European Food Research and Technology (2020) 246:833–843
https://doi.org/10.1007/s00217-020-03453-8

ORIGINAL PAPER

Evaluation of hazelnut and walnut oil chemical traits from conventional cultivars and native genetic resources in a non-traditional crop environment from Argentina

M. Cecilia Cittadini[1] · Darío Martín[2] · Silvia Gallo[2] · Gastón Fuente[2] · Romina Bodoira[1] · Marcela Martínez[1] · Damián Maestri[1]

Received: 3 December 2019 / Revised: 6 February 2020 / Accepted: 8 February 2020 / Published online: 17 February 2020

Abstract

The oil content and oil-quality responses of several hazelnut and walnut cultivars were evaluated in a new, non-traditional crop environment in north-western Patagonia. Moreover, two Argentinean landraces were studied for the first time. Oil contents were in the ranges 66–72% (hazelnuts) and 74–79% (walnuts). Oleic acid predominated largely (78.4–84.4%) in hazelnut oils, whereas linoleic acid did in walnut oils (52.2–60.9%). Concentrations of individual fatty acids from the two local landraces were similar to those from most commercial cultivars grown worldwide. Total tocopherol concentrations varied largely among oils from each nut species (404–534 mg/kg, hazelnuts; 319–424 mg/kg, walnuts). All hazelnut and walnut genotypes showed good oil yield and quality traits in the crop environment evaluated as compared with data from by the USDA National Nutrient Data Base for Standard Reference. Results connected with fatty and tocopherol profiles suggest potential value for breeding purposes towards obtaining nuts and oils with enhanced oxidative stability. Overall, findings contribute in enlarging the biodiversity sources to develop new cultivars with promising marketable quality characteristics.

Keywords Hazenut · Walnut · Genetic resources · Oil composition · Tocopherols · Quality parameters

Abbreviations

AV	Acid value
DWB	Dry weight basis
FA	Fatty acid
I_2V	Iodine value
MUFA	Monounsaturated fatty acid
OC	Oil content
OSI	Oxidative stability index
PCA	Principal component analysis
PUFA	Polyunsaturated fatty acid
SFA	Saturated fatty acid
TTC	Total tocopherol content

✉ Damián Maestri
dmaestri@unc.edu.ar

[1] Instituto Multidisciplinario de Biología Vegetal (IMBIV), Consejo Nacional de Investigaciones Científicas Y Técnicas (CONICET), Universidad Nacional de Córdoba (UNC), Av. Vélez Sarsfield 1611, Córdoba, Argentina

[2] Instituto Nacional de Tecnología Agropecuaria (INTA-EEA Valle Inferior del Río Negro), Camino 4 S/N, IDEVI, Viedma, Río Negro, Argentina

Introduction

Increasing scientific evidences show that tree nuts are really valuable for their health and nutritional properties [1]. They provide a large quantity of calories, monounsaturated and essential polyunsaturated fatty acids (PUFA), vitamins and other nutraceuticals. Many health benefits have been mentioned for the consumption of hazelnuts and walnuts, including reduced risk of cardiovascular and coronary heart disease, type II diabetes treatment, prevention of certain cancers, and the lessening of symptoms attributed to age-related and other neurological disorders [2, 3].

Hazelnut and walnut are two major tree nut crops. While hazelnut is mainly cultivated in Mediterranean Basin countries (worldwide production is widely dominated by Turkey with about 70% of current world output), walnut cultivation is wider spread (China and the USA are the major producers—about 71% of world output—but production from countries of the European Union is important as well) [4].

Hazelnut and walnut are globally consumed as snacks and in confectionary foods. They are nutrient dense foods mainly due to their high lipid contents; as a consequence, the

majority of studies on their chemical and nutritional profiles have been focused on that kernel component.

Oil content from a wide range of hazelnut genotypes varies between 50 and 70% of the kernel weight [5–8]. The average value from commercial cultivars can be estimated at around 65%. As occurs with all vegetable oils, hazelnut oils (HO) are mainly composed of non-polar (i.e., triacylglycerols, TAG) lipids (98.8%) [9]. In mature kernels, OOO and OOL (O = oleoyl, L = linoleoyl) are the major TAG species [10]. Consequently, oleic acid is by far the most abundant fatty acid (FA, about 80% of the total FA content) followed by linoleic, palmitic and stearic acids in a decreasing order of abundance [5–8, 10]. Linolenic acid is found at very low concentration (< 0.1%).

Considerable variability in lipid content has been also found from walnut genotypes of different provenances. Oil percentages between 62 and 71%, 62–67%, 54–68%; 55–68% and 54–72% have been reported in walnut genetic resources native from Turkey [11], Iran [12], Morocco [13], Spain [14] and Italy [15], respectively. Martínez and Maestri [16] have found values as high as 74% oil in kernels from commercial walnut cultivars growing in North-western Argentina. In contrast with HO, walnut oils (WO) are characterized by unusually high amounts of PUFA. Among nuts, WO contains the highest concentrations of both essential (linoleic and linolenic) FA (up to 75% of the total FA content).

As regards minor components present in nut oils, most studies have focused on tocopherols which, in addition to health properties, can effectively enhance the oxidative stability of the oils. Higher total tocopherol contents (TTC) are present in HO as compared to those found in WO; the usual ranges of TTC were reported to be 350–500 and 250–350 mg/kg oil, respectively [10, 17–19]. α-Tocopherol predominates in the former and γ-tocopherol in the latter (about 95 and 90% of the TTC, respectively). Besides tocopherols, squalene—a lipophilic triterpenoid hydrocarbon presents in many fats and oils—has been also found to contribute health benefits and protection against oil oxidative degradation [20, 21]. There is a paucity of information regarding the concentration of squalene in nut oils. A pioneer study by Maguire et al. [22] reports squalene contents ranging from 9 to 186 mg/kg in oils from edible nuts including hazelnuts and walnuts.

While substantial scientific evidences indicate that seed oil contents and their components (i.e., fatty acids, tocopherols) are genetically regulated, there is robust information indicating that they can be also affected by different environmental factors. Regarding nuts, important variations in oil contents, FA and tocopherol profiles have been reported in almonds [23, 24], hazelnuts [5, 8, 10] and walnuts [14, 16, 19, 25] from different provenances.

In the last two decades, interest in nut consumption has expanded hazelnut and walnut cultivation to some regions in the southern hemisphere, where Chile and Argentina emerge as the main producing countries. In Argentina, some cultivation areas of hazelnut and walnut have temperature and precipitation regimes—and other agro-ecological conditions—that differ from those of the Mediterranean Basin, where they are traditionally cultivated. In the present study, the oil content and oil-quality responses of several hazelnut and walnut commercial cultivars were evaluated in a non-traditional crop environment. Moreover, two Argentinean landraces were studied for the first time. While adding new information to nut nutrient databanks, the study also contributes data that may be useful to breeders, growers and food-processing industries.

Materials and methods

Growing site and plant materials

Fruits of thirteen hazelnut (*Corylus avellana* L.) and six walnut (*Juglans regia* L.) genotypes (Table 1) were obtained from experimental orchards at the Estación Experimental Agropecuaria del Valle Inferior (EEAVI-INTA, latitude 40° 48′ S, longitude 63° 05′ W, 6 m above sea level) located at the lower valley of the Black River in the Northeastern region of Argentinean Patagonia. The region is characterized by semiarid, temperate to cold-temperate climate conditions, with low cloudiness, intensive solar radiation and important annual temperature variations. The average annual temperature fluctuates between 14 and 15 °C. Average minimum and maximum temperatures are near 8 and 21 °C, respectively, but absolute minimum and maximum values can reach − 10 °C and 45 °C, respectively. The average annual rainfall is below 400 mm concentrated mainly in summer. The average values of relative humidity during the period covering from full-flowering to complete fruit maturity of the nut species studied (September–March) range between 31 and 39%. The total annual accumulated evapotranspiration is about 1050 mm. Meteorological data were recorded using an automatic weather station placed near the experimental orchard.

The soil texture in the growing site varies from loamy-clay to silty-clay with relatively high content of organic matter (2.2% in 0–20 cm depth, and 1.8% in 20–40 cm depth). Soil pH is weakly basic (7.5).

Hazelnut and walnut trees used in this study were spaced 5 m × 4 m (500 trees/ha) and 8 m × 7 m (178 trees/ha), respectively. They were grown under natural rainfall, plus supplemental irrigation needed to cover crop water requirements. Three trees from each hazelnut and walnut genotypes were sampled during the crop year 2019. Fruits were harvested at full maturity and dried to about 6% kernel

Table 1 Oil content and oil quality parameters from kernels of hazelnut and walnut cultivars

Cultivar	OC	OSI	AV	I_2V
Hazelnut				
Barcelona	$68.62 \pm 0.42^{a,b,c,d}$	16.76 ± 0.25^{a}	$0.05 \pm 0.01^{c,d,e}$	$94.44 \pm 1.02^{d,e,f}$
Camponica	$69.80 \pm 0.09^{d,e}$	$21.45 \pm 1.51^{c,d}$	$0.04 \pm 0.01^{a,b,c}$	$91.44 \pm 1.02^{a,b,c}$
Casina	66.46 ± 0.11^{a}	$17.41 \pm 0.26^{a,b}$	$0.06 \pm 0.02^{d,e}$	96.76 ± 0.91^{f}
Ennis	$68.37 \pm 1.3^{b,c,d}$	16.61 ± 0.43^{a}	$0.05 \pm 0.01^{c,d,e}$	$96.15 \pm 1.17^{e,f}$
Jemtegaard	$68.02 \pm 1.20^{b,c}$	19.02 ± 0.19^{b}	0.07 ± 0.01^{e}	$92.24 \pm 0.44^{b,c,d}$
Nocchione	72.31 ± 0.28^{g}	$21.68 \pm 1.53^{c,d}$	$0.02 \pm 0.01^{a,b}$	$89.96 \pm 0.81^{a,b,c}$
Nociara	$70.51 \pm 0.51^{e,f}$	$21.30 \pm 1.52^{c,d}$	$0.02 \pm 0.01^{a,b}$	$90.08 \pm 0.27^{a,b}$
Nostrale	$71.37 \pm 0.24^{f,g}$	$21.04 \pm 0.38^{c,d}$	$0.04 \pm 0.02^{b,c,d}$	$90.97 \pm 2.77^{c,d,e}$
Riccia di Talanico	$67.18 \pm 0.11^{a,b}$	$17.31 \pm 0.01^{a,b}$	$0.04 \pm 0.01^{a,b,c}$	$96.65 \pm 1.58^{e,f}$
Tonda di Giffoni	$70.94 \pm 0.24^{e,f,g}$	$21.48 \pm 0.49^{c,d}$	0.01 ± 0.01^{a}	$90.80 \pm 0.33^{a,b,c}$
Tonda Gentile Romana	$71.47 \pm 0.61^{f,g}$	22.79 ± 0.89^{d}	$0.02 \pm 0.01^{a,b}$	88.81 ± 0.36^{a}
Willamette	$71.13 \pm 0.08^{f,g}$	$22.42 \pm 0.01^{c,d}$	$0.05 \pm 0.01^{c,d,e}$	$90.13 \pm 0.19^{a,b}$
Local selection	72.25 ± 1.00^{g}	20.95 ± 0.30^{c}	$0.05 \pm 0.02^{b,c,d}$	$90.36 \pm 0.58^{a,b,c}$
Walnut				
Chandler	75.08 ± 0.18^{b}	$3.08 \pm 0.01^{a,b}$	0.06 ± 0.02^{a}	164.88 ± 0.04^{d}
Fernette	77.36 ± 0.11^{d}	2.90 ± 0.08^{a}	0.08 ± 0.01^{a}	165.77 ± 0.93^{d}
Franquette	75.55 ± 0.18^{b}	3.59 ± 0.02^{c}	0.05 ± 0.01^{a}	143.96 ± 0.40^{a}
Howard	76.22 ± 0.19^{c}	$2.93 \pm 0.01^{a,b}$	0.06 ± 0.02^{a}	165.26 ± 0.12^{d}
Tulare	78.98 ± 0.40^{e}	$2.95 \pm 0.02^{a,b}$	0.06 ± 0.01^{a}	160.24 ± 0.31^{b}
Trompito INTA	73.90 ± 0.05^{a}	3.21 ± 0.28^{b}	0.07 ± 0.01^{a}	162.38 ± 0.11^{c}

Each mean value (± standard deviation) is the average of three independent measurements. For each nut species, values in each column with the same superscript letter are not significantly different ($P > 0.05$)

OC oil content (g/100 g kernel, dry basis), *OSI* oxidative stability index (h , temperature 110 °C, airflow rate 20 L/h), *AV* acid value (% oleic acid), I_2V iodine value

humidity. They were shelled manually and the recovered kernels were stored in plastic bags at − 10 °C until processing.

Oil extraction and chemical analyses

Standard AOCS [26] official methods were used to determine moisture and oil contents. In brief, kernel samples (200 g each) were ground using a universal cutting mill (Tecno Dalvo, Argentina). Dry matter content was determined after oven drying at 80 °C for 72 h. Lipid extraction for total oil content determination was performed using Soxhlet devices with *n*-hexane as solvent.

For analytical and oxidative stability determinations, oils were extracted using a pilot-plant screw press (Model CA 59 G, IBG Monforts, Mönchengladbach, Germany) as described previously [23]. Briefly, kernels containing about 6% moisture (w/w) were ground using a homemade stainless steel roller crusher. Particles between 2.4 and 4.8 mm were selected using an automatic screen (EJR 2000 Zonytest, Argentina) to obtain particle sizes suitable for press feeding. The screw press used a 5-mm restriction die and it was operated at 20 rpm. These latter conditions were selected to achieve both appropriate mass compression and oil exudation without causing plugging and allowing continuous operations. The amount of sample pressed in each run was 0.5 kg. All extractions were performed at room temperature (22–25 °C). The screw press was first run for 15 min without seed material but with heating, via an electrical heating ring attached around the press barrel, to raise the screw-press barrel temperature to the desired temperature. Running temperature was constantly monitored with a digital thermometer (TES-1307, Electrical Electronic Corp., Taiwan) inserted into the restriction die. After each run, all press devices were cleaned and dried.

Fatty acid (FA) composition was analyzed by gas chromatography (GC) according to protocols for oil sample preparation and GC conditions previously reported [23]. Identity was confirmed by means of GC (Clarus 580, Perkin-Elmer, Shelton, USA)—mass spectrometry (MS, Clarus SQ8S) analysis. Separations were performed on a CP Wax 52 CB (Varian, Walnut Creek, USA) fused-silica capillary column using helium (flow rate 1 mL/min) as carrier gas. The GC oven temperature was initially maintained at 180 °C (5 min) and then increased at 2 °C /min to 220 °C. Both injector and detector temperatures were set at 250 °C. The FA components were identified by mass spectra matching using the Wiley mass spectra search library.

Tocopherol composition was analyzed by high performance liquid chromatography (HPLC, Perkin-Elmer, Shelton, USA) following analytical methods used previously [23]. Accurately weighted oil samples (1 g each) were diluted with n-hexane to 10 mL. The solutions were filtered through 0.45 µm pore filters. Aliquots of 20 µL of the filtrated solutions were injected into a Supelcosil LC-NH2-NP column (25 cm × 4.6 mm, Supelco, Bellefonte, USA). The mobile phase was n-hexane/ethyl acetate (70/30 V/V) with a flow rate of 1 mL/min. UV detection at 295 nm was performed. Individual tocopherols were identified by comparing their retention times with those of authentic standards (α-, γ- and δ-tocopherols, ICN Biomedicals, Costa Mesa, USA), and were quantified by the external standard method. The linearity of the response was verified by fitting to line results of each one tocopherol individuals (ten standard solutions with known concentrations) covering the concentration range from 2 to 800 ppm, with a linearity regression coefficient $R^2 = 0.99$.

Squalene content determination was performed essentially according to Maestri et al. [23]. Briefly, oil samples (400 mg) were mixed with 1 mL *n*-hexane, 1 mL squalane solution (1 mg/mL *n*-hexane) and 2 mL KOH solution (2 N in methanol). After 1 min of vigorous shaking, the mixture was left to react for 10 min (the time required for hydrolysis of glycerides). After decanting, the upper phase (*n*-hexane) was extracted and washed twice (5 mL every time) with ethanol/water (50/50 V/V). The *n*-hexane phase was recovered and used for GC and GC–MS analyses according to conditions previously used [23]. Squalene was identified by comparing its mass spectra data with those of the Wiley mass spectra search library. Squalene concentration was calculated on the basis of the internal standard (squalane) concentration.

Acid and peroxide values of the oil samples were analyzed according to AOCS [26]. The oil oxidative stability index (OSI) was determined under accelerated oxidation conditions using the Rancimat (Metrohm, Herisau, Switzerland) apparatus. Airflow rate was set at 20 L/h and temperature of the heating block was maintained at 110 °C.

Iodine values (I_2V) were calculated from fatty acid percentages [27] using the formula: $I_2V = (\%\ \text{palmitoleic acid} \times 1.001) + (\%\ \text{oleic acid} \times 0.899) + (\%\ \text{linoleic acid} \times 1.814) + (\%\ \text{linolenic acid} \times 2.737)$.

Statistical analyses

Statistical differences between cultivars were estimated from ANOVA test at the 5% level ($P < 0.05$) of significance for all parameters evaluated. Whenever ANOVA indicated a significant difference, a pairwise comparison of means by least significant difference (LSD) was carried out. Correlation analyses were performed employing Pearson's test. A multivariate statistical analysis of the whole chemical data set from each nut species was performed using principal component analysis. All statistical analyses were done using the InfoStat program (InfoStat version 2018, National University of Córdoba, Córdoba, Argentina).

Results and discussion

Oil content

The oil content (OC) from hazelnuts varied in the range 66.5–72.3 g/100 g kernel (DWB) (Table 1). Statistical significant differences were found between the studied genotypes; *Casina* and *Riccia di Talanico* had the lowest oil contents, whereas *Nocchione* and an Argentinean local selection had the highest ones. All values recorded were higher than the average total fat content of hazelnut kernels (61%) given by the USDA National Nutrient Data Base for Standard Reference [28]. Likewise, the average OC content we obtained from all cultivars (69.9%) resulted markedly higher than the mean values reported from genetic pools of central Italy (60.8%), Slovenia (59.3%), Portugal (58.2%), Greece (56.8%), Spain (55.9%) and France (51.5%) [8]. Regarding data from specific cultivars, the oil contents recorded in *Camponica* (69.8%), *Nocchione* (72.3%), *Nociara* (70.5%), *Nostrale* (71.4%), *Riccia di Talanico* (67.2) and *Tonda di Giffoni* (70.9%) were greater than those from hazelnut collections at central and northern Italy (62.6–63.6%, 62.8%, 62%, 53.1%, 61.3–62.2% and 58.6–63.7% for the named cultivars, respectively) [7, 8].

Oil contents from walnut cultivars varied between 73.9 and 79 g/100 g kernel (DWB) (Table 1); the local genotype named *Trompito INTA* had the lowest, whereas *Tulare* presented the highest one. All values recorded were higher than the average oil content of walnut kernels (65.2 g/100 g) given by the USDA Standard Reference [28]. The average OC from all cultivars (76.2%) resulted higher than those reported for commercial cultivars from walnut collections in Portugal (62.3–66.5%) [29], Turkey (65.8–69.3%) [30], Italy (68.9–72.9%) [15], Spain (62.2–64.2%) [31] and Poland (61.7–68.7%) [32]. On the other hand, data from some specific cultivars (*Chander*, *Franquette*, *Howard*) showed greater OC than the same cultivars from other geographic provenances [15, 29, 31].

Besides the nature of the cultivar, environmental factors such as temperature could affect lipid synthesis. This has been demonstrated in some olive cultivars which show decreased fruit oil concentrations when are grown under warm climate conditions [33]. Although there is still no direct evidence of relationships between temperature and kernel oil concentration in nuts, it is interesting to note differences in oil yields obtained from some walnut cultivars

(*Chandler*, *Franquette*, *Tulare*) growing under temperate to cold-temperate climate conditions (this study) and those from the same cultivars growing under warmer climate conditions at north-western Argentine [16, 34]; OC are found to be 3–5 percentage points higher in cultivars from the former environment. Differences in OC may be also noted with other warm growing environments in Turkey (Adana region, average annual temperature 19.3 °C) [25], and Portugal (Bragança, average annual temperature 16.4 °C) [29]. The association between OC and ambient temperature has been also suggested in hazelnuts [35]. Studying oil accumulation rates during nut development in three Italian cultivars, these latter authors report that the regular process of oil accumulation lessens at the mid-late kernel expansion stages when higher temperatures occur. Regarding variations in kernel OC in other nuts, Kodad et al. [36] have found higher values in almond cultivars growing in northeast Spain as compared with those from central Morocco. Differences were probably attributed to lower temperatures and better water status in the former environment.

To summarize findings from this section, it could be said that all studied hazelnut and walnut genotypes cultivated at north-western Patagonia show good oil yield responses. In most cases, their kernel oil contents are higher than the standard reference values from the USDA National Nutrient Data Base.

Fatty acid composition

Data on FA composition from hazelnut and walnut kernel oils are reported in Table 2. Oleic acid was by far the most abundant FA in all studied hazelnut genotypes (mean value 81.7%). Although it was within a relatively narrow range of concentrations (78.4–84.4%), significant differences can be observed between cultivars. The lowest concentrations were found in oils from *Casina* and *Ennis* cultivars and the highest in *Tonda di Giffoni*, *Tonda Gentile Romana*,

Table 2 Fatty acid composition from kernel oils of hazelnut and walnut cultivars

Cultivar	Fatty acids								
	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	SFA	MUFA	PUFA
Hazelnut									
Barcelona	$5.84 \pm 0.40^{c,d}$	$0.26 \pm 0.06^{a,b,c}$	$2.16 \pm 0.20^{b,c,d}$	$79.54 \pm 0.10^{a,b,c}$	$11.92 \pm 0.58^{d,e}$	$0.09 \pm 0.01^{a,b,c}$	$8.1 \pm 0.59^{b,c,d}$	$79.9 \pm 0.02^{a,b}$	$12.0 \pm 0.57^{d,e}$
Camponica	6.00 ± 0.63^{d}	$0.24 \pm 0.02^{a,b,c}$	2.76 ± 0.37^{d}	$81.79 \pm 0.14^{d,e,f}$	$8.96 \pm 1.14^{a,b,c}$	$0.09 \pm 0.01^{a,b,c}$	8.8 ± 1.00^{d}	$82.1 \pm 0.14^{c,d,e}$	$9.0 \pm 1.14^{a,b,c}$
Casina	$5.79 \pm 0.16^{c,d}$	$0.30 \pm 0.01^{b,c}$	1.32 ± 0.40^{a}	$78.81 \pm 0.44^{a,b}$	13.61 ± 0.70^{e}	$0.10 \pm 0.01^{b,c}$	$7.2 \pm 0.29^{a,b}$	79.1 ± 0.42^{a}	13.7 ± 0.71^{e}
Ennis	$5.79 \pm 0.11^{b,c,d}$	0.33 ± 0.13^{c}	$1.97 \pm 0.33^{a,b,c}$	78.43 ± 0.51^{a}	13.40 ± 0.92^{e}	$0.06 \pm 0.05^{a,b}$	$7.7 \pm 0.44^{b,c}$	78.8 ± 0.42^{a}	13.5 ± 0.87^{e}
Jemtegaard	$5.71 \pm 0.17^{b,c,d}$	$0.23 \pm 0.02^{a,b}$	2.84 ± 0.42^{d}	$80.00 \pm 0.11^{a,b,c,d}$	$11.11 \pm 0.17^{c,d}$	$0.09 \pm 0.01^{a,b,c}$	$8.6 \pm 0.26^{c,d}$	$80.2 \pm 0.12^{a,b}$	$11.2 \pm 0.18^{c,d}$
Nocchione	$5.42 \pm 0.29^{a,b,c}$	$0.25 \pm 0.04^{a,b,c}$	$2.38 \pm 0.09^{b,c,d}$	$83.62 \pm 0.10^{f,g}$	8.20 ± 0.49^{a}	$0.07 \pm 0.01^{a,b}$	$7.8 \pm 0.40^{b,c}$	$83.9 \pm 0.08^{e,f}$	8.3 ± 0.49^{a}
Nociara	$5.51 \pm 0.06^{a,b,c,d}$	$0.21 \pm 0.01^{a,b}$	$2.54 \pm 0.16^{c,d}$	$83.42 \pm 0.22^{f,g}$	8.22 ± 0.01^{a}	Tr^{a}	$8.0 \pm 0.23^{b,c,d}$	$83.7 \pm 0.19^{e,f}$	8.3 ± 0.04^{a}
Nostrale	$5.23 \pm 0.10^{a,b}$	$0.23 \pm 0.05^{a,b}$	$2.52 \pm 0.43^{c,d}$	$81.16 \pm 2.02^{b,c,d}$	$10.76 \pm 2.50^{b,c,d}$	$0.08 \pm 0.01^{a,b,c}$	$7.7 \pm 0.54^{b,c}$	$81.4 \pm 1.97^{b,c,d}$	$10.8 \pm 2.50^{b,c,d}$
Riccia di Talanico	5.03 ± 0.16^{a}	0.20 ± 0.02^{a}	$1.72 \pm 0.01^{a,b}$	$80.34 \pm 2.00^{b,c,d}$	$12.54 \pm 1.85^{d,e}$	0.12 ± 0.01^{c}	6.8 ± 0.18^{a}	$80.6 \pm 2.02^{a,b,c}$	$12.7 \pm 1.86^{d,e}$
Tonda di Giffoni	$5.41 \pm 0.08^{a,b,c}$	0.17 ± 0.01^{a}	2.73 ± 0.09^{d}	$82.97 \pm 0.17^{e,f,g}$	$8.56 \pm 0.27^{a,b}$	$0.09 \pm 0.01^{a,b,c}$	$8.2 \pm 0.14^{c,d}$	$83.8 \pm 0.13^{d,e,f}$	$8.6 \pm 0.25^{a,b}$
Tonda Gentile Romana	6.05 ± 0.23^{d}	$0.24 \pm 0.05^{a,b,c}$	$2.18 \pm 0.03^{b,c,d}$	84.43 ± 0.01^{g}	6.97 ± 0.23^{a}	$0.09 \pm 0.01^{a,b,c}$	$8.3 \pm 0.23^{c,d}$	84.9 ± 0.06^{f}	7.1 ± 0.23^{a}
Willamette	$5.87 \pm 0.23^{c,d}$	$0.21 \pm 0.02^{a,b}$	$1.91 \pm 0.82^{a,b,c}$	83.92 ± 1.01^{g}	7.89 ± 0.37^{a}	$0.09 \pm 0.01^{a,b,c}$	$7.8 \pm 0.59^{b,c}$	84.9 ± 0.97^{f}	8.0 ± 0.37^{a}
Local selection	$5.36 \pm 0.16^{a,b,c}$	0.18 ± 0.02^{a}	$2.44 \pm 0.08^{b,c,d}$	$83.40 \pm 0.50^{f,g}$	8.46 ± 0.59^{a}	$0.09 \pm 0.01^{a,b,c}$	$7.8 \pm 0.05^{b,c}$	$83.6 \pm 0.55^{e,f}$	8.5 ± 0.59^{a}
Walnut									
Chandler	$6.24 \pm 0.01^{a,b}$	Tr	2.47 ± 0.01^{a}	15.66 ± 0.05^{b}	60.93 ± 0.07^{c}	14.71 ± 0.01^{c}	$8.72 \pm 0.01^{a,b}$	15.68 ± 0.05^{b}	75.64 ± 0.06^{c}
Fernette	7.10 ± 0.21^{b}	Tr	$2.65 \pm 0.13^{a,b}$	14.51 ± 0.04^{a}	59.20 ± 0.04^{b}	16.56 ± 0.33^{d}	9.76 ± 0.33^{b}	14.53 ± 0.04^{a}	75.76 ± 0.36^{c}
Franquette	9.70 ± 0.01^{c}	Tr	5.79 ± 0.28^{c}	20.81 ± 0.97^{e}	52.17 ± 0.04^{a}	11.19 ± 0.15^{a}	15.49 ± 0.33^{c}	20.83 ± 0.97^{e}	63.35 ± 4.77^{a}
Howard	7.14 ± 0.01^{b}	Tr	$2.70 \pm 0.01^{a,b}$	$14.93 \pm 0.11^{a,b}$	58.61 ± 0.04^{b}	16.63 ± 0.05^{d}	9.85 ± 0.01^{b}	$14.95 \pm 0.11^{a,b}$	75.24 ± 0.09^{c}
Tulare	$6.75 \pm 0.03^{a,b}$	Tr	3.07 ± 0.13^{b}	16.80 ± 0.18^{c}	60.38 ± 0.31^{c}	13.01 ± 0.04^{b}	9.83 ± 0.10^{a}	16.82 ± 0.18^{d}	73.39 ± 0.28^{b}
Trompito INTA	5.78 ± 0.12^{a}	Tr	2.30 ± 0.28^{a}	18.22 ± 0.01^{d}	60.39 ± 0.59^{c}	13.32 ± 0.43^{b}	8.08 ± 0.16^{b}	18.24 ± 0.11^{c}	73.71 ± 0.16^{b}

Each mean value (± standard deviation) is the average of three independent measurements. For each nut species, the mean values in each column with the same superscript letter are not significantly different ($P > 0.05$)

Fatty acids are expressed as % of total fatty acids; *C16:0* palmitic acid, *C16:1* palmitoleic acid, *C18:0* stearic acid, *C18:1* oleic acid, *C18:2* linoleic acid, *C18:3* linolenic acid, *SFA* saturated fatty acids, *MUFA* monounsaturated fatty acids, *PUFA* polyunsaturated fatty acids, *Tr* trace value < 0.05%

Willamette and the Argentinean local selection. In oils from commercial hazelnut cultivars, the oleic acid percentage usually ranges from 76 to 82% [5, 6, 17, 37, 38] but higher percentages (up to 85%) have been reported from oils obtained in Italy [7, 8]. Regarding oleic acid concentrations in oils from specific hazelnut cultivars it can be seen that, in general, minor variations occur among geographic provenances. For instance, considering our data and those from cultivars in New Zealand [39], Portugal [5] and Italy [7, 8], the oleic acid percentages are in the ranges 79.6–82.8% (cv. *Camponica*), 74.4–78.8% (cv. *Casina*), 75.4–80.4% (cv. *Ennis*), 83.6–83.9 (cv. *Nocchione*), 82.7–83.4% (cv. *Nociara*), 81.1–81.4% (cv. *Nostrale*), 80.2–80.3% (cv. *Riccia di Talanico*) and 79–83.8% (cv. *Tonda di Giffoni*). Linoleic acid percentages varied between 6.97–13.61% and showed the well-known inverse relationship with oleic acid percentages. In all genotypes oleic and linoleic acids together accounted for more than 90% of the total FA content. Concentrations of saturated fatty acids showed minor variations among hazelnut genotypes. They were comprised within narrow ranges (5–6% and 1.3–2.8% for palmitic and stearic acids, respectively). Taken together they varied from 6.8 to 8.8%. In agreement with all references cited previously, linolenic acid was present in very low amounts (< 0.1%).

Differences in FA profiles from walnut cultivars were greater than those observed from hazelnut genotypes. Linoleic acid concentrations varied in range 52.2% (cv. *Franquette*)–60.9% (cv. *Chandler*) matching in general with that found in oils from several commercial walnut cultivars growing in north-western Argentina (52.5–58.9%) [16], but being somewhat lower than those from Turkey (53.2–64.5%) [25], Portugal (57.5–62.5%) [29], Spain (59.8–64.7%) [14, 31], and oils of non-specified varieties from a lot of provenances worldwide (57.3–64.3%) [18]. Considering all cultivars we studied, the average linoleic acid percentage was 58.6% with a variation coefficient of 5.34%. Oleic acid concentrations varied between 14.51 and 20.81%. In agreement with previous studies [16, 34, 40] higher oleic acid contents, and consequently lower levels of both linoleic and linolenic acids, were found in oils from cv. *Franquette*. Linolenic acid concentration was found to be in the range 11.2% (cv. *Franquette*)–16.6% (cv. *Fernette* and *Howard*). It matches well with those reported from walnuts collected in several countries of America, Asia and the European Union [14, 18]. They are usual concentrations in walnut oils from commercial cultivars but lower (6.8–11.8%) [41] and higher (14.4–20.6%) [42] ranges have been found in oils from Chinese and Italian walnut landraces. Concentrations of saturated FA (palmitic and stearic acids together) varied within a relatively wide range (8.1–15.5%) which in general agrees with concentrations obtained from oils of commercial and non-traditional cultivars of diverse provenances [13–15, 25]. Overall, the FA profiles of walnut oils analyzed here compare well with those from several cultivars distributed globally. Concentrations of individual fatty acids from the local genotype named *Trompito INTA* were similar to those from widely cultivated walnut cultivars. Data from the present study and others previously cited suggest that walnut oil fatty acid composition remains relatively constant irrespective of the crop environment.

Regarding FA composition from other nuts, it has been shown that almond FA profile depends strongly on the genetic background and minor effects are found to be due to the crop environment [23, 43]. In addition, the concentration of each FA component is not related to the country of origin of the different cultivars. These findings also emphasize the stability of FA composition in nuts and point out the possibility of breeding aimed to improve both the nutritional value and the stability of the oils.

Tocopherol composition

As regards minor components present in nut oils, recent research has mainly focused on tocopherols and their effects on oil oxidative stability [44, 45]. Among nuts, hazelnuts are one of the richest sources of these compounds [1]. Hazelnut oils analyzed in this study showed total tocopherol contents (TTC) ranging from 404.4 to 534.4 mg/kg oil (Table 3); the lowest concentration was obtained from cv. *Nocchione* and the highest one from the Argentinean local landrace. The above-mentioned concentrations in general match with those from hazelnut oils of varieties worldwide [17]. It is worth noting that most tocopherol fraction was composed of α-tocopherol (up to 99% of TTC) which, in addition to its well-recognized antioxidant properties, is considered to have the highest vitamin E activity [46]. The concentrations we found for this tocopherol homolog (396.6–527.3 mg/kg oil) are higher as compared with those reported from 75 cultivars and local accessions belonging to diverse European hazelnut germplasm collections (102–390 mg/kg oil) [8]. In general they also result greater than that usually found in cv. *Tombul* (345–383 mg/kg oil) [9, 10] which is the most widespread and considered as prime quality variety in Turkey [10].

The TTC varied significantly among oils extracted from the analyzed walnut cultivars (Table 3). Total tocopherols ranged between 319.3 and 424.2 mg/kg oil and comprised predominantly γ-tocopherol (284.4–381.1 mg/kg oil) and minor amounts of δ- and α-tocopherols (18.1–24.5 and 6.21–17.1 mg/kg oil, respectively). This general pattern matches with those reported from walnuts of unspecified varieties arising from seven countries that are major producers of walnut oil [18]. Regarding tocopherol contents in oils from specific cultivars, differences may be found according to geographic provenances. For instance, our results from *Chandler* and *Howard* cultivars indicate higher TTC as compared to those recorded from the same cultivars grown

Table 3 Tocopherol composition and squalene content from kernel oils of hazelnut and walnut cultivars

Cultivar	α-Toc	β-Toc	γ-Toc	δ-Toc	TTC	SQ
Hazelnut						
Barcelona	405.17 ± 11.91^{a,b}	3.84 ± 0.11^{b,c,d,e}	1.35 ± 0.04^{a,b}	4.49 ± 0.85^{c}	414.84 ± 10.91^{a,b}	428.2 ± 32.6^{b,c,d}
Camponica	516.31 ± 13.50^{a,b,c,d}	3.49 ± 0.91^{a,b,c,d}	9.31 ± 1.16^{d}	Nd	528.17 ± 15.55^{a,b,c,d}	627.5 ± 20.7^{f}
Casina	479.70 ± 6.96^{b,c,d,e,f}	11.73 ± 2.33^{h}	4.52 ± 1.50^{d}	Nd	494.97 ± 6.12^{b,c,d,e}	412.5 ± 50.2^{a,b,c}
Ennis	447.73 ± 8.19^{a,b,d,c,e,f}	6.23 ± 0.09^{f,g}	1.12 ± 0.21^{a,b}	1.10 ± 0.75^{b}	456.18 ± 9.23^{a,b,c,d,e}	475.9 ± 7.78^{c,d}
Jemtegaard	499.29 ± 17.49^{c,d,e,f}	7.89 ± 0.49^{g}	1.83 ± 0.98^{a,b}	1.43 ± 0.98^{b}	510.44 ± 15.08^{c,d,e}	406.2 ± 28.8^{a,b}
Nocchione	396.58 ± 14.37^{a}	1.85 ± 0.01^{a}	0.44 ± 0.15^{a,b}	5.56 ± 1.16^{c}	404.43 ± 15.67^{a}	553.9 ± 23.9^{e}
Nociara	419.58 ± 17.27^{a,b,c}	4.28 ± 0.33^{d,e}	4.80 ± 0.38^{d}	0.88 ± 0.48^{a,b}	429.54 ± 16.74^{a,b,c}	563.1 ± 43.9^{e,f}
Nostrale	447.28 ± 33.91^{a,b,d,c,e,f}	2.28 ± 0.39^{a,b,c}	2.11 ± 0.03^{b,c}	0.22 ± 1.94^{a,b}	451.89 ± 32.58^{a,b,c,d,e}	481.9 ± 16.6^{d}
Riccia di Talanico	519.48 ± 28.32^{d,e,f}	4.15 ± 0.60^{c,d,e}	3.89 ± 0.43^{c,d}	Nd	527.52 ± 28.49^{d,e}	352.2 ± 43.9^{a}
Tonda di Giffoni	477.41 ± 18.41^{a,b,d,c,e,f}	1.99 ± 0.68^{a,b}	0.67 ± 0.11^{a,b}	0.34 ± 0.31^{a,b}	480.41 ± 19.25^{a,b,c,d,e}	698.4 ± 4.33^{g}
Tonda Gentile Romana	521.33 ± 11.61^{e,f}	3.07 ± 0.08^{a,b,c,d,e}	Nd	Nd	524.39 ± 11.69^{d,e}	816.3 ± 4.26^{h}
Willamette	443.60 ± 16.87^{a,b,c,d,e}	3.01 ± 0.23^{a,b,c,d,e}	4.31 ± 0.74^{d}	0.73 ± 0.89^{a,b}	451.65 ± 15.00^{a,b,c,d,e}	812.6 ± 43.4^{h}
Local selection	527.28 ± 0.94^{f}	4.48 ± 1.56^{e,f}	0.99 ± 0.95^{a,b}	1.64 ± 0.20^{b}	534.40 ± 1.77^{e}	462.5 ± 28.5^{b,c,d}
Walnut						
Chandler	9.83 ± 1.91^{a,b}	Nd	321.94 ± 0.62^{c}	23.35 ± 0.11^{b}	355.12 ± 1.18^{c}	Nd
Fernette	14.02 ± 1.50^{b}	Nd	308.40 ± 1.81^{b}	19.98 ± 0.89^{a}	342.41 ± 4.21^{b,c}	Nd
Franquette	10.68 ± 1.12^{a,b}	Nd	304.46 ± 0.08^{b}	24.55 ± 0.01^{b}	339.68 ± 1.20^{b}	Nd
Howard	16.38 ± 0.01^{b}	Nd	284.43 ± 0.51^{a}	18.53 ± 2.04^{a}	319.34 ± 1.52^{a}	Nd
Tulare	17.06 ± 6.8^{b}	Nd	389.07 ± 6.13^{d}	18.07 ± 0.98^{a}	424.20 ± 11.97^{d}	Nd
Trompito INTA	6.21 ± 0.68^{a}	Nd	307.23 ± 0.89^{b}	18.95 ± 0.63^{a}	332.29 ± 0.41^{b}	Nd

Tocopherols and squalene (SQ) are expressed as mg/kg oil

Each mean value (± standard deviation) is the average of three independent measurements. For each nut species, the values in each column with the same superscript letter are not significantly different ($P > 0.05$). Nd, not detected

TTC total tocopherols content

in Turkey [25] but lower than those from Spain [31]. Meanwhile, cv. *Franquette* shows greater TTC under the growing environment in Argentina as compared to values obtained in Portugal (211–297 mg/kg) [47] and Spain (170–315 mg/kg) [40].

While the genotype is considered to be a major source of variability for tocopherol composition of nuts [8, 13, 24, 48], the effect of the growing environment and the genotype × environment interaction may be also significant. This latter has been suggested for almond tocopherols which are affected by climatic conditions, mainly temperature and the occurrence of drought during fruit ripening [49]. Increased tocopherol concentrations have been found in almond genotypes cultivated under warm climate conditions [23, 49]. Although the relationship between tocopherol content and environmental temperature has not yet evaluated directly in walnuts, differences in TTC have been observed between crop years differing in temperatures during kernel development [13, 40].

To highlight results concerning tocopherols from both hazelnuts and walnuts, it could be important to note the relatively large genetic variability found in these oil components. It could be also noted the fairly high tocopherol concentrations found in some genotypes growing in Argentina, in particular that from the local hazelnut landrace. Overall, data show potential value for breeding purposes towards obtaining selections with enhanced tocopherol contents.

Squalene content

There are a few published reports on squalene content in nut oils [22, 50]. Among these, hazelnut oils appear to be one of the richest sources of that compound; Maguire et al. [22] and Derewiaka et al. [50] inform 186 and 258 mg/kg oil, respectively. Squalene concentrations in hazelnut oils analyzed in the present study were found to range between 352 and 816 mg/kg (Table 3). There were significant variations among genotypes; *Tonda Gentile Romana* and *Willamette* had the highest squalene concentrations and *Riccia di Talanico* the lowest one. Squalene was not detected in walnut oils analyzed here. Contrarily to hazelnut oils, this compound could be barely present in walnut oils. Maguire et al. [22] have detected only 9.4 mg squalene per kilogram oil in walnuts of an unspecified variety.

Being the biosynthetic precursor of both sterols and non-steroidal triterpenoids, squalene content could vary widely depending on the physiological stage of the analyzed tissue. For instance, the developing olive drupes accumulate significant amounts of squalene but it drops strongly after the beginning of fruit ripening [51]. Hazelnut oils studied here were obtained from nuts harvested at full maturity; so, the squalene concentrations we found are expected to reflect the real amounts present in the mature kernels and differences observed should be attributed to genotype-related variability.

Oil quality and correlations among chemical parameters

The press-extracted oils from the studied hazelnut and walnut genotypes had very low acid values (< 0.1% oleic acid) (Table 1); they were much lower than the maximum values established by the Codex Alimentarius (Codex Standard for Named Vegetable Oils, CX-STAN 210-1999) [45] for non-refined oils. Oil extraction under conditions we used (screw-pressing at room temperature) would not result in thermal and/or hydrolytic cleavage of FA from the glycerol backbone of the triacylglycerols; therefore, the free fatty acid contents we measured may represent the real levels present in the oils. Besides that, peroxide values were not detected in any of the oils analyzed. In summary, these facts indicate that oils were extracted without causing hydrolytic or oxidative spoilage.

The Rancimat method was used to measure the oxidation rates of hazelnut and walnut oils. The corresponding oxidative stability indexes (OSI) are shown in Table 1. The OSI from hazelnut oils varied between 16.6 and 22.8 h (temperature 110 °C, airflow rate 20 L/h) being higher in *Tonda Gentile Romana* and *Willamette* cultivars. All values obtained are higher as compared to those found by Amaral et al. [5] in oils of several hazelnut cultivars (8.9–16.3 h). While these latter oils were oxidized under identical conditions to those obtained in the present study, it should be noted they were extracted by solvent using Soxhlet devices which could decrease the oil oxidative stability. The OSI values from walnut oils were low and varied within a narrow range (2.9–3.6 h) coinciding with data from several walnut oils (2.6–3.4 h) extracted and oxidized under the same conditions we used [16].

The oxidative stability of vegetable oils is strongly related to their FA composition and also to the presence of minor endogenous antioxidant substances, mainly tocopherols. Other phenolic compounds were not found in hazelnut and walnut oils analyzed here. Attempts were made to detect them using the Folin–Ciocalteau reagent [27] but no values were registered in any oil tested.

The iodine value, which is an indicator of the oil unsaturation degree, was found to range between 88.8 and 96.8 (hazelnut oils) and between 143.9 and 165.8 (walnut oils), in general agreement with data reported from oils of a lot of hazelnut and walnut cultivars grown worldwide [17, 18]. Our results from the whole data set from each nut species indicate strong negative correlations between iodine and OSI values (Table 4). Considering concentrations of individual fatty acids, highly significant negative correlations were also found between OSI and both linoleic and linolenic acids. On the contrary, OSI values correlated positively with both oleic acid and TTC thus confirming the contribution of these two latter parameters to lessen oxidation of the oils. A number of reports indicate that squalene prevents lipid peroxidation [[20], and references therein]. A highly significant positive correlation was found between squalene and OSI values suggesting a role of this compound in preserving hazelnut oil oxidative stability.

Interestingly, data from hazelnut genotypes also showed that total oil contents correlated positively with oleic acid and negatively with linoleic acid concentrations. Moreover, a highly negative correlation was detected between oleic and linoleic acid concentrations. The correlation coefficients we found for all the aforementioned associations are in full agreement with those obtained from a set of 75 accessions of the European hazelnut germplasm [8].

On the other hand, data from walnut genotypes revealed significant positive correlations between total oil and tocopherol contents and negative correlations of oleic acid with each of both PUFAs, in general agreement with findings reported previously [16]. Overall, all these data suggest the possibility of different breeding lines focused to enhance kernel oil contents and shelf life of both the kernels and the corresponding oils.

Principal component analysis

Principal component analysis (PCA) was applied separately to each chemical data set (hazelnuts and walnuts) using the parameters that presented significant differences among cultivars of each type of nut. To simplify the analysis, saturated fatty acids and tocopherols were analyzed as total contents. Each score plot (Fig. 1) provided an overview of the oil varieties by showing more than 80% of the total variability. Regarding hazelnut genotypes, the first principal component (PC1) explained 65.5% of the data variability and allowed the separation of the local selection and the cultivars *Camponica*, *Nocchione*, *Nociara*, *Tonda Gentile Romana*, *Tonda di Giffoni* and *Willamette*; the last three genotypes were linked to higher OSI values, oil, oleic acid and squalene contents. The remaining cultivars did not show a clear association with specific chemical parameters, with exception of *Ennis* and *Jemtegaard* cultivars which were linked to linoleic acid concentration. PC2 accounted for a minimal percentage of the data variability; no clear associations

Table 4 Correlations between compositional and quality parameters from kernel oils of hazelnut and walnut cultivars

Hazelnut	OC	SFA	OA	LA	TTC	OSI	I_2V
SFA	0.32 ns						
OA	0.81**	0.26 ns					
LA	−0.81**	−0.50**	−0.97**				
TTC	−0.16 ns	−0.34 ns	−0.07 ns	0.16 ns			
OSI	0.79**	0.35 ns	0.85**	−0.86**	0.02 ns		
I_2V	−0.78**	−0.66**	−0.90**	0.98**	0.22 ns	−0.82**	
SQC	0.57**	0.37 ns	0.69**	−0.72**	0.08 ns	0.75**	−0.71**
Walnut	OC	SFA	OA	LA	LnA	TTC	OSI
SFA	0.06 ns						
OA	−0.34 ns	0.65*					
LA	0.11 ns	−0.96**	−0.70*				
LnA	0.15 ns	−0.56 ns	−0.93**	0.52 ns			
TTC	0.70*	−0.08 ns	0.01 ns	0.28 ns	−0.33 ns		
OSI	−0.48 ns	0.69*	0.87**	−0.72**	−0.78**	−0.23 ns	
I_2V	0.09 ns	−0.91**	−0.90**	0.90**	0.83**	−0.03 ns	−0.84**

OC oil content, *SFA* saturated fatty acids, *OA* oleic acid, *LA* linoleic acid, *LnA* linolenic acid, *TTC* total tocopherol content, *OSI* oxidative stability index, *I_2V* iodine value, *SQC* squalene content

*Significance at $P \leq 0.05$

**Significance at $P \leq 0.01$

nsNo significance

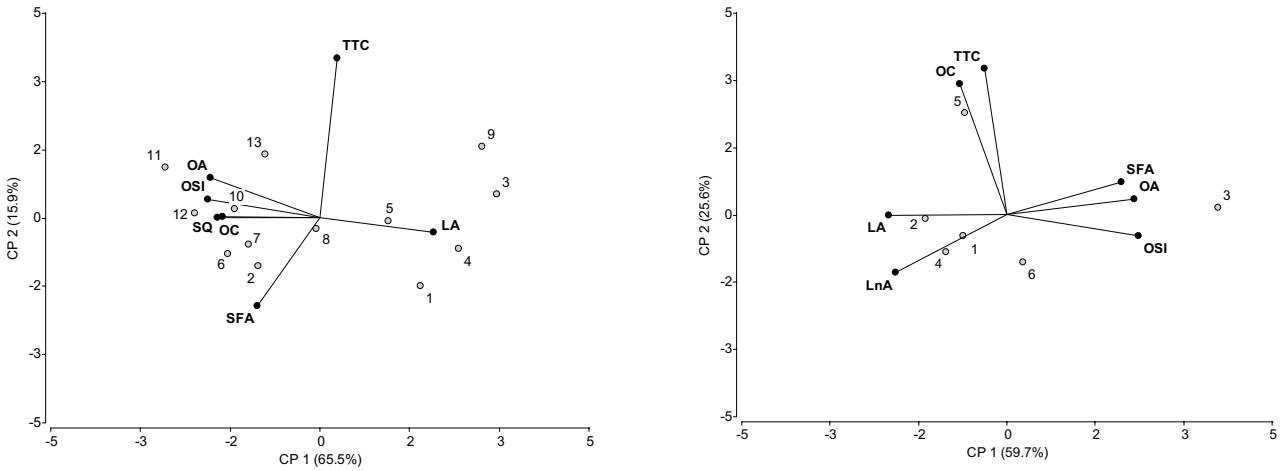

Fig. 1 Score plots of principal components for chemical data (*OC* oil content, *OA* oleic acid, *LA* linoleic acid, *LnA* linolenic acid, *SFA* saturated fatty acids, *TTC* total tocopherol content, *SQ* squalene content, *OSI* oxidative stability index) from hazelnut and walnut genotypes. Hazelnut genotypes: 1, *Barcelona*; 2, *Camponica*; 3, *Casina*; 4, *Ennis*; 5, *Jemtegaard*; 6, *Nocchione*; 7, *Nociara*; 8, *Nostrale*; 9, *Riccia di Talanico*; 10, *Tonda di Giffoni*; 11, *Tonda Gentile Romana*; 12, *Willamette*; 13, Local selection. Walnut genotypes: 1, *Chandler*; 2, *Fernette*; 3, *Franquette*; 4, *Howard*; 5, *Tulare*; 6, *Trompito INTA*

were observed between chemical parameters and cultivars according to this component. Regarding walnut genotypes, the PC1 explained almost 60% of the data variability and discriminated both *Franquette* and *Trompito INTA*—linked to parameters related to higher oil oxidative stability—from the rest of the cultivars. PC2 stressed the separation of cv. *Tulare* which was linked strongly to both oil and TT contents.

Conclusions

In the present study, the oil content and oil-quality responses of several hazelnut and walnut commercial cultivars were evaluated in a new, non-traditional crop environment. Moreover, two Argentinean landraces were studied for the first time.

Most hazelnut and walnut genotypes showed higher oil contents as compared with those from by the USDA National Nutrient Data Base for Standard Reference. Fatty acid compositions from all hazelnut and walnut oils, including the two local landraces, were similar to those from a lot of cultivars distributed globally. A large genetic variability was observed in tocopherol concentrations. In some cases, particularly in a hazelnut local selection, the total tocopherol contents resulted somewhat greater than those usually found in commercial cultivars from different provenances. Interestingly, oil contents from hazelnuts were found to be correlated positively with oleic acid and negatively with linoleic acid concentrations. Likewise, oil contents from walnuts correlated positively with tocopheroI contents. Moreover, in both nut species, oleic and linoleic acid concentrations were negatively correlated. Taken together, these findings could provide basic information for breeding programs aimed to increase both kernel oil content and oil stability.

Overall, this study adds information to compositional database of novel and conventional genotypes from two major nut crops growing in non-traditional plantation sites. In addition, they contribute in enlarging the biodiversity sources to develop new cultivars with promising marketable quality characteristics.

Acknowledgements This work was financed with grants from SeCyT-UNC (Secretaría de Ciencia y Tecnología—Universidad Nacional de Córdoba) and INTA (Instituto Nacional de Tecnología Agropecuaria).

Compliance with ethical standards

Conflict of interest The authors have declared no conflict of interests.

Compliance with ethics requirements This article does not contain any studies with human and animal subjects.

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