Vegetos (2023) 36:1211–1219
https://doi.org/10.1007/s42535-022-00524-x

RESEARCH ARTICLES

Lipid content and composition of *Pistacia atlantica* Desf. subsp. *atlantica* fruits from three geographic origins in Algeria

Amina Labdelli[1] · Abdelhamid Foughalia[1] · Mohammed Tahirine[1] · Kamel Zemour[2,3] · Muriel Cerny[3] · Ahmed Adda[2] · Othmane Merah[3,4]

Received: 3 October 2022 / Revised: 2 November 2022 / Accepted: 3 November 2022 / Published online: 17 November 2022

Abstract

Atlas pistachio fruits are an important source for pharmaceutical uses and human health. However, its chemical composition has not been sufficiently exploited previously. This study, explores the characteristics and chemical composition of the fruit oil of three populations of *Pistacia atlantica* Desf. subsp. *atlantica* grown in three different zones in Algeria (Tiaret T-R, Tiaret T-Z and Laghouat). The oil content has ranged from 50.5 to 67.3% registered in Tiaret (T-R) and Laghouat, respectively. Moreover, the acid index and peroxide value highlighted mean values about of 8.98–25.8 mg KOH/g oil and 0.6–1.4 meq O_2/kg oil respectively. The determination of fatty acids composition by gas chromatography showed that this species is mainly rich in unsaturated fatty acid (UFA). The limited values of UFA are 74.4 for Tiaret (T-R) and 76.4% for Laghouat. Its main compounds were oleic (39.1–49%), linoleic (23.6–31%) and palmitic (21.3–23.6%) acids. Also, the *β*-sitosterol is the main composant of phytosterols which is largely abundant in the extracted oil where its value exceeded 72.8 mg 100 g^{-1}. In summary, the fruit oil of Atlas pistachio is mainly rich in UFA and sterol, which take an important place in several fields. Therefore, it will be important that this species could be exploited in Algeria.

Keywords Atlas pistachio · Oil · Acid value · Peroxide value · Fatty acids · Phytosterols

Introduction

Since antiquity, the plant world has been the main source of human and animal nutrition. Consequently, their traditional medicine uses are very important (Tali et al. 2019; Zemour et al. 2019, 2021). This particularity is due to the diversification of families, genus and species which are distinguished by a series of physiological and biochemical processes depending on the climatic stage in which they are found.

✉ Othmane Merah
othmane.merah@ensiacet.fr

[1] Scientific and Technical Research Centre for Arid Areas (CRSTRA), BP 1682 RP, 07000 Biskra, Algeria

[2] Laboratory of Agro-Biotechnology and Nutrition in Semi-Arid Areas, Faculty of Natural Sciences and Life, University Ibn Khaldoun, BP 78, Tiaret, Algeria

[3] Laboratoire de Chimie Agroindustrielle, Université de Toulouse, INRA, INPT, Toulouse, France

[4] Département Génie Biologique, Université Paul Sabatier, IUT A, 32000 Auch, France

Atlas pistachio are deciduous trees that are smaller species than *Pistacia vera* L. trees. It belongs to Anacardiaceae family which contains 13 or more species. It has been confirmed that oleic, linoleic and linolenic acids have an important role in medicinal uses, such as reducing triacylglycerols, low-density cholesterol (LDL), total cholesterol, glycemic index and neurodegenerative diseases (Thomas et al. 2015; Yahyavi et al. 2019). Also, Godswill et al. (2016) and Chen and Liu (2020) have indicated that polyunsaturated fatty acids (PUFA) are indispensable for brain function, the eyes and the nervous system. In addition, epidemiological studies have shown that PUFA are associated with cardiovascular diseases prevention (Wu et al. 2020). The implications and applications of nutritional indices including the PUFA/SFA are recently clarified (Godswill et al. 2016). However, it has been revealed that environmental conditions effect the fatty acid composition of several crops such as safflower (Zemour et al. 2019, 2021) and sunflower (Ahmed et al. 2021; Roche et al. 2019).

Moreover, preventive action against several diseases is due to bioactive compounds such as tocopherols, sterols and polyphenol (Ben Ahmed et al. 2021; Chelghoum et al. 2020;

Labdelli et al. 2019a, b; Shakerardekani and Yahyazadeh 2020). Many studies have revealed that phytosterols have potential benefits for human health. Indeed, they have cellular functions in plants by regulating membrane fluidity and cellular communication (Brufau et al. 2008; Scolaro et al. 2019). Also, it has been demonstrated that the consumption of sterols influences the immune system and decreases the morbidity and mortality caused by cardiovascular diseases (Moreau et al. 2018; Plat et al. 2019). Generally, the phytosterols occur naturally in small amounts in all sections of plants, where they are present notably in oilseeds (Moreau et al. 2018). However, the phytosterol contents variations in plants are affected by genotype and environmental conditions (Gravé et al. 2019; Rogowska and Szakiel 2020; Salhi et al. 2021). Moreover, it has been reported that the diversity of sterols and their conjugated forms may allow plants to adapt to environmental stresses (Rogowska and Szakiel 2020).

The study of the genetic resources patrimony, especially that has a pharmaceutical and industrial interest, remains a scientific priority to assess it and take profit of their production (Ziyad et al. 2022). In Algeria, the Atlas pistachio is widely located in arid and semi-arid areas (Labdelli et al. 2019a, b; Ziyad et al. 2022). This species has undergone a clear regression of the occupied areas which is inevitably accompanied by genetic erosion leading consequently to reducing the variability within the species (Labdelli et al. 2020a).

The most studied Atlas pistachio oil in Algeria concentrated on the determination of its fatty acid composition only in one region (Guenane et al. 2015; Zouzou et al. 2015; Labdelli et al. 2019a; Chelghoum et al. 2020; Ziyad et al. 2022). However, so far, no detailed comparative study has been recorded on the chemical composition of Atlas pistachio fruits oils from different regions. For that, this study aims to identify the intraspecific diversity of the chemical quality of fruit oils of the three populations of *P. atlantica* Desf. subsp. *atlantica* growing in wild under different environmental conditions in Algeria (semi-arid and arid).

Materials and methods

Geographical origin of fruits

The fruits of Atlas pistachio tree were collected randomly in September 2016 from three different populations from three regions in Algeria (L: Laghouat; T-R: Tiaret Rechaiga, T-Z: Tiaret Zemalet El Emir Abdelkader) (Fig. 1). The fruits were conserved at 4 °C until analysis (Labdelli et al. 2020b). The geographic and climatic conditions of these regions are presented in Table 1.

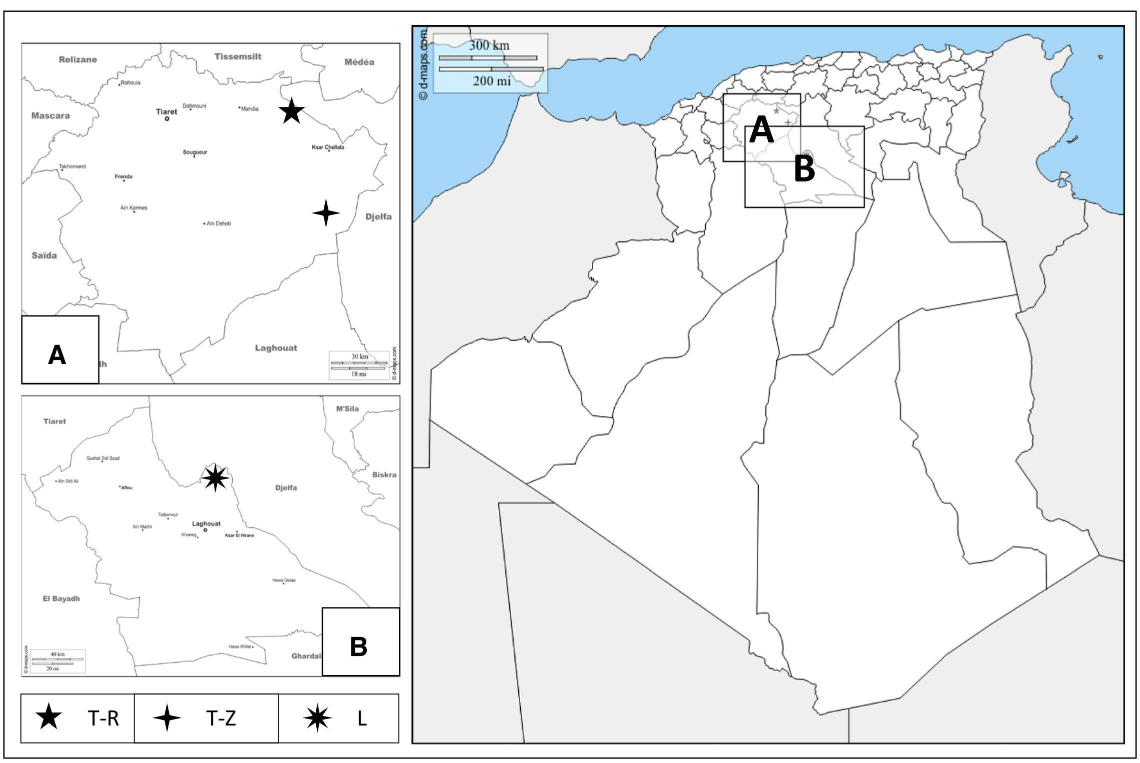

Fig. 1 Map of the sampling sites in Tiaret (**A**) and Laghouat (**B**) department (*L* Laghouat, *T-R* Tiaret-Rechaiga, *T-Z* Tiaret-Zemalet El Emir Abdelkader)

Table 1 Geographic and climatic conditions of the three Atlas pistachio collection sites

Site	Bioclimatic floor	Altitude (m)	Latitude (N)	Longitude (E)	Rainfall (mm)	T M (°C)	T min (°C)	T max (°C)
L	Arid	909	34° 09′ 11″	03° 01′ 09″	120	20	12.8	27
T-R	Semi-arid	808	35° 22′ 33″	02° 09′ 5″	190	17.7	11.4	24.9
T-Z	Semi-arid	873	34° 54′ 45″	02° 13′ 42″	190	17.7	11.4	24.9

T M Mean temperature (°C), *T min* minimal temperature (°C), *T max* maximal temperature (°C). Source: National Meteorology Office of Algeria (ONM) during 2016. *L* Laghouat, *T-R* Tiaret-Rechaiga, *T-Z* Tiaret-Zemalet El Emir Abdelkader.

Chemical analysis

Oil extraction

The oil extraction was carried out for 6 h on ground seed (crushed by the coffee grinder, CCG2013-11, 40G, France) using the Soxhlet method (NF EN ISO 659) with cyclohexane (200 mL). After that, the crude oil was recovered by removing the solvent in a rotary evaporator (IKA RV 10 Digital, Staufen Germany) under low pressure at 50 °C (Labdelli et al. 2019a).

Acid value (AV)

The oil sample (3 g) was dissolved in ethanol (10 mL). The titration is performed with potassium hydroxide solution KOH (0.1 N), using phenolphthalein as a color indicator. The AV is calculated according to the ISO 660 (ISO 2009) (Eq. 1) (Mahboubifar et al. 2016).

$$AV = V \times N \times \frac{56.11}{W}, \quad (1)$$

where V is volume of added KOH in mL; N is normality of KOH; 56.11 is molar mass of KOH and W is weight of the oil sample (g).

Peroxide value (PV)

Firstly, the oil sample (1 g) was dissolved in a mixture of acetic acid/chloroform (3:2, v/v) (12.2 mL). Next, saturated potassium iodide solution (15 mL) was added to the mixture and placed in the dark for 15 min. Then, 60 mL of distilled water and 1 mL of starch solution was added. After, the resulting mixture was titrated with 0.01 N sodium thiosulfate solution ($Na_2S_2O_3$). Finally, the PI is deduced from the Eq. (2) according to the ISO 3660 (ISO 2007) (Mahboubifar et al. 2016).

$$PI = \left(V - V_0\right) \times \frac{N}{W}, \quad (2)$$

where V is initial volume of $Na_2S_2O_3$ solution; V_0 is volume of added $Na_2S_2O_3$ solution; N: sodium thiosulfate normality and W is weight of the oil sample (g).

Fatty acids composition (GC analysis)

The fatty acid methyl esters (FAMEs) were analyzed by gas chromatography coupled to flame ionization detection (Varian 3900). 200 mg of oil was dissolved in 5 mL of organic solvent Terbutylmethyl ether (TBME). After shaking using a vortex-mixer, the esterification was carried out by adding 0.2 M trimethylsulfonium hydroxide (TMSH). Then, the mixture was injected into GC-3800 Chromatograph. The GC was equipped with a CP Select CB 50 m capillary column (D, 0.25 mm). The injector and detector temperatures were set at 250 °C. Oven temperature was increased from 185 to 250 °C (Labdelli et al. 2019a).

Phytosterols composition

For determining the sterol content of the oil fruit, 500 mg of each sample and ethanolic KOH (4 mL, 1 M) (TITRINORM, Prolabo, Pessac, France) was added to tube containing cholestanol (50 µL) (dihydrocholesterol; Aldrich Chemicals Co., Lyon, France). After shaking, the mixture was heated in a water bath for 60 min at 60 °C. Then distilled water (1 mL) and iso-hexane (6 mL) (Merck, Martillac, France) were added. The upper phase that contains the sterol compound was recovered after decantation. Sterol determination was made of two stages. Firstly, the silylation was carried out by addition of N,O-bis[*trimethylsilyltrifluoro*acetamide] (BSTFA) (40 µL) with 1% *trimethylchloro*silane (TMCS) (Restek, Lisses, France). Secondly, one microliter of sterol *trimethyl*silyl ether derivatives was injected into a Perkin-Elmer GC equipped with a CP-SIL 5CB 30 m column (i.d., 0.25 mm) and an on-column injector. Detection was performed with a flame ionization detector (FID). The temperature of detection was fixed at 365 °C, and that of injector was 160 °C until 350 °C (Roche et al. 2019).

Statistical analysis

All of the analyses were carried out in triplicate, and values are expressed as the mean values ± standard deviations (SD). Data statistical analysis was conducted using STATISTICA software package (StatSof, Tulsa, OK, USA). The comparison of the variables was performed using one-way analysis of variance (ANOVA). Mean comparison was performed by using Duncan test at $p \leq 5\%$ probability level of significance. Pearson's correlation test was used for checking the relationship between the fatty acids. The variation tendency of fatty acids (FAs) and the correlation were examined in GraphPad Prism 7 (GraphPad Software, Inc., La Jolla, CA, USA) and XLSTAT 2020 (Adinsoft). The clustered heat maps were conducted by RStudio version 1.1.456 (STATISTICA software).

Results

Oil content, acid value (AV) and peroxide value (PV)

The obtained results demonstrated that the oil content and the acid value are strongly influenced by the geographical areas. However, this effect proved to be insignificant for the measured peroxide value (Table 2). The oil content ranged between 50.53% (Tiaret T-R) and 67.3% (Laghouat) (Table 2).

The ecotypes have shown an AV ranging from 8.9 to 25.8 (mg KOH g^{-1} oil) registered by ecotypes of Tiaret (T-Z) and Tiaret (T-R), respectively (Table 2). The determination of the acid value enables identification of the quality and edibility of oils (Onyeike and Oguike 2003). According to Codex alimentarius (standard CXS 19-1981) and Novidzro et al. (2019), the acid value of edible oils would not exceed 4 mg KOH g^{-1} oil (oleic acid content < 2%) at room temperature. The oil of the Tiaret ecotype (T-Z) is the least altered among the studied ecotypes. However, the results have shown that the oil of Tiaret (T-R) and Laghouat station (L) was strongly altered (Table 2). In our case, this parameter has entered high values and is over the limit in all three oils (from 8.98 to 25.81 mg KOH g^{-1} oil).

According to results, the values of peroxide value are lower and closer to the different stations. They are between 0.6 and 1.4 meqO_2 kg^{-1} oil for Laghouat and Tiaret (TR), respectively.

Table 2 Oil content, acid value (AV), peroxide value (PV) of fruits oils of Atlas Pistachio from three regions in Algeria

Ecotype	Oil content (%)	AV (mg KOH g^{-1} oil)	PV (meq O_2 kg^{-1} oil)
L	67.3 ± 3.91^{a}	23.19 ± 2.6^{a}	0.6 ± 0.5^{a}
T-R	50.53 ± 2.71^{c}	25.81 ± 0.8^{a}	1.4 ± 0.4^{a}
T-Z	59.37 ± 0.21^{b}	8.98 ± 0.6^{b}	1.3 ± 0.6^{a}
Test F	27.92***	109.9***	3.6 ns

Values (means ± SD; n = 3). *L* Laghouat, *T-R* Tiaret-Rechaiga, *T-Z* Tiaret-Zemalet El Emir Abdelkader. Data are represented as mean of three different determinations ± standard deviation. Within each column, lowercase letters indicate significance at $p \leq 0.05$ probability level according to Duncan test. ***Significant at $p \leq 0.001$; ns not significant.

Fatty acids composition

The fatty acids composition (FA) of fruits are shown in Table 3 and Fig. 2a–d. The results indicated some significant differences in the production areas between the compositions of these FAs among the three populations (Fig. 2a, d). The determinate FA was mainly unsaturated (74.4–76.4%) (Table 3). Among this category, the oleic acid (C18:1n9) is the predominate acid determined in Tiaret (T-R) ecotype (39.1%) and Laghouat (L) ecotype (49%), respectively. The Linolenic acid has revealed a value ranging from 23.6% (Laghouat ecotype) to 31% T-R ecotype (Fig. 2b, c). However, the results have indicated that the saturated fatty acids (SFA) remained lower. Indeed, the values of palmitic acid (saturated fatty acid) varied from 21.3 to 23.6% in Laghouat (L) and Tiaret (T-R), respectively (Fig. 2b, c).

A heatmap based on the nine-fatty acids composition of the three populations (Fig. 2a) was merged both of T-R and T-Z (Tiaret) populations into one group, due to their high LA (Linoleic acid) content. While the population of Laghouat (L) was distinguished by its higher OA (Oleic acid) value.

Significant negative and positive correlations were reported with varying degrees between the determined nine fatty acids. In fact, the most important correlations ($p < 0.001$) were observed between ALA and PA ($r = 0.998$, $R^2 = 0.996$), ALA and SA ($r = -0.982$, $R^2 = 0.964$), LA and OA ($r = -0.991$, $R^2 = 0.982$) and SA and PA ($r = -0.980$, $R^2 = 0.961$). There is at least one (positive or negative) correlation between each fatty acid and one of the other eight for the remaining fatty acids.

Sterols composition

The sterol composition of oil fruits is shown in Table 4. The *β*-sitosterol is the dominant compound in the three populations in which the ecotype of Laghouat contains a higher amount (97 mg 100 g^{-1}) than the ecotypes of Tiaret (T-R and T-Z). Atlas pistachio fruits are a good source of phytosterols due to the abundance of demethylphytosterols (DMS) (more than 88.6% of total phytosterols), dimethylphytosterols (DiMS) and methylphytosterols (MS), respectively (Table 4).

Discussion

The results have shown a higher oil content that can reach up to 67.3%. According to the literature, *P. atlantica* Desf. has oil content values ranging from 27.7 to 64% (Guenane et al. 2015; Saffarzadeh and Csapó 1999; Yazdanpanah

Table 3 Fatty acids composition (%) of fruits of Atlas Pistachio in three geographic zones in Algeria

Ecotype		L	T-R	T-Z
Saturated fatty acid (SFA)	C16:0	21.33 ± 0.08[a]	23.59 ± 0.02[c]	22.09 ± 0.05[b]
	C18:0	2.12 ± 0.03[c]	1.83 ± 0.00[a]	2.08 ± 0.01[b]
	C20:0	0.14 ± 0.0[a]	0.15 ± 0.01[a]	0.16 ± 0.0[b]
	Total SFA	23.59 ± 0.11[a]	25.57 ± 0.03[c]	24.33 ± 0.06[b]
Monounsaturated fatty acid (MUFA)	C16:1n7	1.18 ± 0.03[b]	1.04 ± 0.01[a]	1.37 ± 0.03[c]
	C18:1n9	49.05 ± 0.19[c]	39.14 ± 0.04[a]	41.76 ± 0.04[b]
	C18:1n7	1.44 ± 0.01[c]	1.24 ± 0.01[b]	1.18 ± 0.01[a]
	C20:1n9	0.29 ± 0[c]	0.28 ± 0[b]	0.25 ± 0.01[a]
	Total MUFA	51.96 ± 0.23[c]	41.70 ± 0.06[a]	44.56 ± 0.09[b]
Polyunsaturated fatty acid (PUFA)	C18:2n6	23.68 ± 0.09[a]	31.06 ± 0.03[c]	30.07 ± 0.03[b]
	C18:3n3	0.77 ± 0.0[a]	1.67 ± 0.02[c]	1.05 ± 0.0[b]
	Total PUFA	24.45 ± 0.09[a]	32.73 ± 0.05[c]	31.12 ± 0.04[b]
Total MUFA + PUFA		76.41 ± 0.32[c]	74.43 ± 0.11[a]	75.68 ± 0.13[b]
(MUFA + PUFA)/SFA		3.24	2.91	3.11

Values (means ± SD; n = 3). *L* Laghouat, *T-R* Tiaret-Rechaiga, *T-Z* Tiaret-Zemalet El Emir Abdelkader. Within each column, lowercase letters indicate significance at $p < 0.05$ probability level according to Duncan test.

SFA saturated fatty acid, *MUFA* Monounsaturated fatty acids, *PUFA* Polyunsaturated fatty acids, *UFA* Unsaturated fatty acids. C16:0 (Palmitic acid); C16:1n7 (Palmitoleate); C18:0 (Stearic acid); C18:1n-9 (Oleic acid); C18:1n7 (Vaccenic acid); C18:2n-6 (Linoleic acid); C20:0 (Arachidic acid); C18:3n-3 (α-Linolenic acid); C20:1n-9 (Eicosenoic acid).

and Baghereyanmanesh 2015; Zouzou et al. 2015). Consequently, this study indicated the richness of Atlas pistachio in oil extracted from seeds grown in Algeria. However, the oil contents depend on genetic make up, seed maturity stage, organ (fruits, leaves, galls), environmental conditions and methods of oil extraction (Chelghoum et al. 2020; Gravé et al. 2019; Roche et al. 2019; Salhi et al. 2021). Results showed also that the lowest oil content was recorded by T-R ecotype (Table 2). Herein, it has been demonstrated that the oil content is significantly reduced under drought (Roche et al. 2019; Zemour et al. 2021).

The results indicated that the values of acid index ranged from 8.9 to 25.8 (mg KOH g^{-1} oil). This trait has been described by several works (Yousfi et al. 2002, 2003; Gharsallaoui et al. 2016), which reported an acid value ranging from 4.45 to 18.7 (mg KOH g^{-1} oil). This acidity is determined by the intrinsic nature of seeds and lipase action (microbial or plant tissue lipases). Thus, the acidity was significantly related to the oil extraction method (Gharsallaoui et al. 2016; Salhi et al. 2021) and is accompanied by oil rancidity (Onyeike and Oguike 2003).

The obtained results showed that the peroxide values were very low for all the studied ecotypes (> 1.4 meq O_2 kg^{-1} oil). Samavati and Adeli (2014) have estimated that the peroxide value varied between 9.85 and 6.54 (meqO_2 kg^{-1} oil). Furthermore, the results are consistent with those of Farhoosh et al. (2008) and Salhi et al. (2021), who reported a value of 1.94 (meqO_2 kg^{-1} oil) and 1.91 (meq O_2 kg^{-1} oil), respectively. According to Codex alimentarius standard (CXS 19-1981) and Gotoh and Wada (2006), the maximum value of peroxide value for edible oils is fixed at 10 meq O_2 kg^{-1} oil and 30 mEq O_2 kg^{-1}, respectively. Also, this trait is used for determining the oil oxidation quality (Rokosik et al. 2020). According to these results, the extracted oil proves its safety and its higher saturation. Therefore, the oil fruit of Atlas pistachio can be stored over the long term.

In this study, the fatty acid composition consisted mainly of polyunsaturated fatty acids across the studied ecotypes. This is in agreement with previous results (Chelghoum et al. 2020; Labdelli et al. 2019a; Shakerardekani and Yahyazadeh 2020; Yazdanpanah et al. 2015; Zouzou et al. 2015). High oleic acid content (49%) was recorded for Laghouat (L) among all the studied ecotypes. In contrast, Tiaret populations (T-R and T-Z) were characterized by their higher values in linoleic and palmitic acids.

Generally, the fatty acids synthesis pathway determines their chain length and their degree of hydroxylation and saturation. The 16:0 and 18:1 free acids are the main fatty acids in plastid of seed. The relative proportions of these fatty acids are determined by several enzymes such as FATA, FATB, 18:0-ACP desaturase (SAD) and KASII (Bates et al. 2013).

Abe et al. (2018) have indicated that the fatty acid desaturase 2 (FAD2) is the main enzyme that catalyzes the conversion of oleic acid to linoleic acid, while FAD2 mutants exhibit altered oleic and linoleic acid content in many crops (Shockey et al. 2017).

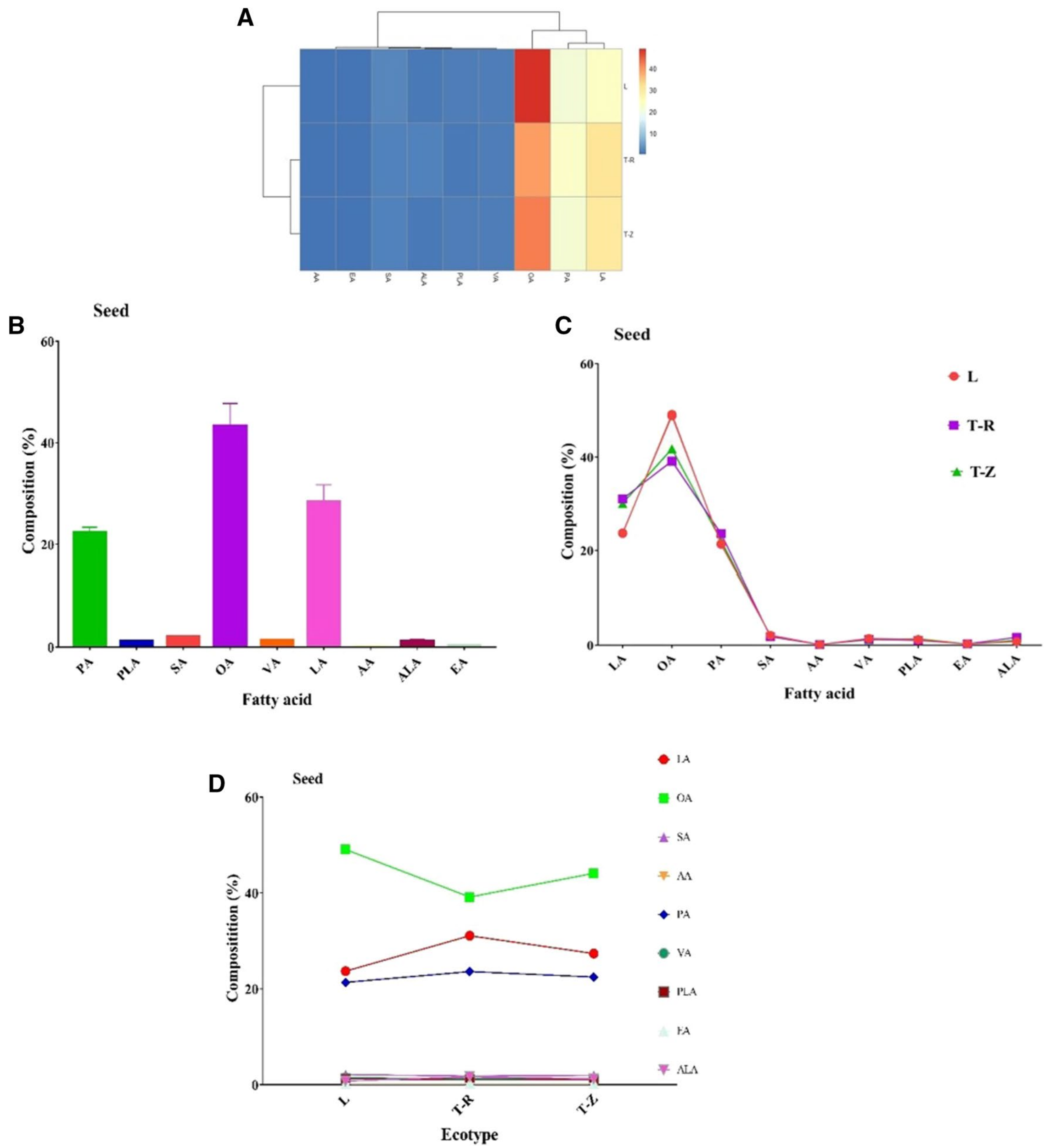

Fig. 2 The heat map (**a**), variation tendency (**b**), production area (**c**) and mean composition (4) of nine fatty acids (FAs) in fruits from three ecotypes (*L* Laghouat, *T-R* Tiaret-Rechaiga, *T-Z* Tiaret-Zemalet El Emir Abdelkader). PA = C16:0 (Palmitic acid); PLA = C16:1n7 (Palmitoleate); SA = C18:0 (Stearic acid); OA = C18:1n-9 (Oleic acid); VA = C18:1n7 (Vaccenic acid); LA = C18:2n-6 (Linoleic acid); AA = C20:0 (Arachidicacid); ALA = C18:3n-3 (α-Linolenic acid); EA = C20:1n-9 (Eicosenoic acid)

The quality of oilseed is affected by the environment and genotype and their interaction (Liersch et al. 2020; Zemour et al. 2019, 2021). Indeed, the variation of fatty acid profile is due to enzyme activity (Dar et al. 2017), environment conditions (Silva et al. 2020) and genotype (Ziyad et al. 2022).

The abiotic stresses affect the function of the delta 12 desaturase enzyme which is responsible for conversion of oleic acid into linoleic acid (Garcés and Manch 1991). Also, the fatty acids biosynthesis involves acyl-CoA elongase and Δ9 and Δ6 desaturases. The activity of these enzymes is at the origin of the increase in the rate of unsaturated fatty acids compared to saturated fatty acids (Sidorov and Tsydendambaev 2014).

The studied genetic diversity has highlighted its richness in β-sitosterol. Salhi et al. (2021) and Yousfi et al. (2002) have indicated 87% and 85% of β-sitosterol, respectively. Phytosterols are biologically active dietary compounds that are involved in important functional processes in the brain.

Table 4 Phytosterols composition (mg 100 g^{-1}) of fruits of Atlas pistachio in three geographic zones in Algeria

	Ecotype	L		T-R		T-Z	
Phytosterols composition		mg 100 g^{-1}	%	mg 100 g^{-1}	%	mg 100 g^{-1}	%
Demethylphytosterols (DMS)	*β*-Sitosterol	97	75.55	72.81	70.72	81.08	83.83
	Campesterol	4.62	3.6	3.07	2.98	3.69	3.82
	Stigmasterol	2.77	2.16	2.25	2.19	2.06	2.13
	δ7-Avenasterol	9.71	7.56	14.14	13.73	3.12	3.23
	Total DMS	114.1	88.86	92.27	89.63	89.95	93
Methylphytosterols (MS)	Citrostadienol	2.45	1.91	2.13	2.07	–	–
	Total MS	2.45	1.91	2.13	2.07	–	–
Dimethylphytosterols (DiMS)	Cycloartenol	8.45	6.58	6.08	5.91	4.89	5.06
	Methylene cycloartanol	3.4	2.65	2.47	2.4	1.88	1.94
	Total DiMS	11.85	9.23	8.55	8.31	6.77	7
Total phytosterols		128.4	100	102.95	100	96.72	100

L Laghouat, *T-R* Tiaret-Rechaiga, *T-Z* Tiaret-Zemalet El Emir Abdelkader.

Ali et al. (2018) and Burg et al. (2013) have demonstrated that plant sterols decrease amyloidogenic transformation and could therefore be an interesting and beneficial dietary compound in Alzheimer's disease. Also, *β*-sitosterol may reduce the risk of heart diseases and inhibit the proliferation of breast, prostate and colon cancer cells (Moreau et al. 2018).

The biosynthesis of sterols is determined by the activity of 3-hydroxy-3-methylglutaryl coenzyme A reductase (HMG–CoA reductase), where it increases under high temperature and drought effect (Kumar et al. 2018). However, Merah et al (2012) have mentioned that the composition of the matrix in which the phytosterols are present affects their final accumulation (Merah et al. 2012). These authors have showed also that the augmentation of the individual sterol may result from the intensification of overall enzymes of biosynthesis pathway and in particular sterol-methyl-transferase 2 (SMT2). This enzyme SMT2 induces the augmentation of *β*-stitosterol and stigmasterol instead of campesterol and its activity is dependent on temperature during grain filling stage (Merah and Mouloungui 2019).

Conclusion

In nature, the Atlas pistachio tree is a wild species with an important nutritional value due to its richness in oil extracted from its seed. This oil is a source of phytosterols and polyunsaturated fatty acids, particularly oleic and linoleic acids. Today, several studies have demonstrated that the variation of fatty acid and sterol composition is mainly due to environmental conditions that greatly influence the enzyme activity responsible for their biosynthesis. The localization of genes encoding this activity could constitute a scientific gain to control the final fatty acid and sterol profile under abiotic stress. Results have demonstrated that *Pistacia atlantica* Desf. subsp. *atlantica* is largely adapted in Algeria and could constitute an important agro-economic source for cosmetics, pharmaceutical and industry fields.

References

Abe K, Araki E, Suzuki Y, Toki S, Saika H (2018) Production of high oleic/low linoleic rice by genome editing. Plant Physiol Biochem 131:58–62. https://doi.org/10.1016/j.plaphy.2018.04.033

Ahmed MA, Hassan T, Zahran H (2021) Heterosis for seed, oil yield and quality of some different hybrids sunflower. OCL 28:25. https://doi.org/10.1051/ocl/2021010

Ali R, Saeed S, Ali S, Sayed S, Ahmed R, Mobin L (2018) Effect of black gram flour as egg replacer on microstructure of biscuit dough and its impact on edible qualities. J Food Meas Charact 12(3):1641–1647. https://doi.org/10.1007/s11694-018-9779-3

Bates P, Stymne S, Ohlrogge J (2013) Biochemical pathways in seed oil synthesis. Curr Opin Plant Biol 16(3):358–364. https://doi.org/10.1016/j.pbi.2013.02.015

Ben Ahmed Z, Yousfi M, Viaene J, Dejaegher B, Demeyer K, Heyden Y (2021) Four *Pistacia atlantica* subspecies (*atlantica, cabulica, kurdica* and *mutica*): a review of their botany, ethnobotany, phytochemistry and pharmacology. J Ethnopharmacol 265:113329. https://doi.org/10.1016/j.jep.2020.113329

Brufau G, Canela M, Rafecas M (2008) Phytosterols: physiologic and metabolic aspects related to cholesterol-lowering properties. Nutr Res 28(4):217–225. https://doi.org/10.1016/j.nutres.2008.02.003

Burg VK, Grimm HS, Rothhaar TL, Grosgen S, Hundsdorfer B, Haupenthal VJ, Zimmer VC, Mett J, Weingartner O, Laufs U, Broersen LM, Tanila H, Vanmierlo T, Lutjohann D, Hartmann T, Grimm MOW (2013) Plant sterols the better cholesterol in Alzheimer's disease? A mechanistical study. J Neurosci 33(41):16072–16087. https://doi.org/10.1523/jneurosci.1506-13.2013

Chelghoum M, Guenane H, Harrat M, Yousfi M (2020) Total tocopherols, carotenoids, and fatty acids content variation of *Pistacia atlantica* from different organs' crude oils and their antioxidant activity during development stages. Chem Biodivers 17(9):e2000117. https://doi.org/10.1002/cbdv.202000117

Chen J, Liu H (2020) Nutritional indices for assessing fatty acids: a mini-review. Int J Mol Sci 21(16):5695. https://doi.org/10.3390/ijms21165695

Codex Alimentarius (standard CXS 19-1981) STANDARD FOR EDIBLE FATS AND OILS NOT COVERED BY INDIVIDUAL STANDARDS CXS 19-1981 Formerly CAC/RS 19-1969. Adopted in 1981. Revised in 1987, 1999. Amended in 2009, 2013, 2015, 2017, 2019

Dar A, Choudhury A, Kancharla P, Arumugam N (2017) The FAD2 gene in plants: occurrence, regulation, and role. Front Plant Sci. https://doi.org/10.3389/fpls.2017.01789

Farhoosh R, Tavakoli J, Khodaparast M (2008) Chemical composition and oxidative stability of kernel oils from two current subspecies of *Pistacia atlantica* in Iran. JAOCS 85(8):723–729. https://doi.org/10.1007/s11746-008-1258-2

Garcés R, Mancha M (1991) In vitro oleatedesaturase in developing sunflower seeds. Phytochemistry 30(7):2127–2130. https://doi.org/10.1016/0031-9422(91)83599-G

Gharsallaoui M, Azouzi H, Chelli-Chaabouni A, Ghrab M, Condoret JS, Ayadi M, Gabsi S (2016) Extraction methods of seed oil and oil quality of *Pistacia atlantica* grown in dry land. In: Kodad O, López-Francos A, Rovira M, Socias i Company R (eds) XVI GREMPA Meeting on Almonds and Pistachios. Zaragoza: CIHEAM, 2016, pp 287–290. http://om.ciheam.org/om/pdf/a119/00007409.pdf

Godswill N, Constant L, Martin B, Kingsley T, Albert D, Thierry K, Sastile M, Hermine N, Emmanuel Y (2016) Effects of dietary fatty acids on human health: focus on palm oil from *Elaeis guineensis* Jacq and useful recommendations. Food Public Health 6(3):75–85. https://doi.org/10.5923/j.fph.20160603.03

Gotoh N, Wada S (2006) The importance of peroxide value in assessing food quality and food safety. JAOCS 83(5):473–474. https://doi.org/10.1007/s11746-006-1229-4

Gravé G, Mouloungui Z, Poujaud F, Cerny M, Pauthe C, Koumba I, Diakaridja N, Merah O (2019) Accumulation during fruit development of components of interest in seed of Chia (*Salvia hispanica* L.) cultivar Oruro© released in France. OCL 26:50. https://doi.org/10.1051/ocl/2019037

Guenane H, Bombarda I, Ould Elhadj M, Yousfi M (2015) Effect of maturation degree on composition of fatty acids and tocopherols of fruit oil from *Pistacia atlantica* growing wild in Algeria. Nat Prod Commun 10(10):1934578X1501001. https://doi.org/10.1177/1934578X1501001023

Kumar MSS, Mawlong I, Ali K, Tyagi A (2018) Regulation of phytosterol biosynthetic pathway during drought stress in rice. Plant Physiol Biochem 129:11–20. https://doi.org/10.1016/j.plaphy.2018.05.019

Labdelli A, Zemour K, Simon V, Cerny M, Adda A, Merah O (2019a) Pistacia Atlantica Desf: A source of healthy vegetable oil. Appl Sci 9(12):2552. https://doi.org/10.3390/app9122552

Labdelli A, Adda A, Bouchenafa N, Rebiai A, Zebib B, Merah O (2019b) Study of seed dormancy origins in three Atlas pistachio ecotypes (*Pistacia atlantica* Desf.). Appl Ecol Environ Res 17(6):13555–13565. https://doi.org/10.15666/aeer/1706_1355513565

Labdelli A, Rebiai A, Tahirine M, Adda A, Merah O (2020a) Nutritional content and antioxidant capacity of the seed and the epicarp in different ecotypes of *Pistacia atlantica* Desf. Subsp. *atlantica*. Plants 9(9):1065. https://doi.org/10.3390/plants9091065

Labdelli A, De La Herrán R, Arafeh R, Resentini F, Trainotti L, Halis Y, Adda A, Merah O (2020b) Genetic variation in damaged populations of *Pistacia atlantica* Desf. Plants 9(11):1541. https://doi.org/10.3390/plants9111541

Liersch A, Bocianowski J, Nowosad K, Mikołajczyk K, Spasibionek S, Wielebski F, Matuszczak M, Szała L, Cegielska-Taras T, Sosnowska K, Bartkowiak-Broda I (2020) Effect of Genotype×environment interaction for seed traits in winter oilseed rape (*Brassica napus* L.). Agriculture 10(12):607. https://doi.org/10.3390/agriculture10120607

Mahboubifar M, Yousefinejad S, Alizadeh M, Hemmateenejad B (2016) Prediction of the acid value, peroxide value and the percentage of some fatty acids in edible oils during long heating time by chemometrics analysis of FTIR-ATR spectra. J Iran Chem Soc 13(12):2291–2299. https://doi.org/10.1007/s13738-016-0948-1

Merah O, Mouloungui Z (2019) Tetraploid wheats: valuable source of phytosterols and phytostanols. Agronomy 9(4):201. https://doi.org/10.3390/agronomy9040201

Merah O, Langlade N, Alignan M, Roche J, Pouilly N, Lippi Y, Bouniols A, Vear F, Cerny M, Mouloungui Z, Vincourt P (2012) Genetic control of phytosterol content in sunflower seeds. Theor Appl Gen 125:1589–1601. https://doi.org/10.1007/s00122-012-1937-0

Moreau R, Nyström L, Whitaker B, Winkler-Moser J, Baer D, Gebauer S, Hicks K (2018) Phytosterols and their derivatives: structural diversity, distribution, metabolism, analysis, and health-promoting uses. Prog Lipid Res 70:35–61. https://doi.org/10.1016/j.plipres.2018.04.001

Novidzro KM, Wokpor K, Amoussou Fagla B, Koudouvo K, Dotse K, Osseyi E, Koumaglo KH (2019) Etude de quelques paramètres physicochimiques et analyse des éléments minéraux, des pigments chlorophylliens et caroténoïdes de l'huile de graines de *Griffonia simplicifolia*. Int J Biol Chem Sci 13(4):2360–2373. https://doi.org/10.4314/ijbcs.v13i4.38

Onyeike EN, Oguike JU (2003) Influence of heat processing methods on the nutrient composition and lipid characterization of groundnut (*Arachis hypogaea*) seed pastes. Biokemistri 15(1):34–43

Plat J, Baumgartner S, Vanmierlo T, Lütjohann D, Calkins K, Burrin D, Guthrie G, Thijs C, Te Velde A, Vreugdenhil A, Sverdlov R, Garssen J, Wouters K, Trautwein E, Wolfs T, van Gorp C, Mulder M, Riksen N, Groen A, Mensink R (2019) Plant-based sterols and stanols in health & disease: "Consequences of human development in a plant-based environment?" Prog Lipid Res 74:87–102. https://doi.org/10.1016/j.plipres.2019.02.003

Roche J, Mouloungui Z, Cerny M, Merah O (2019) Effect of sowing dates on fatty acids and phytosterols patterns of *Carthamus tinctorius* L. Appl Sci 9(14):2839. https://doi.org/10.3390/app9142839

Rogowska A, Szakiel A (2020) The role of sterols in plant response to abiotic stress. Phytochem Rev 19:1525–1538. https://doi.org/10.1007/s11101-020-09708-2

Rokosik E, Dwiecki K, Siger A (2020) Nutritional quality and phytochemical contents of cold pressed oil obtained from chia, milk thistle, nigella, and white and black poppy seeds. Grasas Aceites 71(3):e368. https://doi.org/10.3989/gya.0679191

Saffarzadeh A, Csapó J (1999) The effect of substituting corn with different levels of *Pistacia atlantica* seeds on laying hens performance in first phase of egg production. Acta Agraria Kaposváriensis 3(2):361–368

Salhi M, Gharsallaoui M, Gabsi S (2021) Tunisian *Pistacia atlantica*. Desf extraction process: Impact on chemical and nutritional characteristics. Eur J Lipid Sci Technol 123(11):2100013. https://doi.org/10.1002/ejlt.202100013

Samavati V, Adeli M (2014) Isolation and characterization of hydrophobic compounds from carbohydrate matrix of *Pistacia atlantica*. Carbohydr Polym 101:890–896. https://doi.org/10.1016/j.carbpol.2013.09.069

Scolaro B, de Andrade LFS, Castro IA (2019) Cardiovascular disease prevention: The earlier the better? A review of plant sterol metabolism and implications of childhood supplementation. Int J Mol Sci 21(1):128. https://doi.org/10.3390/ijms21010128

Shakerardekani A, Yahyazadeh S (2020) An evaluation of some physicochemical properties of wild pistachio oil in kerman province.

Pistachio Health J 3(1):76–86. https://doi.org/10.22123/phj.2021.256623.1056
Shockey J, Dowd M, Mack GM, Scheffler B, Ballard L, Frelichowski J, Mason C (2017) Naturally occurring high oleic acid cottonseed oil: identification and functional analysis of a mutant allele of *Gossypium barbadense* fatty acid desaturase-2. Planta 245:611–622. https://doi.org/10.1007/s00425-016-2633-0
Sidorov RA, Tsydendambaev VD (2014) Biosynthesis of fatty oils in higher plants. Russ J Plant Physiol 61:1–18. https://doi.org/10.1134/S1021443714010130
Silva OLL, Macedo ARG, de Lima NEDSC, Campos KD, Araújo LCC, Tiburço X, Pinto ASO, Joele MRSP, da Silva FM, da Silva ACR, Raices RSL, da Cruz AG, Juen L, da Rocha RM (2020) Effect of environmental factors on the fatty acid profiles and physicochemical composition of oysters (*Crassostrea gasar*) in Amazon estuarine farming. Aquac Res 51(6):2336–2348. https://doi.org/10.1111/are.14577
Tali BA, Khuroo AA, Ganie AH, Nawchoo A (2019) Diversity, distribution and traditional uses of medicinal plants in Jammu and Kashmir (J&K) state of Indian Himalayas. J Herb Med. https://doi.org/10.1016/j.hermed.2019.100280
Thomas J, Thomas CJ, Radcliffe J, Itsiopoulos C (2015) Omega-3 fatty acids in early prevention of inflammatory neurodegenerative disease: a focus on Alzheimer's disease. Bio Med Res Int 13:172801. https://doi.org/10.1155/2015/172801
Wu D, Jian C, Peng Q, Hou T, Wu K, Shang B, Zhao M, Wang Y, Zheng W, Ma Q, Li C, Cheng H, Wang X, Zhao L (2020) Prohibitin 2 deficiency impairs cardiac fatty acid oxidation and causes heart failure. Cell Death Dis. https://doi.org/10.1038/s41419-020-2374-7
Yahyavi F, Alizadeh-Khaledabad M, Azadmard-Damirchi S (2019) Oil quality of pistachios (*Pistacia vera* L.) grown in East Azarbaijan. Iran NFS J 18:12–18. https://doi.org/10.1016/j.nfs.2019.11.001
Yazdanpanah E, Baghereyanmanesh R (2015) Quantitative analysis of the seed oil from *Pistacia atlantica* var *mutica* in Boyer Ahmad. Indian J Fund Appl Life Sci 5(4):84–87
Yousfi M, Nedjmi B, Bellal R, Ben Bertal D, Palla G (2002) Fatty acids and sterols of *Pistacia atlantica* fruit oil. JAOCS 79(10):1049–1050. https://doi.org/10.1007/s11746-002-0601-8
Yousfi M, Nadjemi B, Belal R, Ben-Bertal D (2003) Étude des acides gras de huile de fruit de pistachier de l'Atlas algérien. OCL 10(5–6):425–427. https://doi.org/10.1051/ocl.2003.0425
Zemour K, Labdelli A, Adda A, Dellal A, Talou T, Merah O (2019) Phenol content and antioxidant and antiaging activity of safflower seed oil (*Carthamus Tinctorius* L.). Cosmetics 6(3):55. https://doi.org/10.3390/cosmetics6030055
Zemour K, Adda A, Labdelli A, Dellal A, Cerny M, Merah O (2021) Effects of genotype and climatic conditions on the oil content and its fatty acids composition of *Carthamus tinctorius* L. Seeds Agronomy 11(10):2048. https://doi.org/10.3390/agronomy11102048
Ziyad BA, Yousfi M, Heyden YV (2022) Effects of growing region and maturity stages on oil yield, fatty acid profile and tocopherols of *Pistacia atlantica* Desf. fruit and their implications on resulting biodiesel. Renew Energy 181:167–181. https://doi.org/10.1016/j.renene.2021.09.057
Zouzou F, Saib A, Seddik-Ameur A, Djebar H, Legseir B (2015) Chemical composition, toxicity and antioxydant activity of *Pistacia atlantica* Desf. subsp Oil. Res J PharmBiol Chem Sci 6(5):253–259