are presented in Table 3. Cultivar 'Lhamdha' had the lowest La and Aw, while cultivars 'Sefri 4', 'Sefri 5' and 'Bzeq Tir' had significantly higher Aw (Aw > 0.48 g) compared to the other cultivars. The range in size and weight of arils corresponded to the results obtained for Moroccan cultivars (Hmid et al., 2018; Legua et al., 2012), Spanish cultivars (Alcaraz-Mármol et al., 2017; Hernández et al., 2014; Melgarejo-Sánchez et al., 2015), Turkish cultivars (Caliskan and Bayazit, 2013), and Italian cultivars (Ferrara et al., 2014). In fact, favorable environmental conditions of temperature and precipitation favor the production of larger edible proportion. Aw was positively correlated with precipitation (r = 0.410), maximum temperature (r = 0.616) and altitude (r = 0.502), while negatively correlated with minimum temperature (r = -0.638) (Supplemental Table S2). Then, environmental conditions explained the presence of heavy aril weight in cultivars cultivated in the center of Morocco compared with other. Tapia-Campos et al. (2016) recorded the same observation for Mexican cultivars, which showed higher aril weight and proportion with better environmental conditions of temperature and humidity for aril growth.

The woody part (seeds) is consumed with the juice and pulp of fresh arils, and consumers thus have a preference for soft and small seeds (Tapia-Campos et al., 2016). Cultivars 'Sefri 6' and 'Marrakchia' have the smallest seeds, while 'Bzeq Tir' contains the largest and heaviest seeds. The results presented for seeds are in line with those of other Spanish cultivars (Hernández et al., 2014; Melgarejo-Sánchez et al., 2015) and Moroccan cultivars (Hmid et al., 2018; Martínez et al., 2012). The Si specifies the proportion of seed to aril weight (Melgarejo-Sánchez et al., 2015). The Si of the cultivars studied ranged from 7.65% for 'Sefri 6' to 14.27% for 'Lhamdha'. The results of the Si are consistent with those of Spanish cultivars (Alcaraz-Mármol et al., 2017; Hernández et al., 2014; Melgarejo-Sánchez et al., 2015) and Italian cultivars (Ferrara et al., 2014). In general, cultivars with the lowest values in Si and Sw and simultaneously high values in Aw can be considered ideal for fresh consumption (Vazquez-Araujo et al., 2014), however, the seed harness is also an important parameter to consider for cultivars destined to fresh consumption.

2. Colour parameters of pomegranate juice. The attractive red colour of the arils of some pomegranate cultivars is

attributed to the biosynthesis and accumulation of red anthocyanin in the fruit (Shulman et al., 1984). Such red colour is requested by pomegranate juice makers, provided that heat treatment during the production process significantly reduces the colour of the juice (Vazquez-Araujo et al., 2014). The colour coordinates ($L^*a^*b^*$) of the pomegranate juices (Table 3) showed significant differences between the cultivars studied. Cultivar 'Sefri 1' had the lightest juice while 'Sefri 3' had the least-light juice. Indices (a^*) and (b^*), which represent redness and yellowness, respectively, showed significant differences ($p < 0.01$), with the highest redness value (a^*) presented by the sour cultivar 'Lhamdha', followed by the sweet cultivars 'Lahmer' and 'Marrakchia', while 'Sefri 3' had the lowest redness value. For yellow colour, 'Sefri 3' had the highest value while 'Sefri 1' had the lowest value. For the chroma value (C*), which represents "purity" or intensity of colour, the sour cultivar 'Lhamdha' also had the highest value, being purer ($C^* > 60$), followed by 'Lahmer' and 'Marrakchia', while 'Sefri 4' had the lowest juice purity. The colour coordinates of the cultivars studied are consistent with the results reported by Zaouay et al. (2012).

Physicochemical parameters of pomegranate fruit

1. Moisture, TSS and TTA. The mean values of moisture, TSS, TTA and MI obtained for pomegranate juices are shown in Table 4. Significant differences ($P < 0.01$) were found among the studied cultivars. The moisture content ranged from 84.28% 'Lhamer' to 87.32% 'Bzeq Tir'. Our results agreed with those found by Martinez et al. (2006) for Spanish cultivars that varied between 81.5% for 'ME15' and 87.7% for 'CRO1'. The TSS, TTA and MI are commonly used parameters to assess the quality of the pomegranate juice by the juice industry (Melgarejo-Sánchez et al., 2015). TSS values ranged from 15.68 to 17.85 ('Sefri 1' and 'Lahmer', respectively). The TSS results are consistent with the results reported for Italian cultivars (Ferrara et al., 2014), Spanish cultivars (Alcaraz-Mármol et al., 2017; Melgarejo-Sánchez et al., 2015), and Turkish cultivars (Caliskan and Bayazit, 2013). The differences in TSS may be due essentially to cultivar type and to different criteria for selecting the most favorable harvesting time (Martínez et al., 2012). TTA values ranged from 1.83 g L^{-1} for 'Sefri 1' to 28.37 g L^{-1} for 'Lhamdha', without showing significant differences between cultivars, except for the cultivar 'Lhamdha' of which acidity was about 13 times higher than other cultivars. The results found for TTA confirmed that sour and sweet cultivar types is the key determinant of TTA content of pomegranate juice regardless of their sugar contents (Hasnaoui et al., 2011; Li et al., 2015). Previous studies reported similar ranges of TTA. Radunić et al. (2015) reported TTA ranges between 0.37 g 100 mL^{-1} for 'Konjski zub' and 2.16 g 100 mL^{-1} for 'Wild' for Croatian cultivars, while Legua et al. (2012) reported TTA values between 2.44 g L^{-1} for 'Sefri' and 37.51 g L^{-1} for 'Hamde' for other Moroccan cultivars. In fact, the cultivar 'Hamde' cultivated in Bzou (Legua et al., 2012) showed high TTA as the cultivar 'Lhamdha' characterized in this study, their names also are close to each other which means 'sour'. In general, sour cultivars presented very high TTA values compared to sweet or sour-sweet cultivars. The correlation analysis (Supplemental Table S2) showed that TTA correlated positively with Si ($r = 0.663$), which agreed with Hasnaoui et al. (2011) who reported that one of the leading characteristics of sour cultivars is their high seed index (Si).

2. Maturity index. The MI is an essential quality factor as it balances sweetness and sourness and determines taste (Radunić et al., 2015).The MI of the studied cultivars varied considerably from 5.66 for 'Lhamdha' to 93.66 for 'Lahmer'. According to the classification of Martínez et al. (2012), all cultivars were sweet (MI: 31–98) and suitable for direct consumption and production of pomegranate juice, with the exception of 'Lhamdha' which therefore is a sour cultivar. The MI results mentioned a wide range similar to the results reported by other authors (Alcaraz-Mármol et al., 2017; Tehranifar et al., 2010; Zaouay et al., 2012). These differences depend on the cultivar types and climatic conditions (Alcaraz-Mármol et al., 2017).

Total polyphenols contents (TP)

Phenols are secondary metabolites extensively distributed in the vegetables kingdom as one of the most important antioxidant plant components (Djeridane et al., 2007). Their activity is associated mainly to the irredox properties that had an important role in neutralizing free radicals (Zhang et

Table 4. Physicochemical parameters, total polyphenol contents and antioxidant activity of pomegranate fruits of ten Moroccan cultivars harvested in 2018 and 2019*.

Cultivars	Moisture (g 100 g^{-1} FW**)	TSS (%)	TTA (g citric acid L^{-1})	MI	TP (mg GAE kg^{-1})	AA (mg AAE kg^{-1})
Sefri 1	86.13±1.14^{ab}	15.68±0.31^{a}	1.83±0.11^{a}	86.20±5.99^{bc}	632.84±20.10^{a}	597.88±73.70^{a}
Sefri 2	86.14±0.40ab	16.17±0.27^{ab}	2.04±0.14^{a}	79.55±5.53^{b}	814.64±33.81^{a}	842.31±38.63^{bc}
Sefri 3	86.67±0.90^{ab}	16.18±0.10^{ab}	2.07±0.21^{a}	78.99±5.71^{b}	659.50±97.99^{a}	755.03±98.99^{ab}
Sefri 4	86.94±1.20^{ab}	16.20±0.22^{abc}	1.98±0.05^{a}	81.94±3.11^{bc}	738.26±65.71^{a}	729.18±20.04^{ab}
Sefri 5	87.19±1.36^{b}	15.90±0.06^{ab}	2.13±0.04^{a}	74.78±1.53^{b}	827.87±75.83^{a}	941.31±45.88^{cde}
Sefri 6	85.04±0.21^{ab}	17.25±0.51^{bcd}	2.09±0.01^{a}	82.59±2.74^{bc}	932.59±26.09^{ab}	1,059.85±14.91^{ef}
Lahmer	84.28±0.78^{a}	17.85±0.16^{d}	1.92±0.16^{a}	93.66±6.17^{c}	896.76±53.04^{ab}	878.80±53.56^{bcd}
Marrakchia	84.51±0.10^{ab}	17.58±0.10^{cd}	1.88±0.11^{a}	93.62±4.03^{c}	871.66±61.38^{ab}	1,022.68±86.59^{def}
Lhamdha	86.61±1.57^{ab}	16.05±0.81^{ab}	28.37±0.65^{b}	5.66±0.63^{a}	1,168.29±135.8^{b}	1,112.39±5.97^{f}
Bzeq Tir	87.32±1.74^{b}	15.87±0.14^{ab}	1.94±0.08^{a}	81.97±2.38^{bc}	801.52±58.48^{a}	936.85±70.75^{cde}

TSS: Total soluble solids; TTA: Total titratable acidity; MI: Maturity index; TP: Total polyphenols (mg of gallic acid equivalent kg^{-1}); AA: Antioxidant activity (mg of ascorbic acid equivalent kg^{-1}).

* Values followed by the same letters within the same column are not significantly different ($P < 0.01$, $n = 6$).

** FW: Fresh weight.

al., 2010). Phenols are also associated with sensory characteristics (flavour, hardness, astringency) and colour which make them one of the most interesting parameters for evaluating the quality of pomegranate cultivars (Melgarejo-Sánchez et al., 2015). Table 4 showed the results of TP for the studied cultivars. TP varied significantly among the 10 cultivars (from 632.84 to 1,168.29 mg GAE kg^{-1}). The sour cultivar 'Lhamdha' presented the highest TP concentration while the cultivar 'Sefri 1' presented the lowest one. The TP data was in agreement with the results obtained for other Moroccan cultivars, between 410.1 mg kg^{-1} for 'Mesri' and 834.3 mg kg^{-1} for 'Hmade' (Legua et al., 2012), and Indian cultivars from 876.2 mg kg^{-1} for 'G-137' to 1,536.2 mg kg^{-1} for 'Maridula' (Kaur et al., 2014). The reported TP concentrations of pomegranate ranged widely from 8.85 up to 985.37 mg 100 g^{-1} (Garima and Akoh, 2009; Melgarejo-Sánchez et al., 2015; Tehranifar et al., 2010). This broad interval range of TP is related to genetic variability (modification of the biosynthesis path of secondary phenolic metabolites), geographical and climate effects, agricultural practices, growing seasons, and determination assays (Mphahlele et al., 2014; Tehranifar et al., 2010). The correlation analysis (Supplemental Table S2) showed significant positive correlation between TP and red colour intensity a^* (r = 0.708) indicating the richness of red juice in phenolic compounds. Similar results were also reported by Garima and Akoh (2009) and Zaouay et al. (2012), who also have stated positive correlation between juice colour values and anthocyanins contents.

Antioxidant activity

Table 4 showed the results of AA for the studied cultivars. The differences in AA among the studied pomegranate cultivars were statistically significant. The sour cultivar 'Lhamdha' and the sweet cultivar 'Sefri 6' presented the highest antioxidant activity with respectively 1,112.39 and 1,059.85 mg AAE kg^{-1}, while 'Sefri 1' presented the lowest AA with 597.83 mg AAE kg^{-1}. The results found for the AA agreed with those of Li et al. (2015). These results indicated that sour pomegranate had not automatically higher antioxidant activity compared with sweet pomegranates. Higher antioxidant potential was although attributed to higher total polyphenol content present in pomegranate and other fruits (Li et al., 2015; Mphahlele et al., 2014), which was confirmed by the significant positive correlation found between TP and AA (r = 0.792) (Supplemental Table S2). The AA of pomegranate juices was reported between 1,171 and 6,200 mg AAE L^{-1} for Chinese cultivars (Li et al., 2015), and Iranian cultivars (Akhavan et al., 2015). The observed divergence in antioxidant activity may be due to the genotypes, climatic conditions, sample extraction protocols, and to different AA valuations employed by other studies such as ABTS and FRAP assays. Furthermore, pomegranate AA varied depending on the fruit part. The homogenates prepared from the whole fruit revealed an approximately 20-fold higher AA than the level found in aril juice (Tzulker et al., 2007).

The correlation analysis between the studied parameters and the environmental conditions showed that high minimum temperatures and low maximum temperatures promoted the production of saturated red juices rich in TP with high AA. Indeed, maximum temperature was negatively correlated with TP (r = -0.510), AA (r = -0.414), a^* (r = -0.763) and C* (r = -0.759), while minimum temperature was positively correlated with TP (r = 0.479), AA (r = -0.434), a^* (r = 0.569) and C* (r = 0.621). The parameters a^* and C* were also negatively correlated with altitude, insolation and longitude. Thus, the cultivars 'Lahmer', 'Marrakchia' and 'Lhamdha' grown near the coastal town of Essaouira, where the difference between maximum and minimum temperatures, insolation, altitude and longitude were low, presented saturated red juices, with high polyphenol content and high antioxidant activity. Li et al. (2015) reported also that a low difference between the maximum and minimum temperature and a low average temperature during the stage of maturity and harvest is crucial for the production of polyphenols and the improvement of the antioxidant potential for Chinese pomegranate cultivars. While Borochov-Neori et al. (2009)

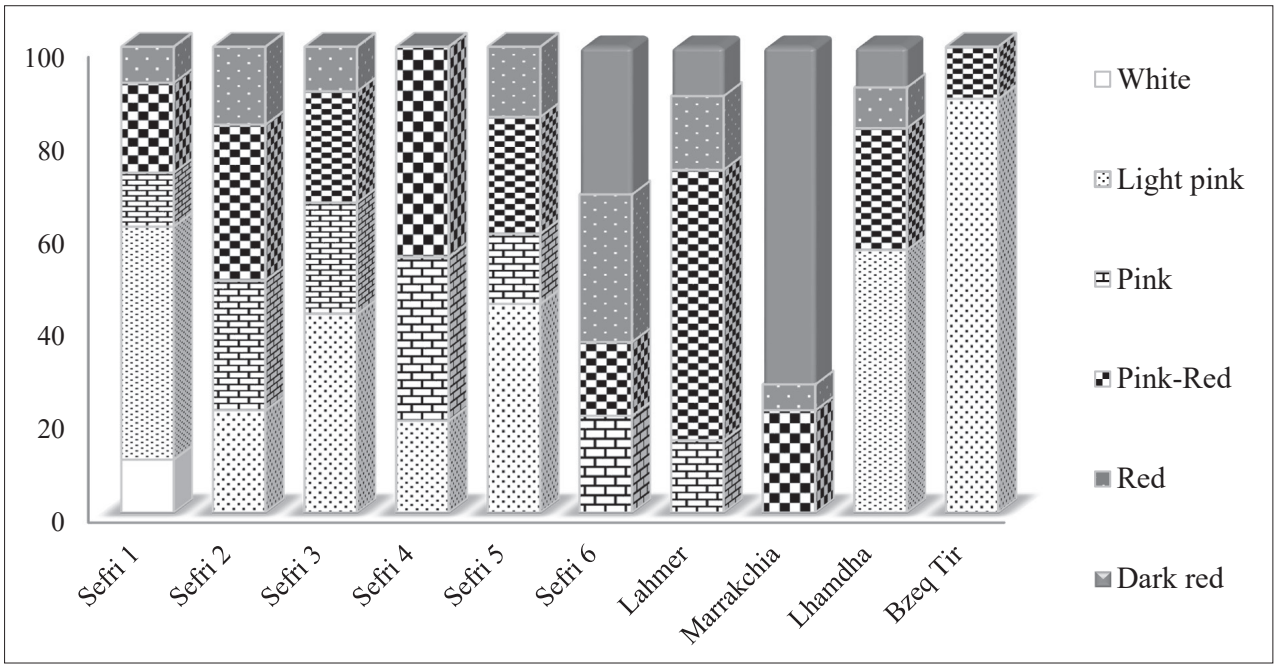


Figure 1. Distribution of citation frequencies of arils colour by the sensory panel for ten pomegranate cultivars harvested in 2018 and 2019.

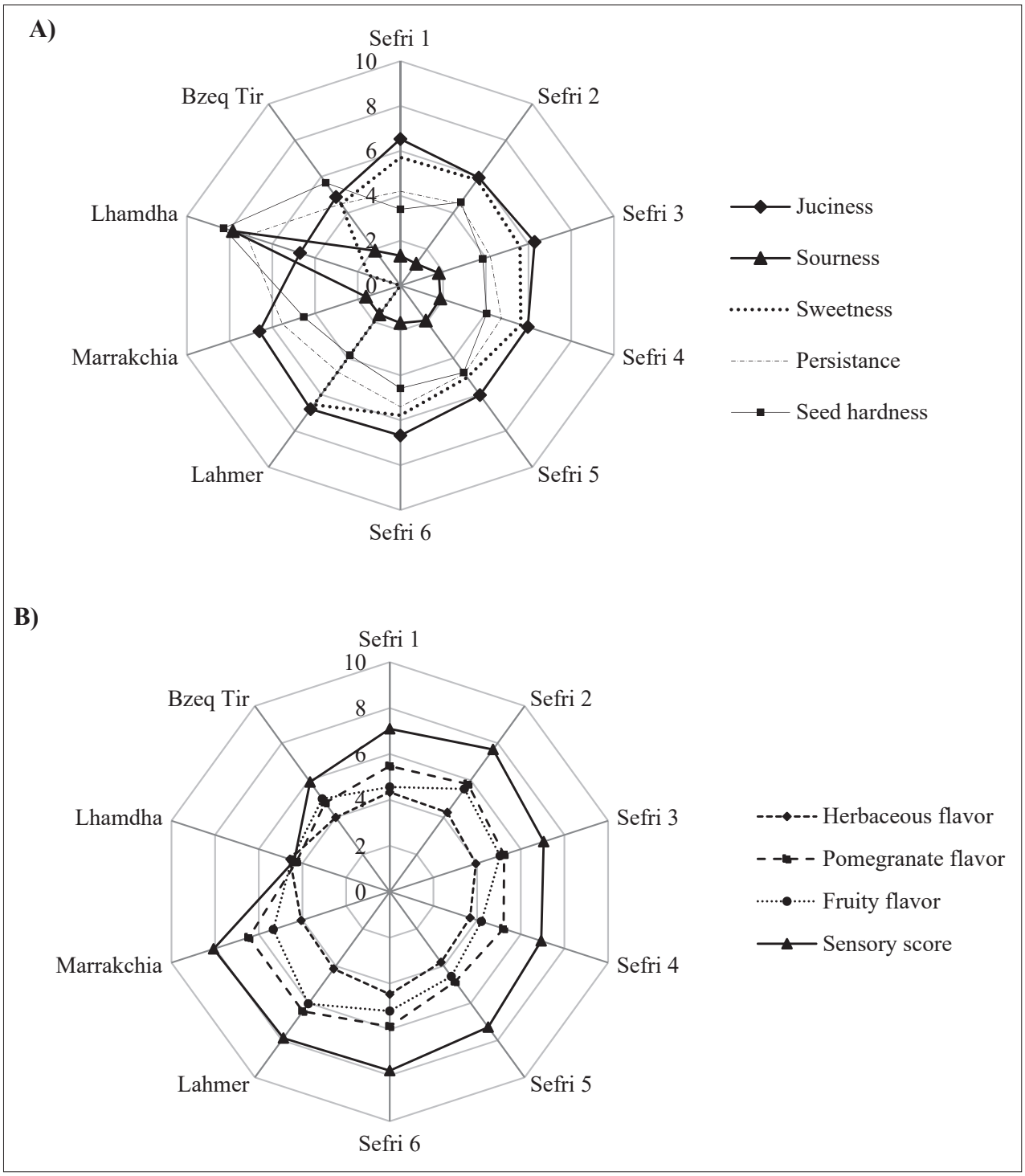


Figure 2. Means of the sensory attributes of pomegranate fruits of ten Moroccan cultivars harvested in 2018 and 2019. A) Mouthfeel attributes; B) Flavour attributes and sensory score.

stated that high temperatures decrease the production of anthocyanins responsible for the attractive red colour of the arils. This could be endorsed also to the concentration effect with the small size of fruits (Fawole and Opara, 2013; Kulkarni and Aradhya, 2005).

Sensory attributes of pomegranate arils and seeds

1. Pomegranate arils colour. The evaluation of arils colour by sensory panel for the ten pomegranate cultivars is shown in Figure 1. The cultivars 'Sefri 6', 'Lahmer' and 'Marrakchia' showed the most intense colour of arils (pink-red, red and deep red), while the cultivar 'Bzeq Tir' presented the lightest ones.

2. Mouthfeel and flavour attributes of pomegranate arils and seeds. Figure 2 presented the results of sensory attributes of pomegranate fruits. The values of mouthfeel, flavour attributes and sensory score varied significantly among the ten cultivars. Except for the cultivar 'Lhamdha' that had sour taste and hard seeds, all cultivars had sweet or slightly sweet taste (mean values of sweetness attribute were between 4.50 and 6.74), and their seeds were tender or semi-hard (hardness results were between 3.4 and 5.66), then were intended

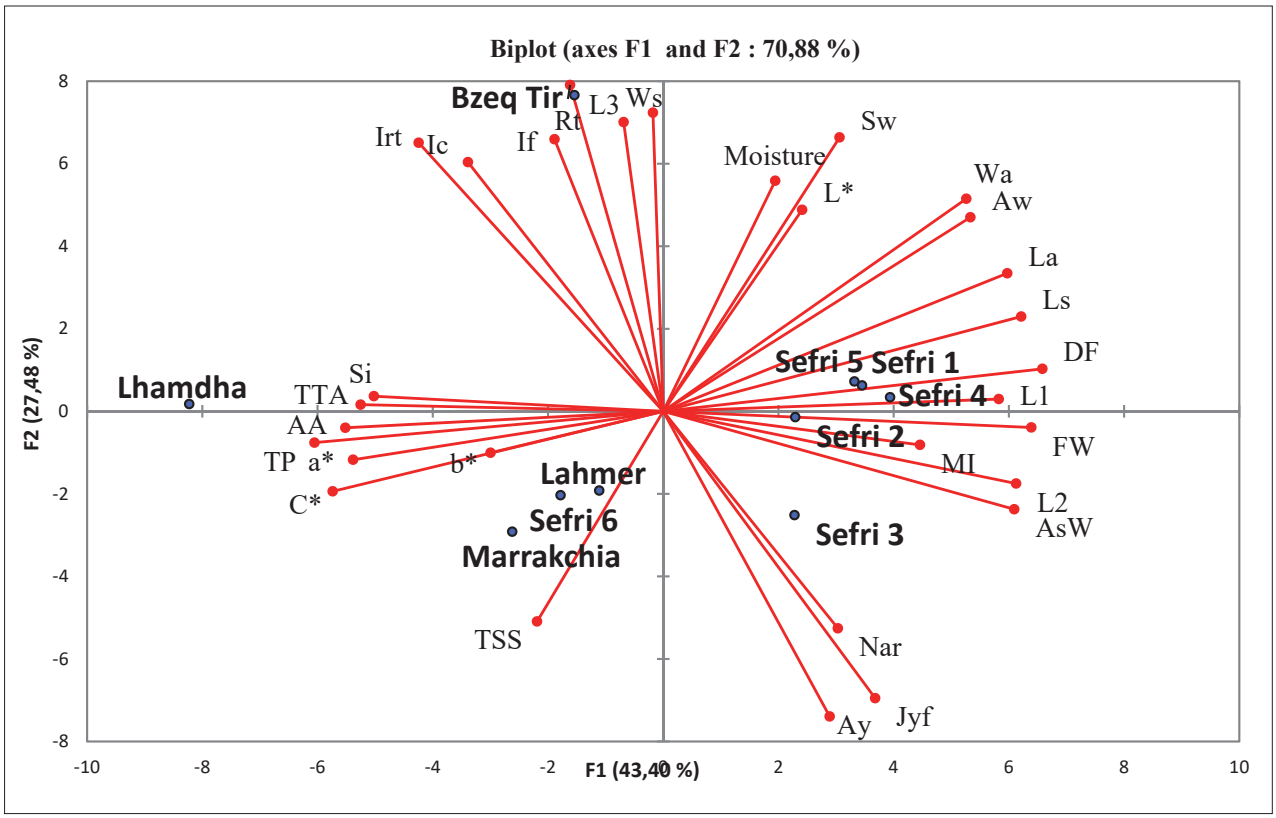


Figure 3. Principal component analysis (PCA) of the first two components (F1 and F2): Segregation of the ten cultivars harvested in 2018 and 2019 based on their morphological physicochemical and biochemical characteristics.

for fresh consumption. In fact, sour cultivars showed higher values of seed hardness compared with sweet cultivars (Alcaraz-Mármol et al., 2017; Caliskan and Bayazit, 2013). This was confirmed by the results of the correlation analysis, the values of sourness attribute were highly correlated with Si (r=0.645) and seed hardness (r=0.682). Sourness attribute was furthermore highly correlated with TTA, *a**, C*, TP and AA parameters (0.958, 0.647, 0.768, 0.733 and 0.459, respectively).

The cultivars 'Sefri 6', 'Lahmer', and 'Marrakchia' presented the highest sensory score and then the most appropriate sensory attributes (juicy, sweet, pomegranate and fruity flavours, low seed hardness and intense colour). Those cultivars showed also high polyphenols contents which confirm the association of phenols to sensory characteristics (Melgarejo-Sánchez et al., 2015). The sensory score was positively correlated with juiciness, sweetness and pomegranate flavour with respectively 0.377, 0.606 and 0.378, while negatively correlated with seed hardness and sourness attributes (-0.427 and -0.596, respectively).

Multivariate analysis

1. Principal component analysis (PCA). PCA was applied to the results to achieve better understanding of the relationships and trends between variables for the different pomegranate cultivars. The first two principal components explained 70.88% of the total variation (Figure 3). The proportion of variation for the first and the second factors were 43.40% and 27.48%, respectively. The first component F1 representing 43.40% of the total variation was positively linked to physical parameters of the fruits L1, L2, DF, FW, AsW, La, Wa, Ls, Aw, MI while negatively linked to Si, TTA, *a**, *b**, C*, TP and AA. The second component F2 accounted for 27.48% of the variance and was positively correlated to L3, Dc, Rt, If, Ic, Irt, Ws, Sw, *L**, moisture, whereas negatively correlated with Ay, Nar, Jyf, TSS. Based on the plot of the principal component scores, the studied cultivars can be separated into distinctive groups based on their physical, physicochemical and biochemical proprieties. The cultivar 'Lhamdha' showed a high negative score on F1. This cultivar was characterized by high TTA, Si, seed yield, red colour juice, high total polyphenols content and antioxidant activity, small fruits and arils. This cultivar can be used as a functional food in medical or cosmetic industry as it showed high TP content, AA and seed index, given that pomegranate seeds have high concentration of sexsteroid hormone (Kho et al., 2010) and their lipid portion showed beneficial biological effects (Caligiani et al., 2010). The cultivar 'Bzeq Tir' presented a large positive score on F2, showing high calyx diameter and index and, high Rt, Irt, If, Ws, Sw and moisture. This cultivar presented then a high non-comestible yield, and could be a source of relevant agri-food by-products (peels and seeds), rich in beneficial molecules to human health. The cultivars 'Sefri 1', 'Sefri 2', 'Sefri 3', 'Sefri 4' and 'Sefri 5' were relatively close to each other along the x-axis and presented a positive score on F1. They were characterized by their large and heavy fruits with high AsW and dimensions. The cultivar 'Sefri 3' was more characterized by high Ay and Jyf. These sweet cultivars could be used for arils fresh consumption or for commercialization of ready-to-eat arils. On the other hand, 'Lahmer', 'Marrakchia' and 'Sefri 6' showed negative scores on F1 and F2. They had small fruits and arils, and combined mutually organoleptic and nutritional properties. They were characterized by their high TSS and red colour juice with high TP and AA. PCA plot provided evidence of cultivars dispersion.

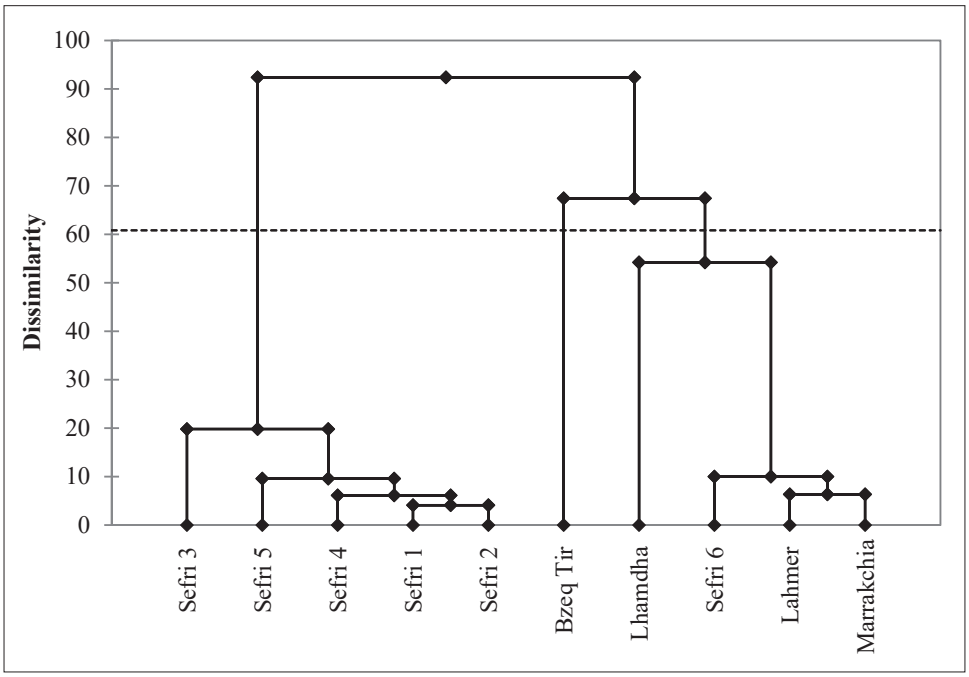


Figure 4. Dendrogram of ten Moroccan pomegranate cultivars harvested in 2018 and 2019 based on their physical, physicochemical, biochemical and sensory parameters.

2. Cluster analysis. Figure 4 showed the results obtained from cluster analysis for the ten studied Moroccan pomegranate cultivars. Four main groups were clustered based on the physical, the physicochemical and the biochemical parameters. The first group consisted of 'Sefri 1', 'Sefri 2', 'Sefri 3' and 'Sefri 4'. The second group included 'Sefri 6', 'Lahmer' and 'Marrakchia', while the third and fourth groups were formed only by the cultivars 'Bzeq Tir' and 'Lhamdha', respectively. Cluster analysis revealed the divergence of cultivars with the same appellation 'Sefri', SF6 was different from 'Sefri 1, 'Sefri 2', 'Sefri 3', 'Sefri 4' and 'Sefri 5', confirming the problem of homonymy or synonymy exposed by Ajal et al. (2014) in the cultivars appellation by analysing genetic diversity.

Conclusions

Statistically significant differences were found between the studied pomegranate cultivars within the determined physical, physicochemical, biochemical and sensory parameters. Except for the cultivar 'Lhamdha', that had sour taste and hard seeds, all cultivars were intended for fresh consumption since they had sweet or slightly sweet taste and their seeds were tender or semi-hard. The sour cultivar 'Lhamdha' could be used as a source of citric acid and polyphenols compounds. It showed high content of these compounds and high antioxidant activity. The cultivars 'Sefri 6', 'Lahmer' and 'Marrakchia' were suitable for fresh consumption based on their attracting characteristics or for production of fresh pomegranate juice with a high potential of health benefit. In fact, they showed the highest sensory score for their arils (juiciness, sweetness, pomegranate and fruity flavours), and their juices were characterized by high total soluble solids, an intense red colour, high total polyphenol contents and antioxidant activity. Indeed, with the exception of the cultivar 'Sefri 6', these cultivars were collected near the coastal town of Essaouira, where the difference between maximum and minimum temperatures, insolation, altitude and longitude were low, which explains their richness in polyphenols, their high antioxidant activity and their saturated red colour. The cultivar 'Bzeq Tir' presented high non-comestible yield, then could be a source of a relevant agri-food by-products rich in beneficial molecules to human health. The cultivars 'Sefri 1', 'Sefri 2', 'Sefri 3', 'Sefri 4' and 'Sefri 5' were characterized by their large and heavy fruits with high arils weight and yield. They could be used also for fresh consumption or for commercialization of ready-to-eat arils as their arils were sweet with tender seeds. In fact, these four 'Sefri' cultivars were harvested from geographical origins with low minimum temperatures, high maximum temperatures, altitudes and precipitations. Such favourable environmental conditions lead to the production of heavy and large fruits with an interesting edible proportion. Cluster analysis revealed the divergence of cultivars with the same appellation 'Sefri', confirming the problem of homonymy or synonymy in the pomegranate cultivars appellation. The results presented in this study clearly demonstrate the importance of exploitation and valorisation of these cultivars, not just for fresh consumption, but also for food and pharmaceutical industries.

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Supplemental Information

Supplemental Information – Table S1 (related to Table 2). Mean values of the physical parameters of pomegranate fruits of ten Moroccan cultivars harvested in 2018 and 2019*.

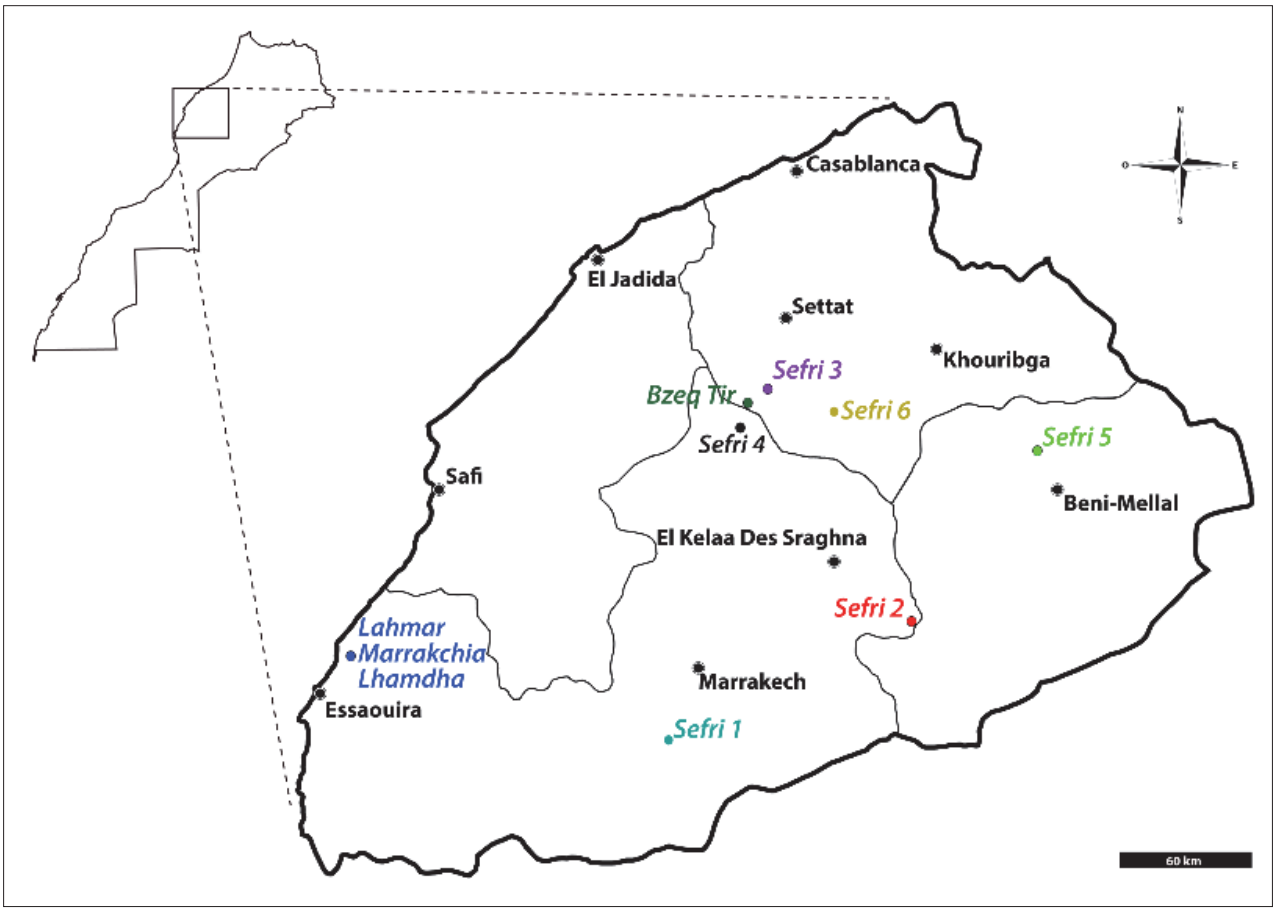
Cultivar	L2 (mm)	L3 (mm)	Nc	Jy** (mL 100 g^{-1} of arils)	Syf* (%) (g 100 g^{-1} of fruit)
Sefri 1	85.17±4.67^{de}	16.31±3.57^{a}	6.35±0.59^{a}	69.17±0.35^{bc}	15.03±0.35^{cde}
Sefri 2	85.61±4.49^{de}	15.30±3.71^{a}	6.90±1.02^{a}	69.76±1.44^{bc}	13.82±0.46^{abcd}
Sefri 3	83.40±7.86^{cd}	15.57±2.83^{a}	6.95±0.89^{a}	73.23±1.99^{c}	14.68±0.78^{bcde}
Sefri 4	86.39±8.78^{de}	17.71±3.74^{ab}	6.95±0.83^{a}	71.44±1.12^{bc}	16.73±0.17^{ef}
Sefri 5	90.45±4.39^{e}	19.68± 1.97^{bc}	6.45±0.76^{a}	71.85±0.64^{bc}	12.36±0.36^{ab}
Sefri 6	74.56±5.80^{ab}	16.80±3.26^{a}	6.45±0.83^{a}	72.83±1.04^{c}	13.61±0.34^{abc}
Lahmer	79.31±6.49^{bc}	16.60±2.33^{a}	7.10±0.97^{a}	69.14±0.83^{bc}	12.19±0.27^{a}
Marrakchia	81.71±8.27^{cd}	17.19±2.51^{a}	6.75±0.85^{a}	71.88±1.81^{bc}	11.92±1.17^{a}
Lhamdha	70.41±6.67^{a}	17.26±3.33^{ab}	6.65±0.67^{a}	60.92±0.93^{a}	18.11±1.30^{f}
Bzeq Tir	74.30±7.28^{ab}	21.95± 2.50^{c}	6.45±0.60^{a}	68.62±0.68^{b}	16.01±0.35^{def}

L2: Fruit length without calyx; L3: Calyx length; Nc: Number of carpels; Syf: Seed yield per fruit; Jy: Juice per 100 g of arils sample.
* The values followed by the same letter within the same column show no statistically significant differences ($P<0.01$; $n=40$; **: $n=6$).

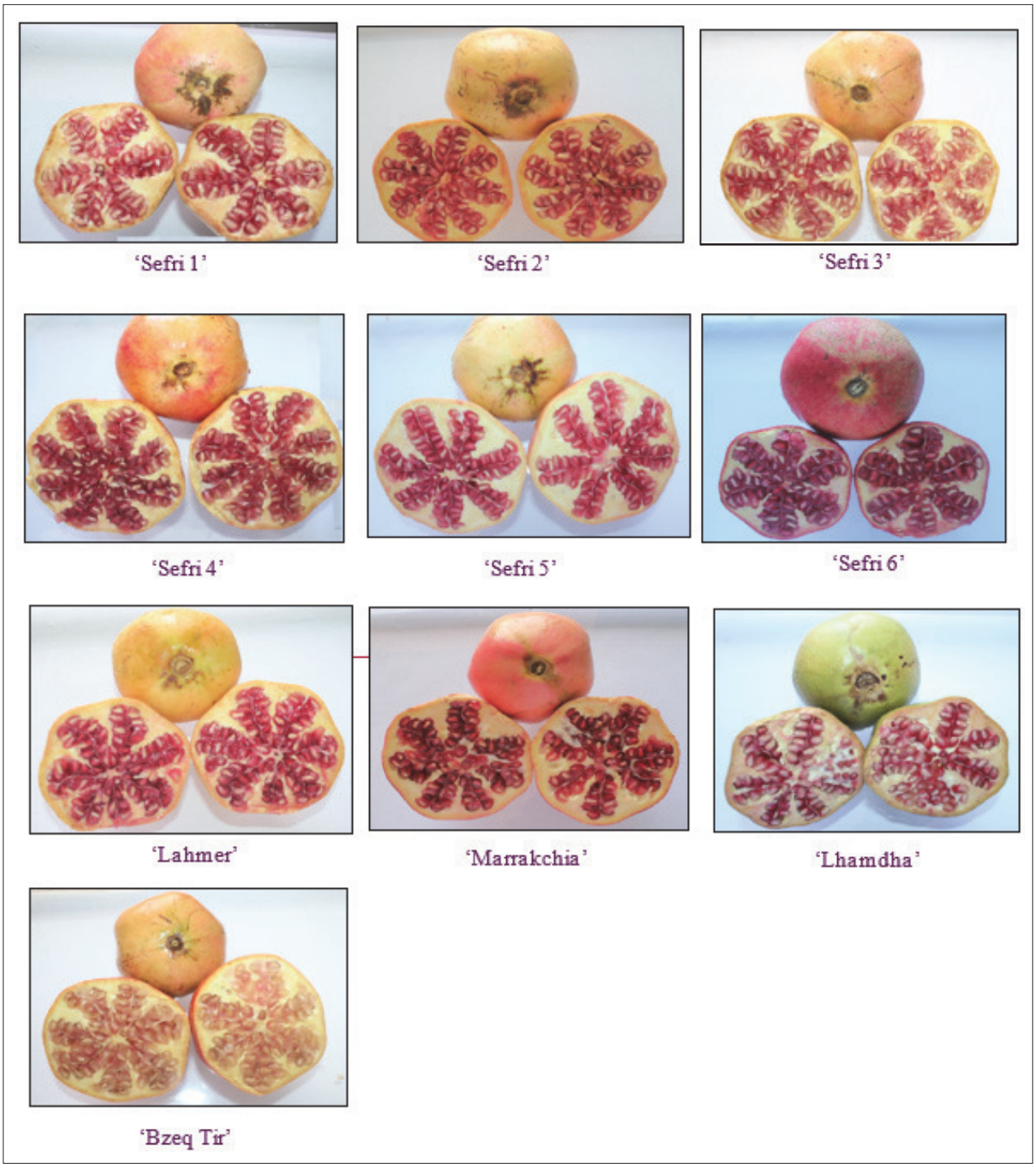
Supplemental Information – Table S2. Correlation analysis. Pearson correlation of morphological, physicochemical, biochemical and sensorial characteristics of ten Moroccan pomegranate cultivars harvested in 2018 and 2019.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1. L1	**1**																									
2. DF	**.800****	1																								
3. Ic	-.289**	-.316**	1																							
4. Irt	-.275**	-.366**	.359**	1																						
5. FW	**.841****	**.906****	-.440**	-.379**	1																					
6. AsW	**.730****	**.817****	-.512**	-.536**	**.933****	1																				
7. Ay	.201**	.277**	-.458**	-.679**	.365**	.656**	1																			
8. Aw	.332**	.443**	Ns	Ns	.375**	.280**	Ns	1																		
9. Si	-.182**	-.256**	Ns	.221**	-.238**	-.224**	-.135**	-.525**	1																	
10. Nar	.482**	.390**	-.425**	-.471**	.497**	.638**	.644**	Ns	Ns	1																
11. Jyf	.317*	.341**	Ns	-.578**	.374**	.536**	.658**	Ns	-.408**	.665**	1															
12. TSS	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	-.407**	Ns	.378**	1														
13. TTA	-.341**	-.492**	Ns	.340**	-.396**	-.371**	Ns	-.628**	.663**	Ns	-.365**	Ns	1													
14. MI	.308*	.462**	Ns	-.363**	.360**	.354**	Ns	.556**	-.608**	Ns	.373**	.304*	-.956**	1												
15. *a**	Ns	-.336**	Ns	Ns	-.284*	-.321*	Ns	-.578**	.514**	Ns	-.320*	Ns	.668**	-.522**	1											
16. C*	Ns	-.398**	Ns	Ns	-.322*	-.320*	Ns	-.659**	.560**	Ns	-.281*	Ns	.758**	-.632**	.937**	1										
17. Moisture	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	.251	Ns	-.347**	-.763**	Ns	Ns	Ns	Ns	1									
18. TP	Ns	-.439**	Ns	Ns	-.362*	-.388*	Ns	-.514**	.548**	Ns	-.410**	Ns	.632**	-.520**	.708**	.645**	Ns	1								
19. AA	-.290**	-.335**	.296**	Ns	-.383**	-.391**	Ns	-.310**	.225*	-.302*	Ns	.286*	.431**	-.313*	.592**	.551**	-.081	.792**	1							
20. Juiciness	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	-.183*	Ns	.420*	.410*	Ns	Ns	Ns	Ns	-.411*	Ns	Ns	1						
21. Sourness	-.275**	-.413**	Ns	**.468****	-.374**	-.342**	-.269**	-.541**	**.645****	Ns	**-.469****	**-.556****	**.958****	**-.936****	**.647****	**.768****	**.593****	**.730****	**.459****	-.303**	1					
22. Sweetness	Ns	.121	Ns	-.228**	.155*	.156*	Ns	.221**	**-.456****	Ns	.422*	**.501****	**-.705****	**.693****	-.381*	-.466*	**-.502****	-.515*	-.331*	**.536****	**-.634****	1				
23. Persistence	-.169*	-.263**	Ns	Ns	-.232**	-.196*	Ns	-.427**	.280**	Ns	-.328	Ns	.399*	-.330	.455*	.349	.120	.529*	**.594****	Ns	.475**	-.240**	1			
24. Seed hardness	-.256**	-.318**	.300**	.395**	-.344**	-.347**	-.331**	-.335**	**.438****	Ns	**-.549****	-.460*	**.609****	**-.618****	**.559****	**.569****	**.644****	**.602****	**.671****	-.316**	**.682****	**-.496****	**.380****	1		
25. Pomegranate flavour	Ns	Ns	-.203**	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	.378**	-.256**	**.435****	Ns	-.200*	1	
26. Fruity flavour	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	-.187*	-.426*	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	.223**	NS	.199*	Ns	Ns	.252**	1
27. Sensory score	Ns	.206**	-.242**	-.320**	.208**	.202**	.198**	**.173***	**-.453****	Ns	.254	.444*	-.385*	.405*	Ns	Ns	-.439*	Ns	Ns	**.377****	**-.596****	**.606****	-.200*	**-.427****	**.378****	**.299****
28. Precipitation	Ns	Ns	Ns	Ns	Ns	Ns	Ns	.410**	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
29. T° max	Ns	Ns	Ns	Ns	Ns	Ns	Ns	.616**	-.459**	Ns	Ns	-.426**	-.479**	Ns	-.763**	-.759**	-.418**	-.510**	-.414**	Ns	-.503*	Ns	Ns	Ns	Ns	Ns
30. T° min	-.441**	-.622**	Ns	Ns	-.562**	-.451**	Ns	-.638**	.444**	Ns	Ns	.513**	-.429**	Ns	-.569**	-.621**	-.383**	-479**	-.434**	Ns	.459*	Ns	Ns	Ns	Ns	Ns
31. Insolation	Ns	Ns	Ns	Ns	Ns	Ns	Ns	.398*	-.427**	Ns	Ns	Ns	-.336*	Ns	-.664**	-.561**	.378*	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
32. Altitude	.374*	.384*	Ns	-.314*	.367*	Ns	Ns	.502**	-.359*	Ns	Ns	-.332*	-.387*	Ns	-.470**	-.545**	Ns	-.386*	-.389*	Ns	-.445*	Ns	Ns	Ns	Ns	Ns
33. Latitude North	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	-.330*	Ns	Ns	Ns	Ns	Ns	-.329*	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
34. Longitude West	Ns	.433**	Ns	Ns	.353**	Ns	Ns	.398*	-.416**	Ns	Ns	-.338*	-.353*	Ns	-.460**	-.481**	.409**	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns

L1: Total fruit length; DF: Fruit diameter; Ic: Calyx index; Irt: Rind thickness index; FW: Fruit weight; AsW: Arils weight; Ay: Aril yield; Si: Seed index; Nar: Total number of arils per fruit; Jyf: Juice yield per fruit; TSS: Total soluble solids; TTA: Total titratable acidity; MI: Maturity index; TP: Total polyphenols; AA: Antioxidant activity. *: correlation significant at $P < 0.05$; **: correlation significant at $P < 0.01$; Ns: not significant.



Supplemental Information – Figure S1 (related to Table 1). Geographical origins of the ten studied pomegranate cultivars indicated in the map of Morocco.



Supplemental Information – Figure S2 (related to Table 2). Pomegranate fruits of the ten studied Moroccan cultivars.