Research Article

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

Sarah Loukhmas,1,2 Ebrahim Kerak,1 Sara Elgadi,2 Fatima Ettalibi,2 Abderraouf El Antari,2 and Hasnaâ Harrak2

1Laboratory of Virology Microbiology Quality and Biotechnology/ETB, Faculty of Sciences and Techniques in Mohammedia, Hassan II University, P.O. Box 146, Yasmina City, Mohammedia 20650, Morocco
2Laboratory of Agri-Food Technology and Quality, Regional Center for Agricultural Research in Marrakesh, Regional Center for Agricultural Research Marrakesh, National Institute for Agricultural Research (INRA), P.O. Box 533, Marrakesh 40000, Morocco

Correspondence should be addressed to Sarah Loukhmas; s.loukh@gmail.com

Received 12 October 2020; Revised 4 April 2021; Accepted 10 May 2021; Published 19 May 2021

Academic Editor: Teresa Zotta

Copyright © 2021 Sarah Loukhmas et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Pomegranate seeds (Punica granatum L.) are quantitatively and qualitatively a relevant agri-food by-product rich in compounds 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].
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,” “Mar-rakchia,” “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 Kelaa 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 weight (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]:

\[
Si = \frac{Sw}{Aw}.
\]

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 PULVERISSETTE 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 

\[
H^* = \tan^{-1}\left(\frac{b^*}{a^*}\right).
\]

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].
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 μL 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; Φ = 0.25 mm; Ft = 0.20 μm). 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:

\[ \text{FAx} = 100 \left( \frac{A_x}{\text{AT}} \right) \]  

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 α = 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±87.64 | 246.72±64.50 | 15.0±0.35             | 7.82±0.58 | 3.00±0.37 | 0.043±0.007 | 0.460±0.068 | 9.50±1.80 | 3.83±0.75       | 20.93±0.81   |
| Sefri 2        | 432.53±59.31 | 241.65±57.83 | 13.8±0.46             | 7.36±0.68 | 2.62±0.30 | 0.039±0.007 | 0.399±0.061 | 9.75±1.57 | 5.33±0.95       | 20.89±0.54   |
| Sefri 3        | 370.07±14.80 | 246.63±69.50 | 14.68±0.78            | 7.33±0.75 | 2.60±0.36 | 0.032±0.004 | 0.402±0.048 | 8.11±1.51 | 3.13±0.84       | 24.48±0.46   |
| Sefri 4        | 589.57±153.28 | 240.62±125.79 | 16.7±0.17             | 7.29±0.80 | 2.76±0.29 | 0.038±0.006 | 0.479±0.058 | 7.95±1.16 | 3.50±0.84       | 22.55±0.99   |
| Sefri 5        | 523.18±80.98 | 291.60±60.96 | 12.36±0.36            | 7.54±0.56 | 2.74±0.30 | 0.039±0.008 | 0.477±0.064 | 8.33±1.98 | 5.00±0.90       | 21.69±0.78   |
| Sefri 6        | 351.98±71.41 | 208.75±46.70 | 13.61±0.34            | 6.76±0.95 | 2.52±0.36 | 0.028±0.006 | 0.399±0.063 | 7.03±1.35 | 5.14±0.90       | 23.61±1.25   |
| Lahmer         | 337.87±70.69 | 193.26±42.73 | 12.19±0.27            | 6.76±0.83 | 2.89±0.41 | 0.035±0.007 | 0.399±0.043 | 8.70±1.53 | 4.17±0.99       | 24.69±0.74   |
| Marrakchia     | 317.94±71.22 | 174.91±40.62 | 11.92±1.17            | 6.51±0.74 | 2.61±0.41 | 0.029±0.005 | 0.343±0.042 | 8.56±1.39 | 4.14±0.90       | 19.56±0.29   |
| Lhamdha        | 246.90±53.27 | 131.30±46.89 | 18.11±1.30            | 6.72±1.10 | 2.97±0.45 | 0.035±0.005 | 0.227±0.075 | 17.10±5.86 | 8.44±0.73       | 17.59±0.19   |
| Bzeq Tir       | 365.49±71.74 | 228.67±69.42 | 16.01±0.35            | 7.06±0.66 | 2.71±0.32 | 0.032±0.006 | 0.354±0.060 | 9.18±1.62 | 6.00±0.92       | 21.67±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).
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 ($-84^\circ$).

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 “Lhamda” to 1.87 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 “Lhamda.” 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    | L*        | a*        | b*        | C*        | H* (degree) | Chlorophyll content (mg/kg) | Pheophytin content (mg/kg) | IC50 (mg/mL) |
|--------------|-----------|-----------|-----------|-----------|-------------|-----------------------------|---------------------------|--------------|
| Sefri 1      | 91.55b±0.66 | −13.85bc±0.40 | 93.20bc±0.53 | 94.22bc±0.58 | −81.55abcdef±0.20 | 0.57±0.01 | 1.91±0.03 | 3.53±0.00 | 4.61±0.05 | 0.91±0.03 |
| Sefri 2      | 94.34bc±0.43 | −13.72bc±0.18 | 101.10b±0.32 | 102.04bc±0.34 | −82.24±0.08 | 0.49±0.00 | 1.65±0.01 | 3.62±0.03 | 4.76bc±0.00 | 1.14±0.04 |
| Sefri 3      | 95.12b±0.44 | −14.56ab±0.09 | 97.66c±0.05 | 98.74d±0.05 | −81.52abcdef±0.05 | 0.62±0.00 | 2.05±0.01 | 3.53±0.21 | 5.03cd±0.03 | 0.98±0.00 |
| Sefri 4      | 87.20a±0.41 | −15.29±0.16 | 73.44±0.22 | 75.02±0.23 | −78.24±0.108 | 0.31±0.00 | 1.02±0.01 | 3.58±0.00 | 4.59bc±0.28 | 0.95±0.05 |
| Sefri 5      | 93.37c±0.13 | −13.88bc±0.07 | 96.96c±0.10 | 97.94c±0.11 | −81.86±0.03 | 0.18±0.00 | 0.59±0.00 | 3.53±0.00 | 5.39d±0.00 | 0.80b±0.00 |
| Sefri 6      | 85.61a±1.43 | −8.66±0.64 | 104.93b±1.24 | 105.29b±1.28 | −85.28±0.29 | 1.87±0.03 | 3.23±0.09 | 3.45±0.02 | 5.01cd±0.00 | 1.76±0.01 |
| Lahmer       | 90.64abc±0.23 | −10.01±0.08 | 111.36abc±0.26 | 111.81abe±0.27 | −84.86±0.30 | 1.30±0.01 | 3.87±0.06 | 3.67±0.00 | 5.34±0.13 | 0.94±0.01 |
| Marrakchia   | 93.16cd±0.25 | −13.56±0.05 | 96.00bc±0.24 | 96.96c±0.25 | −81.96bc±0.01 | 0.53±0.00 | 1.77±0.02 | 3.75±0.14 | 5.21cd±0.00 | 0.69±0.03 |
| Lhamdha      | 93.39cde±0.20 | −14.94±0.09 | 94.72cd±0.17 | 95.89cd±0.18 | −81.04±0.04 | 0.12±0.00 | 0.39±0.01 | 3.56±0.02 | 4.67bc±0.13 | 1.80±0.02 |
| Bzeq Tir     | 94.90bc±0.05 | −14.43abc±0.07 | 93.01b±0.06 | 94.13b±0.06 | −81.18abc±0.04 | 0.43±0.00 | 1.44±0.01 | 3.65±0.04 | 4.06±0.00 | 1.00cd±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).
| 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±0.00 | 0.000±0.00 | 0.04±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.06±0.00 |
| Pentadecanoic acid C15: 0 | 0.05±0.00 | 0.05±0.00 | 0.03±0.00 | 0.04±0.00 | 0.04±0.00 | 0.04±0.00 | 0.04±0.00 | 0.05±0.00 | 0.04±0.00 | 0.04±0.00 |
| Palmitic acid C16: 0 | 4.60±0.13 | 4.24±0.21 | 4.47±0.00 | 3.96±0.09 | 4.08±0.05 | 4.44±0.00 | 4.41±0.21 | 4.64±0.02 | 4.61±0.01 | 4.67±0.06 |
| Palmitoleic acid C16: 1 | 0.00±0.00 | 0.00±0.00 | 0.02±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.05±0.00 | 0.00±0.00 | 0.00±0.00 |
| Margaric acid C17: 0 | 0.07±0.01 | 0.04±0.00 | 0.05±0.00 | 0.07±0.01 | 0.04±0.00 | 0.05±0.01 | 0.05±0.02 | 0.06±0.00 | 0.04±0.00 | 0.08±0.01 |
| Heptadecanoic acid C17: 1 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 |
| Stearic acid C18: 0 | 1.85±0.14 | 1.86±0.01 | 1.94±0.00 | 1.74±0.03 | 1.82±0.04 | 1.82±0.05 | 1.93±0.02 | 1.86±0.01 | 1.76±0.18 | 2.08±0.03 |
| Oleic acid C18: 1 | 3.87±0.24 | 4.38±0.08 | 5.37±0.00 | 4.30±0.05 | 4.08±0.03 | 5.54±0.09 | 6.35±0.01 | 6.53±0.03 | 5.53±0.19 | 5.38±0.06 |
| Linoleic acid C18: 2 | 5.29±0.19 | 5.98±0.04 | 6.27±0.00 | 5.46±0.13 | 5.45±0.00 | 5.43±0.00 | 7.12±0.03 | 7.70±0.04 | 5.51±0.02 | 6.21±0.01 |
| Linolenic acid C18: 3 | 0.00±0.00 | 0.05±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 |
| β-Eleostearic acid C18: 3 | 0.33±0.00 | 0.38±0.05 | 0.22±0.00 | 0.28±0.05 | 0.30±0.05 | 0.06±0.01 | 0.59±0.03 | 0.32±0.00 | 0.33±0.04 | 0.23±0.09 |
| Punicic acid C18: 3 | 80.67±0.81 | 79.62±0.31 | 78.72±0.00 | 80.09±1.40 | 80.10±0.11 | 79.16±0.55 | 75.57±0.13 | 75.84±0.17 | 79.05±0.34 | 73.74±0.22 |
| a-Eleostearic acid C18: 3 | 1.89±0.04 | 2.01±0.06 | 1.94±0.00 | 2.13±0.35 | 2.33±0.03 | 1.75±0.08 | 2.55±0.02 | 1.69±0.03 | 1.66±0.04 | 3.12±0.10 |
| Catulpic acid C18: 3 | 0.38±0.03 | 0.53±0.01 | 0.37±0.00 | 1.08±0.08 | 0.74±0.04 | 0.44±0.04 | 1.35±0.03 | 0.34±0.00 | 0.36±0.01 | 1.59±0.08 |
| Arachidic acid C20: 0 | 0.50±0.05 | 0.41±0.00 | 0.19±0.00 | 0.16±0.03 | 0.45±0.03 | 0.40±0.03 | 0.00±0.00 | 0.38±0.01 | 0.42±0.00 | 0.36±0.09 |
| Gadoleic acid C20: 1 | 0.45±0.04 | 0.44±0.02 | 0.38±0.00 | 0.38±0.06 | 0.49±0.04 | 0.43±0.05 | 0.05±0.00 | 0.50±0.03 | 0.50±0.00 | 0.60±0.03 |
| Behenic acid C22: 0 | 0.06±0.00 | 0.04±0.00 | 0.00±0.00 | 0.32±0.03 | 0.00±0.00 | 0.41±0.03 | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 0.04±0.00 |
| Total UFA | 92.88±0.33 | 93.38±0.20 | 93.28±0.00 | 93.71±0.04 | 93.57±0.08 | 92.87±0.30 | 93.57±0.16 | 93.03±0.05 | 93.05±0.14 | 92.67±0.15 |
| Total SFA | 7.12±0.33 | 6.62±0.20 | 6.72±0.00 | 6.29±0.04 | 6.43±0.08 | 7.14±0.30 | 6.43±0.16 | 6.97±0.05 | 6.95±0.14 | 7.33±0.15 |
| UFA/SFA ratio | 13.06±0.64 | 14.11±0.44 | 13.88±0.30 | 14.91±0.09 | 14.56±0.18 | 13.03±0.59 | 14.60±0.39 | 13.34±0.11 | 13.38±0.30 | 12.65±0.29 |
| MUFA | 4.32±0.29 | 4.82±0.10 | 5.77±0.00 | 4.68±0.01 | 4.57±0.16 | 5.97±0.06 | 6.40±0.01 | 7.05±0.06 | 6.09±0.19 | 5.98±0.36 |
| PUFA | 88.56±0.61 | 88.56±0.29 | 87.52±0.00 | 89.03±0.05 | 89.00±0.24 | 86.90±0.36 | 87.17±0.15 | 85.98±0.12 | 86.95±0.33 | 86.69±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.
approximately 84% of the oils fatty acids (especially the bioactive conjugated linolenic isomers, representing the three fatty acids. PSO is, therefore, a rich source of linoleic acid with values higher than 80%. 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 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).

### 3.2.6. 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 antioxidant activity (IC50) 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].

### 3.2.7. 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             |     |     |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| Oil yield      | -0.652** | 1   |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| Seed hardness  |     |     |           |               | -0.591** | -0.561** |      |      |    |    |    |    |          |              |            |          |
| Syf            |     |     |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| Punicic acid   |     |     |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| MUFA           |     |     |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| PUFA           |     |     |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| L*             |     |     |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| a*             |     |     |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| b*             |     |     |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| C*             |     |     |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| H* (deg)       |     |     |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| Chlorophyll    |     |     |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| Pheophytin     |     |     |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| IC50 (mg)      |     |     |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| Precipitation  |     |     |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| Maximum T°     | 0.609** | -0.462* | 0.375* |               |     |              |      |      |    |    |    |    |          |              |            |          |
| Minimum T°     |     |     |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| Altitude       | 0.607** | -0.363* | 0.379* |               |     |              |      |      |    |    |    |    |          |              |            |          |
| Sunshine hours |     |     |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| Latitude north |     |     |           |               |     |              |      |      |    |    |    |    |          |              |            |          |
| Longitude west  | 0.613** | -0.546* |     |               |     |              |      |      |    |    |    |    |          |              |            |          |

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.
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 phaeophytin 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.

Acknowledgments

The authors are grateful to the technical staff of the Agri-Food Technology and Quality Laboratory of Regional Center for Agricultural Research in Marrakesh, National Institute for Agricultural Research (INRA, Morocco), for providing support during the development of this research. The authors would also like to extend their thanks to Mr Lahbib Loukhmas and to the pomegranate producers for their assistance during sample collection. This research was performed at the Regional Center for Agricultural Research in Marrakesh belonging to the National Institute for Agricultural Research in the framework of the research activities of the Laboratory of Agri-Food Technology and Quality (INRA, Morocco) in collaboration with the Laboratory of Virology, Microbiology, Quality, and Biotechnology of Faculty of Sciences and Techniques in Mohammedia, Hassan II University (Morocco).

References

[1] P. Legua, P. Melgarejo, A. Haddioui et al., “Characterization of six varieties of Moroccan pomegranate,” *Options Méditerranéennes. Séries A Mediterranean Seminars*, vol. 103, pp. 83–86, 2012.
[2] V. Verardo, P. García-Salas, E. Baldí, A. Segura-Carretero, A. Fernandez-Gutierrez, and M. F. Caboni, “Pomegranate seeds as a source of nutraceutical oil naturally rich in bioactive lipids,” *Food Research International*, vol. 65, pp. 445–452, 2014.
[3] I. L. P. D. Melo, E. B. T. D. Carvalho, A. M. D. O. E. Silva et al., “Characterization of constituents, quality and stability of pomegranate seed oil (*Punica granatum* L.),” *Food Science and Technology*, vol. 36, no. 1, pp. 132–139, 2016.
[4] P. Górnaś and M. Rudzińska, “Seeds recovered from industry by-products of nine fruit species with a high potential utility as a source of unconventional oil for biodiesel and cosmetic and pharmaceutical sectors,” *Industrial Crops and Products*, vol. 83, pp. 329–338, 2016.
[5] P. Górnaś, A. Soliven, and S. Dalija, “Seed oils recovered from industrial fruit by-products are a rich source of tocopherols and tocotrienols: rapid separation of α/β/γ/δ homologues by RP-HPLC/FLD,” *European Journal of Lipid Science and Technology*, vol. 117, pp. 773–777, 2014.
[6] A. M. M. Costa, L. O. Silva, and A. G. Torres, “Chemical composition of commercial cold-pressed pomegranate (*Punica granatum*) seed oil from Turkey and Israel, and the use of bioactive compounds for samples’ origin preliminary discrimination,” *Journal of Food Composition and Analysis*, vol. 75, pp. 8–16, 2018.
[7] L. Fernandes, J. A. Pereira, I. Lópeè-Cortés, D. M. Salazar, E. Ramalhosa, and S. Casal, “Lipid composition of seed oils of different pomegranate (*Punica granatum* L.) cultivars from Spain,” *International Journal of Food Studies*, vol. 4, no. 1, pp. 95–103, 2015.
[8] A. Caligiani, F. Bonzanini, G. Palla, M. Cirilini, and R. Bruni, “Characterization of a potential nutraceutical ingredient: pomegranate (*Punica granatum* L.) seed oil unsaponifiable fraction,” *Plant Foods for Human Nutrition*, vol. 65, no. 3, pp. 277–283, 2010.
[9] C. Venkitasamy, L. Zhao, R. Zhang, and Z. Pan, “Pomegranate,” in *Integrated Processing Technologies for Food and Agricultural By-Products*, pp. 181–216, Elsevier Inc., Amsterdam, Netherlands, 2019.
[10] K. Koba and T. Yanagita, “Potential health benefits of pomegranate (*Punica granatum*) seed oil containing conjugated linolenic acid,” *Nuts and Seeds in Health and Disease Prevention*, pp. 919–924, 2011.
[11] A. M. Goula and K. G. Adamopoulos, “A method for pomegranate seed application in food industries: seed oil encapsulation,” *Food and Bioproducts Processing*, vol. 90, no. 4, pp. 639–652, 2012.
[12] A. Emami, M. H. F. Nasri, M. Ganjkhanlou, L. Rashidi, and A. Zali, “And-linolenic acids in muscle and adipose tissues of kid,” *Animal Feed Science and Technology*, vol. 209, pp. 79–89, 2015.
[13] A. Drahun, R. B. Kostogryz, A. Filipiak-Florkiewicz et al., “Effect of dietary pomegranate seed oil on laying hen performance and physicochemical properties of eggs,” *Food Chemistry*, vol. 221, pp. 1096–1103, 2017.
[14] A. Haddioui, “La culture du grenadier (Punica granatum L.) au Maroc,” CIEAHM-Options Méditerranéennes, vol. 103, no. 5, pp. 79–81, 2012.

[15] MAPM, DREF, Produits Agricoles labellisés au Maroc Plan Maroc Vert, Ministère de l’Agriculture, du Développement Rural et des Eaux et Forêts, Rabat, Morocco, 2019th edition, 2019.

[16] MAPM, Produits du Terroir du Maroc: Catalogue National, Ministère de l’Agriculture et de la Pêche Maritime, Rabat, Morocco, 2014th edition, 2014.

[17] S. Loukhas, E. Kerak, M. Outaki, M. Belaqziz, and H. Harrak, “Assessment of minerals, bioactive compounds, and antioxidant activity of ten moroccan pomegranate cultivars,” Journal of Food Quality, vol. 2020, Article ID 8844538, 10 pages, 2020.

[18] S. Moukrim, S. Lahsini, M. Rhazi et al., “Climate change impacts on potential distribution of multipurpose agro-forestry species: Argania spinosa (L.) Skeels as case study,” Agroforestry Systems, vol. 93, no. 4, pp. 1209–1219, 2019.

[19] A. Oukabli, “Le Grenadier,” Bulletin Mensuel d’Information et de Liaison du PNTTA, vol. 123, pp. 77–80, 2004.

[20] J. J. Martínez, F. Hernández, H. Abdelmajid et al., “Physico-chemical characterization of six pomegranate cultivars from Morocco: processing and fresh market aptitudes,” Scientia Horticulturae, vol. 140, pp. 100–106, 2012.

[21] L. Vázquez-Araújo, P. N. Nuncio-Jáuregui, P. Cherdchu, F. Hernández, E. Chambers, and À. A. Carbonell-Barrachina, “Physicochemical and descriptive sensory characterization of Spanish pomegranates: aptitudes for processing and fresh consumption,” International Journal of Food Science & Technology, vol. 49, no. 7, pp. 1663–1672, 2014.

[22] International Organisation for Standardisation, Sensory Analysis—General Guidance for the Design of Test Rooms (ISO 8589-2007). International Organisation for Standardisation, Geneva, Switzerland, 2nd edition, 2007.

[23] P. Melgarejo-Sánchez, J. J. Martínez, P. Legua, R. Martínez, F. Hernández, and P. Melgarejo, “Quality, antioxidant activity and total phenols of six Spanish pomegranates clones,” Scientia Horticulturae, vol. 182, pp. 65–72, 2015.

[24] IOC, Spectrophotometric Investigation in the Ultraviolet, IOC, Madrid, Spain, 2019.

[25] B. B. Wolf and S. Langley, “Cultural factors and the response to pain: a review,” American Anthropologist, vol. 70, no. 3, pp. 494–501, 1968.

[26] E. Psomiadou and M. Tsimidou, “Pigments in Greek virgin olive oils: occurrence and levels,” Journal of the Science of Food and Agriculture, vol. 81, no. 7, pp. 640–647, 2001.

[27] B. Moktan, J. Saha, and P. K. Sarkar, “Antioxidant activities of soybean as affected by Bacillus-fermentation to kinema,” Food Research International, vol. 41, no. 6, pp. 586–593, 2008.

[28] W. Elfallah, M. Ying, N. Nasri, H. Sheng-Hua, F. Guasmi, and A. Ferchichi, “Fatty acids from Tunisian and Chinese pomegranate (Punica granatum L.) seeds,” International Journal of Food Science and Nutrition, vol. 62, no. 3, pp. 200–206, 2011.

[29] IOC, Determination of Fatty Acid Methyl Esters by Gas Chromatography, vol. 33, 1st edition, 2017.

[30] M. Radunić, M. Jukić Špika, S. Goretta Ban, J. Gadže, J. C. Díaz-Pérez, and D. Maclean, “Physical and chemical properties of pomegranate fruit accessions from Croatia,” Food Chemistry, vol. 177, pp. 53–60, 2015.

[31] G. Ferrara, A. Giancaspro, A. Mazzeo et al., “Characterization of pomegranate (Punica granatum L) genotypes collected in Puglia region, Southeastern Italy,” Scientia Horticulturae, vol. 178, pp. 70–78, 2014.

[32] A. Tehranifar, M. Zarei, Z. Nemati, B. Esfandiyari, and M. R. Vazifeshenas, “Investigation of physico-chemical properties and antioxidant activity of twenty Iranian pomegranate (Punica granatum L.) cultivars,” Scientia Horticulturae, vol. 126, no. 2, pp. 180–185, 2010.

[33] I. Hmid, H. Hanine, D. Elshammi, and A. Oukabli, “The physico-chemical characteristics of Morrocan pomegranate and evaluation of the antioxidant activity for their juices,” Journal of the Saudi Society of Agricultural Sciences, vol. 17, no. 3, pp. 302–309, 2018.

[34] O. Caliskan and S. Bayazit, “Morpho-pomological and chemical diversity of pomegranate accessions grown in Eastern Mediterranean region of Turkey,” Journal of Agriculture, Science and Technology, vol. 15, pp. 1449–1460, 2013.

[35] F. Hernández, P. Legua, R. Martínez, P. Melgarejo, and J. J. Martínez, “Fruit quality characterization of seven pomegranate accessions (Punica granatum L.) grown in southeast of Spain,” Scientia Horticulturae, vol. 175, pp. 174–180, 2014.

[36] F. Alcaraz-Mármol, N. Nuncio-Jáuregui, F. García-Sánchez, J. J. Martínez-Nicolás, and F. Hernández, “Characterization of twenty pomegranate (Punica granatum L.) cultivars grown in Spain: aptitudes for fresh consumption and processing,” Scientia Horticulturae, vol. 219, pp. 152–160, 2017.

[37] L. Fernandes, J. A. Pereira, I. López-Cortés, D. M. Salazar, E. Ramalhosa, and S. Casal, “Fatty acid, vitamin E and sterols composition of seed oils from nine different pomegranate (Punica granatum L.) cultivars grown in Spain,” Journal of Food Composition and Analysis, vol. 39, pp. 13–22, 2015.

[38] A. Fadavi, M. Barzegar, and M. Hossein Azizi, “Determination of fatty acids and total lipid content in oilseed of 25 pomegranates varieties grown in Iran,” Journal of Food Composition and Analysis, vol. 19, no. 6-7, pp. 676–680, 2006.

[39] S. A. Mahesar, A. H. Kori, S. Tuﬁal, H. Sherazi, A. A. Kandhro, and Z. H. Llaghari, Fruit Oils: Chemistry and Functionality, Springer Nature, Basingstoke, UK, 2019.

[40] H. K. Cavdar, D. K. Yanik, U. Gok, and F. Gogus, “Optimisation of microwave-assisted extraction of pomegranate (Punica granatum L.) seed oil and evaluation of its physicochemical and bioactive properties,” Food Technology and Biotechnology, vol. 55, no. 1, pp. 86–94, 2017.

[41] Z. Amri, H. Lazreg-Aref, M. Mekni et al., “Oil characterization and lipids class composition of pomegranate seeds,” BioMed Research International, vol. 2017, Article ID 2037341, 8 pages, 2017.

[42] H. Özçan, “The comparison of the quality properties of some commercial cold pressed seed oils,” Journal of the Turkish Chemical Society, Section A: Chemistry, vol. 6, no. 2, pp. 149–156, 2019.

[43] M. Tsimidou, G. Blekas, and D. Boskou, “Olive oil,” Encyclopedia of Food Sciences and Nutrition, vol. 97, pp. 4252–4260, 2003.

[44] Y. R. Kang, J. Park, S. K. Jung, and Y. H. Chang, “Synthesis, characterization, and functional properties of chlorophylls, phophytins, and Zn-phophytins,” Food Chem. vol. 245, pp. 943–950, 2017.

[45] D. F. Alfeaka and S. A. Al-Hilfi, “Fatty acids composition by (GC-MS) and most important physical chemicals parameters of seed oil pomegranate and grape seeds,” Journal of Biology, Agriculture and Healthcare, vol. 6, no. 8, 2016.

[46] European Parliament and the Concll of the European Union, “Regulation (EC) No 1333/2008 of the European Parliament...”
ans of the Council of 16 December 1998 on food additives,” *The Official Journal of the European Union*, vol. 54, pp. 16–33, 2008.

[47] T. Kaseke, U. Linus, and O. Amos, “Heliyon Fatty acid composition, bioactive phytochemicals, antioxidant properties and oxidative stability of edible fruit seed oil: effect of preharvest and processing factors,” *Heliyon*, vol. 6, pp. 1–15, 2020.

[48] S. Özgül-Yücel, “Determination of conjugated linolenic acid content of selected oil seeds grown in Turkey,” *Journal of the American Oil Chemists’ Society*, vol. 82, no. 12, pp. 893–897, 2005.

[49] E. Tapia-Campos, M. C. Castañeda-Saucedo, J. d. P. Ramirez-Anaya, K. Alarcón-Dominguez, E. H. Valdés-Miramontes, and O. Núñez-Maciel, “Physical-chemical characterization of fourteen pomegranate genotypes of southern Jalisco, Mexico,” *Scientia Horticulturae*, vol. 199, pp. 163–169, 2016.

[50] E. A. Ajal, R. Jbir, P. Melgarejo, F. Hernández, A. Haddioui, and A. S. Hannachi, “Efficiency of Inter Simple Sequence Repeat (ISSR) markers for the assessment of genetic diversity of Moroccan pomegranate (*Punica granatum* L.) cultivars,” *Biochemical Systematics and Ecology*, vol. 56, pp. 24–31, 2014.