Research Article

Oil Content, Fatty Acid Composition, Physicochemical Properties, and Antioxidant Activity of Seed Oils of Ten Moroccan Pomegranate Cultivars

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Pomegranate seeds (*Punica granatum* L.) are quantitatively and qualitatively a relevant agri-food by-product which is rich in molecules beneficial to human health. In order to valorize this resource, this study aims to evaluate and to compare, for the first time, the characteristics of fruit seeds and seed oils of ten pomegranate cultivars grown in the Center of Morocco. Physical and biometric parameters of seeds, fatty acid composition, physicochemical criteria, and antioxidant activity of seed oils were determined. The results showed significant differences between the ten studied cultivars. The seeds yielded oil contents ranging from 17.59% to 24.69% and presented high contents of polyunsaturated fatty acids (PUFAs) exceeding 89%. The major fatty acid was punicic acid, which represented more than 80% of fatty acids, while other fatty acids such as linoleic acid, oleic acid, and palmitic acid could be considered a minority. Oils showed yellow colour due to the contents of chlorophyll (0.12–1.87 mg/kg) and pheophytin (0.39–3.87 mg/kg) and presented high antioxidant activity (IC₅₀: 0.69–1.80 mg/mL). Therefore, the studied pomegranate seeds had a very good oil yield, and these oils have presented an optimal fatty acid composition and high levels of antioxidant activity. Thus, they could be useful in the formulation of novel foods or used as preservatives and functional components in food industry.

1. Introduction

Pomegranate (*Punica granatum* L.) is one of the ancient fruit trees of the Punicaceae family that has been cultivated for centuries and highly appreciated for its delicious fruit taste [1]. The pomegranate seeds are quantitatively and qualitatively a relevant agri-food by-product rich in compounds beneficial to human health. The oil contained in pomegranate seeds has attracted increasing interests due to the abundance of conjugated fatty acids; the most important of them is punicic acid, a positional and geometric isomer of α -linolenic acid [2, 3]. The pomegranate seed oil (PSO) is

also a rich source of health-beneficial compounds. It showed high content of phytosterols [3, 4], tocopherols [5], especially γ -tocopherol [3, 5, 6], and phenolic compounds [7]. Phytosterols have the ability to inhibit cholesterol absorption, while tocopherols act as natural preservatives and their presence in seed oils is habitually linked with the relative abundance of unsaturated fatty acids [8]. PSO is shown to acquire antioxidant, antitumor, and anti-inflammatory properties [9]; it also modulates lipid metabolism and has antiobesity properties [10]. Thanks to its medicinal and nutritional properties, the PSO has been considered as a functional ingredient in the food industry [11–13]. In

Morocco, in spite of the evolution of its production, pomegranate is less valued compared to other producer countries. The major production part is marketed locally with low processing and exploitation of by-products [14]. To this end, many efforts are being made to promote this fruit. In the Beni-Mellal/Khenifra region, the “Sefri Ouled Abdellah” cultivar has been labelled as “Protected Geographical Indication (IGP)” within the Green Morocco Plan [15]. Moreover, the pomegranates from four other regions “Ain Lahjar,” “Tmassine,” “Skhour Rhamna,” and “Sour Laaz” have been named as flagship local products [16]. In this context, this study aims to valorize the by-products from the main cultivars in these regions. To the best of our knowledge, the majority of these cultivars were characterized for the first time, especially “Lhamdha,” “Bzeq Tir,” “Marrakchia,” “Lahmer,” “Sefri 1,” “Sefri 2,” “Sefri 3,” “Sefri 4,” and “Sefri 6.” The characteristics of pomegranate seeds and seed oils were evaluated and compared in terms of physical and physicochemical criteria, fatty acid composition, and antioxidant activity. The obtained results will allow us to better evaluate the potential of the PSO to be used as functional or nutraceutical food ingredients.

2. Materials and Methods

2.1. Plant Material. Ten pomegranate cultivars named “Sefri 1” for “Sefri” cultivated in Lalla Takerkoust (Amizmiz region), “Sefri 2” for “Sefri” cultivated in Sour Laaz (El Kelâa Des Sraghna region), “Sefri 3” for “Sefri” cultivated in Tmassine (Settat region), “Sefri 4” for “Sefri” cultivated in Sidi Abdellah (Skhour Rhamna region), “Sefri 5” for “Sefri” cultivated in Ouled Abdellah (Beni-Mellal region), “Sefri 6” for “Sefri” cultivated in Beni Meskine (Settat region), “Lahmar,” “Marrakchia,” and “Lhamdha” cultivated in Ain Lahjar (Essaouira region), and “Bzeq Tir” cultivated in Machraa Ben Abou (Settat region) (Table 1) were harvested in six important production regions in Central Morocco [17]. The numbers 1 to 6 have been assigned in this study to the name “Sefri” to differentiate between the six cultivars. Except for the cultivar “Lhamdha” which is a sour cultivar, the nine others cultivars are sweet. Four fruits per tree were collected at random from the middle of the tree in the four geographical orientations. A total of 32 fruits per cultivar were harvested. Meteorological data were downloaded from the Worldclim dataset (Table 1) [18]. They included precipitation (mm), insolation (hours), and maximum and minimum temperature (°C) from the pomegranate fruit bloom at the middle of April 2018 to pomegranate harvest at the middle of October 2018 [19].

2.2. Biometric and Physical Parameters of Pomegranate Arils and Seeds. Thirty fruits per cultivar were analysed. Each pomegranate fruit was cut in the equatorial zone and peeled and the arils were detached manually. The fruit (FW, g) and arils weights (AsW, g) were evaluated. The seed yield was calculated as the ratio between acquired grams of seed per 100 g of arils sample, and the seed yield per fruit was then deducted (Syf, g/100 g fruit). Twenty-five arils of each

cultivar were randomly selected from a homogeneous sample and evaluated individually for the following parameters: aril weight (Aw, g), seed weight (Sw, g), maximum seed length (Ls, mm), and seed width (Ws, mm). Arils and seeds were weighed with a precision balance. Seed length and width were measured with a digital electronic caliper with an accuracy of 10^{-2} mm. The proportion of the seeds, or seed index (Si), was calculated as follows [20]:

$$Si = 100 \left(\frac{Sw}{Aw} \right). \quad (1)$$

A panel of eight experts from the Regional Center for Agricultural Research in Marrakech evaluated independently the hardness of the seeds using sensory analysis. A numerical scale with 0 represents none and ten represents extremely hard was used [21]. The sensory analysis was carried out in the Sensory Analysis Laboratory of Food Technology and Quality in the INRA, Marrakesh, established in accordance with the general guidelines for premises of sensory evaluation ISO 8589 [22].

2.3. Seed Oil Extraction. Seeds were obtained by pressing arils with a manual press, which keeps them intact. The seeds were washed, air-dried, and ground to a powder by an electric mill (FRITSCH PULVERISETTE 14). Oil was extracted with 250 mL of *n*-hexane from 40 g of seed powder using a Soxhlet extraction system for 6 hours. At the end of the extraction, the solvent was evaporated in a rotary evaporator under vacuum at 30°C. The obtained oils were then flushed with nitrogen to remove the residual traces of hexane and stored in the dark at 4°C. Oil content was expressed in g/100 g of dry matter of seed powder. The analysis was performed in triplicate.

2.4. Physicochemical Parameters of Pomegranate Seed Oils

2.4.1. Colour Coordinates. The colour of the extracted oils was measured and expressed in CIELAB coordinates (L^* , a^* , and b^*) using a Lovibond PFX195 Tintometer. The coordinate “ a^* ” fluctuates from −100 (green) to +100 (red), “ b^* ” from −100 (blue) to +100 (yellow), and “ L^* ” represents the luminosity dimension fluctuating from 0 (pure black) to 100 (white). The chroma (C^*) and hue angle (H^*) have been calculated as follows: $C^* = (a^{*2} + b^{*2})^{1/2}$ and $H^* = \tan^{-1} (b^*/a^*)$ [23]. The analysis was performed in triplicate.

2.4.2. Extinction Coefficients. The specific extinction coefficients K_{232} and K_{270} were determined according to the IOC standard method [24] using a UV visible spectrophotometer (Varian Cary 50 Bio). The absorption at the wavelengths 232 nm and 270 nm is due to the presence, respectively, of conjugated diene and triene compounds resulting from the oxidation processes. The absorptions at these two wavelengths are expressed as specific extinctions $E1\%$ (the extinction of 1% of oil solution in the prescribed solvent in a 1 cm cell) conventionally indicated by K [24].

TABLE 1: Geographic origins and environmental conditions of pomegranate fruits of ten Moroccan cultivars.

Cultivar	Geographic origin	Latitude north	Longitude west	Altitude (m)	Minimum temperature (°C)	Maximum temperature (°C)	Precipitation (mm)	Insolation (h)
Sefri 1	Lalla Takerkoust, Amizmiz	31° 21' 26" N	8° 8' 7" W	619	14.74	29.98	100.24	2443.62
Sefri 2	Sour Laaz, El Kelâa des Sraghna	31° 49' 47" N	7° 1' 52" W	674	15.17	29.89	115.40	2443.62
Sefri 3	Tmassine, Settât	32° 43' 23" N	7° 41' 30" W	357	16.10	30.22	120.77	2456.92
Sefri 4	Sidi Abdellah, Skhour Rhamna	32° 35' 13" N	7° 49' 7" W	286	16.10	30.22	120.77	2456.92
Sefri 5	Ouled Abdellah, Beni-Mellal	32° 29' 42" N	6° 26' 57" W	463	14.08	28.14	34.73	2451.05
Sefri 6	Beni Meskine, El Borouj, Settât	32° 38' 37" N	7° 23' 18" W	543	16.18	30.96	129.00	2456.92
Lahmer	Ain Lahjar, Essaouira	31° 39' 14" N	9° 35' 32" W	97	17.82	23.27	34.73	2442.68
Marrakchia	Ain Lahjar, Essaouira	31° 39' 14" N	9° 35' 32" W	97	17.82	23.27	34.73	2442.68
Lhamdha	Ain Lahjar, Essaouira	31° 39' 14" N	9° 35' 32" W	97	17.82	23.27	34.73	2442.68
Bzeq Tir	Machraa Ben Abou, Settât	32° 38' 47" N	7° 48' 1" W	201	16.10	30.22	120.77	2456.92

2.4.3. Chlorophyll and Pheophytin Contents. The chlorophyll and pheophytin contents (expressed in ppm) were determined by the methods described by Wolff [25] for chlorophyll and by Psomiadou and Tsimidou [26] for α -pheophytin. The fractions of pheophytin and chlorophyll were quantified at the wavelengths 630, 670, and 710 nm using a UV visible spectrophotometer (Varian Cary 50 Bio).

2.4.4. Antioxidant Activity (AA). The antioxidant activity was measured in terms of radical scavenging ability by the free radical 2,2-diphenyl-1-picrylhydrazyl (DPPH) according to Moktan et al. [27]. Elfalleh et al. advocated that this test is the most confined to successfully determine the antioxidant activity of the conjugated linoleic acid isomers [28]. Briefly, pomegranate seed oil was diluted in *n*-butanol to concentrations ranging from 0 to 100 mg/mL. One hundred μ L of the diluted PSO was added to 3 mL of a solution of DPPH. The mixture was shaken instantly and allowed to stand in the dark at room temperature. After 60 min of reaction, the decrease in absorbance was measured at 517 nm with a UV visible spectrophotometer (Varian Cary 50 Bio). The required amount of antioxidant to reduce the DPPH concentration by 50% was calculated (IC50).

2.4.5. Fatty Acid Composition. The fatty acid composition was determined according to the analytical methods described in the IOC standard [29]. Briefly, 0.1 mL of a methanolic solution of potassium hydroxide (2 N) was added to the oil solution (0.1 g) purified in 1 mL of *n*-heptane to prepare the fatty acid methyl esters (FAME). The mixture was shaken vigorously and let to stand until the upper part became clear. The methyl ester mixture was analysed by gas chromatography performed on a Varian CP 3380 with a flame ionization detector equipped with a capillary column

(CP-Wax 52 CB; $L = 30$ m; $\Phi = 0.25$ mm; $Ft = 0.20$ μ m). For the oven, it was applied a temperature programming from 170 to 180°C at 3°C/min and from 180 to 190°C at 1°C/min and then held isothermally for 25 min. The flame ionization detector was maintained at 230°C, while the injector temperature was 220°C. Nitrogen was used as the carrier gas. The fatty acid identification was attained using control fatty acids. For fatty acids quantification, the percentage of each peak (FAx (%)) was calculated as follows:

$$FAx = 100 \left(\frac{Ax}{AT} \right), \quad (2)$$

where Ax is the individual peak area of each FAME and AT is the total area of all FAME peaks that appear in the chromatogram from C14: 0 to C22: 0.

2.4.6. Statistical Analysis. The data obtained were statistically analysed using the SPSS 22.0 statistical database for windows. One-way analysis of variance (ANOVA) for the comparison of means was executed after a basic descriptive statistical analysis. The significance level was taken at $\alpha = 0.01$. Tukey's HSD test was used to perform multiple comparisons among means. Correlation coefficients (r) were determined using the Pearson Correlation Matrix method to reveal possible relationships between traits. The XLSTAT Addinsoft TM software (XLSTAT, 2016) was used to perform the principal component analysis (PCA) and the cluster analysis (CA).

3. Results and Discussion

3.1. Physical and Biometric Parameters of Pomegranate Seeds. The physical and biometric characteristics of pomegranate fruits, arils, and seeds are described in Table 2. The weight means of the fruits and the arils were, respectively, between

TABLE 2: Mean values of physical and biometric parameters of fruits, arils, and seeds of pomegranate fruits of ten Moroccan cultivars ^(1, 2).

Cultivars	FW* (g)	AsW* (g)	Syf** (g/100 g fruit)	Ls (mm)	Ws (mm)	Sw (mg)	Aw (g)	Si (%)	Seed hardness***	Oil yield (%)
Sefri 1	439.72 ^{de} ± 87.64	246.72 ^{bc} ± 64.50	15.0 ^{cde} ± 0.35	7.82 ^d ± 0.58	3.00 ^c ± 0.37	0.043 ^f ± 0.007	0.460 ^{cd} ± 0.068	9.50 ^{ab} ± 1.80	3.83 ^{ab} ± 0.75	20.93 ^{bc} ± 0.81
Sefri 2	432.53 ^{cde} ± 59.31	241.65 ^{bc} ± 57.83	13.82 ^{abcd} ± 0.46	7.36 ^{bcd} ± 0.68	2.62 ^{ab} ± 0.30	0.039 ^{df} ± 0.007	0.399 ^{bc} ± 0.061	9.75 ^b ± 1.57	5.33 ^{ab} ± 0.95	20.89 ^{bc} ± 0.54
Sefri 3	370.07 ^{bcd} ± 73.54	246.63 ^{bc} ± 69.50	14.68 ^{bcd} ± 0.78	7.33 ^{bcd} ± 0.75	2.60 ^{ab} ± 0.36	0.032 ^{abcd} ± 0.005	0.402 ^{bc} ± 0.048	8.11 ^{ab} ± 1.51	3.13 ^a ± 0.84	24.48 ^e ± 0.46
Sefri 4	589.57 ^f ± 153.28	420.62 ^d ± 125.79	16.7 ^{ef} ± 0.17	7.29 ^{abcd} ± 0.80	2.76 ^{abc} ± 0.29	0.038 ^{cdef} ± 0.006	0.479 ^d ± 0.058	7.95 ^{ab} ± 1.16	3.50 ^a ± 0.84	22.55 ^{cde} ± 0.99
Sefri 5	523.18 ^{ef} ± 80.98	291.60 ^c ± 60.96	12.36 ^{ab} ± 0.36	7.54 ^{cd} ± 0.56	2.74 ^{abc} ± 0.30	0.039 ^{ef} ± 0.008	0.477 ^d ± 0.064	8.33 ^{ab} ± 1.98	5.00 ^{ab} ± 0.90	21.69 ^{bcd} ± 0.78
Sefri 6	351.98 ^{bcd} ± 71.41	208.75 ^{ab} ± 46.70	13.61 ^{abc} ± 0.34	6.76 ^{abc} ± 0.95	2.52 ^a ± 0.36	0.028 ^a ± 0.006	0.399 ^{bc} ± 0.063	7.03 ^a ± 1.35	5.14 ^{ab} ± 0.90	23.61 ^{de} ± 1.25
Lahmer	337.87 ^{abc} ± 70.69	193.26 ^{ab} ± 42.73	12.19 ^a ± 0.27	6.76 ^{abc} ± 0.83	2.89 ^{abc} ± 0.41	0.035 ^{bcd} ± 0.007	0.399 ^{bc} ± 0.043	8.70 ^{ab} ± 1.53	4.17 ^{ab} ± 0.99	24.69 ^e ± 0.74
Marrakchia	317.94 ^{ab} ± 71.22	174.91 ^{ab} ± 40.62	11.92 ^a ± 1.17	6.51 ^a ± 0.74	2.61 ^{ab} ± 0.41	0.029 ^{ab} ± 0.005	0.343 ^b ± 0.042	8.56 ^{ab} ± 1.39	4.14 ^{ab} ± 0.90	19.56 ^{ab} ± 0.29
Lhamdha	246.90 ^a ± 53.27	131.30 ^a ± 46.89	18.11 ^f ± 1.30	6.72 ^{ab} ± 1.10	2.97 ^{bc} ± 0.45	0.035 ^{bcd} ± 0.005	0.227 ^a ± 0.075	17.10 ^c ± 5.86	8.44 ^c ± 0.73	17.59 ^a ± 0.19
Bzeq Tir	365.49 ^{bcd} ± 71.74	228.67 ^{bc} ± 69.42	16.01 ^{def} ± 0.35	7.06 ^{abcd} ± 0.66	2.71 ^{abc} ± 0.32	0.032 ^{abc} ± 0.006	0.354 ^b ± 0.060	9.18 ^{ab} ± 1.62	6.00 ^b ± 0.92	21.67 ^{bcd} ± 0.48

¹FW: fruit weight; AsW: arils weight; Syf: seed yield per fruit; Ls: seed length; Ws: maximum seed width; Sw: seed weight; Aw: aril weight; Si: seed index (Si = (Sw/Aw) × 100). ²Values followed by the same letters within the same column were not significantly different according to Tukey's HSD test ($P < 0.01$; $n = 25$; * $n = 30$; ** $n = 3$; *** $n = 8$).

246.90 g and 131.30 g for the cultivar “Lhamdha” (lowest) and between 589.57 g and 420.62 g for the cultivar “Sefri 4” (highest). These results agreed with the fruit weight presented by other Moroccan cultivars (between 430.8 and 535.1 g) [20], Croatian cultivars (between 189.4 and 595.9 g) [30], and Italian cultivars (169–575 g) [31]. Differences in aril and fruit weights are influenced by cultivar and agro-climatic conditions within regions [23]. The seed yield per fruit varied from 11.92% for “Marrakchia” to 18.11% for “Lhamdha.” These results agreed with those reported by previous studies [31, 32].

Concerning the parameters of individual arils and seeds, the weight of one aril ranged from 0.227 g for the “Lhamdha” cultivar to 0.479 g for the “Sefri 4” cultivar. The cultivars “Sefri 1,” “Sefri 4,” and “Sefri 5” had significantly higher aril weight ($A_w > 0.46$ g) compared to other cultivars. The range found for aril weight agreed with the results reported for Moroccan, Spanish, Turkish, and Italian cultivars ranging from 0.24 to 0.68 g [20, 23, 31, 33–36]. The length, width, and weight of seeds were, respectively, within the range of 6.51 mm for “Marrakchia” and 7.82 mm for “Sefri 1,” 2.52 mm for “Sefri 6” and 3.00 mm for “Sefri 1,” and 0.028 g for “Sefri 6” and 0.043 g for “Sefri 1.” The results presented for pomegranate seeds agreed with those reported for Spanish and Moroccan cultivars [20, 33, 35]. The seed index (Si) which indicated the proportion of the seed compared to the weight of the aril [23] varied from 7.03% for “Sefri 6” to 9.75% for “Sefri 2.” However, the cultivar “Lhamdha” showed significantly higher Si (17.10%) compared to other cultivars. The cultivar “Lhamdha” also presented higher Si compared with the results reported for Spanish cultivars (4.75–15.3%) [23, 35, 36], Italian cultivars (3.7–12.2%) [31], and Moroccan cultivars (6.1–10.7%) [20]. In general, cultivars with the lowest values in Si and S_w and simultaneously high values in A_w can be considered ideal for fresh consumption [21]. The results of seed hardness varied significantly among the ten cultivars. Except for the cultivar “Lhamdha” that had the hardest seeds, all cultivars had tender or semihard seeds and then could be intended for fresh consumption.

The oil contents in pomegranate seeds showed a great variability among the studied cultivars. The oil yield ranged from 17.59% to 24.69%. In particular, “Sefri 3,” “Sefri 4,” “Sefri 6,” and “Lahmer” were the cultivars richest in oil content with values higher than 22%, indicating a promising convenience to extract oil from their seeds. These results were consistent with the results reported by Ferrara et al. [31] for Italian cultivars, 4.9–26.8%. However, they were higher than the data reported for Spanish cultivars, 4.44–13.70% [37], and Iranian cultivars, 6.63–19.3% [38]. It has been reported that the quantity of oil in pomegranate seeds depends upon the geographical location and maturity of cultivated pomegranate fruits [39].

3.2. Physicochemical Parameters of Pomegranate Seed Oils

3.2.1. Colour Coordinates. Colour coordinates of pomegranate seed oil of ten studied Moroccan cultivars are presented in Table 3. The results showed significant differences between the cultivars. Oils revealed a clear yellow

colour with parameters L^* : 85.61–95.12, a^* : (−15.29) – (−8.66), and b^* : 73.44–111.36. The studied oils presented a more intense yellow colour than seed oils extracted from Turkish cultivars ($L^* = 58.91$, $a^* = -5.64$, and $b^* = 22.60$) [40]. The cultivars “Sefri 6” and “Lahmer” showed the most intense and saturated yellow colour with values of chroma (C^*) higher than 100 and hue angle (H^*) inferior (−84°).

3.2.2. Extinction Coefficients. The specific extinction coefficients K_{232} and K_{270} characterize primary oxidation (conjugated dienes) and secondary oxidation (conjugated trienes) products, respectively. They are directly associated with the amount of peroxide in vegetable oils [41]. The determination of these two extinction coefficients can present information on the quality of the oil and its state of preservation [24]. The specific extinction coefficients values K_{232} and K_{270} for the studied oils are shown in Table 3. The results found for K_{232} ranged from 4.06 for “Bzeq Tir” to 5.34 for “Lahmer” and 5.39 for “Sefri 5,” while the results for K_{270} ranged between 3.45 for “Sefri 6” and 3.75 for “Marrakchia,” without showing significant differences among the studied cultivars. These data are close to those reported for Tunisian cultivars: 4.15 for K_{232} and 3.95 for K_{270} [41] and Turkish cultivars: 3.83 for K_{232} and 4.00 for K_{270} [42].

3.2.3. Chlorophyll and Pheophytin Contents. Chlorophylls are responsible for green colour of oils. In the absence of light, chlorophylls may act as weak antioxidants, while in the presence of light, it is recognized that chlorophylls act as robust oxidation promoters [43]. Acidification and thermal processing cause the conversion of chlorophyll to pheophytin, resulting in noticeable discoloration of oils from green to brown [44]. Chlorophyll and pheophytin contents of pomegranate seed oils of the ten studied pomegranate cultivars are shown in Table 3. Oils contained chlorophyll and pheophytin that ranged, respectively, from 0.12 mg/kg and 0.39 mg/kg for cultivar “Lhamdha” to 1.87 mg/kg for cultivar “Sefri 6” and 3.87 mg/kg for cultivar “Lahmer.” The results found for chlorophyll were within the range reported by Amri et al. [41] and Alfekaik and Al-Hilfi [45] for Tunisian and Iraqi cultivars, respectively. The level of chlorophylls depends on genetic factors, extraction technology, and degree of fruit ripening. The level declines as the fruit ripens [43].

3.2.4. Antioxidant Activity. According to the European legislation on food additives, antioxidants are defined as “substances which prolong the shelf life of foods by protecting them against deterioration caused by oxidation, such as fat rancidity and colour changes” [46]. PSO with higher antioxidant activity could then be used as additives in food industry. Table 3 shows the antioxidant activity results obtained for the studied cultivars. PSO presented high antioxidant activity with IC₅₀ that ranged from 0.69 mg/mL for “Marrakchia” to 1.80 mg/mL for “Lhamdha.” Antioxidant activity was within the range found by Amri et al. [41]

TABLE 3: Colour coordinates, physicochemical criteria, and antioxidant activity of pomegranate seed oil of ten Moroccan cultivars*.

Cultivars	Colour coordinates			H^* (degree)		Chlorophyll content (mg/kg)	Pheophytin content (mg/kg)	K_{270}	K_{232}	IC50 (mg/mL)
	L^*	a^*	b^*	C^*	H^* (degree)					
Sefri 1	91.55 ^{bc} ± 0.66	-13.85 ^{bc} ± 0.40	93.20 ^{bc} ± 0.53	94.22 ^{bc} ± 0.58	-81.55 ^{cd} ± 0.20	0.57 ^g ± 0.01	1.91 ^f ± 0.03	3.53 ^a ± 0.00	4.61 ^b ± 0.05	0.91 ^{bc} ± 0.03
Sefri 2	94.34 ^{de} ± 0.43	-13.78 ^{bc} ± 0.18	101.10 ^g ± 0.32	102.04 ^g ± 0.34	-82.24 ^b ± 0.08	0.49 ^e ± 0.00	1.65 ^c ± 0.01	3.62 ^a ± 0.03	4.76 ^{bc} ± 0.00	1.14 ^d ± 0.04
Sefri 3	95.12 ^e ± 0.44	-14.56 ^{ab} ± 0.09	97.66 ^f ± 0.05	98.74 ^f ± 0.05	-81.52 ^{de} ± 0.05	0.62 ^h ± 0.00	2.05 ^g ± 0.01	3.53 ^a ± 0.21	5.03 ^{bcd} ± 0.03	0.98 ^c ± 0.00
Sefri 4	87.20 ^a ± 0.41	-15.29 ^a ± 0.16	73.44 ^a ± 0.22	75.02 ^a ± 0.23	-78.24 ^g ± 0.108	0.31 ^c ± 0.00	1.02 ^c ± 0.01	3.58 ^a ± 0.00	4.59 ^{ab} ± 0.28	0.95 ^c ± 0.05
Sefri 5	93.37 ^{cde} ± 0.13	-13.88 ^{bc} ± 0.07	96.96 ^{ef} ± 0.10	97.94 ^{ef} ± 0.11	-81.86 ^{bcd} ± 0.03	0.18 ^b ± 0.00	0.59 ^b ± 0.00	3.53 ^a ± 0.00	5.39 ^d ± 0.00	0.80 ^{ab} ± 0.00
Sefri 6	85.61 ^a ± 1.43	-8.66 ^e ± 0.64	104.93 ^h ± 1.24	105.29 ^b ± 1.28	-85.28 ^a ± 0.29	1.87 ^j ± 0.03	3.23 ^h ± 0.09	3.45 ^a ± 0.02	5.01 ^{bcd} ± 0.00	1.76 ^e ± 0.01
Lahmer	90.64 ^b ± 0.23	-10.01 ^d ± 0.08	111.36 ⁱ ± 0.26	111.81 ⁱ ± 0.27	-84.86 ^a ± 0.30	1.30 ⁱ ± 0.01	3.87 ⁱ ± 0.06	3.67 ^a ± 0.00	5.34 ^d ± 0.13	0.94 ^c ± 0.01
Marrakchia	93.16 ^{cd} ± 0.25	-13.56 ^c ± 0.05	96.00 ^{de} ± 0.24	96.96 ^{de} ± 0.25	-81.96 ^{bc} ± 0.01	0.53 ^f ± 0.00	1.77 ^e ± 0.02	3.75 ^a ± 0.14	5.21 ^{cd} ± 0.00	0.69 ^a ± 0.03
Lhamdha	93.39 ^{cde} ± 0.20	-14.94 ^a ± 0.09	94.72 ^{cd} ± 0.17	95.89 ^{cd} ± 0.18	-81.04 ^f ± 0.04	0.12 ^a ± 0.00	0.39 ^a ± 0.01	3.56 ^a ± 0.02	4.67 ^{bc} ± 0.13	1.80 ^e ± 0.02
Bzeq Tir	94.90 ^{de} ± 0.05	-14.43 ^{abc} ± 0.07	93.01 ^b ± 0.06	94.13 ^b ± 0.06	-81.18 ^{ef} ± 0.04	0.43 ^d ± 0.00	1.44 ^d ± 0.01	3.65 ^a ± 0.04	4.06 ^a ± 0.00	1.00 ^{cd} ± 0.03

*Values followed by the same letter within the same column were not significantly different according to Tukey's HSD test ($P < 0.01$; $n = 3$).

TABLE 4: Fatty acid composition (%) of oils extracted from pomegranate seeds of ten Moroccan cultivars*.

Fatty acids**	Sefri 1	Sefri 2	Sefri 3	Sefri 4	Sefri 5	Sefri 6	Lahmer	Marrakchia	Lhamdha	Bzeq Tir
Myristic acid C14: 0	0.00 ^a ± 0.00	0.000 ^a ± 0.0	0.04 ^b ± 0.00	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.06 ^c ± 0.00
Pentadecanoic acid C15: 0	0.05 ^a ± 0.00	0.05 ^a ± 0.01	0.03 ^a ± 0.00	0.04 ^a ± 0.01	0.04 ^a ± 0.00	0.04 ^a ± 0.0	0.04 ^a ± 0.01	0.05 ^a ± 0.01	0.04 ^a ± 0.02	0.04 ^a ± 0.00
Palmitic acid C16: 0	4.60 ^{bc} ± 0.13	4.24 ^{abc} ± 0.21	4.47 ^{abc} ± 0.00	3.96 ^a ± 0.09	4.08 ^{ab} ± 0.05	4.44 ^{abc} ± 0.00	4.41 ^{abc} ± 0.21	4.64 ^{bc} ± 0.02	4.61 ^{bc} ± 0.01	4.67 ^c ± 0.06
Palmitoleic acid C16: 1	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.02 ^c ± 0.00	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.05 ^b ± 0.00	0.00 ^a ± 0.00	0.00 ^a ± 0.00
Margaric acid C17: 0	0.07 ^{ab} ± 0.01	0.04 ^a ± 0.00	0.05 ^{ab} ± 0.00	0.07 ^{ab} ± 0.01	0.04 ^a ± 0.00	0.05 ^{ab} ± 0.01	0.05 ^{ab} ± 0.02	0.04 ^a ± 0.00	0.14 ^c ± 0.00	0.09 ^{bc} ± 0.01
Heptadecanoic acid C17: 1	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.07 ^b ± 0.00	0.00 ^a ± 0.00
Stearic acid C18: 0	1.85 ^a ± 0.14	1.86 ^a ± 0.01	1.94 ^a ± 0.00	1.74 ^a ± 0.03	1.82 ^a ± 0.04	1.82 ^a ± 0.05	1.93 ^a ± 0.02	1.86 ^a ± 0.01	1.76 ^a ± 0.18	2.08 ^a ± 0.03
Oleic acid C18: 1	3.87 ^a ± 0.24	4.38 ^a ± 0.08	5.37 ^b ± 0.00	4.30 ^a ± 0.05	4.08 ^a ± 0.03	5.54 ^b ± 0.09	6.35 ^c ± 0.01	6.53 ^c ± 0.03	5.53 ^b ± 0.19	5.38 ^b ± 0.06
Linoleic acid C18: 2	5.29 ^a ± 0.19	5.98 ^b ± 0.04	6.27 ^b ± 0.00	5.46 ^a ± 0.13	5.45 ^a ± 0.00	5.40 ^a ± 0.00	7.12 ^c ± 0.03	7.70 ^d ± 0.04	5.51 ^a ± 0.02	6.21 ^b ± 0.01
Linolenic acid C18: 3	0.00 ^a ± 0.00	0.05 ^{bc} ± 0.00	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.08 ^{bc} ± 0.00	0.10 ^c ± 0.02	0.00 ^a ± 0.00	0.05 ^{bc} ± 0.00	0.05 ^b ± 0.00	0.00 ^a ± 0.00
β-Eleostearic acid C18: 3	0.33 ^b ± 0.00	0.36 ^{bc} ± 0.05	0.22 ^{ab} ± 0.00	0.28 ^b ± 0.05	0.30 ^b ± 0.05	0.06 ^a ± 0.01	0.59 ^c ± 0.03	0.32 ^b ± 0.00	0.33 ^b ± 0.04	2.03 ^d ± 0.09
Punicic acid C18: 3	80.67 ^c ± 0.81	79.62 ^c ± 0.31	78.72 ^{bc} ± 0.00	80.09 ^c ± 1.40	80.10 ^c ± 0.11	79.16 ^c ± 0.55	75.57 ^a ± 0.13	75.84 ^{ab} ± 0.17	79.05 ^c ± 0.34	73.74 ^a ± 0.22
α-Eleostearic acid C18: 3	1.89 ^{ab} ± 0.04	2.01 ^{abc} ± 0.06	1.94 ^{ab} ± 0.00	2.13 ^{abc} ± 0.35	2.33 ^{bc} ± 0.03	1.75 ^{ab} ± 0.08	2.55 ^{cd} ± 0.02	1.69 ^a ± 0.03	1.66 ^a ± 0.04	3.12 ^d ± 0.10
Catalpic acid C18: 3	0.38 ^a ± 0.03	0.53 ^a ± 0.01	0.37 ^a ± 0.00	1.08 ^a ± 0.08	0.74 ^a ± 0.04	0.44 ^a ± 0.04	1.35 ^a ± 0.03	0.34 ^a ± 0.00	0.36 ^a ± 0.01	1.59 ^a ± 0.08
Arachidic acid C20: 0	0.50 ^{bc} ± 0.05	0.41 ^{bc} ± 0.01	0.19 ^{abc} ± 0.00	0.16 ^{ab} ± 0.03	0.45 ^{bc} ± 0.03	0.40 ^{bc} ± 0.03	0.00 ^a ± 0.00	0.38 ^{bc} ± 0.01	0.42 ^{bc} ± 0.00	0.36 ^{bc} ± 0.09
Gadoleic acid C20: 1	0.45 ^a ± 0.04	0.44 ^a ± 0.02	0.38 ^a ± 0.00	0.38 ^a ± 0.06	0.49 ^a ± 0.04	0.43 ^a ± 0.05	0.05 ^a ± 0.00	0.50 ^a ± 0.03	0.50 ^a ± 0.00	0.60 ^a ± 0.03
Behenic acid C22: 0	0.06 ^a ± 0.00	0.04 ^a ± 0.00	0.00 ^a ± 0.00	0.32 ^{ab} ± 0.03	0.00 ^a ± 0.00	0.41 ^b ± 0.03	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.00 ^a ± 0.00	0.04 ^a ± 0.00
Total UFA	92.88 ^{ab} ± 0.33	93.38 ^{ab} ± 0.20	93.28 ^{ab} ± 0.00	93.71 ^b ± 0.04	93.57 ^{ab} ± 0.08	92.87 ^{ab} ± 0.30	93.57 ^{ab} ± 0.16	93.03 ^{ab} ± 0.05	93.05 ^{ab} ± 0.14	92.67 ^a ± 0.15
Total SFA	7.12 ^{ab} ± 0.33	6.62 ^{ab} ± 0.20	6.72 ^{ab} ± 0.00	6.29 ^a ± 0.04	6.43 ^{ab} ± 0.08	7.14 ^{ab} ± 0.30	6.43 ^{ab} ± 0.16	6.97 ^{ab} ± 0.05	6.95 ^{ab} ± 0.14	7.33 ^b ± 0.15
UFA/SFA ratio	13.06 ^{abc} ± 0.64	14.11 ^{abc} ± 0.44	13.88 ^{abc} ± 0.30	14.91 ^c ± 0.09	14.56 ^{bc} ± 0.18	13.03 ^{ab} ± 0.59	14.60 ^{bc} ± 0.39	13.34 ^{abc} ± 0.11	13.38 ^{abc} ± 0.30	12.65 ^a ± 0.29
MUFA	4.32 ^a ± 0.29	4.82 ^a ± 0.10	5.77 ^b ± 0.00	4.68 ^a ± 0.01	4.57 ^a ± 0.16	5.97 ^b ± 0.06	6.40 ^{bc} ± 0.01	7.05 ^c ± 0.06	6.09 ^b ± 0.19	5.98 ^b ± 0.36
PUFA	88.56 ^{cd} ± 0.61	88.56 ^{bcd} ± 0.29	87.52 ^{abcd} ± 0.00	89.03 ^d ± 0.05	89.00 ^d ± 0.24	86.90 ^{ab} ± 0.36	87.17 ^{abc} ± 0.15	85.98 ^a ± 0.12	86.95 ^{abc} ± 0.33	86.69 ^a ± 0.52

*Values followed by the same letter show no statistically significant differences according to Tukey's HSD test ($P < 0.01$, $n = 3$). **UFA: unsaturated fatty acid; SFA: saturated fatty acid; MUFA: monounsaturated fatty acid; PUFA: polyunsaturated fatty acid.

(IC₅₀ = 0.37 mg/mL) and by Melo et al. [3] (IC₅₀ = 3.77 mg/mL) for, respectively, Tunisian and Brazilian cultivars. In fact, the antioxidant activity of the PSO was found to be significantly superior to those of green tea, red wine, and the synthetic antioxidant butylated hydroxyl anisole (BHA) [9]. A significant correlation was found between the antioxidant activity of PSO and the total content of tocopherols [3, 5] suggesting the contribution of tocopherols to the antioxidant properties of this oil. The divergence in antioxidant activity among pomegranate cultivars may due to the genotypes, growing region, and to different antioxidant activity evaluations employed by other studies such as ABTS and FRAP assays [47].

3.2.5. Fatty Acid Composition. The profile of seed oil fatty acids among cultivars is important information in assessing seed oil stability against oxidation and food fortification. Cultivars with PSO high in essential fatty acids could be used to improve the accessibility of these fatty acids in other foods [47]. The fatty acid profile of the studied PSO is presented in Table 4. Total saturated fatty acids (SFAs) were in the range of 6.29 to 7.33% of total fatty acids, with the unsaturated/saturated ratio varying between 12.65 and 14.91. These results were in agreement with those reported by Fernandes et al. [37] for Spanish cultivars. The most important saturated fatty acids were palmitic acid (C16: 0) and stearic acid (C18: 0) ranging, respectively, from 3.96% to 1.74% for “Sefri 4” to 4.67 % and 2.08 % for “Bzeq Tir.” In addition, the extracted pomegranate seed oils presented high contents of unsaturated fatty acids (92.86–93.89%). These results were in agreement with those reported for Spanish cultivars (from 91.8 to 94.2%) [37]. Monounsaturated fatty acids (MUFAs) ranged between 4.32 and 7.05%. The predominant monounsaturated fatty acid was oleic acid (C18: 1 c 9) which was in the range of 3.87% for “Sefri 1” and 6.53% for “Marrakchia.” Polyunsaturated fatty acids (PUFAs) presented the major fatty acid class, ranging between 85.98 and 89.03% of total fatty acids. Linoleic acid (C18: 2n 6c, 9c) was detected with values ranging from 5.29 for “Sefri 1” to 7.70% for “Marrakchia” which agreed with values reported by Verardo et al. [2]. The major polyunsaturated fatty acid was punicic acid (C18: 3 c9, t11, c13) whose content ranged from 73.74% for “Bzeq Tir” to 80.67% for “Sefri 1.” In particular, “Sefri 1,” “Sefri 4,” and “Sefri 5” were the cultivars richest in punicic acid with values higher than 80%. These results were in agreement with those reported by Costa et al. [6]. However, they were lower than values reported by Fernandes et al. [37], Ferrara et al. [31], and Verardo et al. [2] (72.4–84.1%). Punicic acid is the principal conjugated linolenic acid that endorses the potential biological and health benefits of pomegranate seed oil [48]. Three other conjugated linolenic acid isomers were also identified, α -eleostearic acid, catalpic acid, and β -eleostearic acid, which were, respectively, in the range of 1.66–3.12%, 0.34–1.59%, and 0.06–2.03%. The cultivar “Bzeq Tir” demonstrated the highest content of these three fatty acids. PSO is, therefore, a rich source of the bioactive conjugated linolenic isomers, representing approximately 84% of the oils fatty acids (especially the

cultivars “Sefri 1,” “Sefri 4,” and “Sefri 5”). This result agreed with that of Costa et al. [6]. Lastly, among minor fatty acids, the saturated arachidic acid (C20: 0) and behenic acid (C22: 0) and unsaturated gadoleic acid (C20: 1) and linolenic acid (C18: 3n3c, 6c, 9c) were detected with average values less than 1%. The PSO presented significant differences among the studied cultivars ($P < 0.01$); its composition could be influenced by the pomegranate variety, climate conditions, and ripening stage at harvest [22, 41].

3.2.6. Correlation Analysis. Pearson’s correlation analyses were used to examine the interaction among the studied parameters at $P < 0.01$ (Table 5). The oil content of the pomegranate seeds was positively correlated with aril weight, chlorophyll, and pheophytin contents with correlation coefficients of 0.541, 0.586, and 0.664, respectively, while it was negatively correlated with seed index ($r = -0.541$) and seed hardness ($r = -0.472$) indicating that tender pomegranate seeds provide high oil content. Highly significant positive correlations were found between chlorophyll and pheophytin contents and the colour coordinates. The coefficients of correlation were, respectively, 0.945 and 0.847 with a^* , 0.603 and 0.656 with b^* , and 0.592 and 0.648 with C^* . This result confirmed that chlorophyll was the main contributor to the PSO colour. The IC₅₀ was positively correlated with seed hardness ($r = 0.566$), which indicated that oils extracted from tender seeds showed higher antioxidant activity compared to oils extracted from hard seeds.

The correlation between the studied variables and environmental conditions showed that favorable environmental conditions help the production of larger edible proportion. Aw was positively correlated with maximum temperature ($r = 0.609$), altitude ($r = 0.607$), and longitude west ($r = 0.613$) while negatively correlated with minimum temperature ($r = -0.668$) (Table 5), which explained the presence of heavy aril weight in cultivars cultivated in the Center of Morocco compared with other cultivars. Tapia-Campos et al. [49] recorded the same observation for Mexican cultivars. The altitude favors the production of PSO rich in PUFA, especially punicic acid. A significant correlation was found between altitude, PUFA, and punicic acid ($r = 0.598$ and $r = 0.653$ respectively). Minimum temperature is favorable for the production of MUFA ($r = 0.832$) which explained the high content of MUFA in PSO of cultivars cultivated in the coastal town (Essaouira).

3.2.7. Principal Component Analysis (PCA). The first two principal components explained 74.14% of the total variation (Figure 1). The proportion of variation for the first and the second factors was 43.55% and 30.59%, respectively. The first component F1 was positively linked to seed index, seed hardness, antioxidant activity (IC₅₀), and MUFA and negatively linked to oil yield, UFA/SFA, and PUFA. The second component F2 accounted for 30.59% of the variance and was positively correlated to punicic acid. Based on the plot of the principal component scores, the studied cultivars were separated into distinctive groups based on their seed and oil characteristics. The cultivar “Lhamdha” showed a high positive

TABLE 5: Pearson correlation of environmental conditions, morphological, physicochemical, and biochemical characteristics of seeds and pomegranate seed oils of ten Moroccan pomegranate cultivars harvested in 2018.

	Aw	Si	Oil yield	Seed hardness	Syf	Punicic acid	MUFA	PUFA	L*	a*	b*	C*	H* (deg)	Chlorophyll	Pheophytin	IC50 (mg)
Si	-0.652**	1														
Oil yield	0.541**	-0.561**	1													
Seed hardness	-0.457**	0.444**	-0.472**	1												
Syf	Ns	0.517**	Ns	Ns	1											
Punicic acid	Ns	Ns	Ns	Ns	0.454*	1										
MUFA	-0.536*	Ns	Ns	Ns	Ns	-0.738**	1									
PUFA	0.519*	Ns	Ns	Ns	Ns	0.735**	-0.946**	1								
L*	-0.362*	Ns	Ns	Ns	Ns	Ns	Ns	Ns	1							
a*	Ns	Ns	0.462*	Ns	-0.445*	Ns	Ns	Ns	-0.570**	1						
b*	Ns	Ns	Ns	Ns	-0.526**	Ns	Ns	Ns	Ns	0.711**	1					
C*	Ns	Ns	Ns	Ns	-0.523**	Ns	Ns	Ns	Ns	0.700**	1.000**	1				
H* (deg)	Ns	Ns	Ns	Ns	0.536**	Ns	Ns	Ns	Ns	-0.913**	-0.929**	-0.923**	1			
Chlorophyll	Ns	Ns	0.586**	Ns	Ns	Ns	Ns	Ns	-0.605**	0.945**	0.603**	0.592**	-0.824**	1		
Pheophytin	Ns	-0.374*	0.664**	-0.382*	-0.456*	Ns	Ns	Ns	-0.393*	0.847**	0.656**	0.648**	-0.784**	0.903**	1	
IC50 (mg)	Ns	0.460*	Ns	0.566**	0.519*	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	1
Precipitation	0.422*	-0.363*	0.379*	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
Maximum T°	0.609**	-0.462*	0.375*	Ns	Ns	Ns	-0.621**	0.479*	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
Minimum T°	-0.668**	Ns	Ns	Ns	Ns	-0.544*	0.832**	-0.720**	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
Altitude	0.607**	Ns	Ns	Ns	Ns	0.653**	-0.726**	0.598**	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
Sunshine hours	0.391*	-0.386*	0.504**	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
Latitude north	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
Longitude west	0.613**	-0.546*	Ns	Ns	Ns	Ns	-0.539*	0.500*	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns

Aw: aril weight; Si: seed index; Syf: seed yield per fruit; MUFA: monounsaturated fatty acid; PUFA: polyunsaturated fatty acid; T°: temperature. *the correlation is significant at $P < 0.05$; **the correlation is significant at $P < 0.01$; Ns: not significant.

FIGURE 1: Principal component analysis (PCA) of the first two components (F1 and F2): segregation of ten Moroccan pomegranate cultivars based on the physicochemical and biochemical characteristics of their seeds and seed oils (SFA: saturated fatty acid; UFA: unsaturated fatty acid; MUFA: monounsaturated fatty acid; PUFA: polyunsaturated fatty acid).

FIGURE 2: Dendrogram of ten Moroccan pomegranate cultivars based on physicochemical and biochemical characteristics of their seed oils.

score on F1 and F2. This cultivar was characterized by high seed index and seed hardness and low antioxidant activity (high IC50). The cultivars “Bzeq Tir,” “Marrakchia,” and “Sefri 6” presented a positive score on F1 and negative score on F2. They showed important amounts of saturated and monounsaturated fatty acids. The cultivars “Sefri 1,” “Sefri 2,” “Sefri 4,” and “Sefri 5” were relatively close to each other along the x -axis and presented a negative score on F1 and positive score on F2. They were characterized by their high contents of punicic acid, UFA, and PUFA, with tender or semihard seeds. On the other hand, “Lahmer” and “Sefri 3” showed negative scores on F1 and on F2. They provided high yields of oil with relatively high antioxidant activity (low IC50).

3.2.8. Cluster Analysis. The results obtained from cluster analysis for the ten Moroccan pomegranate cultivars are shown in Figure 2. Four principal groups were clustered based on the studied parameters. The first group included “Sefri 1,” “Sefri 2,” “Sefri 4,” and “Sefri 5.” The second group consisted only of cultivar “Lhamdha.” The third group was formed by the cultivars “Bzeq Tir” and “Marrakchia,” while the last group included cultivar “Sefri 6,” “Sefri 3,” and “Lahmer.” Cluster analysis revealed the divergence of cultivars with the same appellation “Sefri.” In fact, “Sefri 6” and “Sefri 3” were different from “Sefri 1,” “Sefri 2,” “Sefri 4,” and “Sefri 5.” This confirmed the problem of homonymy or synonymy in the Moroccan cultivar appellation reported by

Ajal et al. [50] in their study which was based on the assessment of genetic diversity.

4. Conclusions

This study aimed to assess and compare, for the first time, the characteristics of pomegranate seeds and seed oils of ten cultivars grown in the Center of Morocco. Pomegranate seeds of the studied cultivars presented an important oil yield that ranged from 17.59% to 24.69%. The cultivars “Lahmer” and “Sefri 3” provided the highest oil yield, with results exceeding 24%. Oils showed an intense yellow colour with a significant presence of chlorophyll and pheophytin pigments. The studied oils were rich sources of polyunsaturated fatty acids (85.98–89.03%) with high contents of punicic acid that represented 80% of the total fatty acids. Polyunsaturated fatty acids and punicic acid were highly correlated with altitude. The oils also showed high levels of antioxidant activity (IC₅₀: 0.69–1.80 mg/mL). The cultivar “Marrakchia” was rich in monounsaturated fatty acids, while the cultivars “Sefri 1,” “Sefri 4,” and “Sefri 5” presented high contents of polyunsaturated fatty acids. These four cultivars were the most promising, also showing higher antioxidant activities. Based on their fatty acid profile and antioxidant activity, the studied oils could be useful in the formulation of novel foods or used as preservatives and functional components in food, cosmetic, and pharmaceutical industries. Further studies are scheduled for a better characterization and exploitation of this resource, especially the determination of biologically active compounds such as tocopherols, carotenoids, phytosterols, and phenolic compounds.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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