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Sensorial and Physico-Chemical Characterization of Virgin Olive Oils Produced in Çanakkale

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Abstract The objective of the present study was to characterize the virgin olive oils (28 samples from the 2005–06 seasons) produced in the Çanakkale region. The total phenolics of the samples ranged from 34.60 to 162.61 mg gallic acid/kg. Similarly, antioxidant capacity was indicated by a range of 0.25–1.66 mmol Trolox equivalent/kg. Samples with a greater antioxidant capacity also had the highest phenolic content. Viscosity of the samples (60.4–66.3 cP) and instrumental color values (L, a*, and b*) were not statistically different among the five counties. Peroxide values of some samples were out of this range, indicating oxidation problems. The sensory quantitative description (QDA) of the appearance, aroma, flavor and mouthfeel of the olive oil samples was using 14 defining terms developed by the panel. Also, a canonical correlation analysis was performed to investigate the relationship between physico-chemical and QDA measurements. The five geographic counties of Çanakkale were found to be statistically not different from each other ($p > 0.05$). All regions had olive oils which were mostly olive-like, grassy, faintly bitter, very yellow and clear with a small amount of green color.

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Introduction

Olive trees (*Olea europaea* L.) usually grow between the 30° and 40° latitudes and are cultivated in around 35 countries, but most of the production occurs in the Mediterranean region. The three major olive oil producing countries are Spain (providing 40% of the World production), Italy (24%) and Greece (12%), followed by Tunisia (7%) and Turkey (4%). According to 2004 statistics, there are around 107 million olive trees in Turkey, of which 32% are used for edible olive production and 68% are used for olive oil production. Annually 112,000 tons of olive oil is produced, and approximately 70% of it exported to other countries. There is a total of 27,695 ha olive growing area in the Çanakkale province of Turkey. In general 98,946 tons of olives and 21,988 tons of olive oils are produced in the province [1, 2].

The final oil quality obtained from the oil mill depends on many factors, such as olive cultivar and ripening, agricultural practices, methods of harvest and transport, and technological operations adopted to produce the virgin olive oil. Although most of them are controlled or being modified currently, the effect of geographical origin which includes the effects of cultivar, soil and climatic conditions altogether is becoming an important factor to identify and protect the affiliated quality. In 1992, the European Union (EU) set out rules for the designation of origin to protect the high quality of agricultural and food products with systems known as Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI). Authentication is another issue of economical and health importance with regard to virgin olive oils. Adulteration of olive oils is usually performed by mixing the oil with another cheaper edible oil, mixing different quality and pomace olive oils and mixing oils from different geographical origins. There are various analytical approaches to evaluate adulteration, but first the properties of a specific olive must be characterized [3].

Quantitative descriptive analysis (QDA) has been applied to olive oils for characterization, differentiation and classification purposes [4, 5]. Samples from different countries were evaluated by different panels using a diverse range of defining sensory terms. Most commonly used QDA terms were "green, cut grass, bitter, fruity, tomato-like, burning, astringent, hay, muddy, musty, and fusty". Sensory evaluations together with other physical and chemical measurements are commonly used to compare different genotypes, different production regions and agricultural practices by known chemometric techniques.

The objectives of the present study were to characterize the sensorial and physico-chemical properties of the virgin olive oils produced in the Çanakkale region of Turkey, and to determine if any differences exist among the counties in the specific production region. Also, canonical correlation of the measured sensorial and physico-chemical parameters was determined.

Materials and Methods

Sampling of Virgin Olive Oils

Çanakkale is the city of Turkey situated on the Dardanelles which connect the Marmara Sea to the Aegean Sea. It is the second city having soils both in Asia and Europe continents after Istanbul. The total population of the region (city center and counties together) is 464,975 of which around 56% work in the agricultural sector. The area of Çanakkale region is 973,700 and 335,373 ha are occupied in agricultural production. Figure 1 shows the map with the sample numbers of the 28 virgin olive oil samples collected for this study in the 2005–06 harvesting year. The numbers are point specific and used throughout the other tables with the names of the production points or villages of the samples. Sometimes samples were taken from the same factory, but with definite knowledge of where the olives are harvested. All samples produced in dual or triple phase centrifugation systems. The olive and olive oil production properties of the Çanakkale counties are shown in Table 1, the information was taken from the Region Head Office of the Agriculture Ministry [6].

Fig. 1 Map of the Çanakkale showing the collected virgin olive oil sample numbers

Reagents

The analytical grade chemicals of ethanol, methanol, chloroform, cyclohexane, phenolphthalein, sodium thiosulfate, sodium hydroxide, ferrous sulfate, potassium iodide, acetic acid (glacial), citric acid, alum, caffeine, soluble starch, and

Table 1 The virgin olive oil production potential of the counties of Çanakkale region [6]

County name	Total tree (number)	Total olive production (tons)	Total olive oil production (tons)	Producing facilities (number)
Center	132,000	3,300	733	5
Ayvacık	1,620,000	64,800	14,400	21
Bayramiç	282,000	4,500	1,000	9
Biga	3,150	28	6	–
Bozcaada	2,220	42	9	–
Çan	0	0	0	–
Eceabat	342,000	15,390	3,420	4
Ezine	1,290,000	9,030	2,007	25
Gelibolu	29,700	445	99	–
Gökçeada	94,000	376	84	1
Lapseki	45,000	1,035	230	3
Yenice	0	0	0	–
Total	3,840,070	98,946	21,988	68

sodium carbonate anhydrate were purchased from Merck (Darmstadt, Germany). Folin-Ciocalteu reagent, Gallic acid, Trolox (6-hydroxy-2, 5, 7, 8-tetramethylchroman-2-carboxylic acid), ABTS (2, 2-azinobis (3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt, *cis*-3-hexenol, 2-ethyl-1-hexenal, dodeconoic acid, geosmin and potassium persulfate were purchased from the Sigma Chem. Co. (St. Louis, US). Other utensils for sensory analyses were purchased from local markets.

Chemical Analyses

Determination of Acid Value

Total free fatty acids of the samples were measured by titrating 1 g sample dissolved in 95% ethanol against phenolphthalein indicator according to AOCS method Ca 5a-40 [7], and results are given as oleic acid (%).

Determination of Peroxide Value

The peroxide value was determined by reacting the sample dissolved in a mixture of chloroform-acetic acid (2:3) with a solution of potassium iodide in darkness, then free iodine titration with a sodium thiosulfate solution according to AOCS method Cd 8–53 [8]. The results were expressed as milliequivalents of active oxygen per kilogram of oil (meq O_2/kg sample).

Determination of Total Phenolic Compounds

Phenolic compounds were extracted from 10 g of olive oil sample twice with 10 ml of water–methanol (60:40 v/v), and then evaluated colorimetrically using Folin-Ciocalteau reagent. A diluted extract of sample (0.5 ml) was mixed with the Folin reagent (5 ml, 1:10 diluted with distilled water) and Na_2CO_3 solution (4 ml, 1 M). Solutions were maintained at 45 °C in a waterbath for 15 min and the total polyphenols were determined colorimetrically at 725 nm absorbance reading against the gallic acid standard [9]. Results were expressed as mg gallic acid/kg sample.

Determination of Antioxidant Capacity

The antioxidant capacity of oil samples were measured by ABTS radical cation decolorization assay adapted from Rice-Evans et al. [10]. This technique measures the relative ability of antioxidant substances to scavenge the 2,2-azinobis(3-ethylbenzothiazoline-6-sulfonate) radical cation ($ABTS^{*+}$) compared with Trolox. The radical cation was generated in aqueous solution with potassium persulfate reaction for 12–16 h producing a blue/green chromogen with characteristic absorption at 734 nm. Olive oil sample extracts (1 ml), including antioxidant compounds were added to the pre-formed radical cation (1 ml) reduces it ABTS, to an extend on a time-scale (4 min standard for all) depending on the total antioxidant activity present. Thus the extent of decolorization as percentage inhibition of the cation radical is determined as a function of concentration in 4 min time and calculated relative to reactivity of Trolox as a standard, under the same conditions. Results were expressed as mmol Trolox equivalents (TE)/kg sample.

Physical (Instrumental) Measurements

Ultraviolet Absorption Reading

The K_{232} and K_{270} extinction coefficients were calculated from absorbance readings at 232 and 270 nm, respectively with a spectrophotometer (UV-Vis 1240 Shimadzu Spectrophotometer), using a 1% solution of oil sample in cyclohexane and a path length of 1 cm. There was no Al_2O_3 column treatment of the samples prior to spectrophotometry.

Measurement of Refractive Index

The refractive index of virgin olive oil samples was measured in daylight with a 2WAJ model Abbe refractometer, calibrated against pure water at 25 °C.

Measurement of Viscosity

Viscosity measurements of the olive oils were carried out by placing 7.5 ml of sample in a special sample holder, and direct measuring centipoises (cP) with a Brookfield viscosimeter (model DV II + Pro with Rheocalc software, Brookfield Eng. Lab., Inc., MA, US) equipped with LV-SC4-18 spindle at 25 °C.

Measurement of Total Volatiles

Total volatile compounds, including moisture, were measured by an Ohaus MB45 IR light equipped drying scale with 2 g of sample at 105 °C.

Assessment of Instrumental Color

The method of measurement was adopted from Pagliarini and Rastelli [11]. First, the empty 50 ml glass wrapped with Teflon on its sides was placed on the white tile No. 22933049 and a Minolta Camera CR-200, 2-observer (Japan) was calibrated (calibrated readings were $L = 43.23$, $a^* = -0.08$ and $b^* = -0.17$). Then each time 30 ml of samples put into the glass, and the liquid probe of the instrument was immersed into the glass sitting on the white tile, and readings of the CIE lab coordinates are recorded. The Yellowness index (YI = 142.86 b*/L) and Greenness index (GI = $tang^{-1}$ (a*/b*)) were then calculated from CIE lab data [11].

Sensory Measurements

Quantitative Descriptive Analysis (QDA)

Quantitative descriptive analysis (QDA) was conducted on 23 of the 28 virgin olive oil samples due the limited availability of five samples. For the QDA of the samples, the standard published methodology [12] was followed. Also, the techniques of the International Olive Oil Council (IOOC) [13] and published other literature were followed [14].

Panel members were eight students of our department who are regular consumers of and who like olive oils and volunteered for this study. Five of the panelists were female and three were males aging between 21 and 25. There was at least 15 h of training of the panel in this study. At first, around a table, the principles, procedures and cautions of the test were explained to the panel. Then by using very diverse fresh and stored olive oil samples and applying the standard methodology of the QDA, the panelists were asked to identify and define the sensory appearance, aroma, flavor and aftertaste attributes of the olive oil samples. The vocabulary was developed by the panelists under the moderation of the panel leader who was not a participant of the process. After close examination and discussion, the panel has formed the sensory descriptors with their accepted definitions and references shown in Table 2. During the training, potential reference materials (actual foodstuffs, chemicals and others) were used. The panelists quantified the attributes using a 15-cm scale anchored zero from left side to 15 on the right side. The panelists were provided with water, unsalted crackers and a slice of apple with an expectoration cup to cleanse the palate between samples.

In each evaluation session, only four samples were given to each panelist in sessions on different days. The olive oil samples were put in special glasses having a round bottom and thinner head closed with a metal lid. The three-digit coded glasses were filled to ¾ level with the olive oil samples previously heated in a water bath around 28 ± 2 °C, and evaluated by the panel immediately. Duplicate samples were served in different sessions in a randomized order.

Statistics

Qualitative attributes were analyzed using SAS Systems for Windows [15]. Significant differences among the means of

Table 2 The sensory vocabulary developed by the panel for the virgin olive oil QDA analysis

Descriptor	Definition	Reference
Visual descriptors		
Yellowness	Amount of yellow color present	Liquid food dye, sunflower oil
Greenness	Amount of green color present	Liquid food dye, olive leaf
Clarity	Clear, not cloudy	Olive oil clouded by added detergent
Aroma descriptors		
Olive	Intensity of fresh olive odor	Olive paste, olive flower cologne
Grassy	Scent of freshly mown grass	*cis*-3-Hexenol, fresh cut grass
Musty/muddy	Odor of typical fungi and wet soil	2-Ethyl-1-hexanol, geosmin, wet soil
Rancid	Odor of oxidized oil	Very old and oven heated oil
Flavor descriptors		
Acid	Taste of acids	0.05% Citric acid solution
Bitter	Taste of caffeine	0.055 Caffeine solution
Astringent	Oral cavity puckering/dry sensation	0.5% Alum solution, Sugarless tea
Soap	Aroma associated with unscented soap	Dodeconoic acid
Metallic	Aroma associated with metals	Ferrous sulfate, cardboard
Mouthfeel/aftertaste		
Throat catching	Burning sensation of throat after swallowing	Intensity after 30 sn of swallowing
Thickness	Having body, not thin and watery	Coating ability of the oral cavity

Table 3 The measured chemical quality indices of the virgin olive oil samples (mean ± SD) and comparison of the counties by Tukey's test

County (village-sample no)	Acidity (% oleic acid)	Peroxide value (meq O_2/kg)	Total phenols (mg gallic acid/kg)	Antioxidant capacity (mmol TE/kg)
AYVACIK	(1.98 ± 0.636)	(14.48 ± 1.260 B)	(69.97 ± 10.56)	(0.76 ± 0.103)
Tuzla (1)	1.097 ± 0.021	19.390 ± 2.580	51.71 ± 2.98	0.70 ± 0.03
Kadırga (2)	1.732 ± 0.100	20.514 ± 0.561	54.73 ± 1.73	0.74 ± 0.04
Kösedere (3)	0.555 ± 0.005	8.733 ± 0.087	124.73 ± .6.34	1.61 ± 0.18
Babadere (4)	9.472 ± 0.306	16.346 ± 0.810	64.73 ± 25.04	0.55 ± 0.01
Gülpınar (5)	0.784 ± 0.105	8.188 ± 1.583	49.79 ± 1.44	0.58 ± 0.06
Tamış (6)	1.740 ± 0.065	14.340 ± 2.440	91.07 ± 9.61	0.84 ± 0.15
Taşağıl (7)	0.712 ± 0.044	12.672 ± 0.656	34.60 ± 2.21	0.43 ± 0.01
Kocaköy (8)	0.554 ± 0.004	8.779 ± 0.285	72.42 ± 5.19	0.82 ± 0.10
Paşaköy (9)	1.468 ± 0.006	9.957 ± 0.768	85.94 ± 4.13	0.52 ± 0.01
EZİNE	(1.30 ± 0.674)	(16.41 ± 1.337 A,B)	(93.97 ± 11.20)	(0.94 ± 0.109)
Merkez (10)	1.013 ± 0.093	14.722 ± 1.726	81.71 ± 16.6	0.87 ± 0.32
Burgaz (11)	3.679 ± 0.023	16.209 ± 0.448	68.57 ± 2.50	0.64 ± 0.10
Mecidiye (12)	1.103 ± 0.004	19.140 ± 1.537	67.61 ± 1.53	0.70 ± 0.03
Akköy (13)	0.369 ± 0.001	12.903 ± 0.955	162.61 ± 2.88	1.66 ± 0.05
Tavaklı (14)	1.020 ± 0.089	12.112 ± 0.882	78.19 ± 0.38	0.81 ± 0.03
Mahmutiye (15)	0.931 ± 0.002	13.551 ± 0.586	152.23 ± 11.53	1.18 ± 0.18
Derebağlar (16)	1.115 ± 0.010	14.421 ± 0.042	70.17 ± 0.50	0.85 ± 0.09
Yenioba (17)	1.236 ± 0.065	17.924 ± 1.555	70.69 ± 5.76	0.79 ± 0.08
BAYRAMİÇ	(1.42 ± 1.101)	(24.88 ± 2.183 A)	(109.17 ± 18.29)	(0.90 ± 0.178)
Kutluoba (18)	1.563 ± 0.099	19.247 ± 1.353	75.94 ± 8.94	0,81 ± 0,20
Ahmetçe (19)	1.859 ± 0.034	25.330 ± 0.649	125.30 ± 12.50	0.83 ± 0.10
Merkez (20)	0.860 ± 0.105	26.155 ± 0.085	126.26 ± 0.57	1.06 ± 0.06
ECEABAT	(1.74 ± 1.349)	(16.64 ± 2.673 A,B)	(62.54 ± 22.40)	(0.64 ± 0.218)
Merkez (21)	1.824 ± 0.006	18.382 ± 0.420	52.48 ± 4.13	0,64 ± 0,08
Kıraçtepe (22)	1.739 ± 0.114	12.344 ± 0.421	72.61 ± 7.30	0.65 ± 0.06
GÖKÇEADA	(1.77 ± 1.349)	(10.42 ± 2.673 B)	(80.97 ± 22.40)	(0.68 ± 0.218)
Yenimahalle (23)	1.205 ± 0.096	10.382 ± 0.040	93.25 ± 11.59	0.76 ± 0.09
Merkez (24)	2.369 ± 0.038	7.861 ± 0.054	68.70 ± 10.42	0.59 ± 0.07
LAPSEKİ				
Umurbey (25)	2.014 ± 0.019	12.233 ± 0.674	46.33 ± 2.01	0.55 ± 0.18
BOZCAADA				
Merkez (26)	0.846 ± 0.105	29.751 ± 0.156	47.03 ± 4.23	1.07 ± 0.06
ÇANAKKALE				
Merkez (27)	1.197 ± 0.092	11.664 ± 0	125.11 ± 15.59	0.64 ± 0.25
GELİBOLU				
Koruköy (28)	2.997 ± 0.057	19.119 ± 1.570	47.61 ± 7.63	0.25 ± 0.12

Values given in the parentheses in each column compare the five counties by using the Tukey's test at 95% of confidence level

the counties for the chemical and physical measurements were determined by unbalanced analysis of variance using the Tukey's test at 95% of confidence. Similarly, comparison of the sensory measurements was carried out by Kruskal–Wallis test to compare the production counties. Canonical correlation analysis (CCA) was used to investigate the relationships among the physico-chemical measurements and QDA measurements. The analyses were performed with NCSS for windows statistical package program [16]. From CCA, a linear association between predictor variables (physico-chemical measurements) and dependent variables (QDA measurements) were determined. Canonical variables are linear combinations of the original quantitative measurements that contain the highest possible multiple correlation with each group and that summarize among-class variation. CCA is the appropriate technique for identifying relationships between two sets of variables. The goal of CCA is to evaluate the relative contribution of each variable to the derived canonical functions in order to explain nature of the relationship(s). Consider the following two equations:

$$U_{\mathrm{m}} = a_{\mathrm{m}1}X_1 + a_{\mathrm{m}2}X_2 + \cdots + a_{\mathrm{mp}}X_{\mathrm{p}} \quad (p = 1, 2, \ldots, 11) \tag{1}$$

$$V_{\mathrm{m}} = b_{\mathrm{m}1}Y_1 + b_{\mathrm{m}2}Y_2 + \cdots + b_{\mathrm{mq}}Y_{\mathrm{q}} \quad (q = 1, 2, \ldots, 14) \tag{2}$$

Equation (1) and (2) gives the new variables or canonical variates U_{m} and V_{m} which are a linear combination of the X (physico-chemical measurements) and Y (QDA measurements) variables, respectively. The correlation between U_{m} and V_{m} is called canonical correlation (C_{m}). The objective of canonical correlation is to estimate $a_{\mathrm{m}1}$, $a_{\mathrm{m}2, \ldots,}$ a_{mp} and $b_{\mathrm{m}1}$, $b_{\mathrm{m}2, \ldots,}$ b_{mq} such that C_{m} is maximum.

The canonical correlation coefficient between U_{m} and V_{m} is therefore $C_{\mathrm{m}} =$ Corr (U_{m}, V_{m}) and the statistical significance tests for the canonical correlations are tested as follows:

The null (H_0) and alternative (H_1) hypotheses for assessing the statistical significance of the canonical correlations are:

$$H_0: C_1 = C_2 = \ldots = C_{\mathrm{m}} = 0 \text{ and } H_1: C_1 \neq C_2 \neq \ldots \neq C_{\mathrm{m}} \neq 0$$

The H_0 hypothesis, which states that all the canonical correlations are equal to zero, implies that the correlation matrix (R_{XY}) containing the correlations among the X and Y variables equal zero ($R_{XY} = 0$). A number of test statistics can be used for testing the H_0 hypothesis such as Wilks' Lambda (Λ), likelihood ratio test. Wilks' Λ is given by $\Lambda = \Pi_{i=1}^{m}\left(1 - C_i^2\right)$. Significance of likelihood ratio test is also equal to the significance of Wilks' Λ. The statistical significance of Wilks' Λ determined as follows:

$$B = -[N - 0.5\,(p + q + 1)\ln \Lambda].$$

B statistic has an approximate χ^2-distribution with pxq degrees of freedom, where N is the number of cases, ln represents the natural logarithm function; p and q are the number of variables in first and second set [17]. At the end of statistical significance test, rejection of the H_0 hypothesis implies that at least one of the canonical correlations is statistically significant.

Redundancy measure or index (RM) for each canonical correlation also computed to determine how much of the variance in physico-chemical measurements is accounted for by the QDA measurements. Let RM_{V_i/U_i} be the amount of the variance in the QDA measurements (Y) that is accounted for by the physico-chemical measurements (X) for ith canonical correlation (C_i), AV(Y/V_i) is the average variance in QDA measurements or Y-variables that is accounted for by the canonical variate, U_i, and LY_{ij} is the loading of the jth Y-variable on the ith canonical variate. Because C_i^2 gives the shared variance between the canonical variates V_i and U_i, the RM is equal to the product of the average variance and the shared variance. RM, therefore, can be formulated as below [17]:

$$\mathrm{AV}(Y/V_i) = \frac{\sum_j^q \mathrm{LY}_{ij}^2}{q} \text{ and } \mathrm{RM}_{V_i/U_i} = \mathrm{AV}(Y/V_i).C_i^2$$

Results and Discussion

Chemical Analyses

The measured chemical quality indices of the 28 virgin olive oil samples of Çanakkale region are shown in Table 3. The quantity of free fatty acids, measured as acidity (% oleic acid), is a very important quality and classification index for the olive oils. According to the Turkish Standards of Olive Oils (TS 341) [18], there should be a maximum of 1.0, 2.0 and 3.3% acidity in the extra virgin, virgin and ordinary olive oils, respectively. Among the 28 samples, sample four (9.47% acidity) produced in Babadere of Ayvacık county and sample 11 (3.68% acidity) produced in Burgaz of Ezine county were above the TS 341 guidelines. These values were also above the Codex Standard [19] of 0.8, 2.0 and 3.3 g FFA/100 g for extra virgin, virgin and ordinary virgin olive oils, respectively. Most of the collected samples are extra virgin or virgin olive oils (Table 3). Traditionally, consumers of the region like olive oils having acidity max of 1% or less. According to the TS 341 and Codex Standard, the max allowable peroxide value for extra virgin, virgin and ordinary olive oils is 20 meq O_2/kg sample. The peroxide values of 20.5, 25.3, 26.2 and 29.8 meq O_2/kg in samples 2, 19, 20 and 26 are out of the max allowable limits, respectively. The lowest value (8.1 meq O_2/kg sample) was in the sample five produced in Gülpınar village of Ayvacık. The rest of the samples had peroxide values between 10 and 20 meq O_2/kg samples (Table 3). Peroxide values of the samples are usually affected by the conditions before extraction to storage conditions after extraction. Harvest and transportation damage fruit, together with long storage time before olive milling, and improper handling and storage conditions (under elevated temperature, contacting with light and oxygen) cause peroxide value to increase immediately. Hence, total control of the full system is required. Thus, high peroxide values in samples 2, 19, 20 and 26 may be related to the aforementioned conditions. Compounds having antioxidant activity in olive oils are the polyphenols, tocopherols, carotenoids and chlorophylls [9]. Also, no individual compound was identified as the main cause of the antioxidant activity; instead the total polyphenol content was better correlated with the antioxidant capacity.

Table 4 The measured instrumental quality indices of the virgin olive oil samples (mean ± sd) and comparison of the counties by the Tukey's test

County (village-sample no)	UV absorbance		Refractive index (25 °C)	Viscosity (cP, 25 °C)	Total volatiles (%)
	K_{232}	K_{270}			
AYVACIK	(2.64 ± 0.076)	(0.20 ± 0.017)	(1.47 ± 0)	(63.02 ± 0.517)	(0.20 ± 0.015)
Tuzla (1)	2.61 ± 0.08	0.15 ± 0	1.468 ± 0	66.1 ± 0.01	0.21 ± 0.02
Kadırga (2)	2.71 ± 0.05	0.23 ± 0.01	1.468 ± 0	65.1 ± 0.01	0.09 ± 0.08
Kösedere (3)	2.00 ± 0.03	0.11 ± 0	1.468 ± 0	63.1 ± 0.01	0.21 ± 0.02
Babadere (4)	2.52 ± 0.09	0.24 ± 0.01	1.467 ± 0	60.4 ± 0.01	0.25 ± 0.02
Gülpınar (5)	2.54 ± 0.10	0.15 ± 0	1.467 ± 0	62.0 ± 0.01	0.17 ± 0.02
Tamış (6)	2.95 ± 0.08	0.33 ± 0	1.468 ± 0	63.0 ± 0.01	0.21 ± 0.04
Taşağıl (7)	2.93 ± 0.06	0.20 ± 0	1.468 ± 0	62.0 ± 0.01	0.15 ± 0
Kocaköy (8)	2.79 ± 0.13	0.17 ± 0.01	1.468 ± 0	62.5 ± 0.01	0.16 ± 0.02
Paşaköy (9)	2.69 ± 0.12	0.18 ± 0	1.467 ± 0	63.0 ± 0.01	0.19 ± 0.08
EZİNE	(2.69 ± 0.080)	(0.19 ± 0.018)	(1.47 ± 0)	(62.91 ± 0.548)	(0.19 ± 0.016)
Merkez (10)	2.62 ± 0.06	0.18 ± 0.01	1.468 ± 0	63.5 ± 0.01	0.19 ± 0
Burgaz (11)	2.72 ± 0.15	0.21 ± 0.01	1.468 ± 0	62.1 ± 0.01	0.20 ± 0
Mecidiye (12)	2.87 ± 0.12	0.20 ± 0	1.468 ± 0	62.5 ± 0.01	0.16 ± 0.04
Akköy (13)	2.43 ± 0.04	0.16 ± 0	1.468 ± 0	61.7 ± 0.01	0.23 ± 0.05
Tavaklı (14)	2.52 ± 0.38	0.24 ± 0.01	1.468 ± 0	61.7 ± 0.01	0.19 ± 0
Mahmutiye (15)	2.82 ± 0.09	0.17 ± 0	1.468 ± 0	62.1 ± 0.01	0.20 ± 0.03
Derebağlar (16)	2.89 ± 0.16	0.16 ± 0.01	1.468 ± 0	65.0 ± 0.01	0.17 ± 0.02
Yenioba (17)	2.61 ± 0.14	0.14 ± 0	1.468 ± 0	64.7 ± 0.01	0.14 ± 0.01
BAYRAMİÇ	(2.79 ± 0.131)	(0.18 ± 0.029)	(1.47 ± 0)	(63.50 ± 0.896)	(0.17 ± 0.027)
Kutluoba (18)	2.87 ± 0.12	0.15 ± 0.01	1.468 ± 0	63.0 ± 0.01	0.15 ± 0
Ahmetçe (19)	2.90 ± 0.13	0.24 ± 0	1.468 ± 0	62.5 ± 0.01	0.20 ± 0.05
Merkez (20)	2.59 ± 0.06	0.14 ± 0.01	1.468 ± 0	65.0 ± 0.01	0.14 ± 0
ECEABAT	(2.57 ± 0.160)	(0.17 ± 0.036)	(1.47 ± 0)	(64.45 ± 1.097)	(0.20 ± 0.033)
Merkez (21)	2.66 ± 0.01	0.18 ± 0	1.467 ± 0	66.3 ± 0.01	0.20 ± 0
Kıraçtepe (22)	2.48 ± 0.05	0.16 ± 0	1.468 ± 0	62.6 ± 0.01	0.21 ± 0.02
GÖKÇEADA	(2.41 ± 0.160)	(0.20 ± 0.0369	(1.47 ± 0)	(61.95 ± 1.097)	(0.15 ± 0.033)
Yenimahalle (23)	2.23 ± 0.07	0.17 ± 0	1.468 ± 0	61.9 ± 0.01	0.13 ± 0
Merkez (24)	2.58 ± 0.42	0.23 ± 0	1.468 ± 0	62.0 ± 0.01	0.19 ± 0.08
LAPSEKİ					
Umurbey (25)	2.33 ± 0.05	0.20 ± 0	1.468 ± 0	62.9 ± 0.01	0.18 ± 0.06
BOZCAADA					
Merkez (26)	2.96 ± 0.11	0.23 ± 0.01	1.468 ± 0	65.5 ± 0.01	0.13 ± 0.02
ÇANAKKALE					
Merkez (27)	2.57 ± 0.08	0.13 ± 0	1.468 ± 0	63.0 ± 0.01	0.20 ± 0
GELİBOLU					
Koruköy (28)	2.58 ± 0.15	0.22 ± 0	1.468 ± 0	62.2 ± 0.01	0.14 ± 0.03

Values given in the parentheses in each column compares the five counties by the Tukey's test at 95% of confidence level

Total phenolics of the sample were found to be lowest (34.60 mg Gallic acid/kg) in the Taşağıl of Ayvacık county and the highest in the Akköy of Ezine county (162.61 mg Gallic acid/kg). Values between 50 and 650 mg/kg of polyphenols have been reported [9]. This might be due to both cultivar and processing differences. The antioxidant capacity of the oil samples were measured by an ABTS radical decolorization assay. The highest value of activity was in sample number 13 produced in Ezine/Akköy with 1.66 mmol Trolox equivalent (mmol TE)/kg sample to the lowest in sample 28 of Koruköy in Gelibolu with a value of 0.25 mmol TE/kg. Antioxidant capacity was assayed with very diverse techniques in literature. Hence, it was difficult to compare the results. In one study [10] a similar

Table 5 The measured instrumental color values of the virgin olive oil samples (mean ± SD) and comparison of the counties by Tukey's test

County (village-sample no)	CIELAB			Yellowness index	Greenness index
	L	*a**	*b**		
AYVACIK	(34.61 ± 1.33)	(−13.47 ± 0.56)	(17.65 ± 1.20)	(72.19 ± 2.37)	(−38.82 ± 1.79)
Tuzla (1)	28.68	−10.83	11.64	57.95	−42.92
Kadırga (2)	28.87	−11.18	13.44	66.50	−39.69
Kösedere (3)	33.43	−13.07	16.87	72.09	37.59
Babadere (4)	35.53	−13.13	17.07	68.61	−37.60
Gülpınar (5)	33.33	−13.09	17.24	73.87	−37.23
Tamış (6)	39.36	−15.64	22.12	80.28	−35.00
Taşağıl (7)	35.17	−13.69	17.57	71.36	−37.95
Kocaköy (8)	36.55	−14.46	19.89	77.74	−35.75
Paşaköy (9)	40.53	−16.14	23.06	81.26	−35.00
EZİNE	(35.09 ± 1.41)	(−13.78 ± 0.59)	(18.27 ± 1.27)	(74.20 ± 2.51)	(−37.12 ± 0.90)
Merkez (10)	35.45	−14.00	18.98	76.46	−36.50
Burgaz (11)	35.84	−13.99	18.20	72.52	−37.60
Mecidiye (12)	37.26	−14.76	20.42	78.29	−35.75
Akköy (13)	31.69	−12.17	14.45	65.11	−40.03
Tavaklı (14)	35.38	−13.95	18.80	75.91	−36.50
Mahmutiye (15)	36.90	−14.59	20.03	77.52	−36.12
Derebağlar (16)	31.88	−12.47	15.96	71.49	−37.95
Yenioba (17)	36.31	−14.32	19.39	76.26	−36.50
BAYRAMİÇ	(36.08 ± 2.30)	(−14.23 ± 0.96)	(19.29 ± 2.07)	(76.30 ± 4.10)	(−36.49 ± 1.46)
Kutluoba (18)	36.33	−14.35	19.57	76.93	−36.12
Ahmetçe (19)	38.40	−15.17	20.89	77.69	−36.12
Merkez (20)	33.52	−13.18	17.43	74.26	−37.23
ECEABAT	(32.63 ± 2.82)	(−12.34 ± 1.18)	(16.30 ± 2.54)	(68.62 ± 5.02)	(−38.82 ± 1.79)
Merkez (21)	25.37	−9.61	9.99	56.22	−43.83
Kıraçtepe (22)	39.88	−15.08	22.62	81.01	−33.82
GÖKÇEADA	(35.99 ± 2.82)	(−14.13 ± 1.18)	(18.83 ± 2.54)	(74.20 ± 5.02)	(−37.00 ± 1.79)
Yenimahalle (23)	39.09	−15.55	22.04	80.53	−35.00
Merkez (24)	32.89	−12.71	15.63	67.86	−39.00
LAPSEKİ					
Umurbey (25)	32.21	−12.62	16.29	72.25	−37.60
BOZCAADA					
Merkez (26)	34.08	−13.42	17.85	74.82	−36.86
ÇANAKKALE					
Merkez (27)	35.05	−13.74	18.07	73.63	−37.23
GELİBOLU					
Koruköy (28)	36.43	−14.28	18.97	74.37	−36.86

Values given in the parentheses in each column compare the five counties using the Tukey's test at the 95% confidence level

technique (ABTS assay) and other assays were used with the only difference that they generated the ABTS^{*+} cation by reacting metmyoglobin, instead we used potassium persulfate solution. They [10] reported antioxidant capacity values between 0.78 and 2.64 mmol TE/kg values. Thus, the observed antioxidant capacity values between 0.5 and 1.5 mmol TE/kg are in close agreement with the previously reported data.

The number of samples collected from each county was dependent to the production capacity of the region itself; hence, different numbers of samples for each county were analyzed. In order to compare the counties, only the ones having more than one sample were selected and an unbalanced analysis of variance with means separation by Tukey's multiple comparison test was applied (Table 3). The analysis of variance for acidity value among the five

Table 6 Sensorial color and aroma descriptors of the QDA analysis of virgin olive oil samples (mean ± SE_{mean})

County (village-sample no)	Color descriptors			Aroma descriptors			
	Yellowness	Greenness	Clarity	Olive	Grassy	Rancid	Musty/Muddy
AYVACIK							
Tuzla (1)	7.06 ± 0.96	4.33 ± 0.84	7.91 ± 0.71	3.99 ± 0.99	2.64 ± 0.91	0.79 ± 0.33	0.22 ± 0.07
Kadırga (2)	7.38 ± 1.00	4.54 ± 0.82	9.43 ± 0.71	4.23 ± 1.20	2.20 ± 0.78	0.76 ± 0.46	0.74 ± 0.31
Kösedere (3)	6.97 ± 0.89	4.27 ± 0.76	9.46 ± 0.63	3.81 ± 1.08	2.26 ± 0.96	0.98 ± 0.26	0.14 ± 0.06
Babadere (4)	6.43 ± 0.74	4.53 ± 0.56	5.68 ± 0.62	3.49 ± 1.03	1.90 ± 0.77	0.68 ± 0.23	0.26 ± 0.09
Gülpınar (5)	8.58 ± 0.64	3.95 ± 0.68	9.24 ± 0.50	1.93 ± 0.55	2.20 ± 0.65	0.65 ± 0.26	0.43 ± 0.14
Tamış (6)	6.28 ± 0.72	5.06 ± 0.62	9.82 ± 0.75	4.49 ± 0.95	2.03 ± 0.29	0.84 ± 0.35	0.51 ± 0.12
Taşağıl (7)	9.00 ± 1.01	3.04 ± 0.41	8.85 ± 0.81	2.57 ± 0.61	1.97 ± 0.44	0.47 ± 0.19	0.21 ± 0.05
Kocaköy (8)	7.67 ± 0.86	4.19 ± 0.58	9.63 ± 0.53	4.91 ± 1.01	3.36 ± 0.82	0.56 ± 0.19	0.21 ± 0.11
Paşaköy (9)	9.38 ± 0.90	3.31 ± 0.61	10.28 ± 0.52	2.98 ± 0.65	1.32 ± 0.52	0.53 ± 0.24	0.31 ± 0.13
EZİNE							
Merkez (10)	8.16 ± 0.63	3.82 ± 0.46	9.28 ± 0.60	4.72 ± 1.16	3.74 ± 1.15	0.43 ± 0.15	0.57 ± 0.29
Burgaz (11)	7.96 ± 0.61	3.81 ± 0.62	6.22 ± 0.79	3.79 ± 0.78	2.38 ± 0.64	0.67 ± 0.31	0.70 ± 0.21
Mecidiye (12)	8.62 ± 0.78	3.89 ± 0.62	10.43 ± 0.55	2.96 ± 0.72	1.59 ± 0.56	1.14 ± 0.56	0.71 ± 0.18
Akköy (13)	7.34 ± 1.02	2.57 ± 0.70	2.93 ± 0.56	2.65 ± 0.56	2.10 ± 0.65	0.59 ± 0.28	0.33 ± 0.10
Tavaklı (14)	5.03 ± 0.74	6.69 ± 0.79	8.77 ± 0.60	2.72 ± 0.57	1.46 ± 0.47	0.79 ± 0.31	0.42 ± 0.16
Mahmutiye (15)	8.62 ± 0.83	3.82 ± 0.61	10.04 ± 0.60	3.49 ± 0.78	1.94 ± 0.57	0.51 ± 0.20	0.43 ± 0.17
BAYRAMİÇ							
Kutluoba (18)	6.99 ± 0.69	4.07 ± 0.54	7.86 ± 0.72	1.89 ± 0.74	0.91 ± 0.48	1.51 ± 0.56	0.91 ± 0.28
Ahmetçe (19)	4.70 ± 0.79	8.60 ± 0.70	9.63 ± 0.75	3.22 ± 0.72	1.52 ± 0.45	0.89 ± 0.34	0.68 ± 0.21
ECEABAT							
Merkez (21)	7.41 ± 0.89	4.21 ± 0.77	4.70 ± 0.94	4.06 ± 1.26	4.68 ± 1.36	0.79 ± 0.31	0.63 ± 0.18
Kıraçtepe (22)	6.12 ± 0.88	6.08 ± 0.75	10.93 ± 0.63	4.88 ± 0.97	3.04 ± 0.79	0.54 ± 0.21	0.39 ± 0.17
GÖKÇEADA							
Yenimahalle (23)	7.23 ± 0.76	5.32 ± 0.62	8.64 ± 0.58	3.09 ± 0.77	1.41 ± 0.45	0.87 ± 0.31	0.74 ± 0.30
Merkez (24)	8.61 ± 0.82	4.33 ± 0.80	11.13 ± 0.49	4.01 ± 0.81	3.22 ± 0.83	0.450 ± 0.195	0.37 ± 0.12
LAPSEKİ							
Umurbey (25)	6.95 ± 1.32	5.78 ± 1.37	9.69 ± 0.65	3.07 ± 1.01	2.08 ± 0.76	0.99 ± 0.35	0.50 ± 0.15
ÇANAKKALE							
Merkez (27)	5.71 ± 0.63	6.86 ± 0.64	9.31 ± 0.66	4.21 ± 1.18	4.18 ± 1.17	0.72 ± 0.36	0.46 ± 0.16

counties of Çanakkale indicated no statistically significant difference ($p = 0.962$). In contrast, the means of peroxide values were significantly different ($p = 0.004$), with the lowest values in Gökçeada and Ayvacık counties, and the highest in Bayramiç county. The other counties were close to both, though the difference was not so large but significant. The measured total phenolics and antioxidant capacity values were statistically not significantly different ($p = 0.131$ and 0.581) among the five counties of Çanakkale. For these measured characteristics, the samples were very similar and authentic to the production region.

Physical (Instrumental) Measurements

The UV absorption characteristics, refractive index, viscosity and total volatiles are measured for all samples and mean values with standard deviations per samples are shown in Table 4. UV spectrophotometric measurements are widely used in both olive oil authentication and quality assessment. Usually K_{232} is accepted as an indicator of the fat autoxidation; however, K_{270} is more useful as a measure of the presence of conjugated dienes and trienes. Furthermore, both measurements have used to determine the addition of refined oils into virgin samples. Addition of refined oils usually causes both values to increase [20]. The Turkish Standard [18] puts a max value of K_{270} as 0.25 for extra virgin and virgin olive oils, and do not define a standard value for K_{232}. Codex Standard [19] defines a max or equal values of 0.22, 0.25 and 0.30 of K_{270} readings for extra virgin, virgin and ordinary olive oils, respectively. For the K_{232} readings, a max or equal value of 2.50 and 2.60 are defined for the extra virgin and virgin olive oils.

Table 7 Sensorial flavor and mouthfeel descriptors of the QDA analysis of virgin olive oil samples (mean ± SE_{mean})

County (village-sample no)	Flavor descriptors					Mouthfeel/aftertaste	
	Acid	Astringent	Bitter	Soap	Metallic	Throat catching	Thickness
AYVACIK							
Tuzla (1)	0.86 ± 0.24	0.76 ± 0.35	1.06 ± 0.24	1.20 ± 0.59	0.36 ± 0.12	5.67 ± 0.90	3.85 ± 0.74
Kadırga (2)	0.90 ± 0.34	0.83 ± 0.39	0.94 ± 0.27	1.60 ± 0.80	0.37 ± 0.11	3.58 ± 0.95	3.78 ± 0.67
Kösedere (3)	0.68 ± 0.24	0.69 ± 0.32	0.54 ± 0.20	0.99 ± 0.47	0.18 ± 0.05	2.95 ± 0.76	4.13 ± 0.77
Babadere (4)	0.52 ± 0.20	0.61 ± 0.20	0.52 ± 0.17	1.49 ± 0.61	0.40 ± 0.10	3.79 ± 0.91	3.94 ± 0.68
Gülpınar (5)	0.89 ± 0.24	0.92 ± 0.31	1.14 ± 0.25	1.75 ± 0.74	0.54 ± 0.16	6.15 ± 1.06	3.96 ± 0.71
Tamış (6)	0.66 ± 0.20	0.46 ± 0.13	0.85 ± 0.23	1.59 ± 0.62	0.47 ± 0.12	4.08 ± 0.83	3.39 ± 0.56
Taşağıl (7)	0.65 ± 0.20	0.62 ± 0.21	0.73 ± 0.21	1.24 ± 0.38	0.34 ± 0.07	4.00 ± 0.71	3.21 ± 0.46
Kocaköy (8)	0.71 ± 0.18	0.72 ± 0.19	0.81 ± 0.21	1.21 ± 0.52	0.31 ± 0.09	3.17 ± 0.56	3.62 ± 0.50
Paşaköy (9)	0.72 ± 0.27	0.62 ± 0.14	0.60 ± 0.13	1.31 ± 0.41	0.52 ± 0.23	2.13 ± 0.65	3.19 ± 0.62
EZİNE							
Merkez (10)	0.82 ± 0.18	0.78 ± 0.32	0.93 ± 0.19	1.29 ± 0.54	0.36 ± 0.09	4.67 ± 1.02	3.72 ± 0.57
Burgaz (11)	0.65 ± 0.19	0.74 ± 0.23	0.95 ± 0.25	0.86 ± 0.28	0.33 ± 0.04	6.12 ± 0.88	3.60 ± 0.64
Mecidiye (12)	0.78 ± 0.31	0.71 ± 0.24	0.54 ± 0.16	1.56 ± 0.72	0.82 ± 0.44	2.94 ± 0.72	3.97 ± 0.69
Akköy (13)	1.00 ± 0.34	0.88 ± 0.30	1.22 ± 0.28	1.48 ± 0.58	0.42 ± 0.10	4.76 ± 1.11	3.25 ± 0.44
Tavaklı (14)	0.56 ± 0.17	0.47 ± 0.17	0.62 ± 0.16	1.14 ± 0.35	0.22 ± 0.05	2.16 ± 0.52	3.25 ± 0.59
Mahmutiye (15)	0.63 ± 0.27	0.53 ± 0.21	0.70 ± 0.20	1.27 ± 0.51	0.38 ± 0.12	2.86 ± 0.68	3.39 ± 0.57
BAYRAMİÇ							
Kutluoba (18)	0.65 ± 0.17	0.42 ± 0.14	0.64 ± 0.21	2.59 ± 1.13	0.64 ± 0.19	2.56 ± 0.55	4.39 ± 0.81
Ahmetçe (19)	0.69 ± 0.28	0.75 ± 0.20	0.61 ± 0.19	1.09 ± 0.54	0.37 ± 0.12	1.96 ± 0.59	3.27 ± 0.63
ECEABAT							
Merkez (21)	1.17 ± 0.34	0.94 ± 0.31	2.19 ± 0.51	1.36 ± 0.64	0.54 ± 0.10	7.33 ± 1.02	4.44 ± 0.81
Kıraçtepe (22)	0.79 ± 0.18	0.62 ± 0.26	0.61 ± 0.17	1.31 ± 0.47	0.29 ± 0.04	3.46 ± 0.68	3.73 ± 0.63
GÖKÇEADA							
Yenimahalle (23)	0.61 ± 0.22	0.71 ± 0.20	0.64 ± 0.18	1.59 ± 0.77	0.24 ± 0.06	3.10 ± 0.72	3.88 ± 0.65
Merkez (24)	0.66 ± 0.19	0.84 ± 0.26	0.49 ± 0.18	1.39 ± 0.53	0.32 ± 0.08	2.84 ± 0.73	3.41 ± 0.61
LAPSEKİ							
Umurbey (25)	0.73 ± 0.22	0.59 ± 0.22	0.57 ± 0.13	2.09 ± 1.02	0.36 ± 0.11	2.64 ± 0.69	4.21 ± 0.73
ÇANAKKALE							
Merkez (27)	0.64 ± 0.26	1.00 ± 0.28	0.73 ± 0.22	1.44 ± 0.86	0.39 ± 0.11	3.54 ± 0.90	4.37 ± 0.79

Only four samples (number 3, 22, 23 and 25) have K_{232} values lower than 2.50, and can be classified as extra virgin or virgin, according to the Codex Standard (Table 4). Turkish Standard (TS 341) does not define K_{232}. All samples had K_{270} values lower than 0.25 and can be classified as extra virgin or virgin according to TS 341 and Codex Standards. Samples numbered 2, 4, 6, 11, 14, 19, 24, 26 and 28 had K_{270} readings higher than 0.20 values, and thus can only be classified as virgin, but not extra virgin according to the Codex Standard. The K_{232} value reportedly is correlated with peroxide value, not only at time zero but also during storage [20]. Higher readings of K_{232} in these samples may indicate improper storage of the oils. In contrast the K_{270} readings of the samples were completely within the limits, as described. A methodological concern may also arise, since the measured peroxide values of the samples have not indicated a real problem of oxidation.

TS 341 define the refractive index range at 20 °C for extra virgin, virgin and ordinary olive oils between 1.4677 and 1.4700 values. All of the samples had refractive index values between 1.467 and 1.468 at 25 °C. It is quite expected a physical constant be within the ranges, as long as there is no purity change of the sample. Viscosity is another physical characterization constant mostly depending to temperature and to some extent to the compositional differences of the vegetable oils. Measured at 25°C with a rotational type instrument, the viscosity of Çanakkale olive oils ranged between 60.4 and 66.3 centipoise (cP) values. Total volatiles (%) including moisture are also shown in Table 4. The Codex Standard [19] and TS 341 [18] put a 0.2% allowable value for total volatile and moisture for extra virgin and virgin olive oils. The samples of Çanakkale have values of total volatiles between 0.09 and 0.25%, mostly within the limits. The amount of water

Table 8 Comparison of the counties for the panel QDA descriptors by the Kruskal–Wallis test (mean ± SE_{mean})

Descriptor	Eceabat	Ayvacık	Bayramiç	Ezine	Gökçeada
Yellowness	5.96 ± 0.61 B	7.40 ± 0.30 A	6.71 ± 0.50 AB	7.34 ± 0.36 A	7.98 ± 0.60 A
(Median)	5.63	7.15	6.25	7.25	8.45
Greenness	6.96 ± 0.60 A	4.58 ± 0.26 B	4.30 ± 0.38 B	4.46 ± 0.32 B	4.24 ± 0.52 B
(Median)	7.38	4.63	4.00	4.50	4.80
Clarity	9.14 ± 0.47 A	9.20 ± 0.30 A	6.77 ± 0.53 B	8.74 ± 0.33 A	9.33 ± 0.42 A
(Median)	9.30	9.50	6.63	9.10	9.13
Olive	3.16 ± 0.51	3.68 ± 0.27	2.69 ± 0.64	3.80 ± 0.39	3.08 ± 0.70
(Median)	3.00	3.50	1.85	3.40	2.03
Grassy	1.46 ± 0.31	2.57 ± 0.23	1.40 ± 0.45	2.75 ± 0.37	2.20 ± 0.49
(Median)	1.38	2.00	0.45	1.20	1.30
Rancid	0.88 ± 0.22	0.65 ± 0.09	1.09 ± 0.31	0.74 ± 0.12	0.82 ± 0.26
(Median)	0.45	0.35	0.63	0.40	0.40
Musty	0.71 ± 0.18	0.41 ± 0.05	0.59 ± 0.16	0.48 ± 0.07	0.59 ± 0.17
(Median)	0.58	0.25	0.43	0.35	0.35
Acid	0.65 ± 0.17	0.73 ± 0.07	2.69 ± 0.13	0.58 ± 0.09	0.80 ± 0.20
(Median)	0.33	0.45	0.43	0.50	0.50
Astringent	0.73 ± 0.14	0.69 ± 0.07	0.51 ± 0.12	0.73 ± 0.11	0.88 ± 0.24
(Median)	0.60	0.45	0.38	0.35	0.20
Bitter	0.62 ± 0.13	0.76 ± 0.06	0.58 ± 0.13	0.92 ± 0.12	1.04 ± 0.18
(Median)	0.43	0.55	0.30	0.65	0.75
Soap	1.34 ± 0.46	1.38 ± 0.17	2.04 ± 0.64	1.43 ± 0.25	1.68 ± 0.53
(Median)	0.30	0.75	0.95	0.60	0.68
Metallic	0.31 ± 0.07	0.40 ± 0.04	0.52 ± 0.11	0.42 ± 0.07	0.46 ± 0.10
(Median)	0.25	0.30	0.40	0.30	0.38
Throat catching	2.53 ± 0.47	3.46 ± 0.24	3.18 ± 0.54	4.14 ± 0.37	4.86 ± 0.76
(Median)	2.63	3.00	3.33	4.25	6.13
Thickness	3.58 ± 0.45	3.52 ± 0.18	4.17 ± 0.52	4.03 ± 0.26	3.87 ± 0.48
(Median)	3.03	3.50	3.75	4.00	3.38

residue in olive oil causes rapid hydrolysis and oxidation of the oil resulting in increasing volatiles and lower sensory properties [21]. The Tukey's means separation test indicated that the physical data of olive oils from counties having more than one sample were not statistically different ($p > 0.5$).

The color values of the samples are shown in Table 5. The luminosity (L) of the samples ranged from 28.68 (sample 1) to 40.53 (sample 9). Similarly, a^* values ranged between −9.61 in sample 21 and −16.4 in sample 9, and the b^* values ranged between 9.97 in sample 21 and 23.06 in sample 9. The YI ranged from 56.22 in sample 21–81.26 in sample 9. Similarly, GI ranged from −42.92 in sample one to the highest of −33.82 in sample 22. Comparison of the five counties for the L, a^*, b^*, YI and GI are also shown in Table 5. As indicated with the p values, there is no significant difference among the producing counties for the instrumental color values of the virgin olive oil samples analyzed.

Sensorial Measurements

The results of the panel QDA evaluation of sensory appearance and aroma attributes of the samples are shown in Table 6. In general sensory "yellowness" of the samples ranged from 4.70 in sample 19 to 9.38 in sample 9. Similar values for "greenness" and "clarity" were between 2.57 (sample 13) and 8.60 (sample 19), and 2.93 (sample 13) and 11.13 (sample 24), respectively. Also, comparison of the five counties for the sensory appearance data by the Kruskal–Wallis test is shown in Table 8, and indicates some differences. For yellowness, the olive oil samples of Eceabat county were lower than those from Ezine and Gökçeada counties. Bayramiç was between them. In contrast, the greenness level was highest in Eceabat county. Bayramiç county had lower clarity values than the other counties. Olive oil color is not an appropriate indicator of quality by itself, but good quality oils had colors ranging from light yellow to weak green [11].

Table 9 The descriptors of the variables used in the canonical coefficients and loadings

Type	Variable	Mean	Standard deviation	Non-missing rows
Y1	Yellowness	7.186	1.265	25
Y2	Greenness	4.742	1.371	25
Y3	Clarity	8.744	1.950	25
Y4	Olive	3.512	0.857	25
Y5	Grassy	2.357	0.914	25
Y6	Rancid	0.745	0.269	25
Y7	Musty/Muddy	0.494	0.219	25
Y8	Acid	0.734	0.146	25
Y9	Astringent	0.698	0.153	25
Y10	Bitter	0.803	0.350	25
Y11	Soap	1.438	0.351	25
Y12	Metallic	0.402	0.141	25
Y13	Throat catching	3.721	1.379	25
Y14	Thickness	3.740	0.386	25
X1	FFA	2.032	2.303	25
X2	PV	15.635	7.254	25
X3	K232	2.638	0.230	25
X4	K270	0.202	5.956E-02	25
X5	TP	78.910	35.088	25
X6	AC	0.769	0.356	25
X7	Vis	62.876	1.337	25
X8	TV	0.184	3.330E-02	25
X9	L	35.402	4.128	25
X10	a*	13.808	1.697	25
X11	b*	36.516	6.743	25

FFA acid value, *PV* peroxide value, *TP* total phenolics, *AC* antioxidant capacity, *Vis* viscosity, *TV* total volatiles

There is a very diverse range of sensory terms used to characterize different olive oil samples [4, 5, 13, 14]. For example, the IOOC [13] suggested negative attributes "fusty, musty-humid, muddy sediment, winey-vinegary, metallic and rancid", and positive attributes "fruity, bitter and pungent". Other negative attributes were denoted as "heated or burnt, hay-wood, rough, greasy, vegetable water, brine, esparto, earthy, grubby and cucumber". The panel in this study did not develop attributes based on negative or positive categories; rather the sensory QDA terms were determined by the regular order of sensory perception of appearance, aroma, flavor and mouthfeel sensations. The mean values of the aroma descriptors of the samples are shown in Table 6. "Olive" was the aroma associated with fresh olive fruit and olive flower, and ranged between 1.89 and 4.91 among the 23 samples. Mostly accepted as a positive attribute, the olive values of the five counties were not significantly different (Table 8). In literature, a similar term, "fruity" was use to characterize olive attribute and was found to fall in the range of 2.6 and 3.9 [5]. "Grassy" is defined as the scent of cut fresh grass, and was measured between 0.91 in sample 18 and 4.68 in sample 21 (Table 6). Panels used to describe a similar perception as "cut grass, grassy, banana skin and green olive" terms was mostly a positive attribute [14]. The grassy values of the five counties were not statistically different as shown together with their median values in Table 8. Mostly as a negative attribute and indicator of oxidative deterioration, the panel evaluated the "rancid" aroma for the samples, ranging from the lowest of 0.43 (sample 10) to the highest of 1.51 (sample 18). The five counties were also not significantly different. "Musty/Muddy" was another aroma descriptor of the panel for the olive oil samples. The measured values were usually very low, ranging from 0.14 to 0.91 values. This aroma is mostly caused by ground harvested or fungus spoiled olives and suggested to be processed separately [21]. In Çanakkale, the ground harvested olives are separated from regular harvest olives throughout processing. The panel QDA descriptors of flavor and mouthfeel are shown in Table 7. Five flavor and two mouthfeel (aftertaste) descriptors were evaluated by the panel. As a taste descriptor, panel mean "acid" values of the samples were between 0.52 and 1.17 values. The "astringency" values of the virgin olive oils were from 0.42 in sample 18 to 1.00 in sample 27. Rial and Falque [5] measured astringency values between 1 and 2.7. Depending on the genotype and agricultural practices as well as processing and storage conditions, differences in sensory terms are possibly expected. Samples "bitterness" was measured between 0.49 and 2.19. Associated with caffeine, phenolics and other chemicals, some level of bitterness is usually a positive attribute [13]. Rial and Falque [5] reported bitterness values of 2.5–3.5. "Soap" flavor is a result of oxidation and very similar to rancid. Soap values of the samples were between 0.86 and 2.59. "Metallic" flavor is a reminiscent of metals, and found between 0.18 and 0.82 for the samples. As can be observed from Table 7, the highest acid and bitter values were in sample 21, also indicating a close association of the two sensory terms. Similarly, may it make a sense, sample 18 had highest soap and lowest astringent values. Comparison of the five counties for the five flavor terms are shown in Table 8, indicating no statistically significant difference by the Kruskal–Wallis test. Panel also evaluated the two mouthfell terms, "throatcatching" and "thickness" ranging between 1.96 and 6.15, and 3.19 and 4.44, respectively (Table 7). These two mouthfeel terms were also not significantly different among the Çanakkale counties ($p > 0.05$, Table 8).

Canonical Correlation Analysis

The canonical correlation analysis (CCA) describes the canonical correlation between the canonical variates formed from the 14 *Y*-variables and 11 *X*-variables described in Table 9. Five canonical correlations were found to be statistically significant by the Wilks' Lambda test (Table 10), and can be used to interpret the relationship between variables. The plots of the canonical correlation of the important canonical variates are shown in Fig. 2. These plots show the relationship or the canonical correlation between the sets of the *X* and *Y* coefficients used to form the canonical variates (*U*'s and *V*'s) to form the canonical variate equations shown in Table 11. The coefficients of *X*'s and *Y*'s yield a perfectly positive correlation ($r = 1$) for the first canonical variate, while for the fifth canonical variate, the correlation of coefficient (canonical correlation) was 0.89, indicated by the little dispersed view of the plot (Fig. 2). It should be kept in mind that all the canonical correlations are independent of each other. R^2 is squared canonical correlation and represents the amount of variance in one canonical variate accounted for by the other canonical variate. For each canonical variate, the cumulative percent explained variation say in *Y* or *X* variables by variation in *X* or *Y* variables are called the redundancy measurements (RM) and shown in Table 10 for the data. Large canonical correlation does not always mean that there is a powerful relationship between the two sets of the variables because canonical correlation maximizes the correlation between linear combinations of variables in two sets but does not maximize the amount of variances accounted for in one set of variables by the other set of variables.

Results of CCA showed that the physico-chemical measurements and QDA measurements of the virgin olive oil samples were expressed by the equations a to *j* when standardized coefficients were used (Table 11). The physico-chemical and QDA measurements were expressed by the equations 1–10 when canonical loadings were used (Table 11). The standardized canonical coefficients of the first canonical variate for the physico-chemical measurements and QDA measurements (*X* and *Y* variables) suggest that the variables *X*1–*X*11 and *Y*1–*Y*14 are influential in forming all canonical variates. The amount of variance accounted for in V_1 by U_1 (R^2) is 100%. For the second, third, fourth and fifth canonical variates, all *X* and *Y* variables were found to be influential, but for each set of canonical variate pairs, the amount of variance accounted for each *V*'s by *U*'s are different, as can be seen from Table 10.

Table 10 Canonical statistics and redundancy measurements

Canonical correlations section

Variate number	Canonical correlation	*R*-squared	*F*-value	Num DF	Den DF	Prob level	Wilks' Lambda
1	1.000000	1.000000	34.90	154	20	0.000000	0.000000
2	0.993461	0.986964	1.10	130	24	0.407047	0.000000
3	0.991103	0.982285	0.92	108	27	0.635891	0.000014
4	0.967914	0.936857	0.66	88	29	0.931046	0.000773
5	0.891831	0.795363	0.49	70	30	0.993147	0.012239

F-value tests whether this canonical correlation and those following are zero

Variation explained section

Canonical variate number	Variation in these variables	Explained by these variates	Individual explained (%)	Cumulative explained (%)
1	*Y*	*X*	13.4	13.4
2	*Y*	*X*	11.6	25.0
3	*Y*	*X*	12.0	37.0
4	*Y*	*X*	5.7	42.7
5	*Y*	*X*	5.7	48.5
1	*X*	*Y*	14.4	14.4
2	*X*	*Y*	5.3	19.7
3	*X*	*Y*	18.6	38.3
4	*X*	*Y*	7.6	45.8
5	*X*	*Y*	6.9	52.7

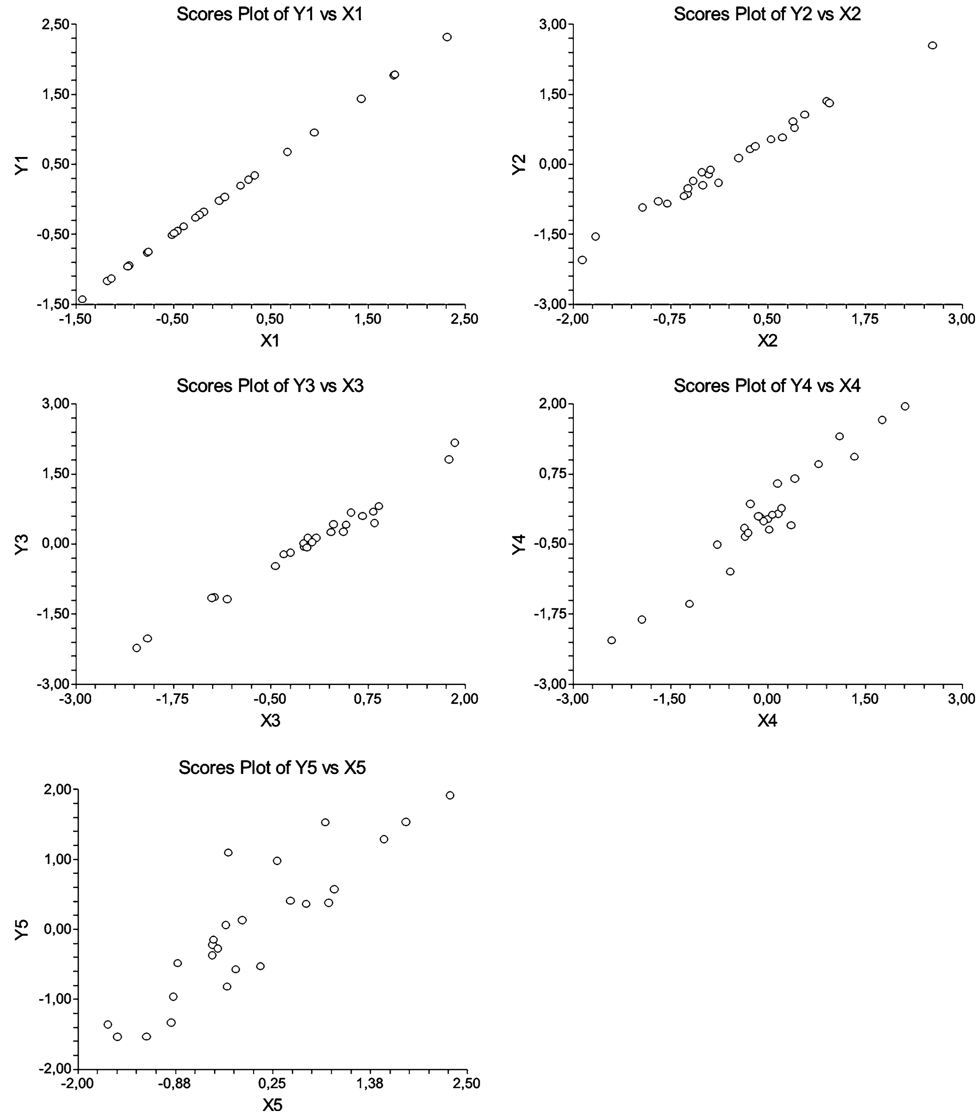

Fig. 2 Slopes of the five statistically significant canonical variates

The coefficients in the canonical equations cannot compare with each other directly, rather their percentage importance defining the canonical variates can be compared. The means and standard deviations of these coefficients are equal to zero and one, respectively. When the equations a and b are analyzed as the first canonical variate (Table 11), it can be seen that as peroxide value ($X2$), total phenolics ($X5$), viscosity ($X7$), total volatiles ($X8$) and b^* value ($X11$) increased. The yellowness ($Y1$), greenness ($Y2$), olive aroma ($Y4$), acid ($Y8$), metallic ($Y12$) and thickness ($Y14$) were also increased, while clarity ($Y3$), grassy ($Y5$), rancid ($Y6$), musty/muddy ($Y7$), astringent ($Y9$), bitter ($Y10$), soap ($Y11$), and throat catching ($Y13$) decreased. The loadings equations for the first canonical variate, Eqs. 1 and 2, on the other hand, present a different picture. When acid value ($X1$), peroxide value ($X2$), K_{232} ($X3$), K_{270} ($X4$), viscosity ($X7$) and total volatiles ($X8$) are increased, the greenness ($Y2$), clarity ($Y3$), olive aroma ($Y4$), rancid ($Y6$), musty/muddy ($Y7$) and soap ($Y11$) are also increased. Similar drawings can also be read for the other four canonical variates and loadings equations in Table 11. The difference between the canonical variate and loadings could happen as a result of small sample size or as a result of multicollinearity in the data [17]. Consequently, sometimes canonical loadings (simple correlations between variables and the canonical variates) are used to interpret the canonical variates. Finally, it must be kept in mind that while both the sign and value of the coefficients are important, the comparison of the coefficients can be done better as the percentage addition to the whole canonical variate.

This study has indicated that Çanakkale region virgin olive oils have chemical and physical quality indices within the legal and acceptable limits. Although especially,

Table 11 Canonical variates and canonical loadings by the canonical correlation analysis

Canonical variates

Standardized canonical coefficients of variates when Physico-chemical measurements (x's) were used to estimate Sensorial (y's) measurements

$U_1 = -\,0.22x_1 + 1.04x_2 - 0.17x_3 - 0.03x_4 + 0.44x_5 - 0.75x_6 + 0.28x_7 + 0.38x_8 - 0.95x_9 - 0.99x_{10} + 1.50x_{11}$ [a]

$V_1 = +\,0.64y_1 + 1.74y_2 - 0.87y_3 + 0.25y_4 - 0.29y_5 - 0.62y_6 - 0.10y_7 + 0.70y_8 - 0.67y_9 - 0.82y_{10} - 0.00y_{11} + 0.23y_{12} - 0.00y_{13} + 0.55y_{14}$ [b]

$U_2 = -0.33x_1 - 0.84x_2 + 0.17x_3 + 0.06x_4 - 0.56x_5 - 0.18x_6 + 0.58x_7 + 0.84x_8 - 0.15x_9 + 1.77x_{10} - 0.94x_{11}$ [c]

$V_2 = +\,1.30y_1 + 0.87y_2 - 0.35y_3 + 0.26y_4 - 0.48y_5 - 0.32y_6 + 0.16y_7 + 0.92y_8 - 0.66y_9 - 0.34y_{10} - 0.23y_{11} - 0.40y_{12} - 0.44y_{13} + 0.14y_{14}$ [d]

$U_3 = +\,0.07x_1 + 0.26x_2 - 0.33x_3 - 0.15x_4 + 0.58x_5 + 0.00x_6 + 0.14x_7 + 0.54x_8 - 1.74x_9 + 2.53x_{10} - 0.74x_{11}$ [e]

$V_3 = +\,0.47y_1 + 0.75y_2 - 0.94y_3 + 0.44y_4 - 0.80y_5 - 0.52y_6 - 0.08y_7 + 0.87y_8 - 0.58y_9 - 0.30y_{10} - 0.35y_{11} + 0.29y_{12} + 0.27y_{13} + 0.45y_{14}$ [f]

$U_4 = +\,0.97x_1 + 0.03x_2 + 0.14x_3 - 0.36x_4 - 0.51x_5 + 0.07x_6 - 0.08x_7 + 0.64x_8 - 5.87x_9 + 6.07x_{10} - 0.42x_{11}$ [g]

$V_4 = -1.36y_1 - 1.26y_2 + 0.61y_3 + 0.00y_4 + 0.27y_5 + 0.39y_6 + 0.14y_7 + 0.03y_8 - 0.22y_9 - 0.08y_{10} - 0.61y_{11} + 0.60y_{12} + 0.01y_{13} - 0.51y_{14}$ [h]

$U_5 = +\,0.16x_1 + 1.15x_2 - 0.19x_3 - 0.43x_4 - 1.16x_5 + 0.84x_6 - 0.15x_7 + 0.44x_8 - 7.49x_9 + 5.51x_{10} + 2.59x_{11}$ [ı]

$V_5 = -0.95y_1 - 1.13y_2 - 0.09y_3 - 1.03y_4 + 0.48y_5 - 0.88y_6 + 0.37y_7 + 0.25y_8 - 0.47y_9 - 0.83y_{10} - 0.41y_{11} + 0.22y_{12} - 0.23y_{13} + 0.66y_{14}$ [j]

Canonical loadings

Correlation between physico-chemical and sensorial variables and their canonical variables

$U_1 = +\,0.11x_1 + 0.71x_2 + 0.20x_3 + 0.26x_4 - 0.32x_5 - 0.34x_6 + 0.70x_7 + 0.09x_8 - 0.22x_9 - 0.27x_{10} - 0.34x_{11}$ [1]

$V_1 = -0.74y_1 + 0.79y_2 + 0.15y_3 + 0.05y_4 - 0.15y_5 + 0.26y_6 + 0.11y_7 - 0.33y_8 - 0.29y_9 - 0.37y_{10} + 0.06y_{11} - 0.18y_{12} - 0.43y_{13} - 0.51y_{14}$ [2]

$U_2 = -0.25x_1 - 0.16x_2 + 0.11x_3 + 0.01x_4 - 0.24x_5 - 0.26x_6 + 0.11x_7 + 0.40x_8 + 0.27x_9 + 0.26x_{10} + 0.24x_{11}$ [3]

$V_2 = +\,0.41y_1 - 0.20y_2 + 0.40y_3 + 0.04y_4 - 0.42y_5 - 0.30y_6 - 0.23y_7 - 0.18y_8 - 0.36y_9 - 0.41y_{10} - 0.23y_{11} - 0.29y_{12} - 0.47y_{13} - 0.51y_{14}$ [4]

$U_3 = -0.17x_1 - 0.12x_2 - 0.43x_3 - 0.35x_4 + 0.82x_5 + 0.76x_6 - 0.08x_7 + 0.68x_8 - 0.03x_9 - 0.03x_{10} - 0.05x_{11}$ [5]

$V_3 = +\,0.06y_1 - 0.33y_2 - 0.73y_3 + 0.00y_4 + 0.02y_5 - 0.07y_6 - 0.12y_7 + 0.53y_8 + 0.11y_9 + 0.59y_{10} - 0.22y_{11} + 0.11y_{12} + 0.58y_{13} + 0.02y_{14}$ [6]

$U_4 = +\,0.69x_1 - 0.15x_2 + 0.08x_3 + 0.16x_4 - 0.15x_5 - 0.22x_6 - 0.14x_7 + 0.28x_8 - 0.27x_9 - 0.26x_{10} - 0.23x_{11}$ [7]

$V_4 = -0.25y_1 + 0.13y_2 + 0.18y_3 + 0.06y_4 - 0.21y_5 + 0.23y_6 + 0.20y_7 - 0.09y_8 - 0.46y_9 - 0.13y_{10} - 0.20y_{11} + 0.31y_{12} - 0.19y_{13} - 0.44y_{14}$ [8]

$U_5 = -0.17x_1 + 0.20x_2 + 0.17x_3 + 0.02x_4 + 0.05x_5 + 0.03x_6 + 0.04x_7 - 0.31x_8 + 0.44x_9 + 0.52x_{10} + 0.55x_{11}$ [9]

$V_5 = +\,0.10y_1 - 0.32y_2 - 0.16y_3 - 0.51y_4 - 0.37y_5 - 0.02y_6 - 0.13y_7 - 0.34y_8 - 0.34y_9 - 0.34y_{10} + 0.20y_{11} + 0.09y_{12} - 0.21y_{13} + 0.10y_{14}$ [10]

improvements for storage conditions to enhance say K_{232} values can be suggested. The panel sensory QDA yields the sensorial definitions of the samples. The mostly grassy and olive aromatic, slightly bitter oils of Çanakkale are very low with regard to the musty/muddy, rancid, metallic and soap characteristics. The oils are defined as very yellow and clear with a small amount of greenness in appearance. When the geographically defined five producing counties are compared, almost all the physico-chemical and sensorial measurements were found to be not statistically different. This may suggest that the place of origin cannot be differentiated for this geographical region (Fig. 1). It is known that the majority of the olive trees (25.3%) belong to the domestic Ayvalık cultivar in the Turkey's Aegean and Mediterranean coastal bands [22]. This study has also proved that canonical correlation analysis is a good choice for making the determination of correlation with latent factors encountered, more feasible and easier.

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