Research Article

Characterization of Fatty Acid Profile of Argan Oil and Other Edible Vegetable Oils by Gas Chromatography and Discriminant Analysis

Ascensión Rueda,[1] Isabel Seiquer,[2] Manuel Olalla,[1] Rafael Giménez,[1] Luis Lara,[2] and Carmen Cabrera-Vique[1]

[1] *Departamento de Nutrición y Bromatología, Facultad de Farmacia, Universidad de Granada, Campus de Cartuja, 18071 Granada, Spain*

[2] *Departamento de Fisiología y Bioquímica de la Nutrición Animal, Estación Experimental del Zaidín (CSIC), Camino del Jueves s/n, Armilla, 18100 Granada, Spain*

Correspondence should be addressed to Isabel Seiquer; isabel.seiquer@eez.csic.es

Virgin argan oil is an emergent oil that is being introduced into specialized international markets as a healthy and luxury food. In order to compare the fatty acid composition of argan oil with that of the eleven other vegetable edible oils, a combination of gas chromatography as analytical technique and multivariate discriminant analysis was applied. This analysis takes into account the conjoint effect of all the variables analyzed in the discrimination between oils and also shows the contribution of each variable to oils characterization. The model correctly classified 100% oil samples. According to the fatty acid composition, argan oil showed closest similarity firstly with sesame oil and secondly with high oleic sunflower oil. Olive oil was close to avocado oil and almond oil, followed by argan oil. Thus, similarities and differences between vegetable oils based on their fatty acid profile were established by the application of multivariate discriminant analysis. This method was proven to be a useful tool to study the relationships between oils according to the fat composition and to determine the importance of the fatty acid variables on the oils classification.

1. Introduction

Virgin argan oil has been investigated due to its particular composition and potential health benefits [1, 2]. This oil is mainly produced in Southwest of Morocco from the nut of the argan tree (*Argania spinosa*, L.) and represents an important fat source in the Magreb area [3]. However, nowadays its consumption has been extended to other countries, that is, USA or Japan. In 2003, Morocco introduced a new regulation to define quality specifications for virgin argan oil and to classify argan oils into different categories [4], being extra virgin argan oil the highest quality category. The traditional extraction method (hand pressure) coexists with the semi-industrial method (mechanical cold pressure without water addition) applied in recently developed cooperatives and that allows obtaining high-quality oils [2]. Recent studies suggest

that argan oil may play a significant role in the prevention of cardiovascular diseases due to its antioxidant potential and its hypolipidemic, hypocholesterolemic, and antihypertensive effects [5, 6]. According to bibliographic data, argan oil is rich in oleic and linoleic acids, polyphenols and tocopherols [7–9], and other minor compounds such as sterols, carotenoids, xanthophylls, squalene, coenzyme Q_{10}, and melatonin [2, 3, 10].

The scientific evidence has largely demonstrated that the "quality" of fat, apart from the "quantity" of fat, has a strong impact on consumer health. Public health institutes of different countries over the world, as well as international organisms such as the FAO/OMS, have established recommended daily intakes for each type of fatty acids (FA), that is, saturated (SFA), monounsaturated (MUFA), and polyunsaturated (PUFA), generally limiting the SFA

intake and promoting MUFA and PUFA consumption [11]. Nowadays, oils rich in unsaturated fatty acids are largely recommended as substitutes of saturated-fats used in industrialized countries [11]. Thus, FA composition occupies a prominent place in evaluating the nutritional quality of oils. This concern for the FA impact has led nutritionists and food manufacturers to look for fats and oils containing specific FA of supposed beneficial effects, while researchers have directed their efforts to compare different oils according to their FA composition [12]. In this line, the nutritional qualities of argan oil have been proposed to be identical to those of olive oil, given that both contain high levels of oleic acid, with linoleic acid as the second major PUFA and being the SFA of both oils palmitic and stearic acids [1]. Thus, FA percentage distribution allows suggesting similarities and distinctiveness among oils. However, the relationships between oils are affected by all the variables and not only by majority FA [13]. Therefore, only using multivariate methods to analyze the combination effects of all variables, holistic information of samples can be obtained.

The aim of this work was to (1) fully characterize the FA profile of argan oil and eleven other vegetable oils, (2) apply multivariate discriminant analysis to study the relationship between oils according to their FA composition, and (3) determine which of the fatty acids accounts the most for the differences on the discrimination of vegetable oils. With this purpose, FA profile of the different oils was performed using gas chromatography.

2. Materials and Methods

2.1. Samples. A total of 14 samples of virgin argan oils, produced in Morocco by the semi-industrial method and commercialized in the Spanish market, were analysed. The other vegetable oils were almond, wheat germ, high oleic sunflower, linseed, walnut, avocado, sesame, grape seed, soybean, pumpkin seed, and virgin olive oil. Four samples of each type of oil were analysed; all of them were purchased from local supermarkets and specialised groceries. Only sunflower and grape seed oils were refined, whereas the remainders were virgin oils. All samples were maintained at temperature of 4°C in an inert nitrogen atmosphere until analysis.

2.2. Apparatus and Chemicals. Main fatty acids were quantified by gas chromatography using a Perkin Elmer Autosystem gas chromatograph (Perkin-Elmer, Norwalk, CT, USA), equipped with a flame ionization detector (FID) and conventional injector. A capillary column Supelco SP^{TM} 2380 (30 m × 0.25 mm i.d., 0.2 μm film thickness) was used. All chemicals were of analytical grade or higher purity unless otherwise stated. The fatty acid standard mix FAME mix 47885-U provided by Sigma (Sigma-Aldrich, Milan, Italy) was used for FA identification, according to their retention times. Sodium methylate 0.2 N, sulphuric acid, and n-hexane were purchased from Panreac (Panreac, Barcelona, Spain) and used to extract fatty acid methyl esters.

2.3. Fatty Acid Analysis. Analyses were carried out in triplicate. For determining the FA composition of oils, adaptation of the official method of the International Olive Oil Council [14], which precision has been statistically assessed by Cert et al. [15], was used. Fatty acids were determined as fatty acid methyl esters (FAME) after treatment of 0.3 g of the oil sample with 5 mL of sodium methylate 0.2 N. FAME were prepared by acidic esterification in the presence of methanolic H$_2$SO$_4$ (4%, v/v); the organic phase was removed with n-hexane (5 mL). The injection volume was 2 μL, and the carrier gas was nitrogen (15 psi). The oven temperature was kept at 60°C for 3 min and was raised to 170°C at a rate of 5°C/min; after 9 min the temperature was raised at 250°C at a rate of 10°C/min. The injector and detector were maintained at 230°C and 250°C, respectively. Individual FAME were identified by comparing their retention times with those of pure standards. Quantification of individual fatty acids was carried out by calculating the corresponding relative percentage of the total FAME, according to the area normalization procedure. In addition, sums of total SFA, MUFA, PUFA, PUFA n-3 and n-6, and SFA/PUFA and n-6/n-3 ratios have been calculated.

2.4. Statistical Analysis. Results of individual FA content and sums of FA of the different oils were analyzed by one-way ANOVA followed by Tuckey test to compare significant variations between means ($P < 0.05$). Moreover, in order to verify the capacity of the FA analysis as a tool for oils characterization a multivariate discriminant analysis was performed. The basic purpose of discriminant analysis is to estimate the relationship between a single categorical dependent variable (the type of oil in this case) and a set of quantitative independent variables (the percentage contents of the fatty acids), since the relationships between oils are affected by all the variables and only analyzing the combination effects by multivariate methods similarities and differences between oils can be established effectively. This analysis can determine which of the independent variables accounts the most for the differences in the average score profiles of the different oils. Moreover, graph representation of this analysis allows assessing the similarity of the oils by their FA composition. All the statistical analyses were carried out using the StatGraphics Centurion XV software (StatPoint Technologies, Inc., USA, 2006).

3. Results and Discussion

3.1. Fatty Acid Profile in Virgin Argan Oil. The fatty acid composition and the related sums and ratios of the 14 samples of virgin argan oil analyzed are summarized in Tables 1 and 2, respectively. Figure 1 shows a chromatogram of a sample of argan oil. Values of the FA analyzed in all the argan oil samples were within the limits established by the Moroccan norm for virgin argan oils [4] as follows (weight % of methyl esters): myristic acid (C14:0) ≤ 0.2, palmitic acid (C16:0) 11.5–15.0, palmitoleic acid (C16:1) ≤ 0.2, margaric acid (C17:0) traces, stearic acid (C18:0) 4.3–7.2, oleic acid (C18:1 n-9) 43.0–49.1, linoleic acid (C18:2 n-6) 29.3–36.0, arachidic acid (C20:0) ≤ 0.5, gadoleic acid (C20:1 n-11) ≤ 0.5, and behenic acid (C22:0)

Table 1: Fatty acid composition (%) of virgin argan oil[*].

Sample number	Myristic C14:0	Palmitic C16:0	Palmitoleic C16:1	Margaric C17:0	Stearic C18:0	Oleic C18:1 n-9	Linoleic C18:2 n-6	Arachidic C20:0	Linolenic C18:3 n-3	Gadoleic C20:1 n-9	Behenic C22:0	Lignoceric C24:0
1	0.12 ± 0.01	12.5 ± 0.14	0.06 ± 0.04	0.02 ± 0.01	6.95 ± 0.14	46.2 ± 0.32	33.0 ± 0.27	0.40 ± 0.02	0.44 ± 0.02	0.15 ± 0.03	0.01 ± 0.00	0.03 ± 0.02
2	0.12 ± 0.02	12.8 ± 0.04	0.09 ± 0.01	0.03 ± 0.04	4.81 ± 0.43	48.1 ± 0.44	32.9 ± 0.13	0.44 ± 0.05	0.40 ± 0.05	0.15 ± 0.00	0.02 ± 0.02	0.06 ± 0.00
3	0.12 ± 0.02	12.8 ± 0.52	0.09 ± 0.00	0.01 ± 0.00	6.96 ± 0.68	42.5 ± 2.67	36.8 ± 1.43	0.42 ± 0.04	0.35 ± 0.03	0.14 ± 0.01	0.02 ± 0.00	0.04 ± 0.00
4	0.12 ± 0.01	12.2 ± 0.21	0.07 ± 0.02	0.02 ± 0.00	5.54 ± 1.11	45.8 ± 2.21	35.3 ± 1.01	0.41 ± 0.03	0.22 ± 0.18	0.14 ± 0.01	0.02 ± 0.01	0.03 ± 0.01
5	0.12 ± 0.00	12.4 ± 0.00	0.07 ± 0.01	0.01 ± 0.00	5.36 ± 1.16	43.4 ± 0.52	36.0 ± 0.29	0.39 ± 0.02	0.35 ± 0.01	0.15 ± 0.04	0.02 ± 0.02	0.04 ± 0.01
6	0.13 ± 0.02	12.1 ± 0.01	0.07 ± 0.01	0.01 ± 0.01	7.00 ± 0.21	46.5 ± 1.94	34.0 ± 3.56	0.42 ± 0.02	0.38 ± 0.03	0.17 ± 0.02	0.04 ± 0.01	0.04 ± 0.01
7	0.13 ± 0.02	12.9 ± 0.90	0.10 ± 0.04	0.01 ± 0.01	6.13 ± 1.51	46.9 ± 4.51	32.5 ± 5.05	0.44 ± 0.04	0.37 ± 0.03	0.18 ± 0.02	0.02 ± 0.00	0.04 ± 0.00
8	0.13 ± 0.02	12.8 ± 0.73	0.06 ± 0.00	0.02 ± 0.01	6.31 ± 0.49	46.4 ± 2.97	33.7 ± 3.85	0.41 ± 0.04	0.37 ± 0.03	0.16 ± 0.02	0.04 ± 0.00	0.05 ± 0.01
9	0.11 ± 0.00	12.4 ± 0.81	0.07 ± 0.00	0.03 ± 0.00	5.84 ± 0.05	46.1 ± 1.33	34.0 ± 3.31	0.43 ± 0.03	0.39 ± 0.03	0.16 ± 0.02	0.05 ± 0.03	0.04 ± 0.01
10	0.11 ± 0.01	12.0 ± 0.04	0.02 ± 0.01	0.02 ± 0.01	6.10 ± 1.06	47.5 ± 0.61	34.7 ± 0.09	0.45 ± 0.02	0.38 ± 0.00	0.14 ± 0.03	ND	0.03 ± 0.01
11	0.10 ± 0.02	11.6 ± 0.28	0.04 ± 0.00	0.01 ± 0.01	4.48 ± 0.54	43.7 ± 0.71	36.1 ± 0.31	0.61 ± 0.28	0.50 ± 0.03	0.17 ± 0.01	ND	0.05 ± 0.02
12	0.14 ± 0.01	12.8 ± 0.44	0.10 ± 0.01	0.01 ± 0.01	7.07 ± 0.11	45.3 ± 0.66	34.4 ± 0.20	0.41 ± 0.02	0.37 ± 0.00	0.16 ± 0.01	ND	0.07 ± 0.02
13	0.10 ± 0.03	14.4 ± 2.25	0.10 ± 0.01	0.03 ± 0.04	4.11 ± 2.41	44.9 ± 4.39	35.4 ± 4.70	0.16 ± 0.08	0.13 ± 0.13	0.16 ± 0.06	0.12 ± 0.01	0.28 ± 0.01
14	0.15 ± 0.01	13.7 ± 1.40	0.08 ± 0.02	0.04 ± 0.01	4.39 ± 2.46	44.7 ± 4.87	35.7 ± 0.52	0.21 ± 0.04	0.15 ± 0.05	0.40 ± 0.02	0.31 ± 0.31	0.16 ± 0.04
Mean	0.12	12.7	0.08	0.02	5.83	45.6	34.6	0.40	0.34	0.17	0.05	0.07
SD	0.01	0.71	0.02	0.01	1.02	1.60	1.32	0.10	0.11	0.07	0.08	0.07

[*]Values are expressed as means ± standard deviation (SD). ND = not detected.

TABLE 2: Sum of fatty acids in virgin argan oil[*].

Sample number	ΣSFA	ΣMUFA	ΣPUFA	ΣPUFA n-3	ΣPUFA n-6	SFA/PUFA	n-6/n-3 ratio
1	20.1 ± 0.02	46.5 ± 0.25	33.5 ± 0.40	0.44 ± 0.03	33.0 ± 0.06	0.60	75.0
2	18.2 ± 0.52	48.4 ± 0.44	33.3 ± 0.08	0.40 ± 0.05	32.9 ± 0.13	0.55	82.2
3	20.1 ± 1.19	42.7 ± 2.64	37.1 ± 1.45	0.35 ± 0.03	36.8 ± 1.42	0.54	105
4	18.3 ± 1.35	46.1 ± 2.18	35.6 ± 0.83	0.22 ± 0.18	35.4 ± 1.01	0.51	160
5	20.0 ± 0.25	43.6 ± 0.55	36.4 ± 0.30	0.35 ± 0.01	36.0 ± 0.29	0.55	102
6	18.8 ± 1.58	46.7 ± 1.94	34.4 ± 3.52	0.38 ± 0.03	34.0 ± 3.55	0.55	89.4
7	19.2 ± 0.45	47.2 ± 4.57	32.9 ± 5.02	0.37 ± 0.03	32.5 ± 5.04	0.58	87.8
8	19.3 ± 0.83	46.6 ± 2.98	34.1 ± 3.81	0.37 ± 0.03	33.7 ± 3.84	0.56	90.3
9	19.2 ± 1.94	46.4 ± 1.34	34.4 ± 3.28	0.39 ± 0.03	34.0 ± 3.30	0.56	87.2
10	17.1 ± 0.54	47.7 ± 0.62	35.1 ± 0.09	0.38 ± 0.01	34.8 ± 0.08	0.49	91.6
11	19.5 ± 0.45	43.9 ± 0.72	36.6 ± 0.27	0.50 ± 0.03	36.1 ± 0.31	0.53	72.2
12	19.6 ± 0.85	45.6 ± 0.65	34.8 ± 0.18	0.37 ± 0.00	34.4 ± 0.19	0.56	92.8
13	19.2 ± 0.24	45.2 ± 0.60	35.5 ± 4.56	0.13 ± 0.13	35.4 ± 4.69	0.55	272
14	18.9 ± 1.35	42.2 ± 0.88	35.9 ± 0.46	0.15 ± 0.05	35.7 ± 0.51	0.53	238
Mean	19.2	45.8	34.9	0.34	34.6	0.55	117
SD	0.84	1.60	1.29	0.11	1.32	0.03	63.0

[*]Values are expressed as means ± standard deviation (SD). ΣSFA = sum of myristic, palmitic, margaric, stearic, arachidic, behenic, and lignoceric acids; ΣMUFA = sum of palmitoleic, oleic, and gadoleic acids; ΣPUFA = sum of linoleic and linolenic acids; ΣPUFA n-3 = linolenic acid; ΣPUFA n-6 = linoleic acid.
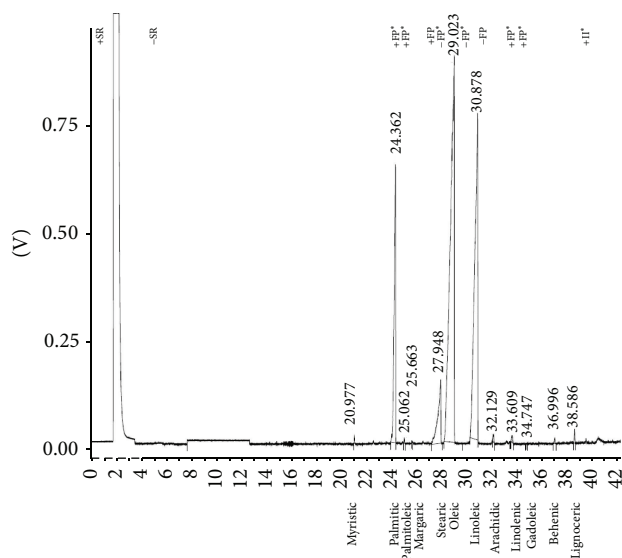

FIGURE 1: Chromatogram of FAME of a sample of argan oil.

≤ 0.2. The only exception was α-linolenic acid (C18:3 n-3), since slightly higher values than that established (≤ 0.3) were found for 11 samples.

Total unsaturated FA (MUFA + PUFA) in virgin argan oils composed 80% of the total FA, in accordance with previous bibliographic data [2, 8, 16, 17]. These fractions corresponded, almost entirely, to oleic and linoleic acids, respectively (average values of 45.6% of oleic acid and 34.6% of linoleic acid). Palmitic acid and stearic acid (12.7 and 5.83% on average, resp.) represented the greatest proportion of SFA in argan oil. In previous studies by our research group including samples of virgin argan oil of very different quality

(extra virgin, fine virgin, ordinary virgin, and lampant) showed oleic acid contents ranging from 36.50 to 47.70% [18].

The clinical relevance and the nutritional value of oleic acid have been extensively described and it is known to have hypocholesterolemic and hypotensive effects [1]. Moreover, argan oil promotes a proper supply of n-6 PUFA, mainly represented by the linoleic acid, precursor of the n-6 series with important pharmacological properties and protective effects against degenerative diseases, such as cardiovascular disease and cancer [19]. It is estimated that 17 to 21 g of argan oil are sufficient to meet the daily needs of linoleic acid [20]. However, only small quantities of n-3 PUFA are provided by argan oil (content up to 0.50% of α-linolenic acid has been found in argan oils from the present assay) and therefore argan oil feeding should be supplemented by an extra supply of n-3 FA. Hilali et al. [8] reported proportions of 0.030–0.10% of α-linolenic acid and Harhar et al. [21] of 0.10–0.20%. Due to the poor linolenic acid content, the n-6/n-3 ratio of virgin argan oil is very high. Because of its FA composition and the elevated presence of minor compounds such as γ-tocopherol, several studies have confirmed the antiatherogenic and hypotensive effects of the argan oil, which can be used for reducing cardiovascular risks [5].

3.2. Fatty Acid Profile in Other Vegetable Edible Oils. Fatty acid composition and the related sums and ratios of the other oils analyzed in the present study are presented in Tables 3 and 4, respectively. Dubois et al. [12] classified vegetable oils according to their FA profiles into different classes and subclasses. Following this classification, four oils of our study may be included in the MUFA class: almond, avocado, extra virgin olive oil, and argan oil. Within this group, the first three belong to the MUFA subclass (>60%), specially rich in oleic acid, with contents ranging from 60.6% (avocado) to

TABLE 3: Fatty acid composition (%) in edible vegetable oils[*].

	Myristic C14:0	Palmitic C16:0	Palmitoleic C16:1	Margaric C17:0	Stearic C18:0	Oleic C18:1 n-9	Linoleic C18:2 n-6	Arachidic C20:0	Linolenic C18:3 n-3	Gadoleic C20:1 n-9	Behenic C22:0	Lignoceric C24:0
Almond oil	0.02[a]	6.73[ab]	0.48[a]	0.05[ab]	1.78[ab]	66.69[ef]	23.9[b]	0.11[ab]	0.14[a]	ND	0.07	0.03[a]
Wheat germ oil	0.12[ab]	21.1[e]	0.12[a]	0.09[ab]	2.79[abc]	15.84[a]	53.0[d]	1.73[e]	4.68[b]	0.24[ab]	0.04	0.20[ab]
Sunflower oil	0.05[ab]	4.98[a]	0.10[a]	0.04[ab]	3.24[abc]	53.11[d]	37.8[c]	0.10[ab]	0.28[a]	0.04[a]	0.03	0.22[ab]
Linseed oil	ND	5.88[ab]	0.03[a]	0.02[a]	3.10[abc]	20.50[ab]	15.0[ab]	0.06[ab]	55.2[d]	0.04[a]	0.05	0.10[a]
Walnut oil	0.13[bc]	8.02[ab]	0.23[a]	0.18[ab]	4.64[cd]	26.31[b]	60.4[de]	0.02[a]	0.05[a]	0.04[a]	0.03	0.01[a]
Avocado oil	0.14[bc]	16.3[d]	4.59[b]	0.34[b]	1.50[a]	60.61[de]	14.7[ab]	0.36[abcd]	0.73[a]	0.09[a]	0.11	0.50[b]
Sesame oil	ND	9.82[bc]	0.11[a]	0.02[a]	5.96[d]	41.12[c]	41.8[c]	0.30[abcd]	0.51[a]	0.12[a]	0.10	0.18[ab]
Grape seed oil	0.05[ab]	7.66[ab]	0.03[a]	0.11[ab]	4.53[cd]	17.65[ab]	69.3[e]	0.16[abc]	0.33[a]	0.02[a]	0.04	0.13[a]
Soybean oil	0.06[ab]	9.17[abc]	0.08[a]	0.08[ab]	3.81[bc]	24.44[ab]	54.0[d]	0.05[a]	8.03[c]	ND	0.05	0.24[ab]
Pumpkin oil	0.22[c]	15.6[d]	0.15[a]	ND	3.38[abc]	24.52[ab]	54.7[d]	0.64[d]	0.43[a]	ND	0.17	0.16[ab]
Olive oil	ND	13.6[cd]	0.50[a]	ND	3.28[abc]	75.40[f]	5.50[a]	0.55[cd]	0.78[a]	0.42[b]	ND	0.03[a]
Argan oil	0.12[b]	12.7[cd]	0.08[a]	0.02[a]	5.83[d]	45.59[c]	34.6[c]	0.40[bcd]	0.35[a]	0.17[a]	0.05	0.07[a]
SEM	0.0064	0.2575	0.0298	0.0173	0.1153	0.5024	0.5200	0.0233	0.1665	0.0152	0.0084	0.0183
P value	<0.0001	<0.0001	<0.0001	0.0070	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	NS	<0.001

[*]Values are expressed as means ± SEM.
[a,b,c,d,e,f]Different superscripts indicate significant differences between oils (one-way ANOVA followed by Tuckey test, $P < 0.05$).
ND: not detected. NS: not significant ($P > 0.05$).

TABLE 4: Sum of fatty acids in edible vegetable oils[*].

	ΣSFA	ΣMUFA	ΣPUFA	ΣPUFA n-3	ΣPUFA n-6	SFA/PUFA	n-6/n-3 ratio
Almond oil	8.79[a]	67.1[ef]	24.0[b]	0.14[a]	23.9[b]	0.37[ab]	171[ab]
Wheat germ oil	26.1[e]	16.2[a]	57.7[d]	4.68[b]	53.0[d]	0.48[ab]	11.3[a]
Sunflower oil	8.65[a]	53.2[d]	38.1[c]	0.28[a]	37.8[c]	0.23[ab]	135[ab]
Linseed oil	9.20[a]	20.6[ab]	70.2[e]	55.2[d]	15.0[ab]	0.13[a]	0.27[a]
Walnut oil	13.3[ab]	26.6[b]	60.4[de]	0.05[a]	60.4[de]	0.22[ab]	1208[c]
Avocado oil	19.2[cd]	65.3[e]	15.5[ab]	0.73[a]	14.7[ab]	1.40[c]	20.1[a]
Sesame oil	16.4[bcd]	41.4[c]	42.3[c]	0.51[a]	41.8[c]	0.39[ab]	81.9[ab]
Grape seed oil	12.7[ab]	17.7[ab]	69.6[e]	0.33[a]	69.3[e]	0.18[ab]	210[b]
Soybean oil	13.5[abc]	24.5[ab]	62.0[de]	8.03[c]	54.0[d]	0.22[ab]	6.72[a]
Pumpkin oil	20.2[d]	24.7[ab]	55.1[d]	0.43[a]	54.7[d]	0.37[ab]	127[ab]
Olive oil	17.5[bcd]	76.3[f]	6.28[a]	0.78[a]	5.50[a]	2.79[d]	7.05[a]
Argan oil	19.2[d]	45.8[cd]	35.0[c]	0.35[a]	34.6[c]	0.55[b]	98.9[ab]
SEM	0.3152	0.5034	0.5825	0.1665	0.5200	0.0271	4.468
P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[*]Values are expressed as means ± SEM.
[a,b,c,d,e,f]Different superscripts indicate significant differences between oils (one-way ANOVA followed by Tuckey test, $P < 0.05$).
ΣSFA = sum of myristic, palmitic, margaric, stearic, arachidic, behenic and lignoceric acids; ΣMUFA = sum of palmitoleic, oleic and gadoleic acids; ΣPUFA = sum of linoleic and linolenic; ΣPUFA n-3 = linolenic acid; ΣPUFA n-6 = linoleic acid.

75.4% (olive oil), that is, obviously, the most representative oil of this group. The MUFA content of olive oil does not differ from that of almond oil, which, in turn, is equal to avocado oil, being these three oils significantly higher from all the other oils of the present study. Almond oil may be included in the MUFA group, although it does not appear in previous studies of edible vegetable oils according to their FA profile [12, 22]. Our results regarding virgin olive oil were similar to data from literature [23] and are in accordance with specifications of trade standards for olive oils defined by the International Olive Oil Council [14]. Olive oil FA composition has been considered as a parameter to characterize the different olive cultivars [24]. Within the MUFA group, argan oil was classified as MUFA + SFA + linoleic subclass, since

TABLE 5: Eigenvalues and standardized coefficients of the discriminant functions from the discriminant analysis[a].

	Functions					
	1	2	3	4	5	6
Eigenvalue	420.30	289.42	44.879	14.333	12.976	4.8675
% Variance	53.22	36.65	5.68	1.81	1.64	0.62
% Accumulated	53.22	89.87	95.55	97.36	98.00	99.62
Coefficients						
Myristic C14:0	0.7519	2.5080	0.2043	−0.1405	−0.8611	1.0247
Palmitic C16:0	11.8615	20.1977	−16.9402	−24.0943	−2.6487	−0.1141
Palmitoleic C16:1	0.2054	−0.0529	−0.8225	−2.6297	−0.1873	0.0954
Margaric C17:0	0.4672	0.3077	−0.2373	−1.1249	0.9900	−0.7060
Stearic C18:0	5.5797	9.7338	−7.1674	−9.8910	−1.0317	−0.0921
Oleic C18:1n9	23.6425	42.4694	−31.9515	−46.7608	−1.7847	1.4056
Linoleic C18:2n6	24.5615	44.4087	−31.6167	−48.231	−1.781	1.1727
Arachidic C20:0	2.2278	3.2195	−0.7927	−3.5122	0.9376	0.4712
Linolenic C18:3n3	9.4127	13.5853	−10.2911	−15.4278	−0.6935	0.4292
Gadoleic C20:1	0.7593	−0.3258	−0.2729	−0.3116	−0.1056	−0.7364
Behenic C22:0	0.4948	1.2594	−0.3754	−1.0258	0.0831	0.7488
Lignoceric C24:0	2.0479	3.4099	−2.2907	−1.7046	0.8047	0.0913

[a]The first six discriminant functions are shown.

average SFA and linoleic acid contents were higher than in the MUFA group/MUFA subclass, although differences do not reach statistical significance in all cases.

The remaining oils analyzed in the present study, grape seed, wheat germ, sunflower, linseed, walnut, sesame, soybean, and pumpkin oils, were oils from the PUFA group, according to Dubois et al. [12]. The PUFA content in this group ranged from 38% in sunflower to 70% in grape seed and linseed oils, with significant differences between the different oils. Grape seed oil belongs to a linoleic acid subclass, as it has 69.3% content of this FA, significantly higher than all the other oils of the present study and similar to previous reported data [12, 22]. Walnut oil was classified in the linoleic + SFA subclass and the highest ratio n-6/n-3 was found in this oil compared with all the other analyzed oils. Wheat germ, sunflower, sesame, soybean, and pumpkin oils were classified in the linoleic + MUFA subclass, since these oils, in addition to contain important proportions of linoleic acid, also have high amounts of MUFA, ranging from 16.2% (wheat germ) to 53.2% (sunflower). Sunflower oil analyzed in the present assay had much higher oleic acid and lower linoleic acid contents than conventional sunflower oils [13], but it was similar to other sunflower oils currently commercialized in the Spanish market [23]. Sesame oil, like argan oil, had oleic and linoleic acids as major FA, without significant differences of these two FA between both oils. Soybean and pumpkin oils have very similar amounts of MUFA, but soybean showed higher PUFA, due to its special content of linolenic acid (8% of total FA, significantly different from all the other oils of our study). Finally, the linseed oil is the only one included in the linolenic + MUFA subclass, with an exceptional content of 55.2% of linolenic acid and thus the lowest ratio n-6/n-3 (0.27) of the total of oils is analyzed. This FA is the precursor of long-chain

derivatives like EPA and DHA, and special effects of linseed oils on cardiovascular disease have been widely studied [24].

3.3. Results of the Discriminant Analysis. With the aim of studying the relationships among the oils under a statistical point of view, a multivariate discriminate analysis was applied. As mentioned, this analysis considers information of all the variables, which provide important information and may have effects on the relationships of oils. Moreover, the analysis establishes discriminating functions which can help predicting the type of oil by the values of all the FA represented in the independent variables.

Table 5 displays the eigenvalues obtained in the present analysis. An eigenvalue in discriminant analysis is the characteristic root of each function; that is, it is an indication of how well that function differentiates the groups, and the larger the eigenvalue is, the better the function differentiates the groups. As it is depicted in Table 5, with the three first functions, the 95.55% of the variance is explained. Table 5 also shows the standardized coefficients of the six first discriminating functions based on the values of the twelve FA analyzed, as discriminant variables. The relative magnitude of the different coefficients allows determining how the different variables affect the discrimination of the oils. Each function is defined by different coefficients, but it may be observed that the most important variables are linoleic and oleic acids, followed by palmitic, linolenic, and stearic acids.

The results of the discriminating analysis can be represented in charts that consist of the possibility to graphically represent the similarity of the type of oil on the basis of two or three dimensions (the discriminating functions). Graphical representation for three dimensions is depicted in Figure 2,
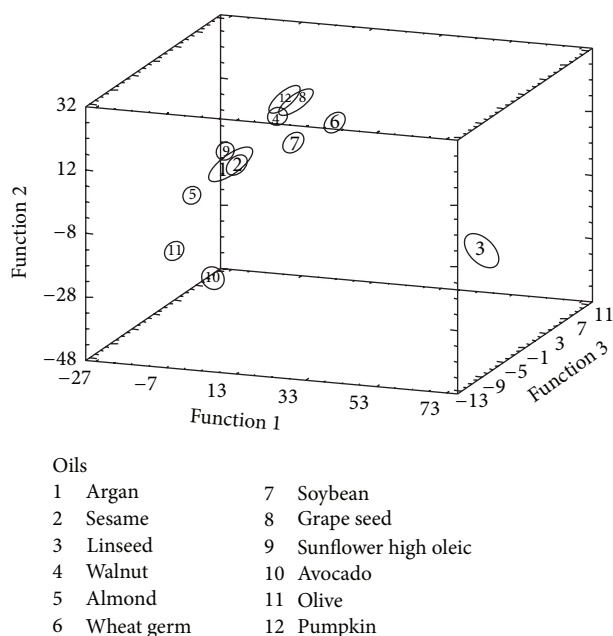
Oils

1	Argan	7	Soybean
2	Sesame	8	Grape seed
3	Linseed	9	Sunflower high oleic
4	Walnut	10	Avocado
5	Almond	11	Olive
6	Wheat germ	12	Pumpkin

FIGURE 2: Similarity of the oils based on the first three discriminating functions of the discriminant analysis.

in accordance with the first three discriminating functions. To avoid overlapping derived from marking all the values, we have used an average value of the discriminant function for each one of the oils, that is, the centroid, which has been represented with different numbers. Similarity of objects in a multidimensional scaling is determined on the basis of the measure of distance, and this measure corresponded to the type of data. It must be taken into account that, even when two oils exhibit similarity in the content of a major FA, small differences in the percentage of a minor FA can completely change the characteristics of the oil [25]. From Figure 2 we can see that oils included in the MUFA group (argan, almond, avocado, and olive oils) are relatively close, where avocado and olive oils are the most similar oils. However, from the visual exploration it may be concluded that argan oil has closest relationships with two oils from the PUFA group: sesame and high oleic sunflower, particularly with sesame oil. There is also a close relationship between walnut, grape seed, and pumpkin oils, whereas linseed differs considerably from the other oils. In order to validate the classification method, it was applied to all the samples in accordance with their FA profile, and the predicted group (kind of oil) was correct in 100% of cases. This proves that this analysis predicts well the corresponding oil observed by means of the chosen predictor variables. The usefulness of the analysis has been previously ascertained by other authors to discriminate the geographical origin of olive oils by their fatty acid composition [26].

4. Conclusions

The fatty acid composition of edible oils is a very important aspect in marketing and human health. Virgin argan oil raises nowadays significant scientific and commercial interests outside the Maghreb area, where it is consumed for centuries. In this study, similarities and differences between argan oil and other edible vegetable oils based on their fatty acid profile were established by the application of multivariate discriminant analysis. This method was proven to be a useful tool to study the relationships between oils according to the fat composition; moreover, the importance of the FA variables for the oils classification may be determined and similarities among oils may be easily visualized by graphical representation.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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