Analytical Characteristics of Virgin Olive Oil from Young Trees (Arbequina cultivar) Growing Under Linear Irrigation Strategies

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ABSTRACT: The effect of a linear (vs. effective crop coefficient, K_c), irrigation strategy applied to young olive trees (Arbequina cv.) on the qualitative and quantitative parameters of virgin olive oil quality was studied. Although linear irrigation strategy did not affect the quality indexes used to classify olive oil by commercial grades, it did influence other important parameters such as total phenol content, bitter index, oxidative stability, and the sensorial appraisal. All of these of olive oil qualities were negatively associated with the amount of applied irrigation water. Pigment content of oils determined by carotenoid and chlorophylls also was negatively associated with the amount of water supplied. No consistent relation was found for α-tocopherol and fatty acid content of olive oil in relation to these treatments.

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Olive trees occupy 8 million ha worldwide with 96% of the trees in the Mediterranean area. The average world production in 1998 and 1999 was about 2.3 million tons. Spain contributed 28–32% of the total olive oil during this period. More than 117,000 ha are grown in Catalonia, representing 5.5% of the Spanish olive crop of which 3,619 are under irrigation (1).

Olive oil consumption increases at a lower rate than its production causing the accumulation of stocks that lead to lower prices and profit. So, this resource must be managed more efficiently to sustain this crop.

A possible way to ease this situation could be the implementation of irrigation in new and existing plantings. However, as water supplies become scarce and cost of water increases, irrigation scheduling methodologies need to be more precise. An approach for saving irrigation water would be the use of regulated deficit irrigation based on the concept of reducing water application during stages of crop development when yield and fruit quality have low sensitivity to water stress. Previous work by our research group (2,3; Tovar, M.J., M.P. Romero, S. Alegre, J. Grirona, and M.J. Motilva, unpublished data) focused on the effect of this irrigation strategy on the qualitative and quantitative parameters of Arbequina oil production. Trials also have been carried out on different olive cultivars to contribute to the knowledge of water requirements by investigating the effect of different irrigation levels on oil quality and production (4–8).

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Another approach would be the determination of the minimum water volume required to optimize crop yield and crop production. Unfortunately, little is known about optimizing water scheduling in young olive trees and its effect on their quantitative (crop yield and oil production) and qualitative response. The interest in young olive trees is due to the fast growth of areas devoted to olive growing in different countries such as Argentina, Australia, and China.

A recent study by Girona *et al*. (9) determined the water production function for the olive cultivar Arbequina, the most important cultivar grown in Catalonia. Irrigation treatments were defined based on different crop coefficients and were applied to determine irrigation water requirements. The study showed that vegetative growth of the tree, fruit yield, and oil yield were positively related to the crop coefficient.

Because quality is an important determinant of olive oil consumption, the objective of this paper was to investigate the effect of linear irrigation on oil quality and composition of young Arbequina olive trees. Quality indexes as defined by EEC Regulations (10) included measurement of total phenols, tocopherols, and oxidative stability. Parameters related to the oil visual perception (chlorophylls, carotenoids, and chromatic ordinates), fatty acid composition, bitter index, and sensory evaluation also were determined.

EXPERIMENTAL PROCEDURES

Plant material. The trial was carried out during 1998 and 1999 in a 5-yr-old olive orchard (*Olea europea* L. cv. Arbequina) planted in a predominantly clay loam soil located in the region of El Segrià (Catalonia, Spain). Trees were spaced 6 × 4 m (417 trees ha^{-1}). Annual rainfall was 316 and 427 mm for 1998 and 1999, respectively, with almost no rain during the summer period.

The experimental irrigation implementation was based on a linear irrigation design where the total applied irrigation water linearly changed with the effective crop coefficient (K_c) used when the water budget method proposed by FAO (11) was applied to determine the crop water requirements (ET_c) using the reference crop evapotranspiration (ET_o) from an agronomic weather station and the effective crop coefficient (K_c):

$$ET_c = ET_o \times K_c \qquad [1]$$

The water budget method calculates the irrigation requirements by subtracting the effective precipitation (P_{ef}) from the ET_c.

Because K_c for the olive tree is almost constant throughout the year, this experimental design allows one to determine the relationship between the applied K_c and vegetative growth, olive and oil production, and oil quality.

Seven irrigation treatments were applied (T1 to T7) from the third week of April to November in 1998 and from the beginning of April to November in 1999, with estimated crop coefficients (K_c) of 0.25, 0.38, 0.50, 0.57, 0.64, 0.71, and 0.85, respectively. Irrigation was not applied in the remaining months because the water balance ($ET_c - P_{ef}$) was negative.

For each treatment ET_c was calculated from modified Penman-determined reference crop water use (ET_o) with data from a weather station close to the experimental field (12). Because olive trees were young, tree size was smaller than fully developed olive trees and a coefficient (K_r) to adjust this situation was applied (13). K_r was used in the ET_c determination as follows:

$$ET_c = ET_o \times K_c \times K_r \qquad [2]$$

As tree growth was modified by the irrigation treatment, K_r was not the same for different treatments and different years. In 1998 $K_r = 0.30$ was imposed to T1 on T4 irrigation treatments and $K_r = 0.40$ on T5 to T7 treatments. In 1999, the K_r imposed on T1 to T3 irrigation treatments was 0.35 and 0.40 to T4 to T7 treatments.

The experimental plot consisted of four blocks and seven irrigation levels. Each experimental unit consisted of seven trees, where only the five central trees were sampled.

Olive trees were daily irrigated with four 8 L h^{-1} drippers placed around the tree. A water meter was installed at the beginning of each line to verify the amount of water applied to each treatment (9). The water applied, expressed as mm/yr, for each irrigation treatment T1–T7 was 44–46, 80–84, 110–117, 125–146, 138–171, 178–219, and 207–259, respectively.

At harvest in November, representative samples from each tree in the experimental design (7 treatments × 4 blocks) were extracted and subjected to physical and chemical analyses.

Oil extraction. An Abencor analyzer (MC2 Ingenierias y Sistemas, Sevilla, Spain) was used to process the olives in a pilot extraction plant. This method determined the industrial yield of the olive, reproducing at laboratory scale the industrial process for milling, beating, centrifuging, and decanting. The unit consisted of three essential elements: the mill, the thermobeater, and the pulp centrifuge. The oil was separated by decanting, transferred into dark glass bottles and stored in the dark at 4°C.

Olive oil analyses. Determination of the free fatty acid content, peroxide value, and ultraviolet absorption characteristics at 270 nm was carried out following the analytical methods described in the Regulation EEC/2568/91 of the European Union Commission (10). Results were expressed as percentage of oleic acid, milliequivalents of active oxygen per kilogram of oil (meq O_2/kg), and absorbance at 270 nm, respectively.

Phenolic compounds were isolated using the modified method described by Vázquez-Roncero *et al.* (14) with triple extraction of an oil-in-hexane solution with a 60% vol/vol water/methanol mixture. The concentration of total polyphenols was estimated with Folin-Ciocalteau reagent at 725 nm. Results were expressed as mg of caffeic acid per kg of oil.

Bitter index (K_{225}) was evaluated by the extraction of bitter components from 1.00 ± 0.01 g oil dissolved in 4 mL hexane, and chromatography on a C18 column (Waters Sep-Pack Cartridges) previously activated with methanol (6 mL) and washed with hexane (6 mL). After elution of 10 mL hexane to eliminate fat, the retained compounds were eluted with 25 mL (1:1) methanol/water. The absorbance of the extract was measured at 225 nm against 1:1 methanol/water (vol/vol) in a 1-cm cuvette (15).

Stability was determined from the oxidation induction time (hours) measured with a Rancimat 679 apparatus (Metrohm Co., Basel, Switzerland) using an oil sample of 2.5 g warmed to 120°C, and 20 L h^{-1} air flow. The time taken to reach a fixed level of conductivity was measured (16,17).

α-Tocopherol concentration was evaluated by high-performance liquid chromatography through direct injection of an oil-in-hexane solution. Detection and quantification were carried out in a Waters 600 apparatus with a photodiode array detector (Waters 996) at 295 nm. The 25 cm × 4 mm i.d. column used was filled with Supelcosil LC-NH2, 5 µm (Supelco, Inc., Bellefonte, PA), and the flow rate was 1 mL/min. The injection volume was 20 µL. The mobile phase consisted of 7:3 hexane/ethyl acetate (vol/vol), and the total running time was 12 min under isocratic conditions with an external standard method. Linearity of the response was verified in comparison to six standard solutions of α-tocopherol of known concentration. Results were expressed as mg α-tocopherol per kg of oil.

Chlorophyll and carotenoid content were evaluated at 670 and 470 nm, respectively, from the absorption spectrum of each oil sample (7.5 g) dissolved in 25 mL cyclohexane (18). These contents were expressed in mg per kg of oil.

A colorimeter (chroma meter type Color-Eye 3000, Macbeth) with a computer program Optiview 1.1, along with the CIELAB colorimetric system was applied to assess oil color. Oil samples were examined without dilution to avoid color variation.

The fatty acid composition of oil was determined by gas chromatography (GC) as fatty acid methyl esters (FAME). FAME were prepared by saponification/methylation with sodium methylate according to Regulation EEC/2568/91 of the European Union Commission as modified (19). GC analysis was performed with a Hewlett-Packard 5890 Series II gas chromatograph (Palo Alto, CA) equipped with a flame-ionization detector, using a capillary column 30 m × 0.25 mm i.d. × 0.20 µm film thickness (SP 2330; Supelco). Column temperature was isothermal at 190°C, the injector and detector temperatures were 220°C. Fatty acids were identified by comparing retention times with standard compounds and as percentage of FAME.

The organoleptic evaluation of oils was carried out according to the European Official Methods of Analysis by the Official Test Panel of Virgin Olive Oil of Catalonia. Only oils from the last crop season of the trial (1999) were evaluated. The panel consisted of 10 trained tasters who performed the flavor description of the oils and their quality grading. The descriptive analysis used a six-point intensity ordinal rating scale from 0 (no perception) to 5 (extreme) to quantify intensity of different sensory attributes (fruity, apple, other ripe fruits, green, bitter, pungent, and sweet). Overall grading used a nine-point scale from 1 (lowest quality) to 9 (optimal quality). Depending on the average score of the panel, the oil was classified as extra virgin (≥6.5), virgin (<6.5 and ≥5.5), ordinary virgin oil (<5.5 and ≥3.5), or virgin lampante olive oil.

Statistical analysis. Regression analysis was carried out to characterize the relationship between irrigation water applied depending on the different irrigation treatments (K_c) and each parameter analyzed for both crop seasons. The version 6.12 SAS System package (SAS Institute Inc., Cary, NC) was used to obtain all the statistical results.

RESULTS AND DISCUSSION

Values of free fatty acid content, peroxide value, and K_{270} are shown in Table 1. No relationship was found with irrigation treatment. Although the peroxide value of oils from the most irrigated treatment, T7, showed a slightly higher value, it is not significant because the average values of free fatty acid content, peroxide value, and K_{270} of all the oils from this trial were considerably lower than the limit established by ECC legislation (9) for high-quality oils.

Total phenol content of oils from different irrigation regimes is shown in Table 2. These data fit a linear model. We found a strong linear relationship ($P < 0.001$) between K_c, that defined the amount of irrigation water applied and polyphenol content of the oil. As the irrigation water applied to olive trees increased, the level of these compounds decreased. A comparison of the independent regressions showed that slopes and ordinates were not statistically different among the two crop seasons.

Phenolic biosynthesis in plants is known to be highly sensitive to environmental conditions. Recent research on olive fruit showed that the activity of phenylalanine ammonia-lyase (EC 4.3.1.5), in the phenylpropanoid pathway and polyphenol content decreased as the irrigation water applied increased (5). A study by our research group confirmed this observation (20). Therefore, olive fruits grown under water deficit should contain a higher level of phenolics.

Evidence for this theory was observed in the total phenol content obtained in 1998 due to lower rainfall compared to 1999 (Fig. 1). Pannelli *et al.* (21) and Ranalli *et al.* (22) also found that rainfall during the growing and ripening of olive fruits influenced phenolic content of olive oil. Conversely, in a year characterized by a higher annual rainfall, phenolic compound content in olive oils was remarkably lower (4; Tovar, J.J., M.P. Romero, S. Alegre, J. Girona, and M.J. Motilva, unpublished data).

Bitter index (K_{225}) and oxidative stability of oils followed the same pattern as total phenol content (Table 2). We found a negative linear relationship between K_c and these parameters. In both cases, K_{225} and oxidative stability, there was not significant differences in regression slopes or ordinates between the two crop seasons. The effect of irrigation on the bitter index and on the stability of oils has also been observed by other researchers (4; Tovar, J.J., M.P. Romero, S. Alegre, J. Girona, and M.J. Motilva, unpublished data).

Bitter taste is one of the characteristic attributes of virgin olive oil. Its intensity varies greatly and influences consumer attraction and acceptance. Montedoro *et al.* (23) reported that phenolic compounds have some importance in the flavor of olive oil. Sacchi *et al.* (24,25) found that total phenol content determined either by colorimetry or by high-performance liquid chromatography is related to the bitter-pungent characterization of oils assessed by panel tests. Although there is no clear or established limit, experience has shown that K_{225} values of the order of 0.360 or higher correspond to quite bitter oils (high or extremely high intensities) which are rejected by many consumers (15). In our trial, oils from the lowest treatment, T1, showed values up to that theoretical value of 0.360. In 1999, where organoleptic evaluation was carried out, tasters pointed out that oils from T1 irrigation treatment showed high intensities of bitterness and pungency, which were not conducive to their direct marketing.

Virgin olive oil stability to autoxidation is mainly due to the composition of triacylglycerols and to phenolic compounds arising from the glycosylated precursors present in the olive fruit. Various researches have found a linear relationship between phenol content and virgin olive oil stability (14,26–29).

α-Tocopherol content of the oils from the different irrigation treatments is shown in Table 2. In general, a negative linear relationship was found between the water supplied to olive trees and α-tocopherol content of the oils.

Chlorophyll and carotenoid contents of the oils from the trees under different irrigation treatments are shown in Table 3. We found a negative linear relationship between K_c and chlorophyll and carotenoid content in both of the crop seasons. Chlorophylls and carotenoids decreased in oils when the water supplied to olive trees increased. The rate of decrease was the same in both years; however, in 1998 the level of chlorophylls was statistically lower than in 1999 even though the ordinates of the linear regressions between K_c and carotenoid content were not statistically different. A possible explanation for this response may relate to the fact that pastes from highly irrigated olives are more fluid due to higher water

TABLE 1
Quality Indexes of Arbequina Cultivar Virgin Olive Oil in Relation to Irrigation Treatment (K_c)[a]

	Free fatty acid content (%)		Peroxide value (meq O_2/kg)		K_{270}	
Irrigation treatment (K_c)	1998	1999	1998	1999	1998	1999
T1 (0.25)	0.17	0.14	5.70	5.49	0.10	0.12
T2 (0.38)	0.15	0.12	5.80	5.38	0.11	0.13
T3 (0.50)	0.13	0.12	5.60	5.56	0.10	0.13
T4 (0.57)	0.15	0.13	5.70	6.51	0.10	0.12
T5 (0.64)	0.14	0.12	5.80	6.22	0.12	0.12
T6 (0.71)	0.13	0.12	5.60	6.37	0.11	0.11
T7 (0.85)	0.15	0.12	6.10	6.28	0.09	0.10
Regression analysis						
Significance level	NS	NS	NS	NS	NS	NS

[a] K_c, effective crop coefficient; K_{270}, absorbance at 270 nm; NS, not significant ($P > 0.05$).

TABLE 2
Means and Regression Analysis of Polyphenol Content, Bitter Index, Stability and α-Tocopherol Content of Arbequina Cultivar Virgin Olive Oil in Relation to Irrigation Treatment (K_c)[a]

	Polyphenols (mg/kg)		Bitter index (K_{225})		Stability (h)		α-Tocopherol (mg/kg)	
Irrigation treatment (K_c)	1998	1999	1998	1999	1998	1999	1998	1999
T1 (0.25)	434.6	382.6	0.426	0.369	22.1	20.3	166.4	144.6
T2 (0.38)	370.7	311.5	0.353	0.305	20.4	18.8	167.8	143.7
T3 (0.50)	350.9	335.3	0.340	0.334	21.2	19.6	153.4	136.0
T4 (0.57)	341.3	281.5	0.324	0.297	20.7	18.0	154.1	131.9
T5 (0.64)	332.6	282.3	0.327	0.294	21.5	17.9	155.3	130.4
T6 (0.71)	275.2	221.6	0.249	0.241	17.0	16.4	153.9	127.8
T7 (0.85)	262.7	225.8	0.264	0.235	18.3	16.5	158.1	126.0
Regression analysis								
Significance level	***	***	***	***	**	***	NS	***
R^2	0.90	0.86	0.86	0.86	0.51	0.84	—	0.94
Ordinate	492.3	437.5	0.476	0.414	23.9	21.9	—	154.2
Slope	–275.0	–262.9	0.270	0.213	–6.64	–6.62	—	–35.5
Ordinates[b]	NS		NS		NS		—	
Slopes	NS		NS		NS		—	

[a]NS, not significant ($P > 0.05$); *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.
[b]Comparison of the independent regressions by dummy variables by each parameter.

content (30). Hence, they pass quickly through the hammer-crush sieves during the milling, suffering less tissue damage and a reduction in the extraction of pigments.

The values of the chromatic ordinates L*, a* and b* of the oils are shown in Table 3. The L* variable lightness index ranges in a scale from 0 for black to 100 for white. The a*

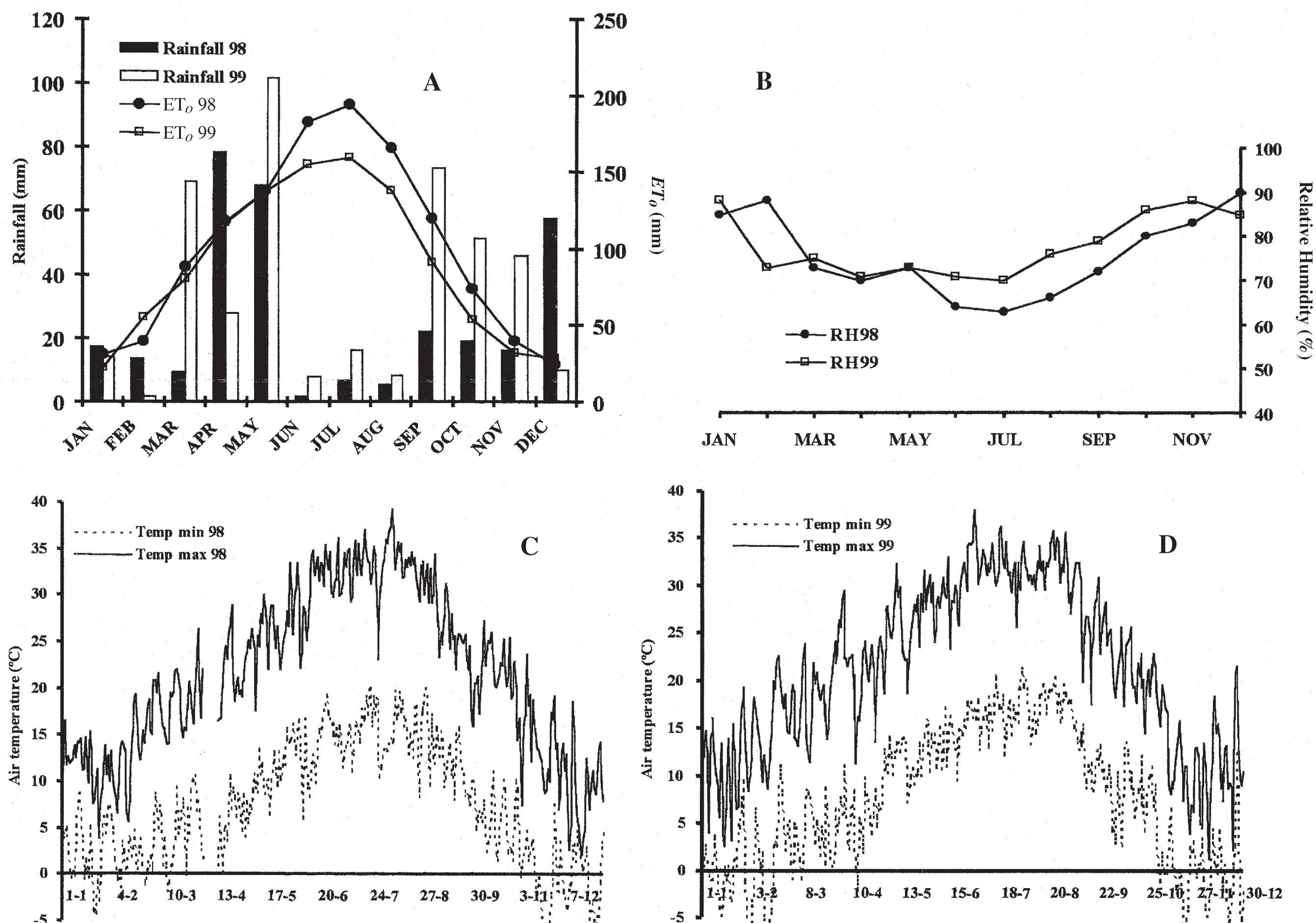

FIG. 1. Rainfall and reference crop evapotranspiration (ET$_o$) (A), relative humidity (RH) (B), and air temperature (C,D) for 1998 and 1999 years.

TABLE 3
Means and Regression Analysis of Chlorophyll and Carotenoid Content and Color of Arbequina Cultivar Virgin Olive Oil in Relation to Irrigation Treatment (K_c)[a]

	Chlorophylls (mg/kg)		Carotenoids (mg/kg)		Chromatic ordinates					
					L*		a*		b*	
Irrigation treatment (K_c)	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999
T1 (0.25)	4.40	8.49	7.71	9.69	90.2	84.0	−3.44	−2.46	85.1	108.4
T2 (0.38)	4.56	9.14	5.63	9.92	90.0	84.7	−4.28	−2.52	81.4	112.3
T3 (0.50)	4.01	8.30	5.43	8.64	89.7	84.0	−4.21	−2.70	77.7	105.7
T4 (0.57)	3.74	7.75	4.76	8.17	90.6	84.3	−4.85	−3.95	72.1	103.4
T5 (0.64)	3.81	7.13	4.56	7.63	90.9	85.7	−5.48	−3.78	66.8	105.1
T6 (0.71)	1.66	5.39	2.4	6.32	94.6	86.6	−5.85	−4.77	38.3	95.8
T7 (0.85)	1.16	5.25	2.21	6.06	94.7	88.3	−6.47	−5.04	32.8	93.9
Regression analysis										
Significance level	**	***	***	***	*	**	***	***	***	***
R^2	0.76	0.80	0.92	0.91	0.64	0.74	0.95	0.87	0.82	0.78
Ordinate	6.07	11.1	9.72	12.1	87.5	81.5	−2.10	−0.84	117.3	119.7
Slope	−4.47	−6.76	−9.06	−7.17	6.30	6.94	−5.10	−4.97	−94.0	−29.0
Ordinates[b]	**	NS	*	NS	NS					
Slopes	NS	NS	NS	NS	***					

[a]Chromatic ordinates of olive oils are characterized as: L*, a* and b*. The L* variable lightness index ranges on a scale from 0 for black to 100 for white. The a* scale measures the degree of red (+ a*) or green (– a*) color, and the b* scale measures yellow (+ b*) or blue (– b*) color. NS, not significant ($P > 0.05$); *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.
[b]Comparison of the independent regressions by dummy variables by each parameter.

scale measures the degree of red (+ a*) or green (– a*) color and the b* scale measures yellow (+ b*) or blue (– b*) color. The color of the oil was affected by the amount of irrigation water supplied to olive trees. The chromatic ordinate L* increased as the irrigation water applied did, as indicates the linear relationship between these two parameters. Irrigation treatments affected L* in the same way for the two crop seasons; the slopes of the two independent linear regressions were not statistically different. What made the two years different was the slightly higher values of L* in 1998. Chromatic ordinates are related to pigment content. Since L* measures the luminosity, if the oil was richer in chlorophylls and carotenoids it would be lower because these pigments would capture part of that light instead of being reflected or transmitted. We have already seen that as the water applied increased chlorophylls and carotenoids decreased and consequently the chromatic ordinate L* increased. We also noticed that in the 1999 crop season, when pigment content was higher, the values of L* were lower.

Chromatic ordinates a* and b* decreased when the irrigation water applied to olive trees increased. The pattern followed by a* was the same in the two crop seasons; their slopes and ordinates were not statistically different. Regarding the chromatic ordinate b*, the rate of its decrease in 1998 was statistically different from that in 1999. In the first year the decrease was more pronounced. There are some works that show the existence of a clear relationship between the values of b* and the carotenoid concentration (18). In 1998, oils from the most irrigated treatments showed a remarkably low carotenoid concentration.

In agreement with previous works in oils of the Arbequina cultivar (31; Tovar, M.J., M.P. Romero, S. Alegre, J. Girona, and M.J. Motilva, unpublished data) we observed a tendency of the ordinate a* toward negative values (green zone) and the ordinate b* toward the blue zone in those oils with lower content of chlorophyll and carotenoid pigments, that is to say in 1998.

Fatty acid composition of the oils from different irrigation treatments is shown in Table 4, where we observe that the effect of water irrigation differs with the year. Palmitic and linolenic acids were not significantly affected by water regime but there was a positive linear relationship between K_c and the percentage of palmitoleic acid. In relation to the rest of the fatty acids, no consistent relation was found. Fatty acid biosynthesis of olive oil depends on uncontrolled features such as weather conditions, the particular characteristics of each oil-producing region (microclimate, soil geochemistry, olive variety) and stage of maturity of olives among other factors. A work by Tsimidou and Karakostas (32) revealed a greater influence of year of harvest compared to origin or cultivar.

Sensory appraisal of the oils is shown in Table 5. The overall grading failed to show any defect in any of the oils, which were classified extra virgin, independent of the irrigation treatment. We found a linear relationship between K_c and the overall grading of the oils, showing higher values than those oils from the less-irrigated treatments. Oils from T1 irrigation treatment obtained a noticeably higher grading than the rest of oils.

The oils of the trial were characterized by their fruity flavor, and we found no relationship between K_c and this attribute, although oils from the most severe treatment (T1) showed a markedly higher value of this attribute. "Fruity" is a fundamental sensation in the virgin olive oil aroma: it is a reflection of the raw material from which oil is obtained. The fragrant flavor of virgin olive oil is produced by the balance between green and fruity notes.

We found no relationship between K_c and the attributes

TABLE 4
Means and Regression Analysis of Fatty Acid Composition of Arbequina Cultivar Virgin Olive Oil in Relation to Irrigation Treatment (K_c)[a]

	Palmitic		Palmitoleic		Stearic		Oleic		Linoleic		Linolenic	
Irrigation treatment (K_c)	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999
T1 (0.25)	13.4	14.6	1.38	1.11	1.71	2.00	70.4	71.6	12.4	10.1	0.81	0.48
T2 (0.38)	13.1	14.4	1.38	1.17	1.72	2.03	71.1	72.1	11.9	9.81	0.84	0.44
T3 (0.50)	13.7	14.6	1.59	1.33	1.70	2.07	71.1	72.0	11.2	9.55	0.81	0.44
T4 (0.57)	13.2	14.5	1.51	1.23	1.66	1.98	71.5	72.7	11.4	9.11	0.82	0.41
T5 (0.64)	13.6	14.5	1.75	1.15	1.69	1.99	71.1	73.1	11.2	8.91	0.75	0.40
T6 (0.71)	13.3	14.6	1.87	1.48	1.58	1.96	71.3	72.9	11.2	8.65	0.78	0.41
T7 (0.85)	13.4	14.5	2.01	1.50	1.55	1.95	70.9	73.3	11.5	8.31	0.77	0.41
Regression analysis												
Significance level	NS	NS	***	**	*	NS	NS	***	NS	***	NS	NS
R^2	—	—	0.90	0.63	0.74	—	—	0.87	—	0.98	—	—
a	—	—	1.00	0.99	1.81	—	—	70.9	—	11.0	—	—
b	—	—	–1.15	–0.53	–0.28	—	—	2.90	—	–3.20	—	—
Ordinates[a]	—		NS		—		—		—		—	
Slopes	—		NS		—		—		—		—	

[a]NS, not significant ($P > 0.05$); *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.
[b]Comparison of the independent regressions by dummy variables by each parameter.

TABLE 5
Means and Regression Analysis of Overall Grading and Sensory Attributes of Arbequina Cultivar Virgin Olive Oil (1999 crop season) in Relation to Irrigation Treatment (K_c)[a]

		Sensory attributes[c]						
Irrigation treatment (K_c)	Overall[b] grading	Fruity	Apple	Other ripe fruits	Green	Bitter	Pungent	Sweet
T1 (0.25)	7.7	2.5	1.1	0.8	2.1	2.6	2.5	1.6
T2 (0.38)	7.3	2.0	0.8	0.7	1.6	2.1	2.4	1.6
T3 (0.50)	7.4	2.2	0.9	0	1.8	2.3	2.5	1.6
T4 (0.57)	7.0	1.7	0	0.8	1.4	1.7	2.4	1.7
T5 (0.64)	7.3	2.1	0.8	0.8	1.8	2.2	2.4	1.7
T6 (0.71)	7.2	2.0	0.8	1.0	1.6	1.6	2.2	1.8
T7 (0.85)	7.1	1.9	0.9	0.8	1.7	1.6	2.0	2.0
Regression analysis								
Significance level	*	NS	NS	NS	NS	*	*	NS
R^2	0.56	—	—	—	—	0.66	0.70	—
a	7.76	—	—	—	—	2.89	2.76	—
b	–0.84	—	—	—	—	–1.57	–0.75	—

[a]NS, not significant ($P > 0.05$); *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.
[b]1 (lowest quality), 9 (optimal quality).
[c]0 (no perception), 5 (extreme).

apple, other ripe fruits, and green. However, we observed that oils from T1 irrigation treatment showed a noticeably higher value of the green odor note, reminiscent of healthy, fresh olive fruits harvested at the right ripening degree.

As the water applied to olive trees increased, bitter and pungent attributes decreased in a linear way as revealed by the relationship found between K_c and these parameters. This result agrees with the work of Salas *et al.* (4), who found that fruity, bitter, and pungent attributes were affected by irrigation, these attributes being more evident in oils from dry-farming orchards and in those from the less-irrigated treatments. Phenolic compounds are closely related to bitter and pungent attributes. The esters of hydroxyphenylethanols are responsible for the bitterness and pepper-like sensation that is occasionally dominant in the taste of olive oils (33). Oils with high content of phenolic compounds are also characterized by an intense fruity flavor and an accentuated green odor note. We observed that the sensory attributes directly related to polyphenols were markedly elevated in oils from T1 irrigation treatment, which showed a significantly higher phenol content.

We found no significant relationship between K_c and the sweet attribute, which refers to the sensation of smoothness of the oil in the mouth, but the oils from the most irrigated treatment (T7) showed remarkably higher values.

Besides these attributes, tasters noted other positive attributes (data not shown). From the sensorial analysis, the attributes green almond, anise, and green banana were perceived in all the oils while the attributes tomato and walnut were only perceived in oils from T5 to T7 treatments, and the attribute green tomato only in those oils from T1 to T4 treatments.

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