Assessment of Genetic Diversity in Moroccan Pomegranate (*Punica granatum* L.) Collection Using Physicochemical Approaches and Study of Effect of Age Trees

Assia EJJILANI[1,2]
Karim HOUMANAT[1]
Fatima GABOUN[3]
Hafida HANINE[2]
Ilham HMID[2]
Abderrahman MEKAOUI[1]
Chems Doha KHALFI[1]
Jamal CHARAFI[1] (✉)

Summary

As with other fruit trees, the pomological and chemical characteristics of pomegranate (*Punica granatum* L.) can vary from year to year and depending on the age of the trees. Physicochemical screening of 19 pomegranate cultivars from a Moroccan *ex situ* collection, whose fruits were harvested from three different years, showed highly or very highly significant differences for most traits. Indeed, fruit weight, diameter and height were relatively higher in 2017, exceeding the values measured in 2018 by 22.8%, 13.5% and 4%, respectively. The weight and length of the aril, some chemical characteristics such as pH, Brix and maturity index also showed higher values in 2017, exceeding the 2018 values by 3%, 7%, 3%, 14% and 80% respectively. On average over the three harvest years, the 'Chelfi' cultivar had the lowest weight, while the 'Khikhou' variety had the highest value. The weight and yield of the aril varied between 266 mg ('OunH') and 670 mg ('Khik') and 50.65 ('Khik') and 73.34 ('Gord'), respectively. For the chemical parameters, the total soluble solids ranged from 14.52 (Grenade_Jaune) to 17.81 (Sefri 2) °Brix. The maximum value of titratable acidity was found for 'Negro_Monsteriosa' (2.87%) and the minimum value for 'Grenade_Rouge' (0.37%). The PCA analysis shows the distribution in groups according to the harvest year, which illustrates the annual variance of the characteristics. The hierarchical analysis shows the presence of gene pools with no obvious geographical structure. The results obtained thus provide a basis for the breeding programs of the species.

Key words

pomegranate, physicochemical parameters, harvest age effect, diversity, *ex-situ* collection

[1] Regional Agricultural Research Center of Meknes, National Institute of Agricultural Research, Avenue Ennasr, P.O. Box 415, Rabat 10090, Morocco

[2] Laboratory of Bioprocess and Biointerfaces, Department of Biology, Faculty of Sciences and Technics, University Moulay Slimane, P.O. Box 523, Beni-Mellal 23000, Morocco

[3] Regional Agricultural Research Center of Rabat, National Institute of Agricultural Research, Avenue Ennasr, P.O. Box 415, Rabat 10090, Morocco

✉ Corresponding author: jamal.charafi@inra.ma

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Introduction

The Pomegranate (*Punica granatum* L.; 2n = 16) is a deciduous fruit highly appreciated thanks to its nutritional and pharmaceutical qualities. The species is consumed as a fresh fruit, but it is also used to produce juice and other processed products (jam, dried arils, etc.). It is widely cultivated in several countries of the world, especially those with a Mediterranean climate, where excellent quality fruit can be obtained. The species cropping is evolving over the years, especially with high-performance genotypes (Ferrara et al., 2014).

In Morocco, the pomegranate cropping is very old and among the important cultivated fruit trees. The production is estimated at 133.000 tons for an area of 12.644 ha. Beni Mellal-Khenifra is the main producer with 45% of national production (MAPMDREF, 2024). Although the genotypic profile in modern orchards consists of a limited number of cultivars, pomegranate appears to be more genetically diverse. The presence of many local denominations with marked phenotypic differences supports this hypothesis of great diversity. The organization of pomegranate genetic diversity at the national level is poorly studied.

As part of the management and conservation of genetic resources, INRA-Morocco maintains a collection of several national and foreign genotypes and varieties of pomegranate. The characterization of this genetic material was performed using pomological and chemical descriptors in a single year of 2009 (Hmid et al., 2018). However, these phenotypic markers are greatly influenced by environmental conditions and a single year is not enough to better elucidate the level of diversity.

In the said context, this study aims to analyse the pomological and chemical performances of Moroccan genetic resources of pomegranate, considering the effect of tree age and harvest year. The main objectives of this work were: (1) to study and evaluate the collected genetic plant materials according to pomological and physiochemical characteristics of the harvest of three years (2009, 2017 and 2018), while at the same time making comparisons with fruit from the same trees in 2009; (2) to determine the effect of the year on all variables and (3) to assess the amount of diversity among the pomegranate trees in the *ex-situ* collection. The genetic variability determined in this study will support the drawing of the genetic breeding programs of the species and determine the most important selection parameters.

Materials and Methods

Plant Material and Culture Conditions

The study was carried out on a total of 19 genotypes of which 11 are local clones and 8 are imported varieties (Table 1), with three replicates per genotype. The collection was planted in triplicates installed in three different years 1981, 1996 and 2017 in the experimental station of the National Institute for Agricultural Research (INRA) at Ain Taoujdate located in the Sais Plain (33° 56′ E, 5° 13′ N, 499 m). The cultivars were planted with a plan of three repetitions spaced 5 × 5 m following a randomized complete block design (RBC). The orchard is drip irrigated from May to mid-October to supplement the annual precipitation to reach a level of 600 mm per year. The studies were carried out for three years (2009, 2017 and 2018) and the samples were collected during the maturity period (September/October). The region experienced a climate typical of the Moroccan Mediterranean zone, with humid and cool winters and hot and dry summers. The general climatic characteristics of the study station are generally typical: average temperatures in the region vary between 12 °C and 25 °C. Temperatures can drop as low as 0 °C to 5 °C. Summer temperatures are higher, often reaching 30 °C to 40 °C. Precipitation: the region experiences a Mediterranean climate with precipitation mainly concentrated in winter and spring and annual precipitation is around 600 mm.

Table 1. List and geographical origin of the cultivars studied

Cultivar	Code	Geographical origin
Chelfi	Chel	Morocco
Ounk Hmam	OunH	Morocco
Djebali	Djeb	Morocco
Sefri 2	Sef2	Morocco
Sefri	Sefr	Morocco
Grenade rouge	GRou	Morocco
Chioukhi	Chkh	Morocco
Djeibi	Djei	Morocco
Grenade jaune	Gjau	Morocco
Bzou	Bzou	Morocco
Khikhou	Khik	Morocco
Wonderful	Wond	USA
Ruby	Ruby	USA
Dwarf semi Evergreen	Dwar	USA
Mollar Osin Hueso	Mola	China
Negro Monsteriosa	Negr	Spain
Gordo de Jativa	Gord	Spain
Zhérie precoce	ZhPr	Tunisia
Zhérie Autumn	ZhAu	Tunisia

Measurement of Physicochemical Properties

Pomegranate samples, including varieties such as ‘Chelfi’, ‘Ounk Hmam’, ‘Djebali’, ‘Sefri 2’, ‘Sefri’, ‘Grenade rouge’, ‘Chioukhi’, ‘Djeibi’, ‘Grenade jaune’, ‘Bzou’, ‘Khikhou’, ‘Wonderful’, ‘Ruby’, ‘Dwarf semi Evergreen’, ‘Mollar Osin Hueso’, ‘Negro Monsteriosa’, ‘Gordo de Jativa’, ‘Zhérie precoce’, ‘Zhérie d’Autumn’, were assessed using 15 pomological criteria based on descriptors from the International Union for the Protection of New Varieties of Plants (UPOV, 2012). Fifteen fruits were taken from each of the three trees, repeated three times. The weight of each fruit, the seeds, the aril and the weight of the rind and endocarp were measured with a 0.001 precision scale and expressed in grams (Table 2). Fruit and calyx diameter, height and length of fruit, aril and calyx, length and thickness of rind were measured with a digital caliper (Table 2). The yield of arils, seeds and fruit rind was also determined.

The total soluble solids and the titratable acidity were performed in triplicates and concerned citric acid by titrating pomegranate juice with 0.1 M NaOH and total soluble solids using digital refractometer (PR-101 ATAGO, Norfolk, VA, USA). The measurement of pH of the juice was performed by a pH meter (Thermo Scientific™ ECPH70042S). The maturity index is given by the ratio between the total soluble solids and the titratable acidity of the juice.

Table 2. Analysis of variance of the varietal and harvest year effect on pomegranate fruit based on physicochemical parameters

	Year	Variety	Year * Variety
WFr	661040.48***	174478.99***	59084.38***
DFr	1432.77***	3560.72***	683.21***
HFr	1193.79305***	2094.39105***	465.51629***
DCa	444.50***	269.75***	129.93***
Hca	145.95***	269.75***	63.17***
NbrSp	4.83***	4.45**	2.03***
WEn	43851.42***	15363.33***	4573.83***
TEc	57.61***	6.16***	1.80***
WSe	11377.42***	661.02***	339.96***
YAr	3728.01***	454.86***	113.84***
YSe	653.46***	43.19***	20.52***
Yju	3336.28***	4121.35NS	944.76NS
WAr	92085.90***	207718.45***	39354.34***
LAr	30.25***	38.49***	3.50***
WdAr	94.17***	16.16***	2.15***
pH	2.53***	0.39***	0.25***
TSS	155.62***	4.26***	3.05***
AT	12.80***	0.67***	1.05***
IM	44638.89***	1234.95***	669.25***

Note: NS - not significant; *, **, *** - indicate a significant difference at the $P < 0.05$, 0.01, and 0.001 level, respectively.

Abbreviations: **WFr**: Weight (g); **DFr:** Fruit diameter (mm); **DCa:** Calyx diameter (mm); **HFr:** Fruit height (mm); **HCa:** Calyx height (mm); **NbrSp:** Number of sepals; **WEn:** Weight of rind + endocarp (g); **TEc:** Rind thickness (mm); **WSe:** Weight of seeds (g); **YAr:** Aril yield (%); **YSe:** Seed/fruit yield (%); **YJu:** Juice/fruit yield (%); **WAr:** Aril weight (mg); **LAr:** Aril length (mm); **WdAr:** Aril width (mm); **AT:** Titratable acidity; **TSS:** Total soluble solids %; **IM:** Maturity index.

Statistical Analyses

Statistical analyses were performed using SAS software version 9.1. Analysis of variance, multivariate studies and correlation indices by Person's index were carried out. The analyses concerned the varietal effect, the effects of the harvest year, the age of trees and the interactions of all these factors were performed. For all physicochemical parameters, cluster analysis, principal component analysis and discriminant factor analysis were conducted using average of the three years. For cluster analysis, a similarity matrix based on Euclidian coefficient was calculated.

Results and Discussion

Varietal, Year, and Interaction Effects on Fruit Parameters

The analyses of variance showed significant variations per year; per cultivar and interaction varieties × year at the significance level $P < 0.001$, $P < 0.01$ and $P < 0.05$ for all characteristics for varieties and interaction factors varieties/year with the exception of juice yield (Table 2).

Firstly, statistical analyses show that for the year factor, the variation is very highly significant or highly significant for all parameters. Studying the averages of all parameters of all varieties for each year (Table 3), we notice that: the harvest year 2017 recorded the highest value of most physical parameters of the fruit. Precipitation throughout August 2017 helped improve pomegranate size and quality, while the lack of preharvest rainfall in 2018 reduced crop productivity and quality due to the lack of water. Regarding the fruit weight the differences between 2017 and those of 2018 and 2009 are 22.8% and 9.15% respectively. Diameter and height differences are 13.51% and 3.79% of 2018 and 12.0% and 1.11% of 2009. Thus, the pomegranates with the highest aril weight are those harvested in 2017, followed by the 2009 harvest, then the 2018 harvest, with a difference of 33.81% and 17.63% respectively.

For chemical parameters, in 2017, the fruits harvested had the highest pH, Brix and ripeness index with a significant difference of 11.94%, 17.99% and 46.27% respectively compared to 2009 and 3, 14.04, 80.05% compared to 2018. Concerning titratable acidity, Table 3 shows that the pomegranates with high acidity are those harvested in 2018 with a difference of 52.84% and 80.49% compared to 2009 and 2017 respectively.

In agreement with our results, (Ferrara et al., 2011) showed a significant effect between two years of some pomological parameters in pomegranate like weight and fruit diameter, chemical values (acidity, pH and MI) and all of the arils and seeds physical characteristics. However, they did not find significative differences for fruit length, sepal's number, calyx length and diameter, juice volume and °Brix. Likewise, in Tunisia, the effect of the year was observed in skin thickness, aril and juice yields (Zaouay and Mars, 2014). Some studies have shown that the physicochemical traits are highly sensitive to climatic conditions, mainly temperature, as reported by (Schwartz et al., 2009), (Borochov-Neori et al., 2011), and (Manera et al., 2012). The annual variation of the pomological and chemical parameters of pomegranate is essentially linked to the climatic conditions and differences between years.

Table 3. Average physical and chemical characteristics of pomegranate fruit for different harvest years

Parameter	2009	2017	2018
Weight (g)	321.33^{b}	353.68^{a}	273.02^{c}
Fruit diameter (mm)	83.42^{b}	94.80^{a}	81.99^{b}
Fruit height (mm)	87.46^{b}	90.02^{a}	86.61^{b}
Calyx diameter (mm)	20.31^{c}	22.76^{a}	21.29^{b}
Calyx height (mm)	15.60^{b}	15.17^{b}	16.67^{a}
Number of sepals	6.91^{a}	6.69^{b}	6.59^{b}
Weight of rind + endocarp (g)	97.16^{c}	146.8^{a}	120.92^{b}
Rind thickness (mm)	2.23^{c}	3.98^{a}	3.2^{b}
Weight of seeds (g)	47.03^{a}	48.16^{a}	29.66^{b}
Aril yield (%)	71.05^{a}	61.70^{b}	61.15^{b}
Seed/fruit yield (%)	14.47^{a}	12.50^{b}	9.54^{c}
Juice/fruit yield (%)	41.71^{ab}	39.95^{b}	49.84^{a}
Aril weight (mg)	359.16^{c}	401.71^{a}	388.76^{b}
Aril length (mm)	11.27^{c}	11.62^{a}	10.84^{b}
Aril width (mm)	7.15^{b}	6.66^{c}	7.94^{a}
pH	3.17^{c}	3.6^{a}	3.49^{b}
Total soluble solids (%)	14.95^{c}	18.23^{a}	15.67^{b}
Titratable acidity (%)	0.58^{b}	0.24^{c}	1.23^{a}
Maturity index	42.18^{b}	78.50^{a}	15.66^{c}

In other species, climatic constraints at the beginning of the cycle, during the cell division phases, lead to a reduction in fruit size at harvest. For example, in citrus (clementine), the most critical phase is the flowering-fertilization period with records of yield reductions ranging from 30 to 60%, but with relative stability of fruit sizes (Gonzales-Altozano and Castel, 1999). This period could also be critical due to a fertilization deficit, especially in fruits such as kiwi and grape berry, where the number of seeds or pips is directly related to the fruit size (Asrey and Das, 2021). In addition, in grapevine, the next period from flowering to flowering (cell division) that is known by rapid enlargement of berries and seeds is the most sensitive to environmental conditions (Ojeda et al., 2000; Deloire et al., 2004; Beker and Zimmerman, 1984 cited in Huglin, 1998). In apricots, reduced growth during this phase is recoverable during the rapid growth phase, if climatic conditions are favorable (Torrecilas et al., 2004). In contrast, for our results by studying the climatic data (Fig. 1), compared to the years 2009 and 2017 whose climatic data are seasonal, the critical period of the pomegranate tree (flowering, maturation) in 2018 experienced lower temperatures. According to (Coutanceau et al., 1995), taste maturity is reached when maximum fruit quality is achieved; before this period acidity is often excessive and sugar content and aroma are insufficient.

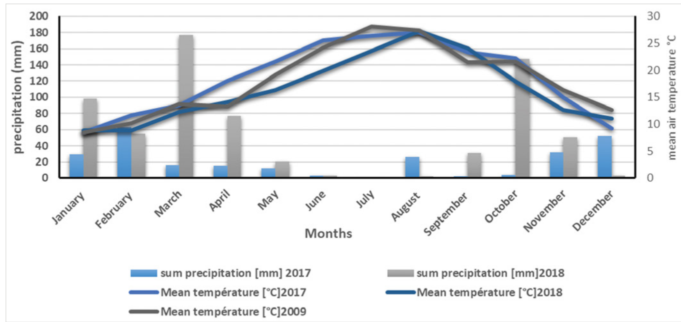

Figure 1. Graph of monthly temperatures and precipitations in harvest years from the climate station in Ain Taoujdate

Regarding the variety factor, it is very highly significant for most parameters and only highly significant for sepal numbers. However, the variability of the juice/fruit yield parameter is not significant. The varietal effect is well known for all species and for most phenotypic traits. A Tunisian study on 28 cultivars has shown that the genotypic part is the main component in the variability of most physicochemical parameters (Zaouay and Mars, 2014). Other studies on pomegranate describing that variation between genotypes state that it is attributed principally to genetic profiles and less to environmental conditions and cultural techniques (Mars and Marrakchi, 1999; Zaouay and Mars, 2014). Similarly, for an *ex-situ* collection of the Cyprus pomegranate, the genotypic part is dominant for the characteristic fruit gross weight, height and diameter. Likewise, genotype effect is predominant on most fruit, aril and seed morphometric, colorimetric and textural traits examined (Kyriacou et al., 2020). These results are supported by the studies of (Chater et al., 2018) who showed that fruit physical traits most resilient to year effect included aril weight, seed hardness, fruit gross weight, fruit shape and rind hue.

Thirdly, for the year/variety interaction the majority of the parameters show very highly significant variations except for the juice/fruit yield parameters which are non-significant. Other research confirms the existence of the effect of cultivar-year interaction on most of the physicochemical parameters of fruits. (Zaouay and Mars, 2014) found that the variety x year interactions is very high for all parameters and they are very noticed at total soluble solids content, titratable acidity and skin thickness. The existence of this type of interaction suggests that the differences between clones differ between years. For fruit trees, the study of this phenomenon is important especially in confirming the varietal adaptability to such an environment. Breeding programs should seek the stability of production traits and their quality between seasons (Silva et al., 2008).

Most of the parameters show very highly significant intra-annual variation (Table 4). In 2018, significant variability was noted for soluble sugar content and in 2009 only for the number of sepals, where the effect was not significant. However, in 2017, parameters showed a highly significant effect on seed yield, a significant effect on maturity index and rind + endocarp weight and a non-significant effect on seed weight, juice/fruit yield, aril weight, aril length and width, pH and soluble sugar content (% Brix). The instability of the level of variation of some physicochemical index from year to year depends on the climate variations, the soil types and the cultural practices which affect the qualitative and quantitative parameters. Singh, (2004) showed the vegetative growth, yield, fruit size, fruit cracking, number and weight of arils varied very highly significantly between two contrasting climates. Thus, another study states that pomegranate growth and production are greatly enhanced by fertile soil and organic or chemical fertilization Mir et al. (2012).

Table 4. Analysis of variance of each harvest year for pomegranate fruit physicochemical parameters

Parameter	2009	2017	2018
Weight (g)	86467.107***	160832.36***	108947.33***
Fruit diameter (mm)	608.11***	686.82***	1324.73***
Fruit height (mm)	1052.47***	959.26***	1828.35***
Calyx diameter (mm)	102.71***	215.36***	385.61***
Calyx height (mm)	74.48***	82.56***	241.54***
Number of sepals	0.80^{NS}	2.75***	5.63***
Weight of rind + endocarp (g)	6916.52***	5700.61*	23583.74***
Rind thickness (mm)	0.94***	2.79***	6.24***
Weight of seeds (g)	423.80***	636.65^{NS}	402.21***
Aril yield (%)	139.25***	81.17*	483.42***
Seed/fruit yield (%)	39.50***	9.68**	316195.94^{NS}
Juice/fruit yield (%)	121.16***	34.11^{NS}	5730.21***
Aril weight (mg)	197009.61***	16501.40^{NS}	100779.74***
Aril length (mm)	22.56***	2.43^{NS}	17.47***
Aril width (mm)	12.34***	0.74^{NS}	6.82***
pH	0.62***	0.03^{NS}	0.18***
Total soluble solids (%)	68.15***	3.10^{NS}	2.34*
Titratable acidity (%)	0.68***	0.003***	3.81***
Maturity index	1415.55***	99210.17*	51.02***

Note: ^{NS} - not significant; *, **, *** - indicate a significant difference at the $P < 0.05$, 0.01, and 0.001 level, respectively.

Descriptive Analysis and Varietal Diversity

For all the pomological characters studied (Table 5), a great variability was observed between all the cultivars. Significant differences were recorded between accessions for all characteristics based on analysis of variance. Fruit size is an important trait attracting consumers for the fresh market. Fruit weight varied greatly among genotypes from a minimum of 215g ('Chelfi') to a maximum of 463g ('Khikhou') with an average of 323g. In comparison with other studies, the mean fruit weight is similar to that of the Italian cultivars (338.7 g; Ferrara et al., (2014)) and Spanish genotypes (333 g) (Hernández et al., 2014)). However, it is higher than that obtained in Iranian cultivars (271 g) (Sarkhosh et al., (2009)) and inferior than the mean for Tunisian and Turkish genotypes (433 g and 406 g, respectively) (Zaouay and Mars, 2014; Durgaç et al., 2008). Shulman et al., (1984), showed that variation in fruit weight depended on cultivar and climate.

For fruit size (height and diameter) the variation is highly significant among cultivars. The lowest length and width of the fruits are 74.6 mm and 78 mm (cv. 'Chelfi'), the highest values are 99 mm and 106 mm and the averages are 85 mm and 89 mm, respectively. Our values are similar to those reported by (Ferrara et al., 2011) and (Adiletta et al., 2018) for Italian accessions. For the Iranian genotypes the means of the diameters were lower (Sarkhosh et al., 2009). For calyx diameter, minimum value was found in the cv. 'Cordo de Jtiva' with 19 mm, the maximum for cv. 'Khikhou' with 29.4 mm and the average was 21.7 mm, while the calyx height varied from 13.2 mm (cv. 'Mollar Osin Hueso') to 22 mm (cv. 'Ounk Hmam') with an average of 18.1 mm. Our findings are comparable with those of Italian cultivars (Ferrara et al., 2011) and greater than Iranian genotypes (Sarkhosh et al., 2009). Although the variation in the sepal numbers is not significant between the years (Table 4), it is very highly significant between the varieties, which shows it is a genetic trait. Thus, the lowest mean number of sepals is 5.87, the highest is 7.11 with an average of 6.61. The number of sepals is similar to that reported for several Italian and Tunisian accessions (Mars and Marrakchi, 1999) and it is a trait probably showing less variability. This phenotypic character is weakly variable and the number of sepals obtained is similar to that of the Italian and Tunisian cultivars (Ferrara et al., 2011; Zaouay and Mars, 2014).

The most important part in the fruit are the arils which contain juice and seed, which contributes to the richness in important chemical components. The parameters that we have measured for the arils constitute the elements that are highly targeted by the consumers, industry and breeders. The results obtained for the physical characteristics of arils and seeds of different cultivars are presented in Table 6. Significant variability was revealed between pomegranate cultivars for all the parameters studied. The weight of aril vary between 267 (cv. 'OunH') and 670 mg (cv. 'Khik'), aril length vary between 9.71 ('OunH') and 12.70 mm ('Khik'), aril width vary between 6.24 ('OunH') and 9.23 mm ('Khik'). Yield of the arils vary between 50.65 ('Khik') and 73.34% ('Gord'). As for seed weight and yield per fruit, vary from 28.62 ('ZhPr') to 51.02 g ('Gord') and from 7.87 ('Khik') to 16.08 % ('Gord'), respectively.

The aril and seed weights are higher than those of Cypriot cultivars Kyriacou et al. 2020) and almost similar to those of Tunisian (Hasnaoui et al., 2011) and Spanish (Martinez-Nicolas et al., 2016) accessions. The seed index (SI) indicates the proportion of seed weight to fruit weight and it shows a large variability among different cultivars. Seed yield ranges from 6.24 to 14.31% and shows a significant negative correlation with aril weight, suggesting that genotypes with large arils tend to be more suitable for juice making. The classification of accessions according to SI shows the existence of two main groups: one group with an index lower than 10, which means that the seed yield is smaller and that the arils are largely made of juice than pulp. In this group we find cultivars like 'Osin Hueso' (9.78%), 'Ruby' (9.78%), 'Khikhou' (7.87%), 'Mollar Osin Hueso' and 'Dwarf semi-Evergreen' (8.98%) which are known for their hard and semi-hard seeds that will be more demanded for transformation. The second group consists of genotypes with large seeds such as 'Gordo de Jativa0 (16.08%) which are cultivars for juice production. In this group we also find Moroccan accessions like 'Djeibi' (12.44%), 'Djebali' (12.68%) and 'Chelfi' (12.22%).

The chemical parameters of fruit juices are characteristics that essentially define consumer preferences. Table 7 shows the chemical characteristics of the fruits of the pomegranate collection, specifically pH, soluble sugar content, titratable acidity and maturity index. Total soluble solids ranged from 14.52 to 17.81 °Brix with cv. 'Grenade Jaune' fruits having the highest value and cv. 'Sefri 2' the minimum content. These data are similar with Spanish cultivars reported as ranging from 12.36% to 16.32% (Martinez et al., 2006). In Turkish cultivars total soluble solids had the minimum of 16% and the maximum of 19% (Poylazoglu et al., 2002).

Table 5. Average of physical traits of the fruits of the nineteen cultivars studied

Cultivar	Fruit								
	WFr	DFr	HFr	DCa	Hca	NbrSp	WEn	TEc	Yju
Sefri	436.20^{a}	94.39^{b}	99.58^{b}	23.99^{cd}	18.29^{bc}	6.85^{abcdef}	173.98^{b}	3.95^{ab}	36.55^{c}
Grenade Jaune	356.47^{b}	87.75^{de}	89.91^{defg}	20.71^{fgh}	15.23^{fgh}	6.40^{gh}	130.41^{cde}	3.18^{def}	42.29^{bc}
Bzou	352.92^{b}	89.09^{bcd}	91.39^{cdef}	19.76^{ghi}	15.72^{efg}	6.41^{gh}	122.98^{def}	3.03^{efg}	44.71^{bc}
Ounk Hmam	351.22^{bc}	85.33^{def}	92.67^{cd}	25.78^{b}	22.04^{a}	7.11^{a}	104.00^{fgh}	2.42^{ij}	40.66^{bc}
Chioukhi	334.19^{bcd}	87.91^{de}	93.55c	25.11^{bc}	17.78^{cd}	6.52^{fgh}	148.32^{c}	2.94^{efgh}	39.01^{bc}
Djeibi	332.52^{bcd}	84.87^{ef}	89.70^{efg}	19.65^{ghi}	13.26^{e}	6.91^{abcde}	99.51^{gh}	2.40^{ij}	47.75^{bc}
Grenade rouge	325.61^{bcde}	88.11^{cd}	89.22^{fg}	21.49^{ef}	14.83^{gh}	6.57^{efgh}	121.66^{ef}	2.85^{fghi}	39.17^{bc}
Wonderful	320.84^{cde}	86.49^{def}	92.68^{cd}	19.52^{ghi}	16.36^{ef}	6.02^{ig}	142.48^{cd}	3.63^{bcd}	39.04^{bc}
Gordo de Jativa	306.51^{def}	83.89^{ef}	85.08^{h}	18.97^{i}	15.48^{efgh}	6.57^{defgh}	83.62^{hi}	1.92^{k}	51.77^{a}
Djebali	305.42^{def}	86.11^{def}	84.08^{hi}	23.50^{cd}	14.52^{ghe}	7.03^{abc}	126.86^{de}	3.38^{cde}	37.97^{c}
Dwarf semi-Evergreen	299.52^{efg}	83.84^{ef}	92.12^{cde}	22.60^{de}	18.04^{cd}	7.08^{ab}	129.74^{cde}	3.77^{abc}	41.43^{bc}
Ruby	277.60^{fgh}	81.59^{fg}	87.97^{g}	21.44^{ef}	16.28^{ef}	6.74^{bcdefg}	124.07^{def}	3.35^{cde}	42.99^{bc}
Mollar Osin Hueso	275.35^{fgh}	81.93^{fg}	83.14^{hij}	19.17^{hi}	13.19^{e}	6.50^{fgh}	97.52^{ghi}	2.56^{hij}	45.14^{bc}
ZhérieAutumn	273.19^{gh}	75.87h	81.17^{j}	21.10^{efg}	14.47^{ghe}	6.45^{gh}	96.09^{hi}	3.25^{def}	44.35^{bc}
Zhérie precoce	250.33^{h}	80.72^{gh}	81.94^{ij}	19.89^{fghi}	14.68^{gh}	6.72^{cdefg}	78.28^{i}	2.58^{hij}	47.70^{bc}
Khikhou	463.13^{a}	99.26^{a}	106.24^{a}	29.39^{a}	19.58^{b}	6.59^{defgh}	251.96^{a}	4.21^{a}	37.91^{c}
Negro Monsteriosa	317.50^{de}	85.97^{def}	89.94^{defg}	20.35^{fghi}	14.19^{he}	5.87^{g}	124.40^{def}	2.97^{efgh}	42.04^{bc}
Sefri 2	353.51^{b}	85.70^{def}	89.73^{efg}	19.07^{i}	14.80^{gh}	6.2^{7hi}	118.11^{efg}	2.37^{j}	46.09^{bc}
Chelfi	214.94^{i}	74.57^{h}	78.35^{k}	21.50^{ef}	16.73^{de}	6.92^{abcd}	84.11^{hi}	2.71^{ghig}	38.71^{bc}
Minimum	214.94	74.57	78.35	18.97	13.19	5.87	78.28	1.92	36.55
Maximum	463.13	99.26	106.24	29.39	22.04	7.11	251.96	4.21	51.77
Average	323.52	85.44	89.39	21.74	16.08	6.61	124.11	3.02	42.44
Standard Deviation	58.38	5.62	6.55	2.76	2.25	0.34	39.24	0.60	4.19
CV%	25.53	28.90	8.29	19.47	23.58	13.57	25.24	23.91	16.10

Note: **WFr** - Weight (g); **DFr** - Fruit diameter (mm); **HFr** - Fruit height (mm); **DCa** - Calyx diameter (mm); **HCa:** Calyx height (mm); **NbrSp:** Number of sepals; **WEn:** Weight of rind + endocarp (g); **TEc:** Rind thickness (mm); **YJu** - Juice/fruit yield (%)

Table 6. Average of physical characterization of the arils and seeds of nineteen cultivars studied

Cultivar	Arils				Seed	
	Weight of Arils (mg)	Length of Arils (mm)	Width of Arils (mm)	Aril yield (%)	Weight of seeds (g)	Seed/fruit yield (%)
Sefri 2	484.59^{b}	11.67^{c}	8.15^{b}	55.70^{j}	45.03^{ab}	10.16^{f}
Grenade Jaune	354.13^{h}	10.96^{ef}	7.04^{g}	63.27^{fghi}	44.66^{abc}	11.52^{bcd}
Bzou	389.83^{ef}	11.22^{e}	7.59^{de}	65.84^{def}	43.12^{bc}	11.39^{cde}
Ounk Hmam	266.98^{l}	9.71^{i}	6.24^{h}	65.66^{defg}	38.18^{cde}	11.99^{bc}
Chioukhi	473.67^{bc}	11.81^{cd}	8.01^{bc}	59.81^{i}	38.99^{bcde}	10.10^{fg}
Djeibi	403.06^{e}	11.13^{e}	7.44^{ef}	71.28^{ab}	43.92^{bc}	12.44^{bc}
Grenade Rouge	377.98^{fgh}	10.69^{f}	7.45^{ef}	62.29^{ghi}	41.87^{bcd}	12.05^{bc}
Wonderful	306.01^{ij}	10.15^{gh}	7.04^{fg}	59.97^{i}	41.76^{bcd}	11.88^{bcd}
Gordo de Jativa	387.35^{efg}	12.03^{bc}	7.77^{cde}	73.34^{a}	51.02^{a}	16.08^{a}
Djebali	293.99^{jk}	9.88^{hi}	6.99^{g}	60.90^{hi}	39.13^{bcde}	12.68^{b}
Dwarf semi-Evergreen	363.09^{gh}	10.76^{f}	7.64^{de}	61.44^{hi}	31.2^{4fg}	8.98^{gh}
Ruby	371.88^{fgh}	11.11^{de}	7.80^{cd}	60.56^{hi}	33.59^{efg}	9.78^{fg}
Mollar Osin Hueso	442.40^{d}	12.03^{bc}	8.16^{b}	62.04^{hi}	30.20^{fg}	9.78^{fg}
Zhérie Autumn	456.09^{cd}	12.00^{bcd}	7.84^{bcd}	68.12^{bcd}	31.26^{fg}	10.30^{ef}
Zhérie precoce	311.12^{ij}	12.17^{b}	8.01^{bc}	70.29^{abc}	28.62^{g}	10.05^{fg}
Khikhou	670.42^{a}	12.70^{a}	9.23^{a}	50.65^{k}	41.81^{bcd}	7.87^{h}
Negro Monsteriosa	321.07^{i}	10.71^{f}	7.15^{fg}	63.90^{efgh}	41.43^{bcd}	12.06^{bc}
Sefri 2	380.49^{efg}	11.18^{e}	7.44^{ef}	67.21^{cde}	36.08^{def}	10.16^{f}
Chelfi	280.82^{kl}	10.24^{g}	7.00^{g}	66.51^{def}	30.66^{fg}	12.22^{bc}
CV%	15.21	7.26	9.94	9.44	25.42	16.10
Minimum	266.98	9.71	6.24	50.65	28.62	7.87
Maximum	670.42	12.7	9.23	73.34	51.02	16.08
Average	386.05	11.17	7.58	63.62	38.56	11.13
Standard Deviation	93.82	0.83	0.63	5.44	6.21	1.78

The maximum value of titrable acidity was found for cv. 'Negro Monsteriosa' (2.87%) and the minimum for cv. 'Grenade Rouge' (0.37%). Consumers prefer high sweetness and moderate to low acidity and the juice production industry tolerates sour fruits (Mayuoni-Kirshinbaum and Porat, 2014). Pareek et al., (2015) classified pomegranate varieties with acidity < 1% as sweet, 1.2% sweet–sour and > 2% sour. According to this classification we find that the cultivars 'Grenade Rouge', 'Zehri precoce', 'Grenade Jaune', 'Gordo de Jativa', 'Sefri' and 'Djebali' are the sweetest and 'Wonderful', 'Sefri 2' and 'Negro Monsteriosa' are the sourest.

Significant variability was found for the maturity index (MI) between cultivars. The Brix/acid ratio was the highest in 'Zehri precoce' (56.75) and the lowest in 'Sefri 2' (8.87). This high variability was also found in Californian pomegranate cultivars (Chater et al., 2018) and (Iranians Akbarpour et al., 2009) cultivars with indices 4.6 - 47.4 and 5.57 - 50.24 respectively. This maturity index is used commonly for the classification of pomegranate varieties between sour and sweet (Martínez et al., 2012). However, this factor is closely related to environmental conditions and the varietal types, and it requires precisions in its use (Mayuoni-

Kirshinbaum and Porat, 2014; Martínez et al., 2012). The pH is also used to determine the level of acidity in taste. The pH ranged from 2.79 'OunH' to 3.78 'Bzou' and the findings of this research are similar to average (3.34) reported by Mustafa Ozgen et al., (2008) but lower than the values of the study of Akbarpour et al., (2009).

Table 7. Average of chemical parameters of the elaborated juices of the nineteen cultivars

Cultivars	pH	Total soluble solids (%)	Titratable acidity (%)	Maturity index
Sefri	3.44^{cd}	16.98^{ab}	0.53^{cde}	53.32^{bc}
Grenade Jaune	3.66^{ab}	17.81^{a}	0.40^{de}	63.75^{a}
Bzou	3.78^{a}	16.04^{bc}	0.87^{c}	28.84^{hi}
Ounk Hmam	2.79^{f}	15.67^{cd}	0.64^{cde}	52.48^{bcd}
Chioukhi	3.30^{de}	16.34^{bc}	0.60^{cde}	41.54^{fg}
Djeibi	3.37^{cd}	16.39^{bc}	0.84^{c}	35.48^{gh}
Grenade rouge	3.52^{bc}	16.27^{bc}	0.37^{e}	55.72^{bc}
Wonderful	3.41^{cd}	17.63^{a}	1.61^{b}	45.78^{def}
Gordo de Jativa	3.67^{ab}	14.55^{de}	0.51^{cde}	50.63^{bcde}
Djebali	3.43^{cd}	16.44^{bc}	0.58^{cde}	49.19^{cde}
Dwarf semi-Evergreen	3.28^{de}	15.54^{cde}	0.70^{cde}	45.51^{def}
Ruby	3.56^{bc}	16.27^{bc}	0.70^{cde}	35.23^{gh}
Mollar Osin Hueso	3.51^{bc}	16.32^{bc}	0.60^{cde}	41.63^{fg}
Zhérie d'Autumn	3.38^{cd}	16.05^{bc}	0.82^{cd}	41.68^{fg}
Zhérie precoce	3.37^{cd}	16.17^{bc}	0.39^{de}	56.75^{ab}
Khikhou	3.53^{bc}	16.14^{bc}	0.67^{cde}	45.14^{ef}
Negro Monsteriosa	3.30^{de}	15.95^{bc}	2.87^{a}	12.72^{j}
Sefri 2	3.16^{e}	14.52^{e}	1.86^{b}	8.87^{j}
Chelfi	3.12^{e}	16.36^{bc}	0.87^{c}	27.45^{i}
CV%	5.66	5.96	48.84	13.94

Note: Values marked with the same letter within the column are not significantly different at $P < 0.05$ level.

Correlation Coefficients

In order to identify relationships between all physicochemical characteristics, all crop years and cultivars were involved in a bivariate correlation using the Pearson model. Correlation coefficient is a statistical measure of the strength of the relationship between two variables. It reflects how similar the measurements of two or more variables are in a data set. Correlated variables can also be used to predict others and could be considered important for the characterization and discrimination of pomegranate genotypes. The correlation coefficients can provide information on the most important traits in assessing genotypes (Norman et al., 2011; Khadivi-Khub & Anjam, 2016). Very highly significant positive and negative ($P < 0.001$) correlations are noted between several variables (Table 8). Several chemical characteristics were found to be significantly correlated with the morphological characteristics of the fruit. Fruit characteristic such as fruit weight (WFr) was positively correlated with calyx diameter (DCa) (r = 0.34***), Fruit height (HFr) (r = 0.79***), weight of rind + endocarp (WEn) (r = 0.82***), rind thickness (TEc) (r = 0. 39***), and weight of seeds (WSe) (r = 0.67). Fruit diameter (DFr) was positively correlated with WEn (r = 0.79***), TEc (r = 0.43***), WSe (r = 0.54***). DCa was positively correlated with HFr (r = 0.39***), calyx height (HCa) (r = 0.22***), number of sepals (NbrSp) (r = 0.26***), WEn (r = 0.47***), rind thickness TEc (r = 0. 33***), aril weight (WAr) (r = 0.12**), and negatively with aril yield (YAr) (r = -0.40***), seed/fruit yield (YSe) (r = -0.25***), Juice/fruit yield (YJu) (r = -0.12*) and juice/fruit yield (LAr) (r = -0.08*). HFr was positively correlated with HCa (r = 0.43***), NbrSp (r = 0.08**), WEn (r = 0.73***), TEc (r = 0.33***), WSe (r = 0.41***) and WAr (r = 0.3***), and negatively correlated YAr (r = -0.34***), YSe (r = -0.17***) and HCa was positively correlated with NbrSp (r = 0.1**), WEn (r = 0.15**), but negatively correlated with YAr (r = -0.21***), aril length (LAr) (r = -0.1**) and pH (r = -0.21**). NbrSp was positively correlated with WEn (r = 0.11*), TEc (r = 0.11*). WEn was positively correlated with TEc (r = 0.64***), WSe (r = 0.36***), WAr (r = 0.36***), aril width (WdAr) (r = 0.10*) at pH (r = 0.27**) total soluble solids (TSS) (r = 0.21*). However, it was negatively correlated with YAr (r = -0.68***) and YSe (r = -0.30***). TEc was positively correlated with pH (r = 0.32***) and TSS (0.36***). WSe was positively correlated with YSe (r = 0.61***) and maturity index (IM) (r = 0.33***) and negatively correlated with aril width (WdAr) (r = -0.27***), aril yield 'YAr' was positively correlated with YSe (r = 0.47***), but negatively correlated with WAr (r = -0.21***), pH (r = -0.35***) and TSS (r = -0.31***). YSe was negatively correlated with WAr (r = -0.32***), LAr (r = -0.22***), and WdAr (r = -0.38***). YJu was positively correlated with WdAr (r = 0.11*). WAr was positively correlated with LAr (r = 0.52***), WdAr (r = 0.41***) and pH (r = 0.30***). LAr was positively correlated with WdAr (r = 0.46***), pH (r = 0.19*), IM (r = 0.17*), and negatively correlated with titratable acidity (AT) (r = -0.23**). WdAr was negatively correlated with IM (r = -0.38***), and TSS (r = -0.31***). Our results have also shown that the pH is positively correlated with TSS (r = 0.33***) and IM (r = 0.22**). TSS was correlated positively with IM (r = 0.55***). It was also correlated negatively with AT (r = -0.16*). AT was negatively correlated with IM (r = - 0.62***). Estimating the correlation between morphological traits could provide information that will help breeders determine the most efficient design for genotype evaluations (Tancred et al., 1995). Correlation estimates also allow comparison of indirect versus direct selection, computation of a correlated response in a second trait if selection pressure is applied to the first, and establishment of a selection strategy in case of difficulties to select for traits (Falconer and Mackay, 1996). In this respect, correlation coefficients for some pomegranate fruit parameters have been reported, such as skin thickness positively correlating with calyx diameter and the fruit weight with fresh and dry aril weight (Zamani et al., 2006). In our study, WFr was positively correlated with DCa (r = 0.34***), HFr (r = 0.79***), WEn (r = 0.82***), TEc (r = 0. 39***) and IM (r = 0.21**), and negatively correlated with YAr (r = -0.17***). Sarkhos et al., (2006) recorded that the anthocyanin content of arils was negatively correlated with fruit size in some Iranian pomegranate genotypes. Karimi and Mirdehghan, (2013) also postulated that fruit juice, arils and seeds characteristics were the main factors that separated the studied pomegranate genotypes. Karimi et al., (2013), showed that the number of seeds in the fruit was correlated with fruit length (r = 0.74). Calyx diameter was positively correlated with fruit weight (r = 0.74). Our results have shown that pH correlates positively with TSS (r = 0.33***) and IM (r = 0.22**). Karimi et al., (2013), showed that fruit characteristics such as AT (r = +0.89) were positively correlated with chlorophyll index, vitamin C (-0.78) and juice pH (r = -0.72). Morphological and biochemical traits seem to have attracted particular substantial interest, as some of them can be used to predict each other based on correlations. Additionally, they can provide information on relationships between variables, which are potentially important for evaluating pomegranate genotypes. The study of plant material based on phenotypic traits is important for maintaining existing genetic variability, managing genetic resources and establishing a germplasm collection (Podgornik et al., 2010).

Principal Components Analysis

There is no detailed work on the influence of age or harvest years of pomegranate varieties. A multivariate analysis was performed using the 10 most discriminating parameters of the mixture of chemical and morpho-agronomic traits for fruits belonging to cultivars of different ages (Fig. 2).

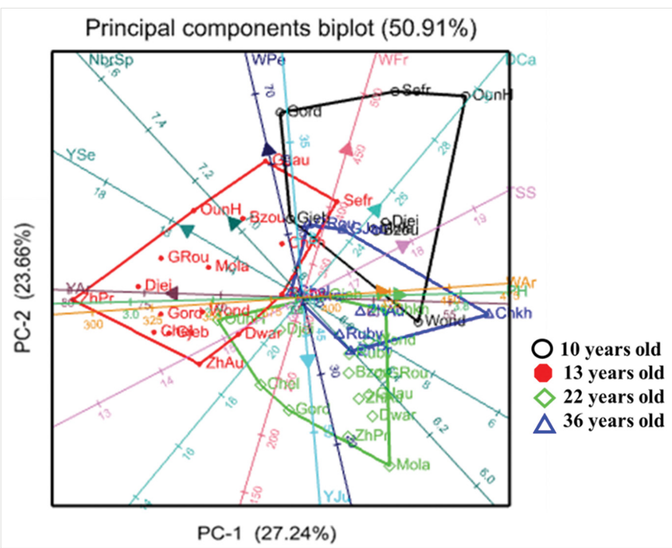

Figure 2. Scatterplot of the first two principal components (PC1/PC2, 50.91% of total variance) for the pomegranate collection studied, based on the most discriminating parameters

The principal component analysis (PCA) drew a graph with a dispersion of genotypes according to the age of the trees. Table 9 shows the contribution of each parameter from the plot of each component. The first principal component (F1) represents 27.24% of the total variance, the second principal component (F2) represents 23.66% and the total of the two axes is 50.9%. The first component is essentially constituted by the positive contribution of the parameters pH and TSS, but with a negative contribution from seed yield and aril yield. The second component is essentially traced by the positive contribution of the parameters fruit weight and seed weight and negatively by the juice yield. The third component is essentially traced by the negative contribution by the calyx diameter.

The analysis of the graph shows groupings of cultivars according to the age of the trees. This structure confirms the effect of tree age on the physicochemical quality of pomegranate fruits. However, the level of variation differs among genotypes. For example, cvs. 'Ruby', 'Dwarf Semi-Evergreen' and 'Wonderful' have relatively stable characteristics between years while cvs. 'Ounk Hmam' and 'Gordo de Jativa' have more variable characteristics. In this context, it can be deduced that that the parameters of the fruit harvested in 2017 (10 and 36 years) are closer to those harvested in 2009 (13 years) and that the fruit of the harvest year 2018 (22 years) is closer to 2009 than 2017. The lower level of variance that was estimated between the fruits harvested in 2009 and 2017, is probably due to the similarity of climate between these two years. The average temperatures (Fig. 1) of the critical months of the fruits (flowering period) were 22.3 °C and 23.7 °C respectively, compared with 2018 where the average temperature was 20 °C. Oukabli et al., (2004), describe that flowering period to fruit maturity (April to the end of September) corresponding to the stage of high cell division is very sensitive to environmental changes. It should be noted that the rainfall was not mentioned because the plots underwent controlled irrigation at 100% of the tree's needs.

Cluster Analysis

Hierarchical cluster analysis based on physicochimical characters perfectly illustrates the great genetic diversity between the pomegranate accessions in the collection. Dendrogram allows to put the accessions into two main groups (A et B) which are also subdivided into several subgroups (Fig. 2). The local genotype ' Khikhou ' has been categorized as a distinct group, with a typical profile. This cultivar is distinct in terms of diameter, weight, height of the fruit diameter of the calyx, weight of the rind, length and width of the aril.

Cluster A is distinguished into two subgroups. The first A-1 is made up of 4 Moroccan cultivars ('Bzou', 'Grenade Jaune', 'Chioukhi' and 'Sefri') and the American cultivar 'Wonderful'. These genotypes are characterized by higher sugar content and similar seed yield. Subgroup A-2 consists of a Moroccan cultivars and the United States variety 'Dwarf semi-Evergreen', characterized by a lower seed yield, similar sugar content and juice yield.

Cluster B is distinguished into 3 subgroups. The first (B-1), characterized by lower fruit weight and height, includes 3 Moroccan cultivars, 4 foreign varieties (2 Tunisian, 1 Chinese and 1 USA). Subgroup B-2 consists of a Moroccan cultivar ('Djeibi') and a Spanish cultivar (Gordo de Jativa) characterized by a higher juice yield for a lower rind thickness. The last subgroup (B-3) includes the Spanish variety 'Negro Monsteriosa' and the Moroccan genotype 'Sefri 2' characterized by the acidity of these fruits and similar fruit diameters.

Table 8. Correlation between agro-morphological and physicochemical traits of the evaluated pomegranate genotypes

	WFr	DFr	DCa	HFr	HCa	NbrSp	WEn	TEc	WSe	YAr	YSe	YJu	WAr	LAr	WdAr	pH	TSS	AT	IM
WFr	1.00000																		
DFr	0.03802	1.00000																	
	0.1934																		
DCa	0.34528	0.01232	1.00000																
	<.0001	0.6703																	
HFr	0.79471	0.03229	0.38838	1.00000															
	<.0001	0.2638	<.0001																
HCa	0.02228	-0.00662	0.22064	0.42678	1.00000														
	0.4463	0.8189	<.0001	<.0001															
NbrSp	0.14276	-0.01513	0.26060	0.08250	0.10192	1.00000													
	<.0001	0.6308	<.0001	0.0087	0.0012														
WEn	0.81871	0.78596	0.47157	0.73022	0.14827	0.10676	1.00000												
	<.0001	<.0001	<.0001	<.0001	0.0019	0.0279													
TEc	0.38927	0.43303	0.32683	0.32911	0.02827	0.10724	0.63868	1.00000											
	<.0001	<.0001	<.0001	<.0001	0.5597	0.0287	<.0001												
WSe	0.66837	0.54446	0.00620	0.40668	-0.08901	0.10344	0.36499	0.10996	1.00000										
	<.0001	<.0001	0.9104	<.0001	0.1055	0.0654	<.0001	0.0516											
YAr	**-0.17256**	**-0.26363**	**-0.39820**	**-0.34078**	**-0.20936**	-0.01202	**-0.67881**	**-0.63411**	0.19477	1.00000									
	0.0003	**<.0001**	**<.0001**	**<.0001**	**<.0001**	0.8054	**<.0001**	**<.0001**	0.0004										
YSe	-0.08455	**-0.12254**	**-0.24571**	**-0.17001**	-0.09441	0.01724	**-0.30311**	**-0.29316**	0.61284	0.46889	1.00000								
	0.0994	**0.0166**	**<.0001**	**0.0008**	0.0653	0.7416	**<.0001**	**<.0001**	<.0001	<.0001									
YJu	-0.07745	-0.05583	**-0.12479**	0.01109	0.05534	-0.05222	-0.09516	-0.03083	-0.07007	0.07435	-0.01029	1.00000							
	0.1134	0.2542	**0.0106**	0.8210	0.2583	0.2938	0.0533	0.5392	0.2063	0.1319	0.8432								
WAr	0.28344	0.29866	0.11674	0.29194	0.03538	0.06094	0.35829	0.16439	0.00572	**-0.20640**	**-0.31617**	0.05326	1.00000						
	<.0001	<.0001	0.0048	<.0001	0.3939	0.2115	<.0001	0.0008	0.9181	**<.0001**	**<.0001**	0.2796							
LAr	0.01391	0.04191	-0.08006	-0.02515	**-0.09689**	0.02612	0.01424	0.02785	-0.09789	0.03674	**-0.21672**	0.02378	0.52004	1.00000					
	0.6881	0.2209	0.0193	0.4626	**0.0046**	0.4955	0.7711	0.5735	0.0804	0.4538	**<.0001**	0.6340	<.0001						
WdAr	**-0.07056**	-0.01783	-0.02347	0.02330	0.01119	-0.04737	0.10385	0.05378	**-0.26762**	**-0.16820**	**-0.37950**	0.11442	0.41445	0.45964	1.00000				
	0.0415	0.6024	0.4932	0.4960	0.7436	0.2163	0.0334	0.2767	**<.0001**	**0.0006**	**<.0001**	0.0216	<.0001	<.0001					
pH	0.08677	0.11918	-0.02145	-0.02004	-0.20724	-0.15394	0.26875	0.32132	0.06354	**-0.35454**	-0.10277	0.10919	0.29629	0.19441	-0.00177	1.00000			
	0.2663	0.1262	0.7838	0.7977	0.0074	0.0583	0.0023	0.0002	0.5037	**<.0001**	0.2766	0.2312	0.0004	0.0154	0.9825				
TSS	0.08655	0.20515	0.02656	0.06640	-0.09862	-0.11671	0.21344	0.35927	-0.00203	**-0.31373**	-0.05865	-0.09991	0.08076	0.08912	**-0.30674**	0.33177	1.00000		
	0.2646	0.0076	0.7326	0.3925	0.2034	0.1494	0.0156	<.0001	0.9829	**0.0003**	0.5335	0.2715	0.3446	0.2686	**<.0001**	<.0001			
AT	-0.08895	-0.08572	-0.01149	0.00243	-0.02254	-0.12813	0.03131	-0.02512	-0.15525	-0.09156	-0.17623	0.06866	-0.12760	**-0.23144**	0.06727	-0.10157	**-0.16320**	1.00000	
	0.2530	0.2707	0.8829	0.9751	0.7725	0.1145	0.7268	0.7801	0.1006	0.3060	0.0607	0.4524	0.1358	**0.0038**	0.4056	0.1929	**0.0351**		
IM	0.20779	0.25591	0.02159	0.07616	-0.14981	0.01463	0.09001	0.21284	0.33513	0.04564	0.28538	-0.11674	0.02847	0.17034	**-0.38538**	0.22217	0.55069	**-0.62302**	1.00000
	0.0070	0.0008	0.7818	0.3279	0.0533	0.8576	0.3143	0.0167	0.0003	0.6104	0.0021	0.2003	0.7403	0.0341	**<.0001**	0.0040	<.0001	**<.0001**	

Note: Values written in bold are statistically significant at $P < 0.05$ level; **WFr:** Weight (g); **DFr:** Fruit diameter (mm); **DCa:** Calyx diameter (mm); **HFr:** Fruit height (mm); **HCa:** Calyx height (mm); **NbrSp:** Number of sepals; **WEn:** Weight of rind + endocarp (g); **Tec:** Rind thickness (mm); **WSe:** Weight of seeds (g); **YAr:** Aril yield (%); **YSe:** Seed/fruit yield (%); **YJu:** Juice/fruit yield (%); **WAr:** Aril weight (mg); **LAr:** Aril length (mm); **WdAr:** Aril width (mm); **AT:** Titratable acidity; **TSS:** Total soluble solids % ; **IM:** Maturity index.

Table 9. Correlation of physicochemical parameters with the first three components of PCR analysis

Parameters	Components		
	1	2	3
Aril weight (mg)	0.29959	0.02059	0.39922
Calyx diameter (mm)	0.27908	0.33574	**-0.50401**
Number of sepals	-0.26212	0.28590	-0.37070
pH	0.36601	0.00918	0.42096
Total soluble solids (%)	0.38244	0.19970	0.12814
Weight (g)	0.16994	**0.56670**	0.02920
Weight of seeds (g)	-0.13137	**0.56492**	0.30828
Aril yield (%)	**-0.49336**	0.01561	0.24201
Juice/fruit yield (%)	0.01983	-0.23895	0.13361
Seed/fruit yield (%)	-0.43987	0.25987	0.28851

The great divergence between the two Moroccan accessions 'Sefri' and 'Sefri 2' shows that they are very distant genetically and that this naming similarity can be due to problems of varietal confusion, homonymy problems or labelling problems during prospecting.

The dendrogram shows the absence of a geographical genetic structure and that the Moroccan cultivars and the foreign varieties mix in the different genetic pools. This finding confirms the results of Ajal et al., (2015) using AFLP and ISSR markers to characterize pomegranate genetic resources in Morocco. As an interpretation, we can deduce that the accessions of the INRA-Morocco pomegranate collection belonging to the different countries originate from the same genetic pools.

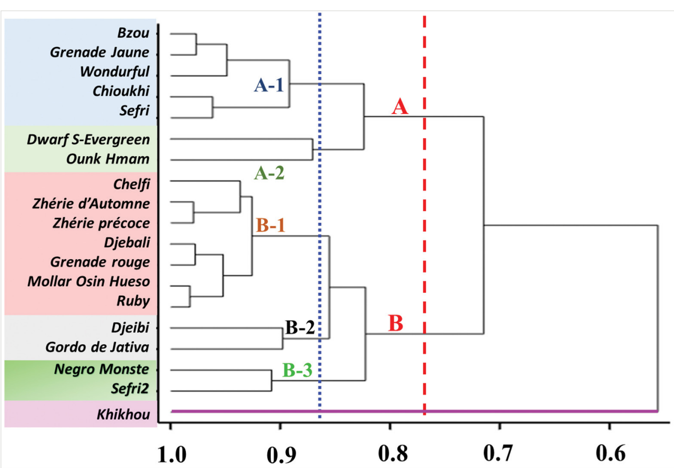

Figure 3. Dendrogram of 19 pomegranate accessions based on squared Euclidean distances calculated on standardized mean physicochemical data across years

Conclusion

The present paper is the first work on the effect of harvest years on a large germplasm of pomegranate of Moroccan and foreign origin grown in Morocco using a mixture of morpho-agronomic and chemical traits. This study showed large variability in physicochemical traits of fruit and juice traits among 19 pomegranate accessions, which suggests that the collection could be a basis for a breeding program. The characterization showed a great diversity between the cultivars for all the characters studied. The variation is from highly significant to very highly significant for the varietal factor, the year factor and their interactions for most of the traits studied. In comparison of the Moroccan accessions with the foreign varieties, we did not notice the existence of a geographical genetic structuring, which probably shows that the pedigrees are very close genetically.

The data show that the stability of the physicochemical traits between years differs among the genotypes, which gives the possibility of selecting varieties more adapted to climatic changes.

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CRediT Authorship Contribution Statement.

Assia Ejjilania: performing technical work, carrying out laboratory manipulations and writing of first version of manuscript. **Karim Houmanat:** redaction of the first version and performed the review. **Hafida Hanine:** performed the review. **Fatima Gaboun:** performed the statistical analysis. **Ilham Hmid:** made old databases available. **Chems Doha Khalfia:** technical and scientific assistance. **Jamal Charafi:** designed the methodology of the research, provided the technical support for designing and conducting research and contributed writing and reviewing of paper.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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