Chemical Composition of Commercial Cornicabra Virgin Olive Oil from 1995/96 and 1996/97 Crops

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ABSTRACT: The chemical composition of commercial Cornicabra virgin olive oils (n = 65) was studied, as was its relationship with oil quality and the influence of the extraction method and production year. The main characteristics of these olive oils were: oxidative stability 53 ± 24 h, mean polyphenol content 162 ± 57 mg/kg (as gallic acid), oleic acid 80.8 ± 0.9%, linoleic acid 4.6 ± 0.6%, and campesterol 4.3 ± 0.1%, which is peculiar to this variety. No clear differences in composition were observed with respect to the different extraction systems (dual-phase/triple-phase decanters and pressure), although oils produced by the dual-phase decanter showed higher oxidative stability and polyphenol content. There were significant differences in major fatty acids and sterols according to the production year.
JAOCS 75, 1305–1311 (1998).

KEY WORDS: Chemical composition, Cornicabra variety, virgin olive oil.

The olive is the most extensive arboreous crop in Spain. It occupies about 2,087,000 ha, of which 1,970,000 ha is for oil production. Olives are grown in 10 autonomous regions, the first of which is Andalucía with 63% of the total area under olive, followed by Castilla-La Mancha (14%), Extremadura (12%), and Cataluña (6%). The Cornicabra variety, the most common in Castilla-La Mancha, covers an area of 300,000 ha largely located in the provinces of Ciudad Real (43%) and Toledo (40%). The fruit is medium to large with a characteristically elongated and asymmetric shape. The fat yield is 22–24% of fresh weight, and the oil is valued for its high stability and good sensory characteristics (balanced aroma, dense sensation, sour and pungent), which makes it suitable for combining with other varieties (1-3). Despite the large amount of Cornicabra olive oil produced, there are no reliable data on its chemical composition and properties in the scientific literature.

This research project examines the chemical composition of commercial Cornicabra virgin olive oils and analyzes its relationship with the quality and some physicochemical properties of the oil. It also examines the influence, if any, of the extraction method and the production year on oil quality parameters.

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Olive oil in Spain is extracted by pressure or centrifugation systems, which vary not only in the physical forces employed to separate the oil phase but also in the amount of water used. A pressure system does not require addition of water to the olive paste. However, when the olives are difficult to process and the oily phase is not easily separated from other phases, or when ripe olives are processed, it is necessary to add water to the oily must in the separation stage before it enters a vertical centrifuge. The pressure system currently has fallen into disuse in Castilla-La Mancha, and centrifugation is the most common procedure since large amounts of olives have to be processed in a short time. There are two centrifugation systems, dual-phase and triple-phase decanters. In the triple-phase decanter a significant amount of water is added and oil, residual water, and solid waste are produced separately. In the dual-phase centrifugation system, no water is added, so that the system yields only oil and a plastic paste containing vegetable solids. The dual-phase decanter was introduced in Spain five years ago, and is now widely used because it greatly reduces liquid waste, thus helping considerably to cut down environmental pollution.

One of the primary causes of loss of olive oil quality is oxidation (4). Because of their role in oil stability, there is a special interest in the concentration of antioxidant compounds like polyphenols in virgin olive oil (5–9). A relationship between polyphenol content and oxidation stability has been reported for virgin olive oil (10,11). Addition of warm water to dilute olive paste before it goes into the centrifugal decanter inevitably lowers the level of natural antioxidants in the resulting oil. In fact, the phenols present in olive paste are soluble in both water and oil phases depending on their partition coefficients and the extraction temperature; addition of water to the paste alters the partition equilibrium and reduces the concentration of water-soluble phenols in the oil. The tocopherols in virgin olive oil are important for their nutritional qualities and for their antioxidant properties, in that they protect the fat components from autoxidation (12). The most effective is α-tocopherol, followed by β and δ. Their antioxidant properties in foods have been known for many years (13), but little is yet known about their contribution to the stability of olive oil. Chlorophyll and carotenoid compounds also play an important role in the oxidative stability of processed foodstuffs because they are antioxidant in the dark and pro-oxidant in the light (14).

To study and characterize the chemical composition of virgin oil obtained from the Spanish Cornicabra olive variety, four series of analytical determinations were chosen: quality indexes as defined by EEC Regulations [free fatty acid content, peroxide value, and spectrophotometric characteristics in the ultraviolet (UV) region]; parameters of interest involved in oxidation processes and therefore related to oil stability (oxidative stability, total phenols, tocopherols and chlorophyll and carotenoids pigments); and fatty acid and sterol composition.

MATERIALS AND METHODS

Oil samples. Virgin olive oil samples ($n = 65$) of Cornicabra variety were collected from industrial oil mills located in the oil-producing areas of Toledo and Ciudad Real (Castilla-La Mancha) during the crop seasons 1995/96 and 1996/97.

Ripeness index at the time of harvesting ranged from 4 (olives with purple/black skin and completely green flesh) to 5 (black skin and violet halfway through flesh), according to the maturation scale proposed by the International Olive Oil Council (15).

Fifty-six oils were extracted using dual-phase ($n = 30$) and triple-phase ($n = 26$) decanter centrifugation, while nine were processed by the older pressure technique. The olive paste was generally obtained using metal hammer crushers with a sieve size of 5–7 mm. Mixing was carried out in continuous horizontal mixers at a temperature of 25–35ºC for about 60 min. Sometimes 1.0–1.5% of micromized mineral talc was added to the olive paste during mixing in order to break up the oil/water emulsion. Horizontal decanters with a capacity of 3000–3500 kg/h turning at a speed of about 3500 rpm were used for oils extracted with centrifugation systems. In triple-phase decanters about 1000–1400 L/h of warm water (30ºC) was added. In the case of press-extraction, the press operated at a pressure of 300–400 kg/cm^2 for 1.0–1.5 h with rams of 70–100 cm diameter.

Samples were filtered through anhydrous Na_2SO_4 and stored at 4ºC in darkness using amber glass bottles without head space until analysis.

Analytical methods. Determination of the free fatty acid content, peroxide value, UV absorption characteristics, and fatty acid and sterol composition was carried out following the analytical methods described in Regulations EEC/2568/91 and EEC/1429/92 of the Commission of the European Union (16).

The free fatty acid content, given as percentage of oleic acid, was determined by titration of a solution of oil dissolved in ethanol/ether (1:1) with ethanol potash.

Peroxide value, expressed in milliequivalents of active oxygen per kilogram of oil (meq/kg), was determined as follows: a mixture of oil and chloroform–acetic acid was left to react with a solution of potassium iodide in darkness; the free iodine was then titrated with a sodium thiosulphate solution.

K_{232} and K_{270} extinction coefficients were calculated from absorption at 232 and 270 nm, respectively, with a UV spectrophotometer (Hewlett-Packard, HP 8452A; Madrid, Spain), using a 1% solution of oil in cyclohexane and a path length of 1 cm.

The Rancimat method was used to evaluate oxidative stability, because it is fast and reliable (17). Stability was expressed as the oxidation induction time (h) measured with the Rancimat 679 apparatus (Metrohm Co., Basel, Switzerland) using an oil sample of 3.5 g warmed to 98ºC, and an air flow of 10 L/h. The time taken to reach a fixed level of conductivity was measured.

Phenol compounds were isolated by triple extraction of a solution of oil in hexane with a water/methanol mixture (60:40). The Folin-Ciocalteau reagent (Merck, Darmstadt, Germany) was added to a suitable aliquot of the combined extracts and the absorption of the solution at 725 nm was measured. Values are given as mg of gallic acid per kilogram of oil (18,19).

Tocopherols were evaluated following the AOCS Method Ce 8-89 (1989) (20). A solution of oil in hexane was analyzed by high-performance liquid chromatography (Waters 2690; Barcelona, Spain) on a silica gel column Lichrosorb Si-60 (particle size 5 μm, 250 mm × 4.6 mm i.d.; Sugerlabor, Madrid, Spain) eluting with hexane/2-propanol (98.5:1.5) at a flow rate of 1 mL/min. A fluorescence detector (Waters 470) was used with excitation and emission wavelengths set at 290 and 330 nm.

Chlorophyll and carotenoid compounds (mg/kg) were determined at 670 and 472 nm in cyclohexane using the specific extinction values, by the method of Minguez-Mosquera (21).

For determination of fatty acid composition, the methyl esters were prepared by vigorous shaking of a solution of oil in hexane (0.2 g in 3 mL) with 0.4 mL of 2 N methanol potash, and analyzed by gas chromatography on a fused silica column (50 m length × 0.25 mm i.d.) coated with SGL-1000 phase (0.25 μm thickness; Sugerlabor) using an HP 5890 chromatographer (Hewlett-Packard). Working conditions were as follows: carrier gas, helium; flow through the column, 1 mL/min; injector and detector temperature, 250ºC; oven temperature, 210ºC; injection volume 1 μL [Regulation EEC 2568/91, corresponding to AOCS Method Ch 2-91 (93)].

Sterols (%) were determined by gas chromatography using a capillary column (25 m length × 0.25 mm i.d.) coated with SGL-5 (0.25 μm thickness; Sugerlabor) using an HP 5890 (Hewlett-Packard). Conditions: carrier gas, helium; flow through the column, 1.2 mL/min; injector temperature, 280ºC; detector temperature, 290ºC; oven temperature, 260ºC; injection volume 1 μL [Regulation EEC 2568/91, corresponding to AOCS Method Ch 6-91 (93)].

Statistical analysis. Statistical analysis was performed using NCSS 6.0 statistical software (22). Differences were considered statistically significant where probability was greater than 95% ($P < 0.05$).

RESULTS AND DISCUSSION

Quality and genuineness criteria for various olive oil types are described in detail in the EEC Regulations (EEC/2568/91 and a later modification EEC/656/95) (15). Results for these olive oil quality indexes (with the exception of sensory analy-

TABLE 1
Quality Indexes of Cornicabra Virgin Olive Oil from 1995/96 and 1996/97 Crop Seasons (*n* = 65 samples)

Quality indexes	Mean ± SD	Minimum and maximum	Percentiles		
			25	50	75
Free fatty acid content (%)	0.08 ± 0.4	0.2–1.8	0.4	0.8	1.0
Peroxide value (meq/kg)	9 ± 4	4–20	7	8	12
K_{232}	1.73 ± 0.24	1.33–2.77	1.56	1.70	1.88
K_{270}	0.15 ± 0.03	0.09–0.24	0.12	0.15	0.17
Oxidative stability (h)	52.7 ± 24.5	8.8–143.4	34.9	49.9	66.4
Polyphenols (mg/kg)	162 ± 57	50–402	124	162	198
α-Tocopherol (mg/kg)	157 ± 37	55–234	137	168	180
Chlorophylls (mg/kg)	9 ± 4	2–23	6	8	10
Carotenoids (mg/kg)	6 ± 2	2–11	5	6	7

sis) are reported in Table 1. This table shows the mean value and the range (minimum and maximum), and also the 25th, median, and 75th percentiles, to give a better description of the distribution of the values observed for each determination.

For the majority of the samples analyzed, the values of the analytical parameters fell within the ranges established for the highest quality category "extra virgin olive oil." Twenty-five percent of the oils analyzed exceeded the 1.0% free fatty acid content that classifies these products as "virgin olive oil." With respect to the other quality criteria, only a couple of samples exceeded the established limits for K_{232} and K_{270} values—one sample in each case.

Results of other analytical determinations: oxidative stability, total polyphenols (expressed as gallic acid), α-tocopherol, and pigments (chlorophyll and carotenoids) are also shown in Table 1.

An interesting and commercially relevant aspect of Cornicabra olive oil is its high oxidative stability. This property is almost certainly related to the concentration of some chemical compounds in the oil, especially antioxidants, and is affected by the extraction conditions used (particularly water addition and temperature) and the storage conditions. In fact, the temperature during extraction can produce oxidation and consequent loss of these compounds. In the case of phenol compounds, because they are moderately water-soluble the amount of water added during processing can affect the amount remaining in the extracted oil.

Oxidative stability of the oils analyzed ranged from a minimum of only 9 h to a maximum of 143 h, with an average of 53 h. A quarter of the samples exhibited stability in excess of 66 h (percentile 75), while in another 25% stability was less than 35 h (percentile 25). According to these results and published data on other Spanish varieties (23), Cornicabra and Picual are the two Spanish olive varieties whose oils are most stable to oxidation. A properly prepared Cornicabra olive oil extracted by centrifugation using good quality olives can easily attain stability upward of 100 h, as observed in the oils prepared at the pilot plant of this University (data not shown).

Virgin olive oil contains phenolic substances which affect its stability and flavor. The concentration of total phenols usually ranges from 50 to 400 ppm, but oils can be found with concentrations of up to 600 ppm, expressed as caffeic acid (9,23). The mean content of total polyphenol compounds in the samples analyzed was 162 mg/kg (as gallic acid), although a wide range of concentrations was observed, from 50 to 402. Twenty percent of the oils contained more than 200 ppm of phenols, and 10% contained less than 100 ppm. As was found with respect to oxidative stability, the polyphenol content of the Cornicabra variety is among the highest of all Spanish olive varieties (1).

Tocopherols are essential for protection of polyunsaturated fatty acids (PUFA) in plants against oxidative deterioration (13). The tocopherol content is highly variety-dependent, with concentrations ranging from 5 to 300 ppm. Usual values reported for good quality oils vary between 100 and 300 ppm (8,24). The α-tocopherol content in the Cornicabra variety oils studied ranged from 55 to 234 ppm, with a mean value of 157 mg/kg; only 5% of the oils analyzed contained less than 100 ppm. Cornicabra olive oil apparently has a slightly lower tocopherol content than other Spanish varieties (1).

The composition and the total natural pigment content of oils are important quality parameters because they correlate with color, which is a basic attribute for evaluating olive oil quality. Pigments are also involved in autoxidation and photooxidation mechanisms (25). Chlorophyll and carotenoids in Cornicabra oils ranged from 2 to 23 ppm and from 2 to 11 ppm, respectively, as expected for virgin olive oils from Spanish varieties (26).

Fatty acid composition of the commercial oils studied is shown in Table 2. The variability of fatty acid composition of the oil samples covered the normal range expected for olive

TABLE 2
Fatty Acid Composition (%) of Cornicabra Virgin Olive Oil from 1995/96 and 1996/67 Crops (*n* = 65 samples)

Fatty acid	Mean ± SD	Minimum and maximum
$C_{16:0}$	8.64 ± 0.51	6.99–10.01
$C_{16:1}$	0.71 ± 0.08	0.49–0.87
$C_{17:0}$	0.06 ± 0.01	0.05–0.07
$C_{17:1}$	0.09 ± 0.01	0.08–0.11
$C_{18:0}$	3.46 ± 0.25	2.86–4.14
$C_{18:1}$	80.84 ± 0.97	78.12–82.46
$C_{18:2}$	4.66 ± 0.62	3.84–6.62
$C_{18:3}$	0.57 ± 0.05	0.48–0.69
$C_{20:0}$	0.49 ± 0.04	0.28–0.57
$C_{20:1}$	0.34 ± 0.02	0.30–0.37
$C_{22:0}$	0.13 ± 0.01	0.12–0.15

TABLE 3
Sterol Composition (%) of Cornicabra Virgin Olive Oil from 1995/96 and 1996/67 Crops (*n* = 65 samples)

Sterol	Mean ± SD	Minimum and maximum
Cholesterol	0.22 ± 0.09	0.07–0.60
Brassicasterol	0.00	0.00–0.00
24-Metilencholesterol	0.07 ± 0.03	0.00–0.16
Campesterol	4.26 ± 0.14	3.83–4.49
Campestanol	0.16 ± 0.07	0.00–0.32
Stigmasterol	0.65 ± 0.19	0.38–1.21
Δ7-Campesterol	0.07 ± 0.03	0.00–0.15
Δ5,23-Stigmastadienol	0.13 ± 0.05	0.05–0.33
Clerosterol	0.89 ± 0.07	0.78–1.00
β-Sitosterol	84.35 ± 1.49	81.18–86.95
Sitostanol	0.03 ± 0.02	0.00–0.06
Δ5-Avenasterol	7.87 ± 1.44	5.21–10.97
Δ5,24-Stigmastadienol	0.77 ± 0.12	0.47–1.09
Δ7-Stigmastenol	0.26 ± 0.21	0.09–1.30
Δ7-Avenasterol	0.28 ± 0.06	0.18–0.44
Apparent β-sitosterol (%)	94.04 ± 0.30	92.71–94.50
Total sterols (mg/kg)	1553 ± 128	1338–2055

oil. Cornicabra oil has a high percentage of oleic acid (80.8 ± 1.0%) and a low percentage of linoleic acid (4.6 ± 0.6%). Cornicabra and Picual are the Spanish varieties with the lowest linoleic acid levels (23). Primary known factors affecting fatty acid composition are latitude, climate, variety, and stage of maturity of the olives when collected.

Sterols are also important constituents of olive oils because they are related to the quality of the oil and are widely used to check genuineness. Sterol composition of the oils is reported in Table 3. All the Cornicabra olive oil samples analyzed showed high campesterol content (4.3 ± 0.1%), which exceeded the threshold established by EEC regulations (4%). Campesterol content was below this threshold in less than 5% of the oils studied, so that is clearly a peculiarity of this olive oil variety. Another unusual feature of the Cornicabra and Hojiblanca varieties is high Δ5-avenasterol content, with a mean value of 7.9 ± 1.4% (27). In the literature this compound has been associated with antioxidant activity (28). As shown in Table 3, all of the olive oil samples contained more than 1000 mg/kg of total sterols, the minimum value established by EEC regulations for the category "extra virgin olive oil," with a mean value of 1553 mg/kg. In the case of apparent β-sitosterol, only one sample contained less than the threshold value of 93%.

Influence of crop season and extraction system. Tables 4, 5, and 6 show the mean values of analytical determinations of Cornicabra virgin olive oil, classified by crop season and extraction system.

With respect to year of production, regardless of the extraction system employed, only minor differences, some of them statistically significant ($P < 0.05$), were observed in the mean values of the quality indexes of the oils (Table 4). The free fatty acid content and K_{270} were higher for the 95/96 season than for 96/97. This was probably due to the smaller than usual 95/96 crop, the consequence of several years of drought followed by heavy rainfall shortly before harvesting (125 L/m^2 in December 1995). Another consequence of low production was that many oil-mills were processing only intermittently, so that fruits became musty and yielded poorer-quality oils. On the other hand, all mean contents of major fatty acids and sterols differed significantly from one season to the other. Oleic acid oil content was slightly greater in 96/97 than the previous year, whereas the reverse was true of the rest of the fatty acids (Table 5). Total sterols and Δ5-avenasterol were higher in 95/96 than 96/97 while β-sitosterol and campesterol were lower (Table 6).

Analysis of extraction system-dependent differences in the mean values of analytical determinations irrespective of the crop year revealed differences in only a few parameters (Tables 4–6). For example, polyphenols and α-tocopherol were greater in centrifuge-extracted oil than in pressure-ex-

TABLE 4
Chemical Composition of Cornicabra Virgin Olive Oils from 1995/96 and 1996/67 Crop Seasons Obtained by Different Extraction Systems

Analytical determination	Extraction system[a]	Crop season 1995/96	1996/97	Total
Free fatty acid content (%)	P	0.83 a[b]	0.88 a	0.86 e
	C3	0.93 a	0.67 a	0.79 e
	C2	0.89 a	0.62 a	0.75 e
	Average	0.90 y	0.68 z	
Peroxide value (meq O_2/kg)	P	13.6 a	9.1 b	11.1 e
	C3	8.9 b	9.4 b	9.2 e
	C2	8.0 b	9.3 b	8.7 e
	Average	9.1 y	9.3 y	
K_{232}	P	1.82 a	1.52 a	1.65 e
	C3	1.85 a	1.71 a	1.77 e
	C2	1.71 a	1.74 a	1.72 e
	Average	1.78 y	1.69 y	
K_{270}	P	0.17 a	0.12 b	0.14 e
	C3	0.17 a	0.14 a	0.15 e
	C2	0.16 a	0.14 a	0.15 e
	Average	0.17 y	0.13 z	
Stability (h)	P	25.5 a	63.0 b	46.3 e
	C3	56.8 b	43.3 a,b	49.5 e
	C2	57.4 b	57.5 b	57.5 e
	Average	53.0 y	52.5 y	
Polyphenols (mg/kg)	P	93 a	132 a,b	115 e
	C3	181 b	147 a,b	168 f
	C2	191 b	162 a,b	171 f
	Average	174 y	151 y	
α-Tocopherol (mg/kg)	P	109 a	155 b	134 e
	C3	170 b	142 a,b	155 e,f
	C2	174 b	157 b	165 f
	Average	164 y	150 y	
Chlorophylls (mg/kg)	P	12.2 a	10.7 a	11.4 e
	C3	7.5 a	8.1 a	7.8 f
	C2	8.7 a	9.1 a	8.9 e,f
	Average	8.7 y	8.9 y	
Carotenoids (mg/kg)	P	6.6 a	6.9 a	6.8 e
	C3	5.6 a	5.8 a	5.7 e
	C2	5.8 a	6.3 a	6.0 e
	Average	5.8 y	6.2 y	

[a]P, pressure; C2, dual-phase; and C3 triple-phase decanter centrifugation systems.
[b]Values with the same letter are not significantly different ($P < 0.05$), with respect to extraction system (e, f, g), crop season (y, z), or both (a, b, c).

TABLE 5
Fatty Acid Composition (%) of Cornicabra Virgin Olive Oils from 1995/96 and 1996/97 Crops Obtained by Different Extraction Systems

Fatty acid	Extraction system[a]	Composition (%) 1995/96	1996/97	Total	Fatty acid	Extraction system	Composition (%) 1995/96	1996/97	Total
	P	8.82 a[b]	8.47 a	8.62 e		P	4.60 a	4.44 a	4.51 e
$C_{16:0}$	C3	8.72 a	8.46 a	8.60 e	$C_{18:2}$	C3	4.90 a	4.62 a	4.75 e
	C2	8.81 a	8.58 a	8.70 e		C2	4.86 a	4.41 a	4.64 a
	Average	8.78 y	8.52 z			Average	4.84 y	4.50 z	
	P	0.71 a	0.67 a	0.69 e		P	0.55 a,c	0.54 c	0.55 e
$C_{16:1}$	C3	0.69 a	0.71 a	0.70 e	$C_{18:3}$	C3	0.59 a,b	0.53 c	0.56 e,f
	C2	0.74 a	0.71 a	0.72 e		C2	0.71 b	0.56 a,c	0.59 f
	Average	0.71 y	0.71 y			Average	0.60 y	0.55 z	
	P	0.05 a	0.06 a	0.05 e		P	0.05 a	0.49 a	0.49 e
$C_{17:0}$	C3	0.06 a	0.06 a	0.06 e	$C_{20:0}$	C3	0.49 a	0.48 a	0.49 e
	C2	0.05 a	0.06 a	0.06 e		C2	0.05 a	0.48 a	0.49 e
	Average	0.05 y	0.06 z			Average	0.05 y	0.48 y	
	P	0.09 a	0.10 a	0.09 e		P	0.33 a	0.33 a	0.33 e
$C_{17:1}$	C3	0.09 a	0.10 a	0.09 e	$C_{20:1}$	C3	0.33 a	0.34 a	0.34 e
	C2	0.09 a	0.09 a	0.09 e		C2	0.34 a	0.34 a	0.34 e
	Average	0.09 y	0.10 z			Average	0.34 y	0.34 y	
	P	3.56 a	3.37 a	3.45 e		P	0.14 a	0.13 a,b	0.14 e
$C_{18:0}$	C3	3.65 a	3.45 a	3.54 e	$C_{22:0}$	C3	0.14 a,b	0.13 b	0.13 e
	C2	3.47 a	3.30 a	3.39 e		C2	0.13 a,b	0.13 b	0.13 e
	Average	3.55 y	3.37 z			Average	0.14 y	0.13 z	
	P	80.64 a	81.41 a	81.07 e					
$C_{18:1}$	C3	80.33 a	81.09 a	80.74 e					
	C2	80.37 a	81.33 a	80.85 e					
	Average	80.40 y	81.24 z						

[a]P, pressure; C2, dual-phase; and C3 triple-phase decanter centrifugation systems.
[b]Values with the same letter are not significantly different ($P < 0.05$), with respect to extraction system (e, f, g), crop season (y, z), or both (a, b, c).

TABLE 6
Sterol Composition (%) of Cornicabra Virgin Olive Oils from 1995/96 and 1996/97 Crops Obtained by Different Extraction Systems

Sterol	Extraction system[a]	Composition (%) 1995/96	1996/97	Total	Sterol	Extraction system	Composition (%) 1995/96	1996/97	Total
	P	0.33 a[b]	0.26 a	0.30 e		P	83.60 a	84.68 a,b	84.14 e
Cholesterol	C3	0.18 b	0.19 b	0.19 f	β-Sitosterol	C3	83.24 a	84.36 a,b	83.65 e
	C2	0.17 b	0.23 a,b	0.20 f		C2	83.58 a	85.78 b	84.78 e
	Average	0.21 y	0.23 y			Average	83.47 y	85.28 z	
	P	4.21 a	4.29 a	4.25 e		P	8.25 a,b,c	7.46 a,b,c	7.85 e
Campesterol	C3	4.31 a	4.29 a	4.30 e	Δ5-	C3	8.94 b	7.90 c	8.56 e
	C2	4.15 a	4.32 e	4.24 e	Avenasterol	C2	8.74 b	6.51 c	7.52 e
	Average	4.21 y	4.30 z			Average	8.71 y	6.98 z	
	P	0.11 a	0.12 a	0.11 e		P	0.81 a	0.76 a,b	0.78 e
Stigmasterol	C3	0.68 a	0.54 a	0.62 e	Δ5,24-	C3	0.82 a	0.74 a	0.79 e
	C2	0.70 a	0.62 a	0.65 e	Stigmastadienol	C2	0.82 a	0.70 a	0.75 e
	Average	0.68 y	0.61 z			Average	0.82 y	0.72 z	
	P	0.09 a	0.10 a	0.09 e		P	0.52 a	0.24 a	0.38 e
Δ5,23-	C3	0.13 a	0.16 a	0.14 e	Δ7-	C3	0.26 a,b	0.20 a,b	0.24 e
Stigmastadienol	C2	0.12 a	0.14 a	0.13 e	Stigmastenol	C2	0.26 b	0.20 a,b	0.23 e
	Average	0.12 y	0.14 z			Average	0.31 y	0.21 y	
	P	0.91 a	0.91 a	0.91 e		P	0.31 a	0.26 a	0.29 e
Clerosterol	C3	0.89 a	0.95 a	0.91 e	Δ7-	C3	0.31 a	0.29 a	0.31 e
	C2	0.86 a	0.91 a	0.89 e	Avenasterol	C2	0.32 a	0.24 a	0.27 e
	Average	0.89 y	0.92 y			Average	0.32 y	0.25 z	
	P	93.69 a	93.95 a	93.82 e		P	1575 a	1417 a	1496 e
Apparent	C3	94.04 a	94.15 a	94.07 e	Total sterols	C3	1614 b	1486 b	1568 e
β-sitosterol (%)	C2	94.14 a	94.05 a	94.09 e	(mg/kg)	C2	1640 b	1505 b	1567 e
	Average	94.02 y	94.05 y			Average	1619 y	1484 z	

[a]P, pressure; C2, dual-phase; and C3 triple-phase decanter centrifugation systems.
[b]Values with the same letter are not significantly different ($P < 0.05$), with respect to extraction system (e, f, g), crop season (y, z), or both (a, b, c).

tracted oil, while chlorophylls appeared to be higher in pressure-extracted oil.

With respect to choice of extraction system and crop season, results show that peroxide value, stability, polyphenols and α-tocopherol in oil extracted by centrifugation were significantly lower than in pressure-extracted oil in the 1995/96 crop. However, this pattern was not observed in the following year (96/97). In fact, contradictory results have been reported in some studies with respect to differences in olive oil composition due to the extraction systems employed. Some authors have reported that oil extraction systems affected the phenol constituents of olive oil (29), whereas others have concluded that there were no such differences between olive oils obtained by pressure and centrifugation systems (30). There was also a small decrease in the mean concentration of total polyphenols in the oils extracted using the triple-phase as compared to the dual-phase decanter, so that the latter was slightly more stable. This effect was observed for both seasons and has been reported by other authors (23,31,32). The decrease of phenol compounds can be explained by their water solubility; higher water/paste ratios are used in triple-phase centrifugation, and therefore larger amounts of phenols are eliminated with water wastes.

ACKNOWLEDGMENTS

The authors wish to express their sincere gratitude to the Spanish Comision Interministerial de Ciencia y Tecnología (CICYT) for supporting this research project ALI95-0197-CO2-02. Thanks are due to José Alba, Francis Gutierrez, and Arturo Cert (Instituto de la Grasa, Sevilla) for useful suggestions.

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[Received March 2, 1998; accepted July 3, 1998]