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Comparison of Oils Originating from Olive Fruit by Different Production Systems

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Abstract In this study eight olive oil samples produced in different processing systems were analyzed and compared. It was shown that extended processing systems tend to result in lower quality oil. Slight differences were observed among the virgin classes of the samples. The antique process sample had higher phenolics content, bitterness, throat catching, and lower values of positive sensory terms. It was shown that the second decantation oil was lower in almost all quality criteria and truly is a lampante, non-food use sample. Quantitative descriptive analysis (QDA) of the samples has indicated that positively defined terms were higher in the virgin class of the samples than the refined class of the samples. But consumer hedonic measurements did not differentiate the samples. Buying intentions of the refined samples were as high as the values for the virgin samples. Models of consumer buying intentions included appearance and flavor as significant factors. Multidimensional scale analyses of data have shown that olive oils can be grouped successfully by common quality and sensory parameters.

Keywords Olive oil · Processing · Sensory · Consumer · Quality · Comparison

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Introduction

Olive oil has been produced for thousands of years in the Mediterranean area and is the only one that is consumed without refining as processed by physical operations. It has been valued for tradition, unique aroma and flavor, higher stability and virginity. Today, many nutritional and functional properties are universally recognized [1].

Beyond genetic, climatic and agricultural factors, the type of processing is a major controllable factor affecting olive oil quality. Regardless of the production system differences, if olives are harvested, transported and processed properly, the oil is usually of excellent quality. There are several different types of olive oil processing systems, from very old traditional processing factories to contemporary continuous systems. In the literature, many studies have characterized and compared very diverse types of olive oils. In processing systems, differences usually exist in the olive crushing techniques, malaxing operations and mostly in the phase separation techniques. Therefore, yield, cost, product quality, pomace quality, and production speed vary greatly [2–4]. The demand to enhance quality standards of olive oils is continually stimulating the development for new technologies.

The quality of olive oil is not the only criteria required by standards [5], but also the expectations of different consumer segments must be taken into account [6]. Therefore, sensorial and consumer tests of olive oil quality have been gaining importance in addition to the common chemical and instrumental analyses.

The aim of the present study was to compare different olive oil samples produced from the same olive type by different production systems and available in the regional markets, by the common physico-chemical quality criteria, sensory description analysis, and consumer tests. Data were

analyzed by statistical techniques to evaluate all measurements altogether.

Materials and Methods

Sampling of Olive Oils

The eight different olive oil samples with the definitions of their names and production systems are shown in Table 1. All samples were produced in the 2007–2008 season from the local variety, Ayvalık, in the region's factories. Sampling was accomplished by personally collecting samples from the donating factory. The refined olive oil and pomace oils were also produced from the region's resources (olive pomace) in different factories located in İzmir, Turkey, and sampled in the same manner. Duplicates of each oil sample were collected.

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 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, dodecanoic acid, geosmin and potassium persulfate were purchased from Sigma Chem. Co. (St. Louis, US). Other utensils for sensory analyses were purchased from local markets.

Physical Analysis

The K_{232} and K_{270} extinction coefficients were calculated from absorbance (UV/Vis Spectrophotometer, Shimadzu, Kyoto, Japan) readings at 232 and 270 nm [7]. The refractive indices of virgin olive oil samples were measured in daylight with a 2WAJ model Abbe refractometer and calibrated against pure water at 25 °C. Viscosity measurements of the olive oils were carried out by placing 7.5 ml of the sample in a special sample holder, and directly measuring the number of centipoises (cP) with a Brookfield viscometer (model DV II + Pro with Rheocalc software, Brookfield Eng. Lab., Inc., MA, US) equipped with a LV-SC4-18 spindle at 25 °C. The colors of the samples were measure instrumentally by a Minolta CR-400 Chroma Meter (Osaka, Japan) by immersing the probe of the instrument into the oil sample put in a Petri dish on a white tile. Readings of the L, a* and b* values were recorded.

Table 1 Definition of the samples used in this study

Oil sample	Production system	Definition of the system
(1) Continuous	Dual-phase centrifugation	Continuous system is composed of metallic mill crushing, malaxing 40 min at 35 °C, and horizontal and vertical centrifugation
(2) Second decantation	Dual-phase centrifugation with added hot water	The pomace produced in (1) is immediately mixed with water at 80 °C with a 1:1.5 ratio, malaxed for 1.5 h, and then centrifuged as above
(3) Organic grown	Dual-phase centrifugation	Olive trees and olive production were from certified 'organic production' and the olive oil produced in system (1)
(4) Antique process	Pressing and slow natural decantation	The whole system is made from stainless steel and composed of stone mill crushing, regular malaxing, super pressing and gravity decantation of the oil and vegetable water phases
(5) Stone press	Stone mill crush and pressing	The system is composed of old stone mill crushing, regular malaxing, hydraulic pressing and vertical centrifugation. There was no added water in this system
(6) Riviera	Mixing of virgin and refined olive oils	This sample has been prepared by mixing the full refined olive oil and virgin olive oil
(7) Refined pomace	Full classical refining of solvent-extracted olive pomace oil	After the season, the pomaces were collected in a factory and the remaining 6–8% oil was extracted with hexane and fully refined
(8) Mixed pomace	Adding a small amount of virgin olive oil into the refined pomace oil	This sample has prepared by mixing around 3–10% of virgin olive oil into the oil produced in (7)

Chemical Analysis

Free fatty acids and peroxide values were determined by Ca 5a-40 and Cd 8-53 of American Oil Chemists Society methods [8, 9]. Total phenolic compounds were determined by the method used previously in our laboratory [7]. Results were expressed as mg gallic acid/kg sample. The antioxidant capacity was measured by the ABTS test adopted from Rice-Evans et al. [10]. Total moisture content, including volatiles, was measured by an Ohaus MB45 IR light equipped drying scale with 2 g of samples at 105 °C. Sterol composition and total sterol analysis were completed by TSE EN ISO 12228 methods [11] on a Gas Chromatograph (Agilant 6890, Sam, US) equipped with capillary column (Supelco SPB-5, 30 m × 0.25 mm i.d. × 0.25 μm) and FID detector. The erythrodiol and uvaol were determined with sterol analysis.

Sensory Descriptive Analysis

Quantitative descriptive analyses (QDA) of the samples followed according to our previous technique [7, 12]. There were eight voluntary panelists (five females and three males, aged 21–25) trained for at least 20 h and experienced in olive oil panels. This panel developed 14 sensory terms to define the oil samples in this study. Under standard defined conditions, each time only four samples were given to each panelist and the whole test repeated.

Consumer Hedonic Test

A 9-point hedonic scale was used to assess the appearance, smell, flavor and buying intentions of 100 different consumers living in the neighborhood by previously used techniques without any given information about the origin and/or kind of the olive oil samples [13].

Statistics

There were three replicates of analyses for the physicochemical parameters, and two replicates of analyses for the sterol content and the QDA analysis. The statistical package programs of Minitab (ver 14.1) and SPSS (ver.10.1) were used for all analyses. Significant differences among the means of the eight olive oil samples for the physicochemical, sensory and consumer measurements were determined by the analysis of variance using the Kruskal–Wallis test at 95% of confidence. Stepwise regression analysis was used to model the buying intentions of the consumers. Multidimensional Scaling (MDS) analysis was used to compare the eight olive oils for the measured properties and by themselves [14, 15].

Results and Discussion

Physical Analyses

The results of common physical properties for the eight different olive oil samples are shown in Table 2. The UV spectrophotometric measurements are widely used in both olive oil authentication and quality assessment. Usually K_{232} is accepted as an indicator of fat autoxidation, and K_{270} is more useful as a measure of the presence of conjugated dienes and trienes, therefore the extent of the oxidation. Also, both have been used to determine any addition of refined oils into virgin samples. Addition of refined oils usually causes both values to increase [1]. The Codex Standard [5] defines a maximum 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} value, a max or equal measurements of 2.50 and 2.60 are defined for the extra virgin and virgin olive oils as well. As observed from the table, there is wide variation among the samples. Higher K_{232} values were observed in the refined group (Riviera, Refined and Mixed Pomace oils) of the samples, as expected. On the other hand, the very low K_{232} value for the second decantation oil is unexpected. The K_{270} value for the second decantation oil is above the limit value, indicating some oxidation problems. Similarly, the value of K_{270} for the antique process oil is higher than the virgin definition. This might be a result of the prolonged processing time. The antique process oil is, by definition, the sample that is not affected with current fast production systems. During phase separation in the antique process sample, which can take hours, some oxidation may inevitably taken place. The refractive index range at 20 °C for extra virgin, virgin and ordinary olive oils are between 1.4677 and 1.4700. Although there are some statistical differences among the samples, all lie within the defined range for olive oils. As a physical constant, refractive index remains within the defined limits, as long as there is no purity change in the sample. Viscosity is another physical characterization constant mostly depending on temperature and compositional differences of the vegetable oils. There were statistical differences among the samples, but the viscosity value for the second decantation oil was markedly higher than others. As indicated in Table 1, this sample was produced from first operation pomace immediately by hot water addition and separating in the same continuous processing line. Compounds causing the viscosity to increase seem to be extracted from the fresh pomace into the oil as well. Total moisture (%) including volatiles is also shown in Table 2. The Codex Standard puts a 0.2% permissible value for total moisture for extra virgin and virgin olive oils. None of the samples exceeded the limit, and refined samples included very low moisture levels,

Table 2 The measured physical and instrumental color quality indices of the oil samples produced from olive fruit (mean ± SD) and comparison of the different samples by Kruskal–Wallis test (mean ± SEM)

Oil sample	UV abs. (K_{232}) ($P < 0.0001$)	UV abs. (K_{270}) ($P < 0.0001$)	Refractive index (25 °C) ($P = 0.0486$)	Viscosity (cP, 25 °C) ($P < 0.0001$)	Total volatiles (%) ($P < 0.0001$)	L ($P < 0.0001$)	a* ($P < 0.0001$)	b* ($P < 0.0001$)
Continuous	1.60 ± 0 G*	0.116 ± 0 H	1.4635 B	67.45 ± 0.25 D	0.020 ± 0 D	53.84 ± 0.200 B	−2.29 ± 0.03 C	31.12 ± 0.315 A
Second decantation	1.79 ± 0 F	0.251 ± 0 E	1.4695 A, B	77.35 ± 0.15 A	0.105 ± 0.005 C	25.52 ± 0.005 E	2.86 ± 0.05 A	2.95 ± 0.005 F
Organic grown	2.56 ± 0 D	0.190 ± 0 F	1.4700 A	67.10 ± 0.10 D	0.110 ± 0 C	48.14 ± 0.040 D	−4.58 ± 0.11G	29.80 ± 0.275 B
Antique process	2.44 ± 0 E	0.261 ± 0.002 D	1.4695 A, B	68.50 ± 0 C	0.150 ± 0 B	53.05 ± 0.005 B	−1.85 ± 0.02 B	24.89 ± 0.030 D
Stone press	2.43 ± 0 E	0.150 ± 0 G	1.4699 A	66.70 ± 0 D	0.170 ± 0 A	53.45 ± 0.390 B	−3.96 ± 0.08 F	31.05 ± 0.380 A
Riviera	2.90 ± 0.001 C	0.898 ± 0.002 C	1.4695 A, B	69.60 ± 0.10 B	0.010 ± 0 E	55.34 ± 0.440 A	−3.89 ± 0.13 C	18.86 ± 0.435 E
Refined pomace	3.14 ± 0.05 A	1.319 ± 0 B	1.4699 A	69.35 ± 0.15 B	0.020 ± 0 D	53.74 ± 0.505 B	−3.02 ± 0.12 D	25.78 ± 0.05 C
Mixed pomace	2.99 ± 0.015 B	1.340 ± 0 A	1.4700 A	66.60 ± 0.60 D	0.020 ± 0 D	49.93 ± 0.065 C	−3.34 ± 0.02 E	24.79 ± 0.075 D

* Capital letters shown in each column compares the eight oil samples by the Kruskal–Wallis test at 95% confidence level

normally. The color values of the samples are shown in Table 2. The luminosity (L) of the samples ranged from 25.52 (second decantation) to 55.34 (Riviera). Similarly, a* values ranged between −4.58 in organically grown olives and 2.86 in second decantation sample, and the b* values ranged between 2.95 in second decantation oil and 31.12 in continuous sample. Similar values of the measurements for virgin olive oils have reported previously [7]. The CIE color values of the second decantation oil seem very different from all other samples, indicated by the dark, dun, green color. During the production of this oil, lots of color pigments including chlorophylls might have been extracted by the hot water addition.

Chemical Analyses

The measured chemical quality indices of the eight olive oil samples are shown in Table 3. The quantity of free fatty acids (FFA), measured as % oleic acid is a very important quality and classification index for the olive oils. There are significant differences among the samples. The Codex Standard [5] defines 0.8 g FFA/100 g, 2.0 g FFA/100 g and 3.3 g FFA/100 g for extra virgin, virgin and ordinary virgin olive oils, respectively. Hence, second decantation oil cannot be a virgin olive oil and it must be refined before use for edible purposes. Also, acidity in organically grown and mixed pomace samples was relatively higher than others. The Codex Standard put a maximum of 20 mequiv/kg oil limit for the peroxide value of extra virgin olive oils. The eight samples were under the limit of the standard, but the peroxide value of the second decantation oil was noticeably higher than others. Since this sample was produced by a prolonged, wet process, it might well be expected to cause the peroxide value to increase. The total phenolic contents of the samples were also significantly different. The highest value was measured in the antique process samples, and the lower values were in the pomace oils. It indicated that total phenolics content of olive oils produced by water addition is lower than dry processing [4]. There are no defined limits of the total phenolics in the standards, but these compounds have been linked to the antioxidant capacity and nutritional value of the samples [7, 16]. It has also been indicated that phenolic compounds in olive oils are important for both natural stability and flavor quality of the samples [1]. In the antique processing, separation of the phases was by gravity and slow. Hence, during this longer processing period, diffusion of the phenolics into the oily phase might have occurred. It has been indicated [16, 17] that antioxidant capacity present in virgin olive oils is mostly caused by the minor components such as polyphenols, tocopherols and some pigments. The antioxidant capacity as TEAC value (mmol TE/kg sample) measured for the samples ranged between 0.081 and 2.484

Table 3 The measured chemical quality indices of the oil samples produced from olive fruit (mean ± SD) and comparison of the different samples by Kruskal–Wallis test (mean ± SEM)

Oil sample	Free fatty acid (% oleic acid) ($P < 0.0001$)	Peroxide value (mequiv O_2/kg) ($P < 0.0001$)	Total phenolics (mg gallic acid/kg) ($P < 0.0001$)	Antioxidant capacity (TEAC) ($P < 0.0001$)
Continuous	0.905 ± 0.005 D*	8.60 ± 0.10 C	84.63 ± 5.285 B	1.456 ± 0.102 B
Second decantation	3.365 ± 0.005 A	18.0 ± 0 A	27.52 ± 2.40 C,D	0.456 ± 0.140 D
Organic grown	1.20 ± 0 B	7.00 ± 0 E	42.61 ± 5.77 C	2.484 ± 0.159 A
Antique process	0.95 ± 0 C	8.00 ± 0 D	168.29 ± 20.29 A	0.757 ± 0.083 C
Stone press	0.785 ± 0.005 E	12.00 ± 0 B	76.65 ± 8.845 B	0.942 ± 0.078 C
Riviera	0.50 ± 0 F	5.00 ± 0 F	18.19 ± 5.575 C,D	0.081 ± 0.036 E
Refined pomace	0.20 ± 0 G	5.00 ± 0 F	15.40 ± 0.095 C,D	0.222 ± 0.084 D,E
Mixed pomace	1.20 ± 0 B	7.50 ± 0 D, E	7.61 ± 1.345 D	0.130 ± 0.0501 E

* Capital letters shown in each column compare the eight oil samples by the Kruskal–Wallis test at the 95% confidence level

TEAC. Although the antique process sample had the highest phenolic content, the highest antioxidant capacity was measured in the organically grown sample. There must be other factors supporting higher antioxidant capacity in the organically grown sample.

The sterol composition (%), total sterol content (mg/kg), and % erythrodiol + uvaol content of the samples are shown in Table 4. The most significant portion of the unsaponifiable fraction of olive oils is made up of sterols. The amount and composition of the sterols are of extreme importance for olive oils for the determination of the level of purity and adulteration. In general, refined olive oils and pomace oils contain larger amounts of total sterols than their virgin counterparts [18]. Also, erythrodiol + uvaol content are used to determine pomace oil adulteration into virgin olive oil. Usually, β-sitosterols account for around 70–90% of total sterols in olive oil. Also, campesterol/stigmasterol ratio is used as an indicator of sample purity in some countries. A total sterol content of virgin olive oils usually ranges between 100 and 220 mg/100 g sample (1,000–2,200 ppm). Of course, differences among the varieties, geographic locations and production systems occur [1, 18]. The Codex Standard [5] has defined certain limit values for the sterols in olive oils. In general, none of the eight samples exceeded the Codex defined limit values for total sterols, nor did they reach the minimum value for the sum of β-sitosterols. Only the level of the delta-7-stigmastenol in the second decantation sample was higher than the limit. Interestingly, total sterols content of the second decantation oil is higher than other virgin oils and closer to the refined group. This result may also indicate that second decantation oil must be treated as crude or semi-crude olive pomace oil. The lowest value of total sterols was in the organically grown sample. On the other hand, % erythrodiol + uvaol of this sample was higher, reaching the values measured in the pomace samples. Another important finding is that, the amount of β-sitosterol is lower in continuous and organically grown samples, and higher in second decantation, stone press and antique process samples, as well as the refined group of the samples. This may indicate that any processing system which is slower than the normal continuous centrifugation systems may cause the β-sitosterol content in oil to increase. This result is especially important for the definition of the authenticity of virgin olive oil samples with named processing systems.

Sensory Analyses

The results of the panel QDA evaluation of the samples are shown in Table 5. All sensory attributes were measured on a scale ranging from the lowest of zero to the highest of 15 as anchored in the evaluation ballot. In the literature, there are some sensory studies with virgin olive oils [7, 12, 19, 20]. Also, the International Olive Oil Council [21] has suggested negative attributes like 'fusty, musty-humid, muddy sediment, winey-vinegary, metallic and rancid', and positive attributes like 'fruity, bitter and pungent' for the definition of olive oil sensory characteristics. Other negative attributes were given 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 mouth feel. In a study [20], evaluation of sensory color of olive oil samples was accomplished by the 'depth of color, brightness, amount of yellow, amount of green, amount of brown and clarity' terms, but the panel in this study was confident to describe olive oil appearance by the three terms, 'yellowness, greenness and clarity'. The second decantation oil sample was found to be much

Table 4 Sterol composition (%) of the oil samples from olive fruit (mean ± SEM)

	Continuous	Second decantation	Organic grown	Antique process	Stone press	Riviera	Refined pomace	Mixed pomace
Cholesterol ($P = 0.049$)	0.06 ± 0.02 C*	0.12 A, B, C	0.10 B, C	0.175 ± 0.015 A	0.10 B, C	0.11 A, B, C	0.15 ± 0.05 A, B	0.09 B, C
Brassicasterol ($P < 0.0001$)	0.025 ± 0.015 B	n.d.	0.01 B, C	0.005 ± 0.005 C	n.d.	0.01 B, C	0.19 A	n.d.
24-Methylene cholesterol ($P < 0.0002$)	0.065 ± 0.005 B, C	n.d.	0.07 B, C	0.12 ± 0.01 B	0.25 ± 0.05 A	n.d.	0.095 ± 0.005 B	0.02 C
Campesterol ($P < 0.0001$)	3.15 B	2.95 ± 0.05 D	2.86 ± 0.01 E	3.285 ± 0.005 A	3.15 B	2.82 ± 0.02 E	3.19 B	3.02 C
Campestanol ($P < 0.0001$)	0.105 ± 0.005 F	0.135 ± 0.025 E, F	0.12 ± 0.01 E, F	0.15 D.E	0.29 ± 0.01 B	0.20 C	0.18 ± 0.01 C, D	0.395 ± 0.015 A
Stigmasterol (P 0.0001)	1.325 ± 0.025 B, C	1.25 ± 0.15 C, D	1.88 ± 0.03 A	1.09 ± 0.01 D	1.07 ± 0.01 D	1.42 ± 0.02 B, C	1.51 ± 0.01 C	1.485 ± 0.015 B
Δ7-Campesterol ($P < 0.0001$)	0.03 ± 0.02 C	0.105 ± 0.005 A	0.05 B, C	0.07 ± 0.01 B	0.055 ± 0.005 B, C	0.105 ± 0.005 A	n.d.	0.12 A
Δ5-24-Stigmastadienol ($P = 0.0648$)	1.15 A	0.69 A	0.56 ± 0.035 A	0.47 A	0.4 A	0.735 ± 0.005 A	0.52 ± 0.375 A	0.78 A
Clerosterol ($P < 0.0001$)	0.71 G	0.71 G	0.93 D	1.22 A	1.02 C	0.75 ± 0.005 F	1.18 B	0.78 E
β-Sitosterol ($P < 0.0001$)	80.51 ± 0.03 H	85.35 ± 0.03 D	81.24 ± 0.005 G	87.73 ± 0.015 A	85.93 ± 0.015 B	84.26 ± 0.01 E	85.71 ± 0.01 C	84.07 ± 0.035 F
Sitostanol ($P < 0.0001$)	0.99 B	0.725 ± 0.025 C, D	0.85 C	0.435 ± 0.015 E	0.44 E	0.74 C, D	2.40 ± 0.01 A	0.685 ± 0.015 D
Δ-Avenasterol ($P < 0.0001$)	10.9 A	5.525 ± 0.005 C	10.85 A	4.55 ± 0.015 D	6.65 ± 0.015 B	6.45 ± 0.005 B	3.39 ± 0.25 E	6.52 ± 0.02 B
Δ5-23-Stigmastadienol ($P < 0.0001$)	0.015 ± 0.01 E	0.87 B	0.04 ± 0.005 D	n.d.	0.03 D.E	0.88 B	0.30 C	0.91 A
Δ7-Stigmastenol ($P < 0.0001$)	0.15 ± 0.03 F	0.53 A	0.435 ± 0.015 C	0.26 ± 0.02 E	0.37 ± 0.005 D	0.49 A,B	0.495 ± 0.005 A, B	0.445 ± 0.015 B, C
Δ7-Avenasterol ($P < 0.0001$)	0.79 A, B	0.66 C	0.82 A	0.415 ± 0.015 E	0.41 ± 0.01 E	0.65 C	0.525 ± 0.075 D	0.715 ± 0.015 B, C
Erythrodiol + uvaol ($P < 0.0001$)	3.09 ± 0.05 B	1.55 ± 0.05 E	4.40 ± 0.10 A	1.87 ± 0.015 C, D	2.04 ± 0.03 C	1.70 ± 0.20 D, E	4.47 ± 0.001 A	4.30 A
Total sterol (mg/kg) ($P < 0.0001$)	1233 F	1545 ± 5 D	1135 H	1204 G	1333 E	1593 C	1861 A	1813 B

n.d. not detected

* Capital letters shown in each row compares the eight oil samples by the Kruskal–Wallis test at 95% confidence level

Table 5 Measured panel sensorial quantitative descriptive analysis (QDA) values of the oil samples produced from olive fruit (mean ± SEM)

Oil sample	Color descriptors			Aroma descriptors			
	Yellow ($P = 0.0004$)	Green ($P < 0.0001$)	Clarity ($P < 0.0001$)	Olive ($P = 0.0389$)	Grassy ($P < 0.0001$)	Rancid ($P = 0.0208$)	Muddy/Musty ($P < 0.0001$)
Continuous	7.812 ± 0.658 A*	5.225 ± 0.593 B	6.743 ± 0.642 C	2.668 ± 0.682 A, B	3.318 ± 0.690 A	0.331 ± 0.133 B	0.106 ± 0.040 B
Second decantation	3.693 ± 0.468 B	9.993 ± 1.108 A	3.787 ± 0.683 D	2.312 ± 0.866 A, B, C	0.575 ± 0.159 D	1.287 ± 0.436 A	1.843 ± 0.391 A
Organic grown	7.287 ± 0.696 A	5.181 ± 0.631 B	10.468 ± 0.580 A, B	3.031 ± 0.539 A	2.068 ± 0.481 A, B, C	0.750 ± 0.226 A, B	0.256 ± 0.555 B
Antique process	7.387 ± 0.498 A	5.118 ± 0.587 B	10.118 ± 0.584 A, B	1.387 ± 0.385 A, B, C	1.281 ± 0.351 D,C	0.637 ± 0.153 B	0.618 ± 0.181 B
Stone press	7.981 ± 0.678 A	5.850 ± 0.695 B	8.937 ± 0.723 B	2.650 ± 0.729 A, B	2.787 ± 0.673 A, B	0.231 ± 0.074 B	0.093 ± 0.063 B
Riviera	6.631 ± 0.744 A	5.581 ± 0.824 B	6.556 ± 0.656 C	1.943 ± 0.513 A, B, C	1.693 ± 0.376 B, C, D	0.493 ± 0.140 B	0.275 ± 0.095 B
Refined pomace	6.918 ± 0.678 A	5.425 ± 0.635 B	11.0 ± 0.575 A	1.087 ± 0.300 B, C	0.600 ± 0.224 D	0.606 ± 0.121 B	0.656 ± 0.253 B
Mixed pomace	6.262 ± 0.815 A	3.600 ± 0.584 B	10.562 ± 0.667 A, B	0.700 ± 0.123 C	0.350 ± 0.081 D	0.468 ± 0.123 B	0.481 ± 0.197 B

	Flavor descriptors					Mouthfeel/aftertaste descriptors	
	Acid ($P = 0.0452$)	Astringent ($P = 0.4236$)	Bitter ($P < 0.0001$)	Soap ($P = 0.1955$)	Metallic ($P = 0.002$)	Throat catching ($P = 0.0005$)	Thickness ($P = 0.048$)
Continuous	0.812 ± 0.181 A,B	0.656 ± 0.179 A	0.743 ± 0.128 B,C,D	0.587 ± 0.166 A	0.350 ± 0.128 B	3.643 ± 0.523 B	4.925 ± 0.566 A,B
Second decantation	0.737 ± 0.176 A,B	0.725 ± 0.170 A	1.081 ± 0.157 B	1.200 ± 0.352 A	1.131 ± 0.306 A	3.656 ± 0.878 B	5.750 ± 0.746 A
Organic grown	0.662 ± 0.135 A,B	0.506 ± 0.129 A	0.525 ± 0.117 C,D	0.768 ± 0.256 A	0.425 ± 0.125 B	2.543 ± 0.568 B	4.700 ± 0.664 A,B
Antique process	1.093 ± 0.224 A	0.668 ± 0.162 A	1.793 ± 0.349 A	1.181 ± 0.288 A	1.275 ± 0.297 B	5.537 ± 0.917 A	4.580 ± 0.623 A,B
Stone press	0.775 ± 0.135 A,B	0.500 ± 0.145 A	0.850 ± 0.150 C,B	0.787 ± 0.237 A	0.525 ± 0.142 B	2.893 ± 0.621 B	4.850 ± 0.494 A,B
Riviera	0.475 ± 0.139 B	0.400 ± 0.135 A	0.418 ± 0.094 C,D	0.500 ± 0.155 A	0.431 ± 0.197 B	1.868 ± 0.446 B	4.468 ± 0.529 A,B
Refined pomace	0.500 ± 0.145 B	0.406 ± 0.116 A	0.318 ± 0.080 D	0.650 ± 0.217 A	0.418 ± 0.146 B	1.962 ± 0.402 B	4.253 ± 0.565 A,B
Mixed pomace	0.368 ± 0.088 B	0.325 ± 0.096 A	0.231 ± 0.037 D	0.493 ± 0.095 A	0.412 ± 0.103 B	1.862 ± 0.407 B	3.406 ± 0.536 B

* Capital letters shown in each column compares the eight oil samples for each sensory descriptor by the Kruskal–Wallis test at 95% confidence level

greener and less yellow than others. Also, clarity of that sample was the lowest (Table 5). These results agree with the instrumental measures of the color (Table 2) of the samples. It was indicated [1, 22] that the color of virgin olive oils is not a quality defining factor and preferences of consumers range greatly with regard to olive oil color. The aroma descriptor 'olive' is related to fresh olive fruit and olive flower, and usually perceived as a very positive property. While organically grown sample had the highest value, the lowest measured was the mixed pomace sample. It indicated that refining of olive oil causes most of the volatile compounds to be lost [18]. In the literature, a similar term, 'fruity' was evaluated between 2.6 and 3.9 [19]. 'Grassy' is defined as the scent of cut fresh grass, and measured between 0.350 (Mixed Pomace) and 3.318 (Continuous) values. Different panels [20] described grassy perception as 'cut grass, grassy, banana skin and green olive'. The 'green' term in one study [19] was valued around 2.3–2.9. This property has usually been defined as a positive sensory character [19, 21]. It is quite interesting that the second decantation oil has a very green color but a very low grassy score. It is most probable that the known C6 green aroma compounds (hexanal, *cis*-3-hexenal, *cis*-3-hexenol, etc.) had been volatilized during the processing [1, 18]. 'Rancid' is usually defined as a negative attribute [21] and valued below one for all samples, except the second decantation oil. It is well known that rancidity in edible oils is produced by extended oxidation reactions. This finding agrees with the UV absorbance (Table 2) and peroxide values (Table 3) measurements. Similarly, measured values of 'Muddy/Musty' were not different among the samples except the second decantation oil. This aroma is mostly caused by ground harvested or fungus spoiled olives [1]. It is very clear that neither analytical indices nor sensory values are within the accepted limits for the second decantation sample to be used as an edible oil.

Five sensory flavor and two mouthfeel (aftertaste) descriptors of the samples are shown in Table 5. As a taste descriptor, the panel's mean 'acid' values had small differences. The antique sample's acid value was highest most possibly due to the prolonged period of phase separation during the processing. The 'astringency' values of the samples were statistically not different. Rial and Falque [19] reported astringency values between 1.0 and 2.7 in their samples. Depending on the genotype and agricultural practices as well as processing and storage conditions, differences in sensory terms are quite expected. The samples' 'bitterness' was measured between 0.231 and 1.793. Associated with phenolics and other chemicals, some level of bitterness is usually a positive attribute [21], and in one study [19] bitterness values of 2.5–3.5 were reported. The antique process sample had a higher bitterness and higher total phenolics (Table 3). 'Soap' flavor is a result of oxidation and very similar to rancid. Soap values of the samples were not significantly different from each other. The 'metallic' flavor was higher in the second decantation sample and the same in the others. The results of these negatively classified attributes were also as expected in that the prolonged processes yielded lower quality samples. One of the two mouthfeel (aftertaste) descriptors, 'throat catching' was significantly higher in the antique process sample (Table 5). This sample also had the higher total phenolics (Table 3) content. There might be an association between the two parameters. Similarly, 'thickness' of the second decantation sample was highest among all the oils, and most possibly caused by higher molecular weight compounds extracted into the oil during the prolonged process and the addition of hot water during the malaxing operation. This sample also had the highest viscosity (Table 2) value, which correlates highly to sensory thickness, as observed.

Consumer Test

The hedonic values of appearance, smell, flavor and buying intention of the samples are shown in Table 6. Although there are some small differences among the samples, the most significantly different measurement was with the second decantation oil sample. It was interesting that hedonic values of the refined samples

Table 6 Hedonic values of the oil samples produced from olive fruit by the regular consumers (mean ± SEM)

Oil Sample	Appearance ($P < 0.0001$)	Smell ($P < 0.0001$)	Flavor ($P < 0.0001$)	Buying Intention ($P < 0.0001$)
Continuous	6.51 ± 0.159 A	6.30 ± 0.180 A, B	5.71 ± 0.202 B, C	6.08 ± 0.206 A
Second decantation	3.78 ± 0.235 B	4.40 ± 0.242 D	3.81 ± 0.270 E	3.57 ± 0.240 C
Organic grown	6.76 ± 0.191 A	5.60 ± 0.213 C	6.08 ± 0.200 A, B	6.05 ± 0.211 A
Antique process	6.33 ± 0.225 A	5.42 ± 0.229 C	5.20 ± 0.241 C, D	5.23 ± 0.251 B
Stone press	6.71 ± 0.155 A	5.85 ± 0.223 B, C	5.98 ± 0.203 A, B	6.14 ± 0.192 A
Riviera	6.40 ± 0.162 A	6.54 ± 0.173 A	6.49 ± 0.176 A	6.31 ± 0.187 A
Refined pomace	6.77 ± 0.187 A	5.98 ± 0.185 A, B, C	5.90 ± 0.202 A, B	5.67 ± 0.225 A, B
Mixed pomace	6.17 ± 0.195 A	5.54 ± 0.188 C	4.87 ± 0.230 D	5.29 ± 0.237 B

Table 7 Regression models of the consumer buying intentions based on the hedonic data

Oil Sample	Regression Models of Buying Intention (BI)	R^2	P
Continuous	BI = −0.04154 + 0.675 Flavor + 0.278 Appearance	59.16	<0.001
Second decantation	BI = 1.394 + 0.586 Flavor + 0.195 Smell	44.28	<0.05
Organic grown	BI = 0.3821 + 0.205 Flavor + 0.586 Appearance	40.02	<0.05
Antique process	BI = 0.1716 + 0.689 Flavor + 0.212 Appearance	49.99	<0.05
Stone press	BI = 0.8815 + 0.358 Flavor + 0.30 Smell	42.87	<0.01
Riviera	BI = 1.895 + 0.273 Flavor + 0.42 Smell	29.31	<0.01
Refined pomace	BI = 4.282 + 0.321 Smell	13.72	<0.001
Mixed pomace	BI = 2.405 + 0.597 Smell	30.47	<0.001

were close to the values of the virgin samples. The hedonic data of the consumers were used to model the consumer buying intentions with the stepwise regression analysis. The results are shown in Table 7. The R^2 values of the models of the continuous and antique process samples barely exceeded 50%. Hence, these two models are statistically meaningful. Both models include 'flavor' and 'appearance' with positive coefficients for the buying intentions of the consumers. Of course, the higher the numbers of consumers in these types of models, the higher the level of fit of the models created. In this study consumers were not provided with the knowledge about the type of the samples, but only told that all samples were from olive fruit. The most popular samples for buyers were riviera, stone press, continuous and organically grown samples. These results indicate that if the consumers were not pre-informed about the olive oil type and/or processing system (i.e. cold-pressed, antique processed, organically grown, riviera), their judgments for liking and buying is influenced only through sensory perceptions. Interestingly enough is that riviera and refined samples can be preferred as much as the virgin samples. The second decantation oil sample had the lowest buying intention value, which is in agreement with the previous lower sensory descriptive values and of analytical measurements. Hence, it may be readily said that olive oil consumers can successfully differentiate samples, and choose those having better sensory qualities. In our previous study, a significant causal relation between the L value and consumer preference of virgin olive oils, and a significant combined effect of appearance and flavor on buying intentions were determined [13]. In another study, it was shown that information of olive oil origin did not affect consumer liking or typical expectations, but did affect the expectations for specific sensory properties [6].

Multidimensional Scaling (Mds) Analysis of the Data

Visual representation of similarities and distances among the eight olive oil samples in terms of the measured physico-chemical properties is shown in Fig. 1. According to the map, the olive oil samples can be separated into three distinct groups. The first group includes continuous, organically grown, antique process and stone press samples. In fact, these are the regular virgin olive oil samples.

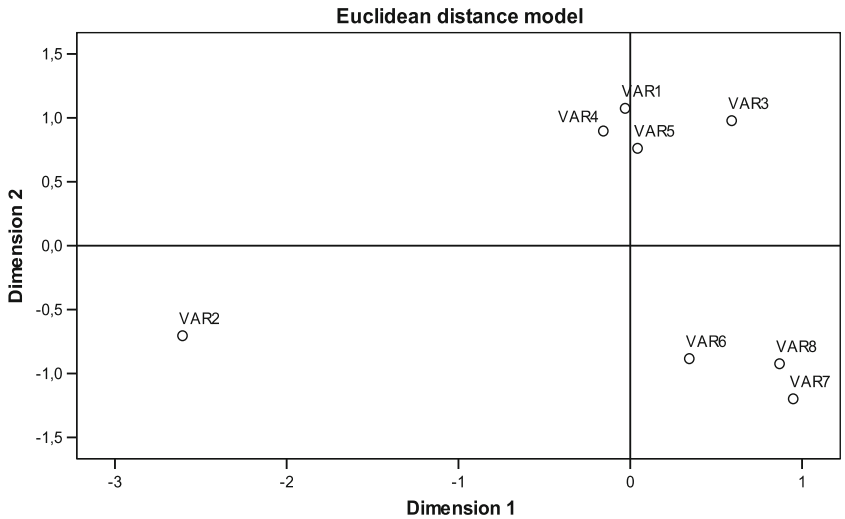

Fig. 1 Geometrical representation of the eight olive oil samples in terms of the measured physico-chemical properties by multidimensional scaling (*var1* continuous, *var2* second decantation, *var3* organically grown, *var4* antique process, *var5* stone press, *var6* riviera, *var7* refined pomace, *var8* mixed pomace) (Stress = 0.04279; *RSQ* 0.9929)

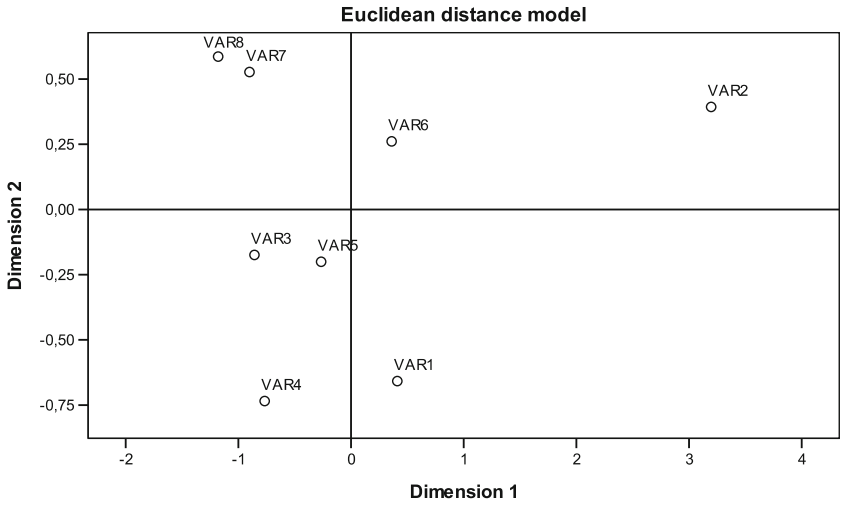

Fig. 2 Geometrical representation of the eight olive oil samples in terms of the measured sensory QDA properties by multidimensional scaling (*var1* continuous, *var2* second decantation, *var3* organically grown, *var4* antique process, *var5* stone press, *var6* riviera, *var7* refined pomace, *var8* mixed pomace) (Stress = 0.03883; *RSQ* 0.99544)

The second group includes riviera, refined and mixed pomace oil samples. These are a distinctly refined group of the samples. The third group includes a very different sample, second decantation oil, which mostly located on the negative dimensions. This result also supports the previous findings that this oil cannot be marketed as ordinary olive oil, and it must be treated as a non-food sample. Adulterating this lampante sample into virgin olive oils is both a legally and technically incorrect practice and must be prevented. On the other hand, finding new uses for the second decantation oil is a challenging research area. If only the sensory QDA values are considered, the geometrical representations of the eight samples can be seen in Fig. 2. Here, it is more difficult to differentiate individual groups; rather, the distantly separated second decantation sample can be easily observed. These MDS maps indicate that olive oils can be grouped very successfully according to the common measurements of quality criteria. These results agree with our previous findings [12].

Conclusions

This study has compared four virgin classes (continuous, organically grown, antique process, and stone press), three refined classes (riviera, refined and mixed pomace) and one unclassified (second decantation) type olive oil samples for common quality criteria, sensory description and consumer behavior. The second decantation sample which is sometimes produced as a fast and easy way of pomace processing, was found totally outside the limits of the virgin olive oil standards. Research is needed for new uses of this oil sample. As one of the main finding from this study, it is found that if the olive processing system is slower than the regular continuous system, the resulting oil is usually lower in quality, contrary to common expectations. The antique process sample was found to have higher bitterness, rancidity, throat catching and total phenolic content. In general, organically grown and stone press samples were not very different from the continuous sample. There were expected differences between the virgin and refined group of samples, especially in the sterol composition. The positively defined ‘olive’ and ‘grassy’ sensory descriptors were usually lower in the refined group than the virgin group of the samples. Unexpectedly, the antique process sample did not have higher values for the positive sensory descriptors. The MDS representations of the samples were clearly shown by the presence of distinct groups, confirming once again the property based classification of olive oil samples. Consumer buying intentions pointed out that the refined groups of the samples are liked just as much as the virgin group of the samples. Hence, if the olive oil samples were presented to the consumers without any label claims, consumer’s choices may be different. In addition, it might be suggested that the market price differences based on the label claims (i.e. antique, stone-press, cold-press) of olive oils must instead consider total quality of the produce to prevent improper marketing strategies.

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