Exploring the Influence of Cultivar Types on Pomegranate Adaptation: A Comprehensive Study on Physiological, Vegetative, and Biochemical Traits

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Summary

Several studies have consistently underscored the crucial role of environmental conditions and cultivar type as the foremost factors impacting pomegranate adaptation. In this research, the productive potential, fruit biochemical traits, vegetative growth and physiological characteristics of eleven pomegranate genotypes were evaluated under Moroccan conditions. The results showed a highly significant variance among these cultivars across all assessed traits except the stomatal area. Fruit yield, fruit weight and juice content exhibited a wide spectrum, ranging from 21.88 - 79.03 kg tree^{-1}, 429.2 - 288.88 g and 34.06 - 47.27% respectively. However, the chemical composition of the juice revealed considerable fluctuations, with total soluble solids ranging between 13.28 and 17.11 °Brix, titratable acidity varied between 0.24 and 2.25% of citric acid. Biochemically, a discernible dissimilarity manifested among the assayed pomegranate cultivars; with a total sugar content varied between 74.14 and 147.56 g GE L^{-1} and a total phenol content of 0.69 - 3.21 g GAE L^{-1} and antioxidant activity of 27.61 - 67.49% respectively. In addition, the data analysis 'Mollar Osin Hueso' and 'Zheri Precoce' exhibited the highest annual shoot growth and leaf area, respectively, while 'Ounk Hmam' showcased the highest stomatal conductance, in stark contrast to the 'Bzou' cultivar, which registered the lowest value. These findings suggest that the cultivar type was the main factor influencing the fruit yield, the fruit physic-biochemical properties, vegetative and physiological traits in pomegranate trees.

Key words

cultivar, vegetative growth, physiological traits, productive potential, *Punica granatum* L

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Introduction

Pomegranate (*Punica granatum* L.) is regarded as one of the most ancient documented species of consumable fruit crops, probably originated in Iran (Khadivi-Khub et al., 2015). Because of the fruit's antioxidant properties, which contribute to health advantages such as preventing cardiovascular and hypertensive diseases, it contains anticarcinogenic (Suman et al., 2019) antimicrobial (Bikiaris et al., 2020; Peran et al., 2020) and antiatherosclerotic compounds even able to reduce LDL oxidation (Jandari et al., 2020). Pomegranate was planted in Asia, in America and in Mediterranean basin, where the optimal climatic conditions allow a great fruit maturity. However, the pomegranate adaptation to the Mediterranean climatic conditions allowed a wide diffusion in various regions thus originating several local genotypes and cultivars over the centuries (Martinez et al. 2006).

The edible parts of pomegranate fruit which include arils (40%) and seeds (10%) are rich in sugars (10%), pectin, organic acids, vitamins, ascorbic acid and polyphenols (Opara et al., 2009). On the other hand, pomegranate is considered one of the most diversified fruit trees around the world, with more than 1000 cultivars and varieties classified by appearance and properties of tree, fruit and flower (Sarkhosh et al., 2006). However, various reports have shown that not only the abundance of the biochemical compounds in the pomegranate fruits depends on genotype type (Fernandes et al., 2017; Adiba et al., 2021a, 2022), but also the postharvest life and storability vary among different cultivars (Jihad Al-Aslan et al., 2023; Moradinezhad and Ranjbar, 2023). Therefore, the study and recognition of such genetic diversity and its magnitude are crucial to a breeding program. In this sense, the informative value of pomegranate tree germplasms is becoming more and more important for the future conservation and sustainable use of pomegranate genetic resources.

In Morocco, the total production of pomegranate fruit in the 2020-2021 seasons surpassed 117 000 T, spanning across an expansive expanse of 14 121 Ha with an average yield of 11 T/Ha (Adiba et al., 2024). The pomegranate fruit yield has been variable from one locality to another depending on the water resources available. For this reason, the pomegranate growth was concentrated in the Marrakech-Safi (48% of the national production) and the Beni Mellal-khenifra (19%) regions (MAPMDREF 2022).

Despite the existence of diverse pomegranate genotypes cultivated across distinct regions of Morocco, there is a limited amount of published research on the diversity of these cultivars in the available literature. To the best of our knowledge, existing studies on this subject have predominantly focused on physical or biochemical traits. Consequently, our current investigation seeks to address this gap by comprehensively analyzing and comparing the fruit yield and quality, juice biochemical characteristics, vegetative properties, and physiological traits of a collection comprising eleven genotypes. The study spans two consecutive years and aims to assess the significance of the cultivar factor in the adaptation of pomegranate crops to a semi-arid environment.

Materials and Methods

Plant Material and Experimental Station Properties

In this research a total of eleven pomegranate genotypes were examined, encompassing seven Moroccan cultivars: 'Ounk Hmam', 'Djebali', 'Sefri', 'Grenade Rouge', 'Gjeibi', 'Grenade Jaune' and 'Bzou' along with four exotic genotypes initially procured from various countries. 'Zheri Precoce' and 'Zheri Automne' originated in Tunisia, 'Gordo de Jativa' originated in Spain and 'Mollar Osin Hueso' originated in China. The pomegranate trees had been planted 12 years before the study commenced, with a spacing arrangement of 5 × 3 m.

The experiment was carried out in the 2020 and 2021 seasons, at the 'Ain Taoujdate' experimental station (x = 512; y = 371; z = 480 m), Meknes, Morocco, which has a semi-arid environment characterized by warm and arid summer conditions. The average temperature and the amount of rainfall in the experimental station in the growing seasons were 28.65 °C and 1067 mm respectively. The soil is slightly calcareous with a high percentage of clay, a moderate abundance of organic matter, and a functional water reserve of 1.7 mm cm^{-1}. Each cultivar was uniformly fertilized with 100 kg of nitrogen, 60 kg of P_2O_5, and 120 kg of K_2O per hectare and received irrigation totaling 3500 m^3 annually, spanning from May to October. Additional information regarding the features of the orchard can be induced in the accompanying study conducted by Adiba et al. (2021a).

Yield and Fruit Physical Characterizations

During the harvest period in late October, a total of twenty fruits were carefully collected from each of the five experimental trees for each cultivar at their full maturity stage. Subsequently, these fruits were promptly transported to the CRRA-Meknes laboratory for detailed analysis. The selection process involved harvesting fruits from various levels of the trees to guarantee a thorough and representative sample for further examination. The fruits used in the analyses were homogeneous for each cultivar, specifically selected from the second wave to ensure uniformity. The measurements of average fruit weight, rind weights and carpellary membrane weight were conducted utilizing the Sartorius Model BL-600 digital balance, ensuring a precision of 0.001 g. The determination of the fruit yield for each cultivar involved the multiplication of the recorded fruit weight by the respective count of fruits per tree. To ensure the accuracy and reliability of the yield estimate, a representative sample of twenty fruits per tree was selected from the main flowering wave. Measurements of equatorial fruit diameter (ED), fruit length (FL), calyx length (CL) and calyx diameter (CD) were conducted using an electronic digital slide caliper (Mitutoyo, USA).

The determination of the fruit yield for each cultivar involved the multiplication of the recorded fruit weight by the respective count of fruits per tree. Additionally, measurements of equatorial fruit diameter (ED), fruit length (FL), calyx length (CL) and calyx diameter (CD) were conducted using an electronic digital slide caliper (Mitutoyo, USA).

Juice Yield and Characteristics of the Arils and Seeds

Fruit juice yield was determined by applying pressure to 10 pre-weighed fruits from each sample, utilizing a commercial pomegranate juicer. Subsequently, for each cultivar, the remaining sampled fruits underwent manual peeling, and a random selection of 20 arils was made from a thoroughly mixed sample. The weights of both the arils and seeds were ascertained using a precise weighing instrument (Mettler AJ50). Furthermore, measurements for aril width (AW), aril length (AL), seed length (SL) and seed width (SW) were obtained using a digital caliper (Mitutoyo, USA).

Juice Chemical and Biochemical Properties

The examination of juice's chemical composition involved assessing total soluble solids (TSS), pH, titratable acidity (TA) and maturity index (MI), which is expressed by the ratio between the TSS and TA. Indeed, the total soluble solids (TSS), pH and titratable acidity (TA) of juice of each station were examined. The TSS determination was executed employing a digital refractometer (PR-101 ATAGO, Norfolk, VA, USA), meticulously calibrated with distilled water. The quantification of TA, expressed as a percentage of citric acid was affected using a meticulous titration procedure wherein 2 ml of the pomegranate juice underwent titration with 0.1 M sodium hydroxide. The pH of the fruit juice of the three pomegranate cultivars was measured using a pH meter.

However, the biochemical analyses were focused on the investigation of total sugar content, amino acids, anthocyanins concentration, total phenols compounds and antioxidant activity in the juice. In this sense, the total sugar content of the pomegranate fruits was measured using a modified version of the Dubois et al. (1956) method. In this process, 100 µl of pomegranate juice diluted with distilled water at a ratio of 1:100 was combined with 500 µl of phenol and 2.5 mL of sulfuric acid. The mixture was vortexed, allowed to stand for 10 minutes, and then incubated in a water bath at 30 °C for 20 minutes. The absorbance was then measured at 480 nm for both samples and controls. The SSC was expressed as grams of glucose equivalent (g GE) per liter of pomegranate juice.

The total amino acids content was determined following the method by Yemm et al. (1955), with some adjustments. In summary, 50 µl of filtered and diluted juice of pomegranate juice was combined with 0.5 mL of 80% ethanol, 0.5 mL of 0.2 M citrate buffer (pH 5), and 1 mL of ninhydrin-acetone solution. The mixture was incubated at 95 °C for 15 minutes, followed by the addition of 8 mL of distilled water. Absorbance readings were taken at 570 nm using a glycine solution as the standard. The results were expressed as milligrams of glycine equivalent (mg GlyE) per liter of juice.

The total anthocyanin content in the juice samples was measured using the pH differential method, which involved two buffer systems: potassium chloride buffer at pH 1.0 (0.025 M) and sodium acetate buffer at pH 4.5 (0.4 M). The TAC results were reported as milligrams of cyanidin-3-glucoside per liter of pomegranate juice.

The total polyphenolic content was assessed using the Folin–Ciocalteu reagent, with gallic acid solution as the standard. A sample of filtered pomegranate juice (300 µl), diluted at a 1/100 ratio with a methanol-water solution (60:40) was combined with 1.5 mL of Folin-Ciocalteu reagent diluted tenfold. After 8 minutes, 1.2 mL of 7.5% Na_2CO_3 was added and the mixture was incubated in the dark for 90 minutes and absorbance was then recorded at 750 nm. The TPC was expressed as grams of gallic acid equivalent (g GAE) per liter of juice.

The antioxidant activity of pomegranate juice in scavenging the free radical DPPH was assessed following the method outlined by Siano et al. (2016). Specifically, 0.25 mL of the phenolic extract of pomegranate juice was combined with 0.5 mL of a methanolic DPPH solution (6×10^{-6} M). The mixture was thoroughly vortexed and then incubated for 30 minutes in the dark at room temperature. The absorbance at 517 nm was measured using a spectrophotometer. For the negative control, the absorbance of the DPPH in 80% methanol was recorded. The DPPH scavenging effect was expressed as the percentage of DPPH discoloration calculated as follows.

Additional information regarding the methodologies employed can be accessed in the corresponding research conducted by Adiba et al. (2021b).

Vegetative Growth

In mid-July, various growth parameters were assessed for each cultivar, including shoot length, leaves density, leaf area, and concentrations of chlorophylls *a* and *b*. The determination of shoot length involved summing the lengths of twelve branches (two-year-old) per cultivar, identified and tagged from the cardinal directions of the pomegranate trees. To normalize for the inherent variability induced by branch vigor, the cumulative shoot lengths within each branch were transformed into the total shoot length per meter. The assessment of foliage density on the designated shoots entailed the enumeration of leaves within a 10 cm segment of the shoot. The leaf area of the ten most mature leaves per tree was ascertained from shoots of commensurate lengths, employing a leaf area meter (ADC, Bioscientific Ltd).

Chlorophyll concentrations (chlorophylls *a* and *b*) in leaves were determined based on the Singh et al. (1975) method: 5 mg of the pulverized leaf material was stirred with one ml of 80% acetone for 90 min to ensure the extraction of all chlorophyll pigments. Subsequently, the resulting extract underwent centrifugation at 4000 rpm for 15 minutes at 4 °C. The optical density (OD) of the supernatant was then assessed at 645 nm and 663 nm. The calculation of leaf pigments content was performed using a designated formula (2 and 3):

$$\text{Chlorophyll-}a = [12.7\ (OD_{663}) - 2.69\ (OD_{645})] \quad (2)$$

$$\text{Chlorophyll-}b = [22.9\ (OD_{645}) - 4.86\ (OD_{663})] \quad (3)$$

Leaves Stomatal Traits

The stomatal conductance (SC) of pomegranate leaves was assessed at approximately midnight, with measurements conducted on 10 leaves per tree utilizing a portable porometer (type AP4, Delta-T-Devices, UK). The leaf stomatal density was assessed through the utilization of the impression approach, quantified as the stomatal count per leaf area unit (Dennis and Jeffrey, 2009). The removal of the abaxial epidermis from ten leaves per tree was conducted by employing adhesive tape, followed by a meticulous application of nail varnish to the central region. Subsequently, an adhesive transparent tape was utilized to eliminate the thin layer of nail varnish from the leaf surface. The prepared impressions were affixed to a glass slide and meticulously examined beneath a photomicroscope outfitted with a computer attachment. (Micros, Austria). Stomatal density (SD) was assessed by tallying the number of stomata per square millimeter of the leaf. The dimensions of stomatal pore length (SL) and width (SW) were quantified for open stomata. The determination of stomatal area (SA) was carried out utilizing equations (4) and (5).

$$SA = SL \times SW \tag{4}$$

$$SAI = SA \times SD \times SW \tag{5}$$

Leaf proline and content cuticular wax concentration were analyzed as described by Adiba et al. (2023).

Statistical Analysis

The discernible distinctions amidst the pomegranate genotypes were scrutinized through the application of analysis of variance (ANOVA). This statistical method allowed for a comprehensive examination of the variations in vegetative growth, physiological traits and fruit quality across the different cultivars. The Student-Newman and Keuls test (SNK) was conducted to compare trait means among all analyzed traits. SNK is a post-hoc test designed to identify specific differences between individual groups, providing a more detailed understanding of the distinctiveness of each cultivar in terms of the studied parameters. Furthermore, Cluster analysis was employed to identify patterns and groupings within the dataset. This technique helped categorize the tested genotypes based on similarities or dissimilarities in the assessed parameters.

Results and Discussion

Yield and Fruit Physical Traits

The data in Table 1 illustrates the yield and physical characteristics of the eleven pomegranate cultivars. A notable distinction was observed among the pomegranate cultivars across all parameters studied among the various cultivars. Notably, the fruit yield ranged from 21.88 kg tree^{-1} ('Mollar Osin Hueso') to 79.03 kg tree^{-1} ('Ounk Hmam'). According to the productivity classification of pomegranate proposed by Melgarejo, (1993), it seems that the eleven pomegranate cultivars tested in this experiment were classified as follows: 'Ounk Hmam', 'Djebali', 'Grenade Rouge', 'Zheri Precoce', 'Gordo de Jativa' and 'Grenade Jaune' are high productive cultivars (>40 kg tree^{-1}), while 'Sefri', 'Zheri Automne', 'Bzou', 'Gjeibi' and 'Mollar Osin Hueso' are the cultivars with average production (20 - 40 kg tree^{-1}). Similar production levels were observed in four cultivars (ME14, ME15, PTO7 and CRO1) growing in southeastern Spain (Martinez et al., 2006).

The highest fruit weight (FW) was revealed in 'Sefri' and 'Zheri Automne' by a mean value of 429.2 g and the lowest was revealed in 'Gjeibi' (288.88 g). Our values overlap with values reported in several studies of different pomegranate cultivars under different countries' conditions. In this sense, a characterization of 87 pomegranate cultivars growing in Iran reported that the fruit weight of this collection ranged from 69.77 to 341.91 g (Khadivi-Khub et al., 2015), while Tehranifar et al. (2010) induced that the fruit weight of 20 cultivars growing in the same country was ranged between 197 and 315 g. However, under Spain's environmental conditions, the pomegranate fruit weight varied between 333.50 and 464.25 g in seven cultivars (Hernández et al., 2014), between 175.95 and 478.64 g in nine cultivars (Fernandes et al., 2017) and between 286.6 and 507.6 g in an accession of six cultivars (Tozzi et al., 2020). On the other hand, in Italy, the pomegranate fruit weight ranged between 192.6 and 622.3 g in thirteen cultivars (Ferrara et al., 2014) and between 168.9 and 574.9 g in an accession of eight cultivars (Ferrara et al., 2011). In particular, the research in Egypt El-Sese, (1988) and China Liu et al. (1997) reported a high average fruit weight of pomegranate of 604.3 and 659 g for the Manfalouty and Qingpitian cultivars respectively. However, other factors than the cultivar tested may exert a pivotal influence on the variability of pomegranate fruit weight, including pedo-climatic and agricultural conditions (Tehranifar et al., 2010).

In the same time, the lowest (79.01 mm) and the highest (102.93 mm) equatorial fruit diameter (EFD) were observed in 'Gjeibi' and 'Sefri', respectively. Consequently, it can be posited that there exists a profound correlation between the weight of the fruit and its corresponding diameter. As regarding fruit length (FL), a maximum was found in 'Zheri Automne' (95.93 mm) followed by 'Grenade Jaune' (93.86 mm) and 'Gordo de Jativa' (93.74 mm), whereas the lower fruit length was detected in the 'Zheri Precoce' (84.04 mm) and 'Djebali' (85.21 mm). In several previous studies, a wide variation was found in equatorial fruit diameter of pomegranate cultivars that varied between 49.12 mm and 106.3 mm while fruit length ranged between 43.51 mm and 91.2 mm (Ferrara et al., 2011; Martinez et al., 2012; Gadze et al., 2013; Khadivi-Khub et al., 2015).

The calyx length (CL) and calyx diameter (CD), varied greatly among genotypes, from a minimum of 10.636 - 17.41 mm in 'Zheri Automne' and 'Gjeibi', to a maximum of 26.43 - 30.66 mm in 'Ounk Hmam' and 'Zheri Automne' respectively. Martinez et al. (2012) induced that the calyx length and calyx diameter of five cultivars growing in Morocco ranged between 16.81 - 23.3 and 12.4 - 21.93 mm respectively, while Ferrara et al. (2014) noted that the calyx diameter of cultivars obtained from Israel was bigger than the cultivars from Italy, with no significant variations observed in the calyx length of these fruits.

As for skin weight plus the weight of carpellary membranes (SW+CMW), a notable difference was revealed among the cultivars examined. The highest SW+CMW was observed in 'Gordo de Jativa' with an average of 172.1 g, while the lowest SW+CMW was detected in 'Zheri Automne' (89.61 g). These results indicated that the values of fruit skin percentage of the studied cultivars were lower than those reported by Tehranifar et al. (2010).

Juice Yield and Characteristics of the Arils and Seeds

The concentration of fruit juice in pomegranates stands as a crucial factor in the industrial manufacturing of pomegranate products. The juice yield of the eleven genotypes analyzed varied between 34.06 and 47.27% (Table 2). The 'Zheri Precoce' cultivar had the highest juice content value (47.27%). However, the lowest was detected in 'Zheri Automne' and 'Mollar Osin Hueso' cultivars with a mean value of 34.91%.

Table 1. Mean values of the yield and the principal morphological fruit parameters of the eleven pomegranate cultivars in 2020-2021 seasons

Cultivars	Y (kg tree^{-1})	FW (g)	EFD (mm)	FL (mm)	CL (mm)	CD (mm)	SW+CMW (g)
O. Hmam	79.03 ± 8.45^{a}	393.08 ± 39.12^{abc}	93.63 ± 6.56^{bcd}	91.69 ± 5.98^{abc}	26.43 ± 4.43^{a}	23.52 ± 3.59^{bc}	158.62 ± 13.38^{ab}
Djebali	65.72 ± 8.12^{ab}	300.07 ± 28.54^{bcd}	84.44 ± 6.01^{def}	85.21 ± 4.15^{de}	15.57 ± 3.91^{bcd}	24.09 ± 4.89^{bc}	160.75 ± 14.87^{ab}
G. Rouge	52.92 ± 7.98^{bc}	350.65 ± 36.12^{abcd}	89.92 ± 6.23^{bcde}	90.84 ± 5.62^{abc}	14.17 ± 2.51^{bcd}	19.94 ± 3.42^{cd}	135.37 ± 12.25^{bc}
Z. Precoce	50.70 ± 7.44^{bc}	297.30 ± 26.62^{cd}	85.58 ± 6.59^{cdef}	84.04 ± 4.83^{e}	17.20 ± 3.82^{b}	21.49 ± 3.76^{cd}	106.75 ± 10.62^{cd}
G. Jativa	46.52 ± 6.96^{bcd}	354.45 ± 30.45^{abcd}	83.89 ± 5.01^{ef}	93.74 ± 6.45^{ab}	14.99 ± 2.42^{bcd}	19.29 ± 4.55^{cd}	172.1 ± 16.90^{a}
G. Jaune	41.09 ± 6.78^{bcd}	401.25 ± 45.76^{ab}	97.50 ± 5.14^{ab}	93.86 ± 5.48^{ab}	18.09 ± 4.32^{b}	21.35 ± 3.84^{cd}	130.60 ± 13.65^{bc}
Sefri	38.57 ± 4.50^{cd}	429.72 ± 42.50^{a}	102.93 ± 7.92^{a}	87.10 ± 5.72^{cde}	16.54 ± 3.09^{bc}	28.21 ± 4.56^{ab}	159.46 ± 16.43^{ab}
Z. Automne	36.12 ± 5.42^{cd}	412.68 ± 38.45^{a}	94.94 ± 6.72^{abc}	95.93 ± 5.57^{a}	10.63 ± 2.67^{d}	30.66 ± 4.58^{a}	89.61 ± 8.98^{d}
Bzou	34.71 ± 4.42^{cd}	353.41 ± 37.52^{abcd}	91.77 ± 5.56^{bcde}	89.71± 4.92^{bcd}	18.11 ± 3.17^{b}	19.93 ± 4.34^{cd}	130.03 ± 14.76^{bc}
Gjeibi	28.86 ± 3.52^{cd}	288.88 ± 27.79^{d}	79.01 ± 5.89^{f}	86.89± 5.42^{cde}	13.65 ± 3.63^{bcd}	17.41 ± 3.12^{d}	116.07 ± 11.32^{cd}
Mollar O.H	21.88 ± 3.2^{d}	345.57 ± 30.85^{abcd}	86.33 ± 6.14^{cdef}	91.05± 5.40^{abc}	11.55 ± 2.86^{cd}	20.41 ± 4.56^{cd}	106.13 ± 12.54^{cd}

Note: The values followed by the same letter show no statistically significant differences ($P < 0.05$).

Y: Yield; FW: Fruit weight; EFD: Equatorial fruit diameter; FL: Fruit length; CL: calyx length; CD: Calyx diameter; SW+CMW: Skin weight plus weight of carpellary membranes.

Table 2. Mean values of the principal morphological parameters of pomegranate arils of the eleven pomegranate cultivars in 2020-2021 seasons

Cultivar	JC (%)	AY (%)	AW (g)	MAL (mm)	MAW (mm)	SW (g)	MSL (mm)	MSW (mm)
Z. Automne	34.60 ± 4.32^{e}	72.90 ± 6.45^{a}	0.5144± 0.0314^{a}	11.65 ± 3.89^{ab}	7.96 ± 1.21^{abc}	0.0262 ± 0.0032^{e}	6.90 ± 1.029^{abc}	2.60 ± 0.325^{abc}
G. Jativa	46.71 ± 5.12^{ab}	72.66 ± 8.09^{a}	0.3729± 0.0177^{bc}	11.53 ± 3.76^{ab}	7.15 ± 1.13^{cd}	0.0355 ± 0.0032^{cd}	6.97 ± 1.521^{abc}	2.60 ± 0.465^{abc}
Bzou	37.83 ± 5.45^{de}	72.14 ± 8.42^{a}	0.3779± 0.0246^{bc}	10.66 ± 3.52^{bcd}	7.40 ± 1.52^{cd}	0.0400 ± 0.0072^{bc}	7.40 ± 2.352^{ab}	2.46 ± 0.375^{abc}
Gjeibi	42.56 ± 3.12^{bc}	69.37 ± 7.22^{ab}	0.3993± 0.0271^{bc}	10.72± 3.34^{bcd}	6.44 ± 1.15^{de}	0.0419 ± 0.0084^{bc}	7.18 ± 2.575^{abc}	2.29 ± 0.365^{bc}
Z. Precoce	47.27 ± 6.49^{a}	68.26 ± 6.32^{abc}	0.2353± 0.0238^{d}	11.89 ± 3.49^{ab}	7.50 ± 2.06^{bcd}	0.0355 ± 0.0045^{cd}	7.46 ± 1.176^{ab}	2.77± 0.487^{ab}
Mollar O. H	35.23 ± 4.11^{e}	61.10 ± 6.45^{bc}	0.4539± 0.0155^{ab}	12.49 ± 3.45^{a}	8.74 ± 1.43^{ab}	0.0402 ± 0.0079^{bc}	7.28 ± 1.389^{abc}	2.90 ± 0.229^{a}
Sefri	40.19 ± 5.32^{cd}	60.73 ± 5.87^{bc}	0.4173± 0.0243^{bc}	11.56 ± 3.45^{ab}	8.96 ± 1.42^{a}	0.0536 ± 0.0104^{a}	7.53 ± 1.467^{a}	3.03± 0.425^{a}
G. Rouge	42.97 ± 4.82^{abc}	59.91 ± 5.14^{bc}	0.3682 ± 0.0212^{bc}	10.31± 3.43^{cd}	7.04 ± 1.67^{cd}	0.0288± 0.0082^{de}	6.72 ± 1.654^{abc}	2.92± 0.356^{a}
O. Hmam	44.83 ± 4.07^{ab}	59.87 ± 5.56^{bc}	0.2755± 0.0157^{d}	8.96 ± 3.02^{e}	5.23 ± 1.65^{e}	0.0314± 0.0035^{de}	6.46 ± 1.865^{bc}	2.28 ± 0.239^{bc}
G. Jaune	40.18 ± 4.32^{cd}	58.94 ± 5.45^{c}	0.3635± 0.0368^{c}	11.06 ± 4.49^{bc}	6.90 ± 1.87^{cd}	0.0465± 0.0034^{ab}	7.00 ± 1.437^{abc}	2.43 ± 0.276^{abc}
Djebali	44.66 ± 4.96^{abc}	48.32 ± 5.17^{d}	0.2809 ± 0.0253^{d}	9.74 ± 3.35^{de}	6.20 ± 1.22^{de}	0.0276± 0.0076^{de}	6.33 ± 1.325^{c}	2.03 ± 0.123^{c}

Note: The values followed by the same letter show no statistically significant differences ($P < 0.05$).

JC: Juice content; AY: aril yield; AW: Aril weight; MAL: Maximum aril length; MAW: Maximum aril width; SW: Seed Weight; MSL: Maximum seed length; MSW: Maximum seed width.

In comparison with similar previous studies (Fadavi et al., 2005; Tehranifar et al., 2010), the present results suggested some interesting genotypes such as 'Zheri Precoce', 'Gordo de Jativa' and 'Ounk Hmam' which should receive attention in the industrial production of pomegranate juice.

The presented data revealed that the arils yield was divided into cultivars tested on six homogenous groups. The first group was represented by 'Zheri Automne', 'Gordo de Jativa' and 'Bzou', where the highest arils yield value was detected (72.57% on average). However, the last group was represented by the 'Djebali' cultivar with the lowest arils yield (48.32%). The values of arils yield reported in the bibliography consulted are found between 41.1% and 65.9% (Al-Maiman & Ahmad 2002; Tehranifar et al., 2010; Martínez et al., 2012; Hernández et al., 2014). Moreover, the aril weight of the eleven pomegranate fruits ranged from 0.5144 g aril^{-1} in 'Zheri Automne' to 0.2639 g aril^{-1} on average in 'Zheri Precoce', 'Ounk Hmam' and 'Djebali' cultivars. Similar results were reported by Tehranifar et al. (2010) in twenty Iranian pomegranate cultivars (0.241 and 0.596 g aril^{-1}). On the other hand, the study of Zarei et al. (2013) on nine genotypes of pomegranate growing under Iranian conditions reported the lowest aril weight variability (0.242 g aril^{-1} and 0.490 g aril^{-1}). However, Hernández et al. (2014) revealed a high aril weight variation (0.395 to 0.646 g aril^{-1}) of seven pomegranate cultivars growing under Spanish environmental conditions. Thus, the study of the most important cultivar in Turkey (Hicaznar) indicated an average aril weight of 0.3 g/aril (Gözlekçi & Kaynak, 1998). Alternatively, research on Italian cultivars has revealed a variation in mean aril weight, with 'Neirena' cultivar exhibiting the lower end at 0.3 g aril^{-1} and 'Dente di Cavallo' cultivar displaying a higher mean at 0.6 g aril^{-1}, as documented by Barone et al. (2001).

Similarly, the results of the aril dimensions induced a significant difference between the pomegranate cultivars tested. Both maximum aril length and maximum aril width remarked the lowest values in the 'Ounk Hmam' cultivar, by an average of 8.96 and 5.23 mm respectively. However, the longest arils were observed in 'Mollar Osin Hueso' and the widest arils were detected in the Moroccan cultivar 'Sefri' by the values of 12.49 mm and 8.96 mm respectively. The high variability in the aril diameter between the pomegranate cultivars in the previous work was detected in other countries between other pomegranate accessions and the values of aril length and width were in a narrower range to values detected in other Mediterranean countries (Martínez et al., 2012; Hernández et al., 2014).

The seed weights of the eleven pomegranate cultivars examined in this study ranged from 0.262 g ('Zheri Automne') to 0.536 g ('Sefri'). These findings align with results reported in previous research conducted on diverse pomegranate cultivars in various geographic and climatic conditions. In this way, Martínez et al. (2012) reported that the seed weight of six Moroccan cultivars was ranged between 0.031 and 0.048 g. Thus, Tehranifar et al. (2010) induced high seed weight variability (0.021 and 0.59 g) among twenty pomegranate cultivars growing under Iran conditions. Moreover, Martínez et al. (2006) found that the seed weight of five Spanish pomegranate varieties was between 0.041 and 0.061 g. On the other hand, Ferrara et al. (2011) revealed that the mean value of eight Italian pomegranate accessions was 0.022 g, which was lower than the value reported in our studied cultivars.

As shown in Table 2, there are wide variations in maximum seed length (6.333 - 7.53 mm) and maximum seed width (2.03 - 2.95 mm on average) among the studied pomegranate cultivars. In fact, the highest maximum seed length and maximum seed width were revealed in the 'Sefri' cultivar, while the lowest value of maximum seed length and width were detected in the 'Djebali' cultivar. Our data are very similar to recent seed diameter values (6.7 - 7.3 mm and 2.0 - 2.6 mm) reported for five Spanish pomegranate genotypes (Martínez et al., 2006). Martínez et al. (2012) also revealed that the seed length and diameter of a collection of six Moroccan accessions ranged between 11.05 - 13.19 mm and 6.45 - 8.27 mm. Therefore, the last results are higher than the ones presented in this work.

Juice Chemical and Biochemical Properties

The chemical characterization of the eleven pomegranate cultivars tested in the present research varied greatly among genotypes (Table 3). However, the total soluble solids (TSS) varied from a minimum of 13.59 °Brix ('Zheri Precoce' and 'Gordo de Jativa') to a maximum of 17.11 °Brix ('Grenade Jaune'). In comparison with TSS values reported in other scientific works, the results of Ferrara et al. (2014) reported that total soluble solids of thirteen Italian pomegranate genotypes varied between 15.7 and 18.5 °Brix. However, in Spain, the investigation of the nutraceutical characteristics of six pomegranate cultivars indicated that the TSS of this collection was ranged between 14.07 and 18.13 °Brix. Moreover, high values of total soluble solids (16.0 and 19.0 °Brix) were detected in a Turkish pomegranate collection of thirteen cultivars (Poyrazoğlu et al., 2002). Based on the minimum value (14.5 °Brix) provisional reference guideline for the juice of pomegranate fruits proposed by the Association of the Industry of Juice and Nectars (AIJN), it is seen that only 'Zheri Precoce' and 'Gordo de Jativa' did not meet the demand. On the other hand, Alcaraz-Mármol et al. (2017) report that total soluble solids do not undergo high variations and for this reason, they are not used to distinguish and classify the pomegranate varieties.

The highest pH value of the tested pomegranate collection was reported in the 'Grenade Rouge' (4.13) followed by 'Zheri Precoce' (3.96), while the mean pH value of 2.94 was detected in the 'Ounk Hmam' cultivar. The same variability was often detected in various pomegranate collections, including the Mediterranean pomegranate cultivars (Martínez et al., 2012; Ferrara et al., 2014). However, as seen in Table 3, the values of titratable acidity in studied genotypes are ranged from an average of 0.25% of citric acid ('Gjeibi' and 'Grenade Rouge') up to 2.25% of citric acid ('Ounk Hmam'). It is lower than these reported in the Tunisian, Georgian and Iranian pomegranate juice, in which a respective average of titratable acidity of 0.1 - 2.4 g citric acid/100g (Zaouay et al., 2012), 1.5 - 2.97 g citric acid/100g (Rajasekar et al., 2012) and 0.33 - 2.44 g citric acid/100g (Tehranifar et al., 2010) were detected.

The maturity index (MI) was also measured to distinguish and classify the sourness of the eleven pomegranate cultivars tested in this study. The MI values ranged from an average of 6.90 ('Djebali' and 'Ounk Hmam') to 64.61 ('Gjeibi'). The results reported in the literature show that the maturity index in pomegranate juice is cultivar dependent (Alcaraz- Mármol et al., 2017; Tozzi et al., 2020). According to the classification reported by Martínez

Table 3. Mean values of the chemical and biochemical traits of the eleven pomegranate cultivars of 2020 and 2021 seasons

Cultivars	TSS (°Brix)	pH	AT (% of citric acid)	MI	SSC (g GE l⁻¹)	AAC (g GlyE l⁻¹)	TPC (g GAE l⁻¹)	TAC (mg l⁻¹)	AA (%)
G. Jaune	17.11 ± 2.17[a]	3.53 ± 0.91[de]	0.97 ± 0.034[g]	17.60 ± 3.31[d]	147.56 ± 14.82[a]	2.81 ± 0.81[f]	2.25 ± 0.99[d]	185.96 ± 23.54[a]	42.60 ± 5.76[d]
Sefri	16.24 ± 2.54[b]	3.38 ± 0.49[f]	1.60 ± 0.073[c]	10.21 ± 1.92[f]	115.35 ± 11.93[c]	3.05 ± 0.45[f]	2.59 ± 0.92[c]	43.36 ± 4.43[i]	45.05 ± 3.72[cd]
Bzou	15.97 ± 2.87[bc]	3.61 ± 0.83[cd]	1.23 ± 0.073[e]	12.65 ± 3.13[e]	107.53 ± 9.44[d]	4.10 ± 0.36[e]	1.78 ± 0.54[e]	92.33 ± 9.45[f]	52.34 ± 4.54[b]
Gjeibi	15.88 ± 2.33[bc]	3.47 ± 0.34[ef]	0.24 ± 0.032[j]	64.61 ± 12.45[a]	97.99 ± 10.85[e]	4.83 ± 0.89[d]	1.77 ± 0.34[e]	132.98 ± 19.32[d]	52.71 ± 3.81[b]
Mollar O. H	15.50 ± 1.99[cd]	3.68 ± 0.67[c]	1.33 ± 0.074[d]	11.65 ± 3.92[ef]	125.22 ± 13.54[b]	8.93 ± 1.35[a]	3.00 ± 0.89[b]	114.52 ± 12.93[e]	66.42 ± 6.92[a]
Djebali	15.09 ± 2.09[de]	3.19 ± 0.85[g]	2.10 ± 0.064[b]	7.18 ± 1.23[g]	104.37 ± 10.39[de]	3.85 ± 0.76[e]	0.90 ± 0.01[h]	158.21 ± 13.04[c]	34.77 ± 2.83[e]
G. Rouge	15.07 ± 2.12[de]	4.13 ± 0.92[a]	0.26 ± 0.004[j]	57.28 ± 9.23[b]	121.45 ± 15.11[bc]	2.99 ± 0.56[f]	3.21 ± 0.13[a]	171.80 ± 26.46[b]	67.49 ± 4.67[a]
O. Hmam	14.92 ± 2.17[de]	2.94 ± 0.58[h]	2.25 ± 0.085[a]	6.63 ± 1.03[g]	83.98 ± 9.04[f]	1.68 ± 0.43[g]	1.34 ± 0.04[g]	76.80 ± 10.48[g]	36.54 ± 3.98[e]
Z. Automne	14.75 ± 1.65[e]	3.96 ± 0.34[b]	0.83 ± 0.005[h]	17.78 ± 3.92[d]	89.42 ± 8.36[f]	7.81 ± 1.23[b]	1.41 ± 0.02[f]	86.76 ± 12.32[fg]	37.73 ± 4.90[e]
Z. Precoce	13.90 ± 2.01[f]	3.98 ± 0.85[b]	0.64 ± 0.007[i]	21.52 ± 5.56[c]	106.12 ± 12.65[de]	5.96 ± 0.92[c]	0.69 ± 0.01[i]	62.22 ± 7.25[h]	27.61 ± 5.82[f]
G. Jativa	13.28 ± 2.65[f]	3.47 ± 0.76[ef]	1.08 ± 0.023[f]	12.26 ± 2.02[ef]	74.14 ± 8.34[g]	3.71 ± 0.95[e]	3.22 ± 0.65[a]	122.00 ± 13.22[de]	49.71 ± 4.63[bc]

Note: The values followed by the same letter show no statistically significant differences ($P < 0.05$)
TSS: total soluble solids; TA: titratable acidity; MI: maturity index; SSC: Soluble sugar content; AAC: Amino acids content; TPC: Total phenolic content; TAC: Total anthocyanin content; AA: antioxidant activity

et al. (2006), among all the cultivars tested, only 'Ounk Hmam' can be classified as a sour cultivar because it is the only cultivar characterized by an MI value lower than 7. The maturity index has been identified as a preeminent indicator of pomegranate fruit maturity, contingent upon various factors, including climatic conditions and the specific cultivar type (Fawole and Opara 2013).

The mean values of the biochemical properties of the eleven pomegranate juices are shown in Table 3. The highest total sugars concentration was found in 'Grenade Jaune' (147.56 g GE l^{-11}), followed by 'Mollar Osin Hueso' (125.22 g GE l-1), while 'Gordo de Jativa' was characterized by the lowest value (74.14 g GE l^{-1}) followed by 'Ounk Hmam' (83.98 g GE l^{-1}) and 'Zheri Automne' (89.42 g GE l^{-1}). These findings align closely with the results reported by Poyrazoğlu et al. (2002).

Several studies have revealed that the sourness and sweetness of fruit juice are significantly linked to the citric acid concentration (Karadeniz, 2004; Albuquerque et al., 2006). However, in pomegranate juice, the literature showed that the sugar content has also an important role in the determination of the fruit sourness (Hasnaoui et al., 2011).

Data analyses revealed noteworthy variations in the amino acids content of the eleven pomegranate juices among the cultivars tested, with approximate values ranging between 1.68 mg GlyE l^{-1} and 8.93 mg GlyE l^{-1}. On the other hand, high diversity was detected between the cultivars tested on the total anthocyanins content, total phenol content and antioxidant capacity, with the respective values of 0.69 - 3.22 g GAE l^{-1}, 43.36 - 185.96 mg l^{-1}) and 27.61 - 67.49%. Similar conclusions were detected in the other pomegranate collection grown under diverse climatic situations (Tehranifar et al., 2010; Hmid et al., 2017; Tozzi et al., 2020).

Vegetative Growth

The results for shoot length, leaf area, foliage density, chlorophyll-*a*, chlorophyll-*b*, stomatal area, stomatal density and stomatal conductance in all pomegranate genotypes analyzed are given in Table 4. Indeed, distinct variances were observed across all assessed parameters, with the exception of the stomatal area. The average shoot length for the pomegranate cultivars tested varied within the range of 498.36 cm m^{-1} for 'Mollar Osin Hueso' and 64.33 cm m^{-1} for 'Zheri Precoce'. Numerous studies have demonstrated significant disparities in shoot growth among various pomegranate cultivars. These differences predominantly arise from the distinct characteristics inherent in each cultivar, including imbalances in indigenous hormonal levels like cytokinins, variations in chlorophyll pigments content and the crucial role of sucrose in the maintenance of osmotic potential (Yaseen et al., 2009; Singh and Patel, 2014; Liu et al., 2020).

On the other hand, the 'Zheri Precoce' cultivar induced the highest leaf area with an average of 5.98 cm^2 followed by 'Grenade Rouge' with an average of 4.806 cm^2, while the lowest value was reported in 'Gjeibi' and 'Djebali' cultivars with an average of 2.362 cm^2. The 'Bzou' and 'Djebali' cultivars were characterized by the highest mean foliage density of 42.67 and 39.00 leaves per 10 cm of shoot respectively, followed by 'Sefri' and 'Gordo de Jativa' with an average of 34.00 leaves per 10 cm of shoot, while the lowest foliage density was found in 'Mollar Osin Hueso' (25.33 leaves), 'Grenade Jaune' (26.00 leaves) and 'Ounk Hmam' (26.00 leaves). These results were in line with the work of Khattab et al. (2012) which reported values of leaf area between 5.77 and 5.60 cm^2 and foliage density of 22.80 and 22.09 leaves in pomegranate cv. Manfalouty under the Egypt conditions in the 2007 and 2008 seasons respectively.

Table 4. Mean values of the vegetative and physiological traits of the eleven pomegranate cultivars of 2020 and 2021 seasons

Cultivars	SL (cm)	LA (cm^2)	FD (leaves)	Cha (g 100 g^{-1})	Chb (g 100 g^{-1})	SC (mmol m^{-2} s^{-1})	SA (μm^2)	SD (Stomata. mm^{-1})
Mollar O. H	498.36 ± 48.59^{a}	3.439 ± 0.971^{d}	25.33 ± 4.34^{d}	3.18 ± 0.82^{g}	21.13 ± 5.30^{c}	4.02 ± 0.36^{d}	0.979 ± 0.023	512.55 ± 47.38^{bc}
Gjeibi	439.80 ± 41.23^{b}	2.363 ± 0.615^{h}	27.67 ± 5.96^{cd}	6.35 ± 1.73^{c}	11.20 ± 3.48^{g}	5.53 ± 0.45^{bc}	0.833 ± 0.002	522.75 ± 65.05^{bc}
Sefri	387.62 ± 35.39^{c}	3.262 ± 0.720^{e}	34.00 ± 6.71^{b}	5.76 ± 1.60^{d}	13.79 ± 4.28^{e}	3.88 ± 0.23^{de}	1.394 ± 0.054	509.15 ± 52.48^{bcd}
Djebali	307.60 ± 27.16^{d}	2.361 ± 0.418^{h}	39.00 ± 5.48^{a}	5.45 ± 1.23^{d}	12.59 ± 4.54^{f}	3.78 ± 0.22^{de}	0.907 ± 0.003	501.5 ± 48.04^{cd}
G. Jaune	244.86 ± 19.21^{e}	2.666 ± 0.942^{g}	26.00 ± 5.71^{d}	3.80 ± 0.90^{f}	22.55 ± 7.82^{b}	5.27 ± 1.03^{bc}	0.976 ± 0.063	518.5 ± 63.22^{bc}
O. Hmam	241.93 ± 20.74^{e}	3.953 ± 1.211^{c}	26.00 ± 4.81^{d}	8.59 ± 2.82^{a}	12.17 ± 3.39^{f}	6.59 ± 1.97^{a}	0.962 ± 0.038	510.00 ± 59.64^{bcd}
G. Rouge	168.39 ± 13.28^{f}	4.806 ± 1.145^{b}	31.67 ± 6.49^{bc}	4.39 ± 1.65^{e}	18.30 ± 5.02^{d}	3.54 ± 0.38^{de}	1.048 ± 0.028	504.9 ± 54.04^{bcd}
G. Jativa	130.45 ± 12.76^{g}	3.999 ± 1.042^{c}	34.00 ± 6.17^{b}	7.74 ± 1.38^{b}	10.56 ± 1.34^{g}	5.84 ± 1.65^{b}	1.498 ± 0.039	528.7 ± 63.47^{b}
Z. Automne	91.77 ± 11.58^{h}	2.996 ± 0.870^{f}	31.33 ± 5.18^{bc}	8.39 ± 2.02^{a}	18.22 ± 3.28^{d}	4.93 ± 0.27^{c}	1.242 ± 0.049	487.9 ± 38.68^{d}
Bzou	77.88 ± 8.36^{hg}	3.030 ± 1.067^{f}	42.67 ± 7.26^{a}	4.70 ± 1.27^{e}	24.27 ± 5.03^{a}	3.22 ± 0.40^{e}	1.123 ± 0.012	516.8 ± 52.37^{bc}
Z. Precoce	64.33 ± 9.21^{g}	5.981 ± 1.445^{a}	29.33 ± 4.14^{bcd}	4.41 ± 1.04^{e}	12.17 ± 2.28^{f}	4.16 ± 0.34^{d}	0.878 ± 0.015	600.1 ± 58.36^{a}

Note: The values followed by the same letter show no statistically significant differences ($P < 0.05$).

SL: Shoot length; LA: Leaf area; FD: Foliage density; Ch*a*: Chlorophyll (*a*); Ch*b*: Chlorophyll (*b*); SC: Stomatal conductance; SA: Stomatal area; SD: Stomatal density.

As for leaves' chlorophyll pigment concentration, a significant variation was observed among the pomegranate cultivars. Indeed, 'Ounk Hmam' and 'Zheri Automne' were the richest cultivars in chlorophyll (*a*) by an average of 8.49 g 100 g^{-1} of leaves powder, while 'Mollar Osin Hueso' (3.18 g 100 g^{-1}) was detected as the poorest cultivar in chlorophyll-*a*. The Moroccan cultivar 'Bzou' presented the highest chlorophyll-*b* concentration (24.27 g 100 g^{-1}), followed by 'Grenade Jaune' (22.55 g 100 g^{-1}) and 'Mollar Osin Hueso' (21.13 g 100 g^{-1}), while the remaining cultivars ranged from 10.56 to 18.30 g 100 g^{-1}.

The chlorophyll pigment concentration exhibits a robust correlation with the leaves serving as the primary determinant of the verdant coloration inherent to the leaves. It is tasked with transforming water and carbon dioxide into carbohydrates and oxygen through the use of sunlight. Several factors including quantity and quality of light, the volume of water and minerals assimilated, as well as the biochemical metabolites generated within the plant system (Özreçberoğlu et al., 2020). However, in this study, all cultivars' trees were installed in the same orchard and all measured traits were determined in the same year and under the same conditions, which reinforced the idea that all differences in the chlorophyll pigments are due to the cultivar physiological properties.

Differences in stomatal characteristics, including stomatal area, stomatal density and stomatal conductance, were notably observed across various pomegranate genotypes. These stomatal traits played a significant role as key parameters in regulating the water status of the trees and influencing their photosynthetic processes. The stomatal conductance of the pomegranate cultivars tested was found within 3.22 - 6.52 mol m^{-2} s^{-1}. The highest stomatal conductance was observed in 'Ounk Hmam' (6.52 mol m^{-2} s^{-1}) and the lowest was detected in 'Bzou' (3.22 mol m^{-2} s^{-1}). However, no discernible disparity was detected in the stomatal area between the cultivar leaves tested. However, the stomatal density varied greatly among cultivars, from a minimum of 687.09 stomata mm^{-2} ('Zheri Automne') to a maximum of 600.01 stomata mm^{-2} ('Zheri Precoce').

Stomatal properties serve as a prominent indicator for assessing the water status of plants, exhibiting a close correlation with the water potential of leaves. Simultaneously, these stomatal characteristics play a crucial role in orchestrating the reciprocal flow of gases betwixt leaves and the ambient atmosphere. They exert significant influence on a plant's adaptation to varying climatic conditions, contributing to the broader dynamics of global carbon and water cycles. As evidenced by Liu et al. (2018), these traits have far-reaching implications, exerting a substantial impact on the growth of shoots and fruits within the plant. The present conclusions are in parallel to the results found in pomegranate (Parvizi et al., 2016; Pourghayoumi et al., 2017), olive (Guerfel et al., 2009) and apple trees (Massonnet et al., 2007).

Cluster Analysis

Clustering analysis plays a crucial role in the comprehensive assessment of pomegranate collections by allowing researchers to categorize cultivars based on multiple traits simultaneously (Adiba et al., 2021; Hamdani et al., 2022). This approach provides a more holistic understanding of genetic diversity and trait associations, which is essential for effective breeding and conservation strategies. Previous studies have demonstrated the effectiveness of clustering in revealing relationships among pomegranate cultivars, highlighting variations in productivity, growth patterns and biochemical properties (Mena et al., 2011;

Adiba et al., 2021, 2022). By grouping cultivars into distinct clusters, specific genotypes with desirable traits can be identified, facilitating targeted breeding programs and optimizing cultivar selection for different agro-climatic conditions.

The findings from the multivariate analysis of eleven genotypes based on all the treated characteristics are presented in Figure 1. The results reveal three distinct clusters, each representing highly homogeneous groups of the eleven cultivars tested based on their potential productivity, vegetative growth and physiological traits. Cluster CI contained five genotypes, further delineated into two homogeneous subgroups (CI-1 and CI-2). Within the initial subgroup (CI-1), two genotypes, 'Zheri Precoce' and 'Bzou', were distinguished by minimal vegetative expansion, while their foliage exhibited the most elevated stomatal density. The second subgroup (CI-2) was formed by 'Grenade Rouge', 'Gordo de Jativa' and 'Zheri Automne' cultivars, where the highest fruit weight was detected by an average value of 372.59 g and the highest arils yield.

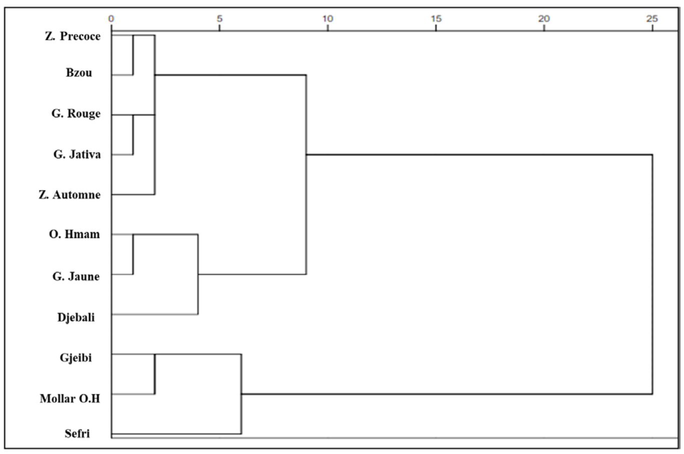

Figure 1. Cluster analysis of the studied pomegranate cultivars based on the measured traits using Euclidean distance

However, their arils had the lowest juice quantity. Biochemically, these cultivars were characterized by the highest total phenol content and the highest antioxidant activity in comparison with the other cultivars tested. The second cluster (CII) included three cultivars, 'Ounk Hmam', 'Grenade Jaune' and 'Djebali' where the highest yield was detected. However, their arils had the lowest weight and dimensions associated with the lowest leaves area and density. The leaves' chlorophyll content analyses reported that these cultivars had high chlorophyll-*a* concentration while the chlorophyll-*b* was medium in comparison with the other pomegranate groups, with respective average values of 5.94 and 15.89 g/100g. On the other hand, 'Gjeibi', 'Mollar Osin Hueso' and 'Sefri' cultivars were characterized by the highest shoot length, low leaf area and leaf density which induced a low fruit yield and fruit weight, form the third group.

Conclusion

In conclusion, the comprehensive investigation into the diversity of the eleven pomegranate cultivars, conducted under Moroccan climatic conditions, has shed valuable light on the multifaceted interplay between cultivar selection and the resultant physiological, vegetative and biochemical traits of pomegranate trees. The bottom line is that, the vast array of variations observed in fruit yield, fruit weight, juice content, biochemical composition, vegetative growth, and physiological traits underscores the pivotal role of cultivar selection in shaping pomegranate cultivation outcomes. The cultivar-specific variations in sugar content, phenolic levels and antioxidant activity further emphasize the potential for tailoring pomegranate products to meet specific market and consumer demands. The distinct vegetative growth patterns and physiological responses displayed by these cultivars illustrate the nuanced interplay between genotype and environmental factors, with 'Mollar Osin Hueso', 'Zheri Precoce', 'Ounk Hmam' and 'Bzou' standing as striking examples of this divergence. This research serves as a valuable resource for pomegranate growers, providing insights into the selection of cultivars best suited for specific ecological conditions and desired product profiles, thereby fostering sustainable and economically viable pomegranate cultivation in Morocco and beyond.

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CRediT Authorship Contribution Statement.

Adiba Atman: performing most of the experiments and writing of first version of the manuscript. **Farid Moradinezhad, Rachid Razouk** and **Said Ezrari:** editing and scientific assistance. **Abdelmajid Haddioui:** contributed to supervision of work and review of the manuscript. **Hakim Outghouliast** and **Anas Hamdani:** contributed to the editing of the manuscript. **Jamal Charafi:** conceptualization, investigation and review of the manuscript.

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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