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ORIGINAL PAPER

Geographical Classification of Turkish Virgin Olive Oils from the Aegean Region for Two Harvest Years Based on Their Fatty Acid Profiles

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Abstract In this study, the fatty acid compositions of Turkish virgin olive oils produced in the Aegean region, the major olive production zone of Turkey, were classified by chemometric methods: Principal Component Analysis (PCA) and Discriminant Analysis (DA). A total of 268 oil samples were examined over the course of two harvest years (2001–2002 and 2002–2003). The samples were divided into six groups according to the olive growing zones: Edremit Gulf (Ayvalik cultivar), Izmir province (Ayvalık, Memeli, Memecik and Gemlik), Aydın province (Memecik, Manzanilla and Gemlik), Muğla (Memecik), Manisa (Gemlik, Domat, Uslu, Ayvalık), İzmir Peninsula (Erkence cultivar) and Firms (poly-cultivar or commercial blends). Consistent with discriminant analysis (DA), the predicted grouping in terms of the two harvest years were correctly separated as 74.5 and 74.8%, respectively. The highest levels of predicted grouping for the two harvest years were found in the Edremit Gulf (Ayvalık cultivar), Muğla province (Memecik cultivar) and İzmir peninsula (Erkence cultivar) groups (as 90–100%). In addition to oleic, linoleic, linolenic, margaric, margoleic, total *trans* isomers of linoleic, oleic/linoleic and palmitic/linoleic were determined to be the best descriptive components for the oil samples.

Keywords Virgin olive oils · Fatty acids · Geographical origin · Principal component analysis · Discriminant analysis · Prediction model

Introduction

Virgin olive oil, obtained by physical methods from the fruits of olive trees (*Olea europaea L.*), has become a very important agricultural product for most of the countries of the Mediterranean basin. The consumption of virgin olive oil, the main oil source of the traditional Mediterranean diet, is of special interest to consumers due to its unique sensory properties and nutritional and health-promoting effects. The health advantages are due largely to its fatty acid composition, a particularly high level of monounsaturated fatty acids (mainly oleic acid), and the naturally occurring antioxidants such as phenols, tocopherols and carotenoids [1].

One of today's major problems in the agro-food industry, including the olive oil sector, is to identify objective tools to trace raw materials, like virgin olive oil from certain locations or cultivars, as well as finished products from the producer to the consumer. The authenticity and traceability of virgin olive oil are of great importance for the protection of the consumer. Determination of the compositional variability of virgin olive oils produced from certain location or cultivar is necessary for the proper classification of oils as well as for prevention of blending monocultivar oils. The chemical composition of virgin olive oils might differ due to geographical, agronomic and technological influences. Differences in composition due to

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geographic origin provide the basis of legislation such as protected denomination of origin (PDO) and protected geographical indication (PGI). PDO and PGI certification enables labeling of food products by growing area, and provides extra economical benefits for producers of designated areas. In Europe, two regulations introduced the Protected Designation of Origin (PDO) of traditional products. The first one protects traditional products (Council Regulation, EEC-N.2081/92) about designations of origin and geographical indication, the second one (Council Regulation, EEC-N.2082/92) defines product types, olive oil included. In fact, virgin olive oils are produced from one certain genetic variety of olive (monocultivar) or a mixture of several cultivars (coupage or blend). Monocultivar olive oils have certain specific characteristics related to the olive cultivar from which they are elaborated. Coupage or blend olive oils are obtained from several olive cultivars to achieve a special flavor or aroma [2]. There are many well known cultivars used for olive oil in Turkey, many of which are region specific. Economically important Turkish olive cultivars and their corresponding production percentages are Memecik at 45%, Ayvalık at 20%, Domat at 1.4%, Gemlik at 11%, Nizip Yağlık at 2%, Kilis Yağlık at 2.8% and Uslu at 1% [3]. The production of monocultivar virgin olive oils originated from certain geographic zones has also been recently increased in the Turkish olive oil sector because they have a higher market price and reliable quality. The PDO of three zones (Edremit Gulf Olive Oils, Ayvalik Olive Oils and South Aegean Olive Oils) have been certified by the Turkish Patent Institute to authenticate oils produced from two economically important domestic cultivars (Ayvalik and Memecik) of the main olive growing regions of Turkey [4].

Major and/or minor components such as triacylglycerols, fatty acids and sterols in combination with chemometrics have been employed for classification and characterization of virgin olive oils based on cultivar, geographical origin and harvest year. Among the components of olive oil, fatty acid profiles are extremely useful for characterization and discrimination of an olive cultivar or its geographical location [2, 5]. There are several studies on geographical characterization of virgin olive oils from Turkish [6–10] and North countries of Mediterranean basin [11–24] based on fatty acid profiles.

In recent years, multivariate statistical methods, such as principal component analysis (PCA), hierarchical cluster analysis (HCA), discriminant analysis (DA) and classification analysis (CA), have been used extensively to classify and characterize virgin olive oils based on their geographical origins. The PCA method, one of the simplest and most used methods, is based on variable reduction by linear combination of initial variables that define principal components (PC). It is possible to reduce the set of variables without losing the essential initial information [2, 5, 18, 25]. The data produced by instrumental chromatographic techniques, gas chromatography (GC) and high pressure liquid chromatography (HPLC), for the characterization of virgin olive oil from different locations or cultivars are evaluated with these sophisticated methods (PCA, HCA, CA and DA). Multivariate statistical (PCA, DA or CA) evaluation of data is not a solution, but is a very promising approach for the evaluation of analytical data as to the geographical origin of a virgin olive oil sample. However, some studies have attempted to verify and classify the origins of certain virgin olive oils from major olive oil-producing countries (Italy, Spain, France, Greece, and nowadays Turkey), using their fatty acid profiles aided by multivariate statistical methods, such as principal component analysis (PCA), hierarchical cluster analysis (HCA) and discriminant analysis (DA) [5, 6, 9–22, 24]. Although Turkey is the world's fifth largest producer of olive oil (5%) and contributes 11.3% of the world's exports [3], there is a lack of data elucidating the characterization and classification of olive oil produced and marketed in Turkey.

This study addresses the need to evaluate by chemometric methods, PCA and DA, the classification and discrimination of virgin olive oils originating from the Aegean region, Turkey's major olive oil production zone, based on fatty acid profile, a reliable indicator for discrimination and classification of oils of PDO.

Materials and Methods

Locations and Experimental Material

The virgin olive oil samples were collected from plants utilizing a number of different processing systems: classical systems (hydraulic presses—known as the wet system and super presses—the dry system) and continuous systems (three phase, dual phase and Sinolea) in Izmir province between November and February of two consecutive harvest years (2001–2002 denoted by 1 and 2002–2003 denoted by 2). These samples were divided into six subgroups based on the important olive cultivation districts of Aegean region of Turkey:

1. The Edremit Gulf (EG) sub-group: This sub-group contains Ayvalik olive varieties widely grown in locations around Ederemit Gulf at Balikesir province: Ayvalık, Gömeç, Burhaniye, Havran and Edremit, and also the Ayvacık district of Çanakkale province (Fig. 1). This cultivar is locally known as Edremit, Edremit Yağlık, Şakran, Midilli and Ada Zeytini [26]

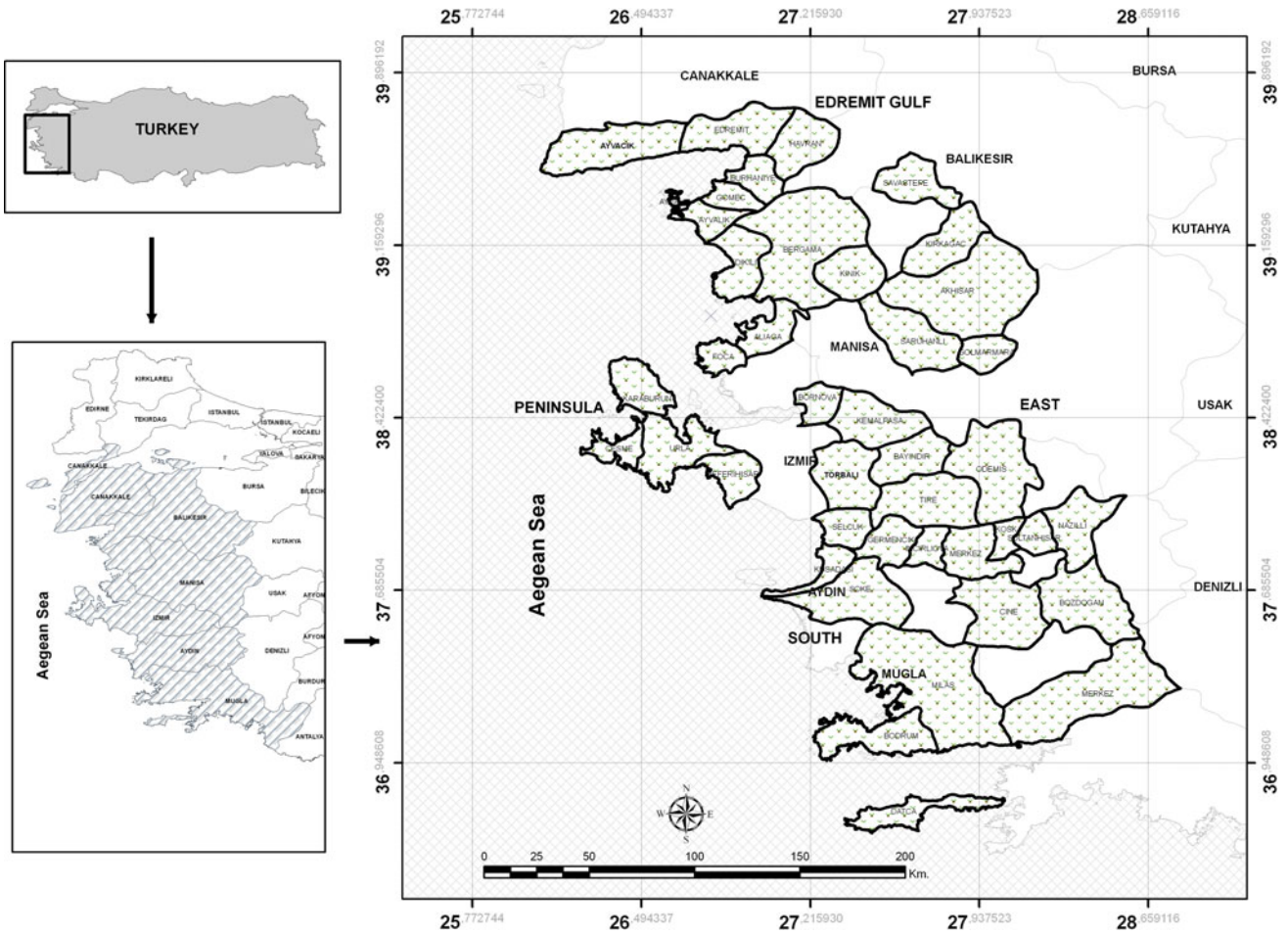

Fig. 1 Geographical areas of the six olive growing zones in Aegean region of Turkey

2. İzmir Province sub-group: This sub-group contains different olive varieties and zones. Ayvalik olive varieties widely grown in locations in the north zones of this sub-group: Aliağa, Bergama, Yeni Şakran, Kınık, Çandarlı and Dikili. The East locations of this sub-group were Kemalpasa and Orchard of Olive Research Institute and this zone include different olive cultivars such as Memeli, Memecik, Domat and Gemlik. Also, Memecik olive variety, known under locally names as Tas arasi, Asiyeli, Gulumbe, Sehir and Yaglik, is grown in the south of this zone (Ödemiş, Tire, Torbalı, Bayındır and Selçuk) [26] (Fig. 1).
3. The Aydin Province sub-group: Memecik olive variety is grown in the Aydin Province (Kuşadası, Söke, Germencik, İncirliova, Merkez, Köşk, Sultanhisar, Nazilli, Bozdoğan, Çine). This sub-group includes only Manzanilla plantations of Turkey and also, there are limited orchards covering the Gemlik variety [26] (Fig. 1).
4. The Muğla Province sub-group: Memecik olive cultivar is grown in the Muğla (Milas, Bodrum, Merkez and Datça). The origin center of Memecik cultivar is this sub-group (Milas) [26] (Fig. 1).
5. The Manisa Province sub-group: This sub-group contains different olive cultivars Gemlik, Domat and Uslu. In this district is widely grown Gemlik cultivar since 20 years. The locations of this sub-group were Akhisar, Saruhanlı, Gölmarmara and Kırkağaç. The origin center of Domat and Uslu cultivars is this sub-group (Akhisar) [26] (Fig. 1).
6. Izmir Peninsula (IP) sub-group: Erkence, known locally as Hurma Kaba and Hurma Erkence, is the primary domestic olive cultivar of this section. Locations of this sub-group were Urla, Seferihisar, Mordogan and Karaburun [26] (Fig. 1).
7. Firms (F) samples sub-group: This group covers the blended commercial virgin olive oil samples of unknown locations or domestic olive cultivar(s). These

poly-cultivar oils were packaged and labelled by various firms in Izmir.

A map of olive growing zones in Aegean region of Turkey is given in Fig. 1.

A total of 268 virgin olive oil samples were collected from five sub-groups in Izmir province during two harvest years. One hundred and five (105) of these samples were from the 2001–2002 harvest years and one hundred and sixty-three (163) oil samples were collected from 2002–2003 harvest years.

The fatty acid profiles were determined using a capillary gas chromatographic method described by the European Union Commission [27]. Fatty acid methyl esters (FAMEs) were prepared by treatment with sodium methylate according to a cold methylation method (35). A gas chromatograph (HP 6890) using a capillary column DB-23 (30 m × 0.25 mm ID and 0.25 μm film thickness 50% cyanopropyl, J & W Scientific, Folsom, CA, USA) was employed. The oven temperature was programmed from 170 to 210 °C at 2 °C/min and then held at 210 °C for 10 min. The carrier gas was helium (0.5 ml/min) and the injector and detector (FID) temperatures were 250 °C. The split ratio was 1:100 and the injected volume was 0.2 μl. Each sample was injected in triplicate ($n = 3$). Fatty acid standards had linear calibration curves through the origin ($R^2 = 0.99$). The GC method was validated for fatty acid determination of oil samples within 95% confidence limits. A standard FAME mixture was used as a standard (Sigma-Aldrich Chemicals 189-19). All fatty acid peak areas were calculated by HP 3365 Chemstation program and recorded as peak area percentages [27].

Principal Component Analysis (PCA), a common technique for finding patterns in data of high dimensions, and Linear Discriminant Analysis (LDA) with cross-validation (CV), were performed. Statistical package SPSS version 15.0 was used (SPSS 2001) for multivariate analysis [28].

Results and Discussion

The virgin olive oil samples were characterized according to their fatty acid profiles and 19 individual parameters: palmitic (p) C16:0; palmitoleic (po) C 16:1n7; margaric (m) C 17:0; margaroleic (mo) C 17:1n8; stearic (s) C 18:0; oleic (o) C 18:1n9; Linoleic (l) C18:2n6; Linolenic (ln) C18:3 n3; Arachidic (a) C 20:0; gadoleic (g) C 20:1n9; behenic (b) C 22:0; lignoseric (lg) C 24:0; elaidic (ea) C 18:1 *t*; *trans* linoleic (C 18:2 *t*) + *trans* linolenic (C 18:3 *t*) (tlln) and Total Trans FA (tfa); Oleic/Linoleic (ol); Palmitic/Linoleic (pl); Linoleic/Linolenic (lln); Squalene (Sq). The statistical parameters of fatty acid profiles for two harvest years (2001–2002 and 2002–2003) are reported in Table 1.

The fatty acid composition is a quality parameter and authenticity indicator of virgin olive oils. As shown in Table 1, numerous *cis–trans* isomers of fatty acids were detected in the oil samples produced from important domestic olive grown in cultivars in Aegean region of Turkey. A typical chromatogram of a virgin oil sample extracted by three phase continous system in Edremit Gulf for 2001/2002 harvest years is shown in Fig. 2.

As seen in Table 1, the range for individual fatty acids during two harvest years virtually covered the full range of the IOOC [29] and the Turkish Food Codex standards [30]. The mean linolenic acid level of virgin olive oil samples in Aegean region of Turkey was below the maximum value fixed by the IOOC (1.0%) [29] and by the Turkish Codex (0.9%) [30]. The contents of linolenic acid were between different ranges for the two harvest years (Table 1). The linolenic acid range (0.41–1.01 %) from the first harvest year (2001–2002) was broader than the range (0.37–0.86 %) of the second harvest year (2002–2003). The differences were remarkable for oleic acid, the major fatty acid of olive oil. The range of oleic acid values (18:1n9) was determined for two harvest years (Table 1). The oleic acid levels (60.68–79.30%) for the second harvest year (2002–2003) were generally higher than those (60.30–76.92 %) of the first harvest year (2001–2002). The linoleic acid (18:2n6) levels for the two harvest years ranged from 8.08 to 17.17% and 5.36 to 18.76%, respectively (Table 1). The oleic acid/linoleic acid ratios (minimum value of 7) [9], as an indicator for cultivar characterization and oxidative stability, for the two harvest years ranged from 3.85 to 9.52 and 3.27 to 14.77, respectively. The nutritional (18:2/18:3, l/ln) fatty acid ratios (a value considered to be optimal) of the oil samples of domestic cultivars ranged from 10.17 to 39.93 and 8.93 to 26.76 for the two harvest years, respectively. It is reported that the ratio of linoleic/linolenic correlates with the bitterness and green perception of oils due to the contribution of volatile compounds to virgin olive oil flavor. For example, (*E*)-hex-2-enal contributes to green odor but also an intense bitter taste. Empirical results on the subject state that the lower the ratio, the higher the bitterness [9].

The distribution of fatty acids in virgin oil samples was in agreement with those of commercial and monocultivar oils collected from different locations of Turkey [6–10] and countries of the Mediterranean basin [11–24]. The variations in fatty acid profile of oil samples differ slightly, depending on the olive cultivar, growing conditions, harvest time and locations. Primary factors affecting fatty acid contents, especially oleic acid level, may originate from latitude, climate, olive cultivar and/or stage of fruit maturity during harvest [6, 8, 9, 15].

Virgin olive oils are classified into two types based on their fatty acid compositions. The first type of olive oil is characterized by low linoleic and palmitic and high oleic

Table 1 Statistical parameters for the fatty acid composition of Turkish virgin olive oil samples collected from different locations of Aegean Region during two harvest years (2001–2002 and 2002–2003)

Functions	Crop year 2001–2002			Crop year 2002–2003		
	$N = 105$			$N = 163$		
	Min.	Max.	Mean and Standard Deviation	Min.	Max.	Mean and Standard Deviation
p	9.62	18.97	13.272 ± 1.61	8.45	15.97	12.452 ± 1.02
po	0.61	1.70	0.891 ± 0.18	0.59	1.26	0.843 ± 0.13
m	0.04	0.25	0.135 ± 0.05	0.03	0.18	0.099 ± 0.04
mo	0.06	0.30	0.198 ± 0.07	0.05	0.33	0.164 ± 0.07
s	2.13	3.66	2.920 ± 0.29	1.04	3.38	2.50 ± 0.32
o	60.30	76.92	69.707 ± 2.87	60.68	79.30	72.427 ± 3.16
l	8.08	17.17	11.100 ± 1.89	5.36	18.76	9.93 ± 2.31
ln	0.41	1.01	0.688 ± 0.14	0.37	0.86	0.582 ± 0.09
a	0.22	0.56	0.428 ± 0.06	0.25	0.54	0.408 ± 0.05
g	0.19	0.50	0.306 ± 0.04	0.20	0.40	0.309 ± 0.04
b	0.07	0.19	0.118 ± 0.02	0.07	0.16	0.119 ± 0.02
lg	0.00	0.08	0.052 ± 0.01	0.03	0.08	0.054 ± 0.009
ea	0.00	0.08	0.01 ± 0.001	0.00	0.06	0.01 ± 0.006
tlln	0.03	0.17	0.07 ± 0.002	0.01	0.12	0.05 ± 0.02
tfa	0.03	0.22	0.09 ± 0.03	0.02	0.14	0.06 ± 0.02
ol	3.85	9.52	6.479 ± 1.22	3.27	14.77	7.739 ± 2.04
pl	0.63	1.76	1.221 ± 0.20	0.77	2.29	1.307 ± 0.26
lln	10.17	39.93	16.655 ± 3.91	8.93	26.76	17.458 ± 4.69
Sq	0.17	1.24	0.49 ± 0.17	0.20	1.68	0.59 ± 0.18

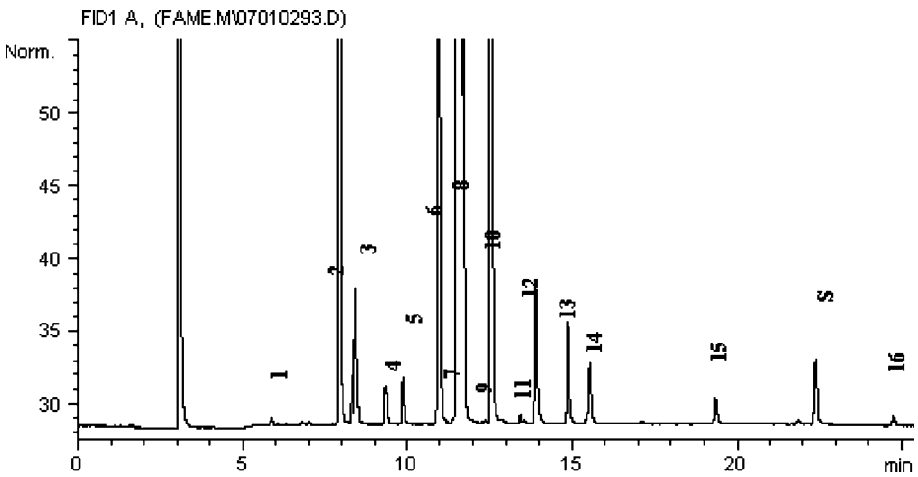

Fig. 2 A typical chromatogram of a virgin oil sample extracted by three phase continuous system in Edremit Gulf for 2001/2002 harvest years. *1* Myristic; *2* Palmitic (p); *3* Palmitoleic (po); *4* Margaric (m); *5* margaroleic (mo); *6* Stearic (s); *7* Elaidic (ea); *8* Oleic (o); *9* *trans*-Linoleic (Linoelaidic acid); *10* Linoleic (l); *11* *trans* Linolenic; *12* Linolenic (ln); *13* Arachidic (a); *14* Gadoleic (g); *15* Behenic (b); Squalene (S), *16* Lignoseric (lg)

levels. The second type is characterized by high linoleic and palmitic and low oleic levels. The virgin olive oils of the North Mediterranean (Spanish, Italian, Turkish and Greek) are of the first type, while North African origin oils, especially Tunisian, are of the second type [1, 9].

With respect to the analysis, levels of total *trans* isomers for the oils samples ranged among 0.03–0.22% and 0.02–0.14% for the two harvest years, respectively. According to official norms, total *trans* fatty acids in virgin olive oils should be 0.1% maximum. The total levels of *trans* fatty acid isomers [sum of elaidic acid (C 18:1 *t*) and (C 18:2 *t* + C 18:3 *t*] of most of the oil samples were generally within acceptable IOOC regulation limits [29], and the Turkish Food Codex standards [30]. The distribution of *trans* fatty acids was similar to those reported in Turkish virgin olive oils [9].

Olive oil contains large amounts of squalene, a terpenoid hydrocarbon, with antioxidant properties. Squalene levels for the two harvest years ranged from 0.21–1.24% to 0.25–0.99 1.22%, respectively. The differences in squalene

levels between olive oils may depend on the specific cultivar and the altitude at which the trees are grown [1]. These findings are generally in accordance with Turkish [9] and French [19] olive oils.

To select the best model with the minimum number of dimensions explaining the data structure, PCA was applied (using 19 fatty acids components) to the grouped oil samples (total of 268) according to their geographical locations. The exclusion rule employed was based on the amount of residual variability to tolerate [31], retaining a sufficient number of PC's capable of explaining a percentage of variance >80% or when the contribution of the $(p + 1)$ th component to variance explained was very small (<5%). Using this rule, the first two PC is sufficient because they described 86.74 and 89.73% of the sample variability (Table 2). This is in accordance with criteria of Jollife [32, 33] which suggests rejecting those PC having eigenvalues <0.7.

The first two functions and the relative weight of the original data set from the two harvest years were given in Figs. 3 and 4, respectively. Also, shown in Figs. 3 and 4, were the plots of the weights of the original set of variables on the plane of the first two PCs from the two harvest years, respectively.

Analysis of PCA results showed that the first principal component (PC1) and the second principal component (PC2) explained 26.35 and 21.87% of the total variance (Table 2), respectively, for the first harvest year (2001–2002). Also, these values are highly correlated to palmitic (p), margoleic (mo), oleic (o), linolenic (ln), *trans* linoleic + *trans* linolenic (tlln), oleic/linoleic (ol), palmitic/linoleic (pl) for PC1, and margaric (m), linoleic (l) and linoleic/linolenic (lln) for PC 2, respectively (Fig. 3). These fatty acids best describe the virgin olive oil samples in 2001–2002 harvest years.

In the second harvest year (2002–2003), the first PC accounted for 38.10% of the total variance (Table 2) and was highly correlated to palmitoleic (po), *trans* linoleic + *trans* linolenic (tlln), total trans fatty acid (TFA), oleic/linoleic (ol), linoleic/linolenic (lln). The second PC accounted for 17.05% of variance and is highly correlated to palmitic (p), margaric (m), margoleic (mo), oleic (o), gadoleic (g), lignoceric (lg) and palmitic/linoleic (pl) (Fig. 4). These parameters best described the oil samples from the second harvest year. Figures 3 and 4 showed that the all oil groups for the two harvest years are obviously separated due to the different domestic olive cultivars of Aegean region of Turkey.

In light of the chemometric analysis, oleic (o), linoleic (l), the major fatty acids in olive oil, and margaric (m), margoleic (mo), the minor fatty acids, as well as total *trans* isomers of linoleic and linolenic (tlln), and the oleic/

Table 2 Variance values explained by the Principal Components for Turkish virgin olive oil samples collected from different locations of Aegean Region during two crop years (2001–2002 and 2002–2003)

Crop year 2001–2002				Crop year 2002–2003		
$N = 105$				$N = 163$		
Principal Components	Eigenvalue	Variance %	Total Variance %	Eigenvalue	Variance %	Total Variance %
p	5.006	26.350	26.350	7.245	38.130	38.130
po	4.154	21.865	48.215	3.240	17.051	55.180
m	2.887	15.195	63.410	2.411	12.692	67.872
mo	2.133	11.224	74.634	1.629	8.572	76.444
s	1.269	6.680	81.314	1.414	7.441	83.885
o	1.031	5.426	86.740	1.110	5.844	89.729
l	0.679	3.571	90.311	0.547	2.881	92.610
ln	0.571	3.007	93.319	0.416	2.191	94.801
a	0.400	2.103	95.422	0.352	1.853	96.654
g	0.276	1.452	96.874	0.205	1.080	97.734
b	0.208	1.095	97.969	0.174	0.914	98.648
lg	0.178	0.936	98.904	0.113	0.592	99.240
ea	0.135	0.710	99.614	5.861E-02	0.308	99.549
tlln	2.681E-02	0.141	99.755	5.076E-02	0.267	99.816
tfa	1.947E-02	0.102	99.858	1.143E-02	6.014E-02	99.876
ol	1.276E-02	6.713E-02	99.925	1.010E-02	5.315E-02	99.929
pl	1.067E-02	5.618E-02	99.981	5.787E-03	3.046E-02	99.960
lln	3.611E-03	1.901E-02	100.000	4.535E-03	2.387E-02	99.984
Sq	−1.391E-15	−7.322E-15	100.000	3.119E-03	1.642E-02	100.000

p Palmitic, *po* palmitoleic, *m* margaric, *mo* margaroleic, *s* stearic, *o* oleic, *l* Linoleic, *ln* linolenic, *a* arachidic, *g* gadoleic, *b* behenic, *lg* lignoseric, *ea* elaidic, *tlln* *trans* linoleic + linoleic, *tfa* total *trans* FA, *ol* oleic/linoleic, *pl* palmitic/linoleic, *lln* linoleic/linolenic, *sq* squalene (Sq)

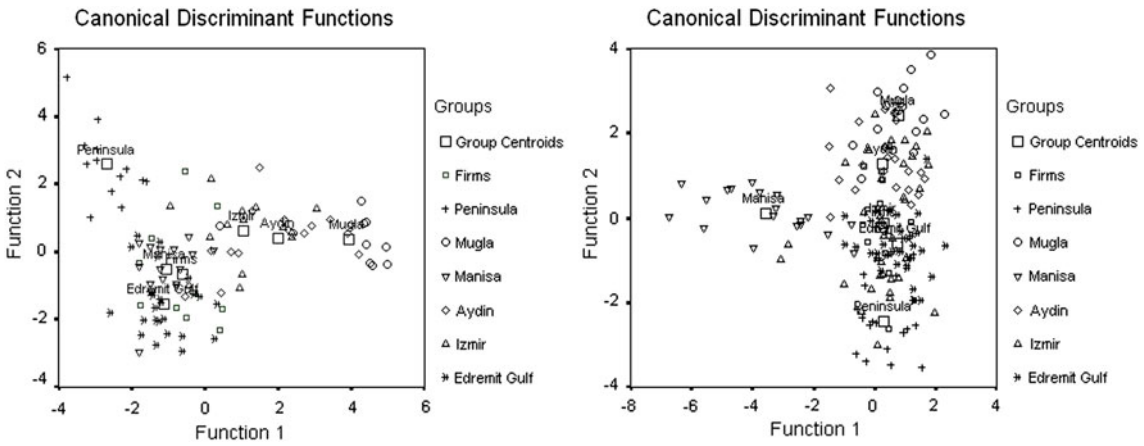

Fig. 3 Score plot of Turkish virgin olive oil samples on the plane identified by the first two components (*left*) 2001–2002 years, (*right*) 2002–2003 years

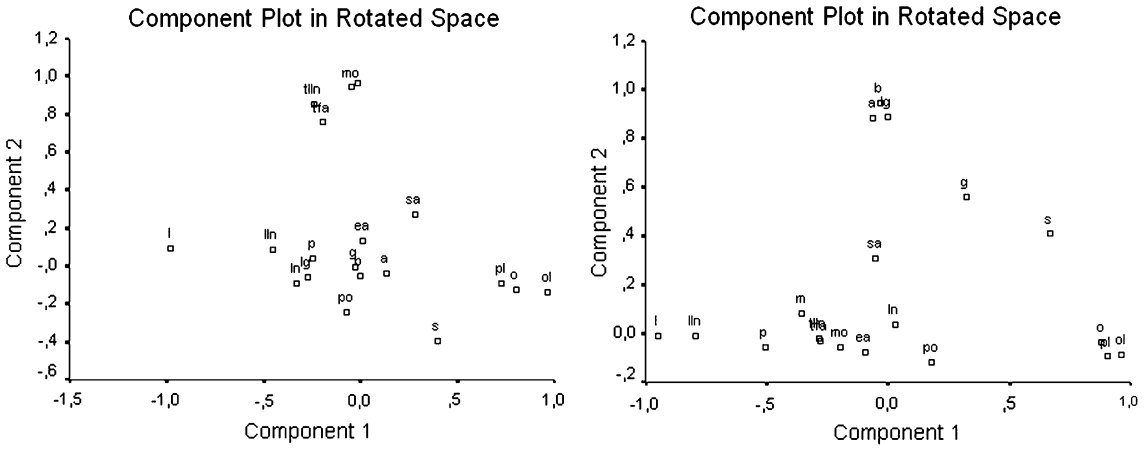

Fig. 4 Plot of the weights of the original set of variables on the plane of the first two components (*left*) 2001–2002 years, (*right*) 2002 – 2003 years. Fatty Acid Abbreviations: *p* Palmitic , *po* Palmitoleic, *m* Margaric, *mo* Margaroleic, *s* Stearic, *o* Oleic, *l* Linoleic, *ln* Linolenic, *a* Arachidic, *g* Gadoleic, *b* Behenic, *lg* Lignoseric, *ea* Elaidic, *tlln Trans* Linoleic + Linoleit*fa* c, Total *Trans* FA , *ol* Oleic/Linoleic, *pl* Palmitic/Linoleic, *lln* Linoleic/linolenic, *Sq* Squalene

linoleic (ol) ratio, the palmitic/linoleic (pl) ratio were common parameters for the characterization of Turkish virgin olive oil from different locations of Aegean for two harvest years. On the other hand, these parameters best describe the oil samples in two harvest years (2002–2003).

After PCA treatment, canonical discriminant analysis (Table 3) was applied to these parameters in order to classify the oil samples taken from Aegean region of Turkey into separate groups. The eigenvalue of the first crop year (2001–2002) associated with the first function contributed 51.30% to the variance of the original data and the second contributed 22.0%. The eigenvalue of the second crop year (2002–2003) associated with the first function contributed 30.90% to the variance of the original data and the second contributed 28.0%.

The levels of predictive probability in the differentiation of groups concerning virgin olive oil samples for two crop years were shown in Table 4. Overall, 74.5% of the cross-validated samples (total of 105) for first crop year (2001–2002) were correctly classified, while 100% from the Peninsula, 87.5% the Edremit Gulf, 81.3% from the Manisa province, 80% from the Mugla province, 64.3% from the Izmir province, 60% from the Aydın province, and 30% from the Firms were wrongly classified. Three Edremit Gulf samples from the first harvest year were identified as The Manisa province. Three Izmir province samples were classified the Aydın province and one sample apiece were grouped in the Edremit Gulf and the Manisa province. The one sample apiece from Aydın province were associated with the Edremit Gulf and the Izmir

Table 3 Canonical discriminant analysis for Turkish virgin olive oil samples collected from different locations of the Aegean Region for two harvest years (2001–2002 and 2002–2003)

Crop year 2001–2002				Crop year 2002–2003			
$N = 105$				$N = 163$			
Canonical discriminant function	Eigenvalue	Variance %	Canonical correlation	Eigenvalue	Variance %		Canonical correlation
1	3.939[a]	51.3	0.893	1.809[a]	30.9		0.802
2	1.692[a]	22.0	0.793	1.637[a]	28.0		0.788
3	0.728[a]	9.5	0.649	1.423[a]	24.3		0.766
4	0.502[a]	6.5	0.578	0.771[a]	13.2		0.660
5	0.470[a]	6.1	0.565	0.120[a]	2.0		0.327
6	0.348[a]	4.5	0.508	0.091[a]	1.6		0.289
Test of functions	Wilks' Lambda	Chi-Square	DF	Sig. Level	Wilks' Lambda	Chi-Square	DF	Sig. Level
1 through 6	0.015	373.94	108	0.000	0.026	545.28	114	0.000
2 through 6	0.072	232.59	85	0.000	0.072	391.40	90	0.000
3 through 6	0.194	144.93	64	0.000	0.191	246.91	68	0.000
4 through 6	0.336	96.53	45	0.000	0.462	115.02	48	0.000
5 through 6	0.505	60.50	28	0.000	0.819	29.83	30	0.474
6	0.742	26.40	13	0.015	0.916	13.00	14	0.526

province and the two samples apiece were classified as the Muğla province and the Firms (blend oils). Two Manisa province samples were classified as Edremit Gulf and the one sample was associated with the Firms (blend or coupage oils). Two Muğla province samples were identified as the Izmir province. Three Firms oil samples were identified as the Edremit Gulf and the two samples were classified the Manisa province. Also, the one sample apiece were identified as the Izmir province and the Peninsula.

The data set (163 samples) for the second harvest year (2002–2003) showed that 74.8% of the cross-validated samples were correctly classified, while 100% from the Peninsula, 95.0% from the Edremit Gulf, 94.1% from the Muğla province,89.5% from the Manisa province, 87% from the Aydın province, 33.3% from the Izmir province and 18.2% from the Firms were wrongly classified. Two Edremit Gulf samples from the second harvest year were classified as İzmir province. Ten Izmir province samples were identified as the Edremit Gulf and six samples were classified in the Aydın province. Also, two samples appiece were associated with the Manisa and the Muğla provinces, the Peninsula and the Firms sub-groups. Two Aydın province samples were classified as the Izmir province and the one sample was identified as the Mugla province. Two Manisa samples was associated with the Edremit Gulf. The one Muğla sample was classified as the Aydın province. Five Firms oil (blend oils from unknown origin) samples from the second harvest year were classified as the Edremit Gulf and three samples were grouped as the Izmir province. Also, one Firms sample was associated with the Peninsula. Cumulatively 70.0 and 81.8% of the Firms oils for both harvest years, respectively, were recognized as belonging to known groups (cultivar oils) on the basis of fatty acid profile. These relatioships among oil groups during two harvest years appeared to be due to the homogenous or heterogenous olive cultivar areas, commercial blending or coupaging depend on olive and oil exchanges among different olive growing zones in Aegean region of Turkey. As a general rule, during blending, around 40% of the Firms oils consist of the Ayvalık cultivar while the Erkence cultivar is dominant in the Peninsula oils.

Similar investigations based only on fatty acid compositional data for Greek [11, 13], Italian [12, 14–18], Spanish [20, 21, 24], French [19] and Turkish [6, 9, 10] oils resulted in a few defined regions and crop years. These studies were carried out using different software packing programs (SAS, SPSS, SIMCA), including PCA, HCA and DA.

The results of this study showed that application of chemometric methods, PCA and DA, to fatty acid composition is quite successful for the classification of virgin olive oil samples with respect to variety, geographical origin and harvest year, as a model based on Aegean region of Turkey.

On the other hand, it was indicated that the discrimination results from the Edremit Gulf, the Peninsula, the Muğla and the Manisa zones would correctly be classified (100–80%) for monocultivar or growing area using fatty

Table 4 Classification results of Turkish virgin olive oil samples collected from different locations of Aegean Region for two harvest years (2001–2002 and 2002–2003)

Crop year 2001–2002									Crop year 2002–2003							
$N = 105$									$N = 163$							
Predicting grouping									Predicting grouping							
Actual group	Number of cases	Edremit Gulf	İzmir	Aydın	Manisa	Muğla	Peninsula	Firms	Number of cases	Edremit Gulf	Izmir	Aydın	Manisa	Muğla	Peninsula	Firms
Edremit Gulf	24	21	0	0	3	0	0	0	40	38	2	0	0	0	0	0
		87.5	0.0	0.0	12.5	0.0	0.0	0.0		95.0	5.0	0.0	0.0	0.0	0.0	0.0
Izmir	14	1	9	3	1	0	0	0	36	10	12	6	2	2	2	2
		7.1	64.3	21.4	7.1	0.0	0.0	0.0		27.8	33.3	16.7	5.6	5.6	5.6	5.6
Aydin	15	1	1	9	0	2	0	2	23	0	2	20	0	1	0	0
		6.7	6.7	60.0	0.0	13.3	0.0	13.3		0.0	8.7	87.0	0.0	4.3	0.0	0.0
Manisa	16	2	0	0	13	0	0	1	19	2	0	0	17	0	0	0
		12.5	0.0	0.0	81.3	0.0	0.0	6.3		10.5	0.0	0.0	89.5	0.0	0.0	0.0
Mugla	10	0	2	0	0	8	0	0	17	0	0	1	0	16	0	0
		0.0	20.0	0.0	0.0	80.0	0.0	0.0		0.0	0.0	5.9	0.0	94.1	0.0	0.0
Peninsula	13	0	0	0	0	0	13	0	17	0	0	0	0	0	17	0
		0.0	0.0	0.0	0.0	0.0	100.0	0.0		0.0	0.0	0.0	0.0	0.0	100.0	0.0
Firms	10	3	1	0	2	0	1	3	11	5	3	0	0	0	1	2
		30.0	10.0	0.0	20.0	0.0	10.0	30.0		45.5	27.3	0.0	0.0	0.0	9.1	18.2
Percent of cross-validated cases correctly classified 74.5%									Percent of cross-validated cases correctly classified 74.8%							

acid profiles. The Ayvalık, Memecik and Erkence oils from different growing regions could be differentiated based on their fatty acid profiles with PCA and DA results. This research is a step towards the subjective characterization and classification of economically important areas in oil production for utilization in the Turkish food industry. Use of the multivariate approach on the fatty acid profiles of virgin olive oil taken from six sections of Aegean region, Turkey's main olive oil production, during two crop years appears to be advantageous for reducing the data set compressing the variance into smaller number of axes. The results of this investigation gives the possibility of evaluating data to control labelling and of building up the reference set necessary for establishing criterion of geographical origin, especially Aegean region of Turkey, and ultimately increasing competitiveness of these products on the market.

Future work on characterization of virgin olive oils from the Aegean region of Turkey should be carried out with investigations covering different parameters (triacylglycerols, sterols, phenolic compounds and volatile compounds) in terms of building a more comprehensive data bank.

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