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Sensory analysis and volatile compounds of olive oil (cv. Cobrançosa) from different irrigation regimes

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RESUMEN

Análisis sensorial y compuestos volátiles del aceite de oliva cv. Cobrançosa procedente de diferentes regímenes de riego

Este estudio tiene como objetivo evaluar el efecto de distintas estrategias de riego en la composición relativa de los compuestos volátiles y en la calidad sensorial. El experimento se realizó en el Noreste de Portugal, dentro de la denominación de origen protegida “Azeites de Trás-os-Montes”. Se compararon tres tratamientos de riego: T2-riego máximo, los árboles recibieron el equivalente de agua para satisfacer el 100% de la evapotranspiración (ET_c) estimada para el olivo; T1-riego deficitario continuo (30% ET_c) y T0-sin riego. Los datos presentados corresponden a dos campañas agrícolas (2005-2006). La cantidad total de compuestos volátiles se redujo conforme aumentó la cantidad de agua aplicada. Los sabores picante y amargo fueron más fuertes en los aceites de T0 y T1, que tenían mayores concentraciones de polifenoles, encontrándose una relación positiva entre esta variable y el atributo amargo. En 2005, el año más seco, el Análisis de Componentes Principales separó los tres tipos de aceites de oliva, mientras que los agregó en un solo grupo en 2006, indicando que no hay efecto del riego en los compuestos volátiles en los años con una primavera lluviosa. Esto sugiere que el efecto del estado hídrico del olivo en estas variables se produce a lo largo del ciclo de cultivo y no sólo durante la fase de acumulación de aceite.

En general, el aceite de oliva cv. Cobrançosa es más amargo que picante y tiene un atributo típico a frutos secos que se confirma con una fuerte relación positiva entre el benzaldehido y las notas sensoriales de otras frutas como las almendras y las nueces.

PALABRAS CLAVE: Aceite de oliva virgen – Análisis de Componentes Principales – Atributos sensoriales.

SUMMARY

Sensory analysis and volatile compounds of olive oil (cv. Cobrançosa) from different irrigation regimes

The aim of this study was to assess the effect of different irrigation strategies on the sensory quality of virgin olive oil (VOO) from the cv. “cobrançosa” integrated into a protected denomination of origin of “Azeite de Trás-os-Montes” in the Northeast of Portugal. Three irrigation treatments were applied: (T2)-full irrigation, which received a seasonal water equivalent of 100% of the estimated crop evapotranspiration (ET_c), (T1)-continuous deficit irrigation (30% ET_c) and (T0)-rainfed treatment. Data were collected from two consecutive crop years (2005-2006). Olive oil samples were analyzed for volatiles by GC-MS and the results compared with sensory evaluation data. Total volatile compounds tended to decrease with the amount of water applied. The characteristics pungent and bitter were more pronounced in olive oils from T0 and T1, which had higher polyphenolic concentrations, with a strong positive relationship with this variable and the bitter attribute. The Principal Components Analysis clearly separates the three olive oils from 2005, the driest year, and aggregates into a single group the three samples from 2006, suggesting no effect of irrigation on volatile compounds in years with a rainy spring and a marked effect in years with severe drought, suggesting that the effect of the trees' water status on these variables occurs throughout the crop season and not just during the oil accumulation phase.

In general, olive oil from the cv. Cobrançosa is more bitter than pungent and has a typical nutty sensory attribute shown by a strong positive relationship between benzaldehyde and the sensory notes of almonds and nuts.

KEY-WORDS: Principal Components Analysis – Sensory attributes – Virgin olive oil.

1. INTRODUCTION

When virgin olive oil (VOO) is extracted from fresh, sound olives (*Olea europaea* L.) and perfectly processed using mechanical systems, it is characterized by a delicate and exclusive flavor highly appreciated by consumers, which determines their preference. It is well known, that its peculiar delicious taste and aroma are dependent on its volatile compounds profile (Morales and Tsimidou, 2000). According to Morales *et al.,* (1995) the profile of these compounds is in agreement with the sensory attributes recognized and evaluated by assessors. Nevertheless, not all volatile compounds contribute to the sensory quality, since the contribution of these substances depends on their concentration and on their odor threshold to stimulate and be perceived by olfactory sense and taste. Therefore, GC-sniffing methods are widely applied to study the relationship and the impact of these substances on the sensory quality of olive oil (Morales *et al*., 1994).

It is well accepted that volatile compounds in olive oil are mainly produced by the oxidation of polyunsaturated fatty acids (Kalua *et al*., 2007) through the lipoxygenase pathway (LOX). This explains why the biochemical pathways are responsible for the particular profiles of the monovarietal virgin olive oils despite the fact that external factors (climate, soil, irrigation, harvesting and extraction conditions) transform the final sensory profile (Aparicio and Morales, 1998; Morales and Aparicio, 1999). It has been stated that C6 compounds (aldehydes, alcohols and acetyl esters), the major components of the total volatile compounds in virgin olive oil (60-80%), are responsible for the positive aroma perceptions in olives such as the green (green leaves or grass) odor notes and the astringency of the virgin olive oils (Angerosa *et al*., 2000); whereas chemical oxidation and exogenous enzymes, frequently from microbial activity, are associated with sensory defects. Together, the processing and storage of the fruit and the oil, make a great contribution to the flavor and overall quality of olive oil (Angerosa, 2002; Venkateshwarlu *et al*., 2004, Morales *et al.* 2005; Vichi *et al*., 2009; Biasone *et al*., 2012). Virgin olive oils of high quality showed a reasonable quantity of C5 alcohols and C5 carbonyl substances (Angerosa et al., 2000). According to Salch *et al.,* (1998) and Morales *et al.,* (1999), the simultaneous detection of pentene dimers and C5 compounds, suggests another via of the LOX pathway, leading to the production of C5 compounds. Additionally Morales *et al.,* (1999), found that C5 compounds were minor contributors to a green sensory perception. As a result, since sensory quality plays an important role in deciding the preference of consumers, numerous efforts have been made to make clear the relationships between the sensory attributes recognized by the assessors of virgin olive oil and its volatile composition (Aparicio and Morales, 1998; Aparicio *et al*., 1997; Morales *et al*., 1995). The aim of this study was to assess the effect of different irrigation strategies on olive oil volatile composition and its relationship with the sensorial quality of virgin olive oil (VOO) from the cv. Cobrançosa, integrated into a protected denomination of origin of "Azeite de Trás-os-Montes" in the Northeast of Portugal.

2. MATERIALS AND METHODS

2.1. Study site and experimental conditions

The experiment was conducted during 2005 and 2006, in a 10-year-old commercial olive orchard (*Olea europaea* L. cv "Cobrançosa"), with a tree spacing of 6 m x 6 m, located in the Vilariça Valley (41.33º N, 7.04º W; 240 m altitude), a typical olive growing area of Northeast Portugal. Three irrigation treatments were applied: full irrigation (T2), which received a seasonal water equivalent of 100% of the estimated crop evapotranspiration (ET_c), continuous deficit irrigation (T1), which received a volume of water equivalent to 30% of the estimated ET_c and a rainfed treatment (T0). The experimental layout consisted of three adjacent blocks each made up of four rows with twenty olives trees, where only the six central trees were used for sampling. Additional information about climatic conditions, amount of water applied, irrigation water quality and soil properties may be found in Fernandes-Silva *et al*., (2010).

2.2. Yield and olive oil samples

Harvesting was carried out in the middle of December of each year. Each olive tree was manually harvested and the yield weighed at the site. The olive ripeness index was determined immediately before harvesting according to Beltran *et al.,* (2008). In each year subsamples of about 3 kg of each tree/treatment were collected, and mixed to complete a sample of 18 kg which was used for VOO extraction. Due to logistic reasons olives were stored for 5 and 3 days in 2005 and 2006, respectively, in perforated plastic boxes (≈10kg) in a refrigerator (relative humidity 80% and ambient temperature of 4 °C) until processing. The paste underwent malaxation at 25 °C for 30 min and the oil was extracted with a two-phase decanter (model Oliomio 50). Olive oil was stored in the dark in dark glass bottles and ambient temperature of 4 °C until analytical determinations were made.

2.3. Analytical determinations

2.3.1. Volatile compounds

A volatile compound analysis was performed using gas chromatography-mass spectrometry (GC-MS) after headspace solid phase microextraction (HS-SPME) of the olive oil volatiles. The following procedure and working conditions for HS-SPME were chosen: a 10 mL of olive oil aliquot was put into a 40 mL vial, then 0.2 mL of 2-octanol internal standard (IS) solution (50 mg L^{-1}, in refined oil) was added, and then the vial was sealed with a Polytetrafluoroethylene (PTFE) silicone septum. The olive oil sample and IS solution aliquot weights were measured and recorded (± 0.001 g). During SPME extraction, the olive oil sample was stirred at a speed of 1800 rpm. A 2 cm Divinylbenzene/Carboxen/Polydimethylsiloxane SPME fiber was exposed to the oil headspace for 60 min at 60 °C and then immediately transferred to the GC-MS injection port at 270 °C for 0.5 min in splitless mode, and kept in the hot injector for 5 min to ensure complete fiber desorption.

An Agilent 6890N gas chromatograph coupled to an Agilent 5973N mass selective detector was used for GC-MS analysis. Compounds were separated on an Innowax capillary column (30 m × 0.25 mm × 0.5 μm, Agilent). The temperature program was: 5 min at 40 °C, from 40 °C to 200 °C at a rate of 4 °C/min, from 200 °C to 240 °C at 10 °C min^{-1} and 15 min at 240 °C. The injector was kept at 270 °C, while the helium flow rate was 0.9 mL min^{-1} (35 cm s^{-1}). The mass spectrometer scanned from m/z 26 to 250, the ion source was set at 240 °C and the spectra were obtained by electron impact (70 eV). Sample compound identification was aided by the use of the Wiley spectra database (Wiley Registry of Mass Spectral Data, 2001) and by comparing the linear retention indices (LRI) of the compounds with published LRI's. The results from the chromatographic analysis of the olive oil volatiles are expressed as the normalized peak area relative to the internal standard (i.e., the ratio of the compound peak area count by the peak area count for the internal standard).

2.3.2. Sensory analysis

Sensory analysis was carried out by a trained panel, composed of staff members of the Technical Studies Laboratory at Institute of Agronomy, Technical University of Lisbon, according to the current EU regulation (EU 1989/2003 which replaced the ECC 2568/91). The panelists were experts in virgin olive oil sensory evaluation, recognized by the International Olive Council. For the sensory analysis each sample of 15 mL was tasted for its bitterness, pungency and fruitiness, which are positive attributes, and any negative attributes, according to the official procedure, in a normalized cup at 28 ± 2 °C. Results were expressed as the mean intensity of the sensory perceptions of the tasters.

2.4. Statistical analysis

A correlation analysis (Pearson's correlation) was made with Statistica for Windows release 7.0. A multivariate analysis with Principal Components Analysis was also made with the same software.

3. RESULTS AND DISCUSSION

3.1. Volatile Compounds Composition and Sensory Analysis

The genetic effect related to cultivar is one of the most important aspects of the volatile composition of olive oil (Kiritsakis, 1998; Youssef *et al*., 2011). However, climatic and agronomic conditions of olive growing can affect the volatile composition of olive oils obtained from the same cultivar (Angerosa *et al*., 2004). Table 1 reports the volatile compounds found in the different irrigation regimes, more than 20 volatile compounds were identified (Figure 1). The response to water status in terms of volatile compounds was variable between the two years, with higher relative levels in 2005 in all treatments. Apart from this response, it is possible to identify a decreasing trend of these substances from rainfed to the well irrigated treatment, whereas the response of the deficit treatment was not so clear. A similar decrease was also observed in other studies (Servilli *et al*., 2007; Stefanoudaki *et al*., 2009), which may reflect an activation of the lipoxygenase pathway due to stress, while other researchers (Gómez-Rico *et al.,* 2009) have shown that volatile compounds were higher in irrigated olive oils. In 2005, alcohols were the major group, followed by aldehydes, hydrocarbons and acids. In 2006, the major group was aldehydes which varied by around 40% of the total volatiles, followed by hydrocarbons, alcohols and acids. According to Kalua *et al*. (2007) the major volatile compounds reported in virgin olive oils are the C6 and the C5 and the aroma of olive oil is attributed to aldehydes, alcohols, esters, hydrocarbons and ketones. These substances, which are responsible for the positive green sensory notes in VOO are produced via the lipoxygenase pathway (LOX) during the crushing of the olive fruit and olive paste malaxation and are incorporated into the oily phase (Sánchez and Harwood, 2002). In both years, and in all treatments, except for T0 in 2005, among the C6 compounds produced via the lipoxygenase pathway (LOX), *trans*-2-hexenal (bitter, green, almond) was the predominant; 1-Hexanol (fruity, green olives odor) is the one which revealed a more pronounced variation, increasing with tree water status. In 2005 its relative level was 2.5 and 3.1 times higher in T1 and T2, respectively; whereas in 2006 it was only 1.3 times higher in T1. In relation to *cis*-3-Hexenol (green odor) a lack of response was observed in 2005, whereas in 2006 it decreased with irrigation, from 20 to 40% in T1 and T2, respectively. The highest relative level of hexanal (green sweet odor) was observed in 2005, in T1, and the lowest in T2, while in 2006 this compound was much lower in all treatments, with small differences between rainfed and irrigated treatments. According to Angerosa *et al.* (2002), among the contributors to high quality olive oil, the most important ones, besides *cis*-3-hexenal, are *cis*-3-hexen-1-ol and hexanal, for their low odor thresholds, and *trans*-2-hexenal.

The sensory profile for olive oils from the three irrigation treatments is shown in Figure 2. In both years, the characteristic pungent and bitter attributes are more pronounced in olive oils from T0 and T1, which had higher polyphenolic concentrations (Fernandes-Silva *et al*., 2013). This relationship is more prominent in 2005, the year with the higher stress level (Fernandes-Silva *et al.,* 2010). In general, it is possible to note that the olive oil from cv. Cobrançosa in rainfed conditions is more bitter than pungent. The other notes perceived in the VOO of this cultivar are olive fruity, other fruits like almonds and nuts, which are typical of this cultivar (Gouveia, 1985), and are only perceived in

Table 1
Balance of volatiles in virgin olive oils of cv. Cobrançosa from different irrigation regimes in 2005 and 2006. T0-Rainfed, T1 and T2 = irrigated with 30% and 100% ET_c, respectively

Component	Peak area ratio (x100)[a]						
	2005			2006			
	T0	T1	T2	T0	T1	T2	LRI
Aldehydes							
Acetaldehyde	3.7	8.1	6.4	4.5	2.5	5.3	706
Hexanal	30.4	44.3	20.6	6.6	9.0	9.1	1086
Trans-2-Hexenal	232.0	404.3	222.9	277	264.4	241.4	1233
Pentanal	4.5	5.5	4.3	2.3	1.3	1.3	984
Benzaldehyde	4.1	4.6	5.4	2.6	1.8	2.1	1534
Nonanal	11.5	15.9	13.0	12.0	9.3	10.1	1399
Trans-2-Heptenal	3.4	6.6	5.1	4.0	3.8	6.8	1332
trans,trans-2,4-Heptadienal	22.9	24.2	25.2	17.1	8.4	14.7	1473
Alcohols							
Ethanol	287.3	289.6	142.8	69.4	20.7	37.9	920
1-Hexanol	13.1	32.9	40.7	28.8	37.9	28.4	1356
cis-3-Hexenol	23.4	23.9	24.4	37.0	22.3	28.6	1388
1-Octanol	4.6	15.3	5.4	4.1	3.6	4.3	1558
Benzyl alcohol	4.3	9.3	13.2	6.1	5.7	6.9	1881
2-Phenylethanol	40.3	55.2	76.3	41.3	31.3	39.5	1918
trans-2-hexenol	34.9	172.5	103.0	13.5	75.9	20.6	148
Acids							
Acetic acid	84.9	72.9	35.8	64.3	50.2	38.5	1450
Hexanoic acid	15.8	22.0	15.2	8.9	11.9	11.6	1846
Octanoic acid	7.6	26.2	8.6	6.2	6.6	6.9	2057
hydrocarbons							
trans-β-Ocimene	49.3	10.7	6.2	12.9	10.0	27.3	1260
α-Copaene	8.9	3.1	1.9	2.7	1.2	0.8	1498
E,E-α-Farnesene	105.5	270.5	104.0	185.4	132.7	162.2	1751
Esters							
Methyl 2-methoxybenzoate	4.0	12.9	6.6	9.2	14.4	21.4	2075
Ethyl acetate	2.5	0.9	1.1	1.2	0.7	0.1	805
Ethyl 2-methylbutanoate	0.47	0.31	0.22	0.11	0.09	0.08	1058
Hexyl acetate	0.16	0.20	0.09	0.20	0.13	0.09	1280
Total volatiles	999.5	1531.6	888.7	817.4	725.8	726.0	

[a] Data show means of peak area ratios compared to the internal standard (2-octanol).

2005, the driest year (Fernandes-Silva *et al.*, 2010). The perception of the apple attribute in 2005 is only present in T0, whereas in 2006 it is present in all olive oils from the three treatments, with the lowest intensity in T1. All virgin olive oils obtained using the different irrigation treatments were classified as extra virgin by mean of the organoleptic evaluation carried out by the recognized olive oil panel.

3.2. Multivariate analysis

The results of GC-MS and sensory evaluation were analyzed by Principal Component Analysis (PCA) (Statistica 7.0, StatSoft Inc., 2004). Figure 3A shows the projection of the variables on the plane defined by the first and second principal components. The first principal component explains 43.5% of the

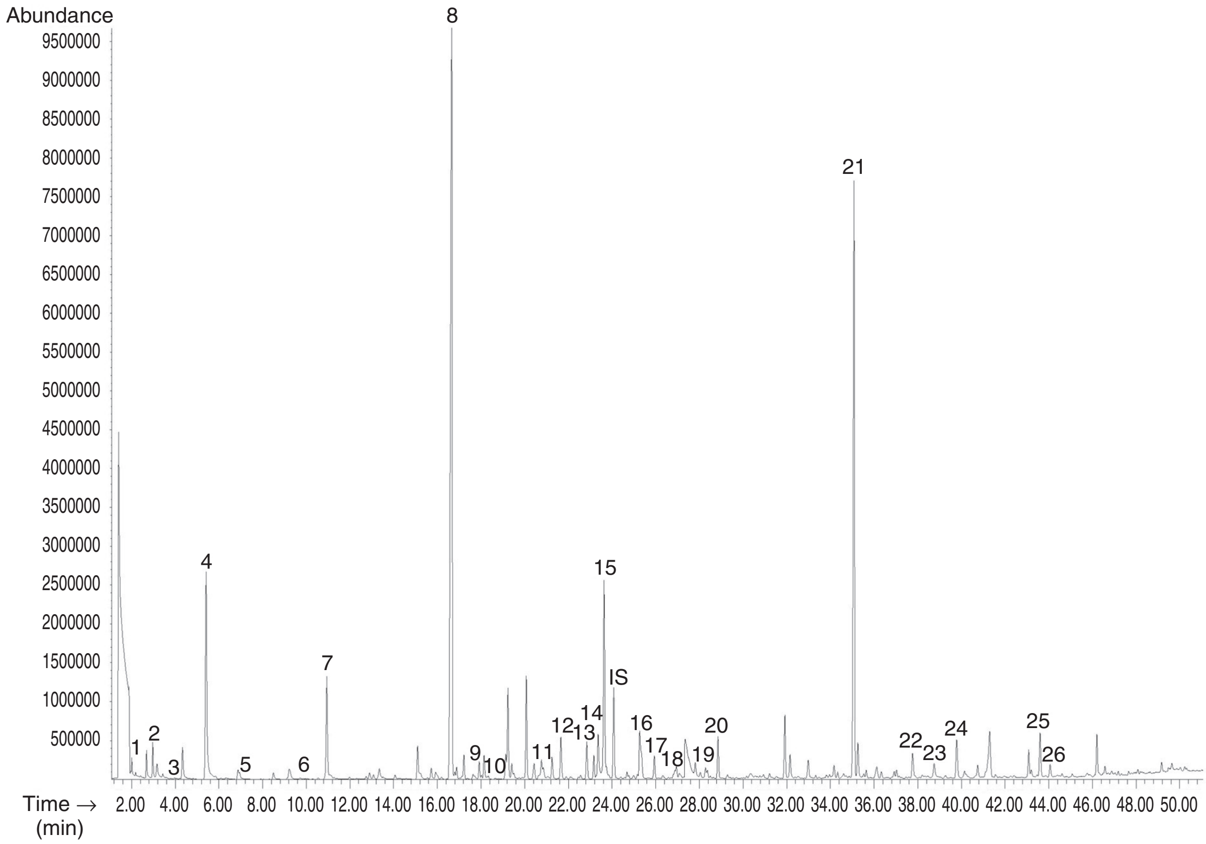

Figure 1
Gas chromatography-mass spectrometry chromatogram of VOO from deficit irrigation (T1-30%ETc) in 2005. 1- Acetaldehyde; 2- Acetone; 3- Ethyl acetate; 4- Ethanol; 5- Pentanal; 6- Ethyl 2-methylbutanoate; 7- Hexanal; 8- trans-2-Hexenal; 9- trans-β-Ocimene; 10- Hexyl acetate; 11- 2-Heptenal; 12- 1-Hexanol; 13- cis-3-Hexenol; 14- Nonanal; 15- trans-2-hexenol; 16- Acetic acid; 17- trans,trans-2,4-Heptadienal; 18- α-Copaene; 19- Benzaldehyde; 20- 1-Octanol; 21- E,E-α-Farnesene; 22- Hexanoic acid; 23- Benzyl alcohol; 24- 2-Phenylethanol; 25- Octanoic acid; 26- Methyl 2-methoxybenzoate. IS- 2-octanol internal standard.

total variability between the olive oil samples. This factor is mainly associated with analytical parameters such as the aldehydes (pentanal, hexanal, trans-2-hexenal, nonanal, acetaldehyde, benzaldehyde, *trans,trans*-2,4-heptadienal), the acids (hexanoic acid, octanoic acid), 1-octanol, ethanol, and 2-phenylethanol, and the descriptors “other fruits”, “cut grass”, “olive fruity” and “apple”. The second principal component explains 27.7% of the total variability between the samples. This factor is mainly associated with the analytical parameters 1-hexanol, α-copaene, acetic acid, ethyl acetate and trans-β-ocymene, and the “sweet” and “bitter” descriptors and total polyphenols. The two principal components explained 71.2% of the variability between the six olive oil samples. Additionally, the Principal Components Analysis (PCA) clearly separates the three olive oils from 2005, the driest year, and aggregates into a single group the three samples from 2006, indicating no effect of the treatments (Figure 3B). In fact the stress level was much higher in 2005 than in 2006. In 2005 the soil water content did not reach its maximum capacity in winter, the spring was abnormally dry, and there was no rainfall until mid autumn; while in the winter of 2005/2006 the soil water reserve was recharged and the spring of 2006 was slightly rainy (89.5 mm), and summer precipitation was 141.5 mm (Fernandes-Silva *et al.*, 2010) occurring during fruit set and formation. These results seem to indicate that the effect of tree water status on polyphenols and total volatile compounds occurs throughout the crop season and not just during the oil accumulation phase. This behavior has been observed for totals polyphenols in other studies for the cv. “Cornicabra” (Moriana *et al.*, 2007) and cv “Cobrançosa” (Fernandes-Silva *et al.*, 2013). In Turkey, Kiralan *et al.* (2012) reported differences in the composition of olive oil volatile compounds of the cultivar “Gemlik” according to the geographical area with respect to the variability of climatic conditions. Theses authors founded that the composition of volatile compounds in virgin olive oil from areas characterized by the highest annual mean temperature, relative humidity and annual rainfall differed (West Mediterranean) from the other locations by the presence of benzaldehyde and ethylbenzene. They also observed that hexanal was correlated with samples recorded in areas with low altitude and mean annual relative humidity. (East Mediterranean). Similarly, Issaoui *et al.*, (2010) found the highest concentration of (E)-2-hexenal in oils from olive trees grown at low altitude and high temperatures (south of Tunisia), whereas this compound was not detected in olive oils from trees grown at higher altitude and low temperatures (north of Tunisia). On the other hand, (E)-3-hexenyl acetate

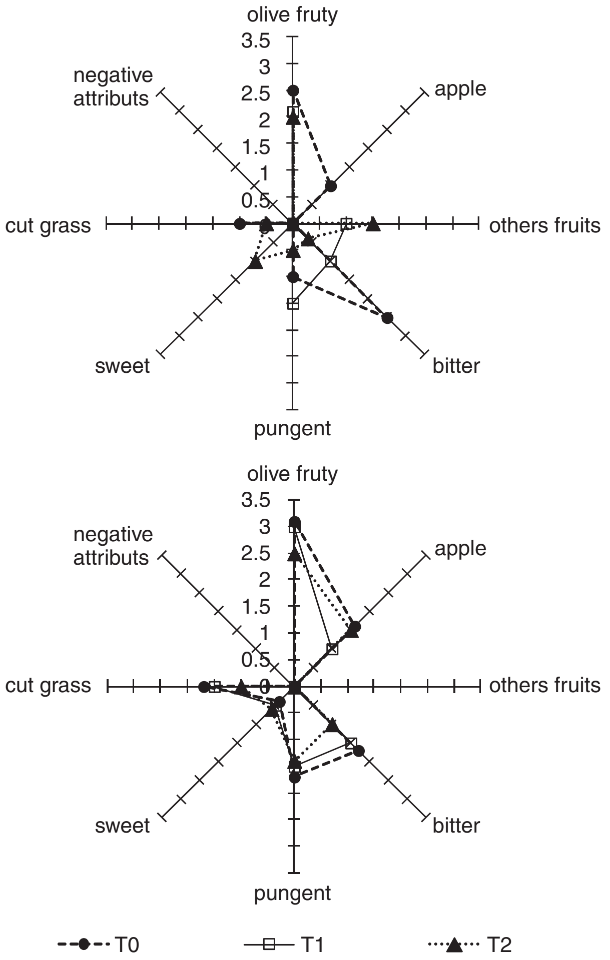

Figure 2
Sensory profile of virgin olive oils from cv. Cobrançosa from different irrigation regimes in 2005 (A) and 2006 (B). T0-Rainfed, T1 and T2 = irrigated with 30% and 100% ETc, respectively.

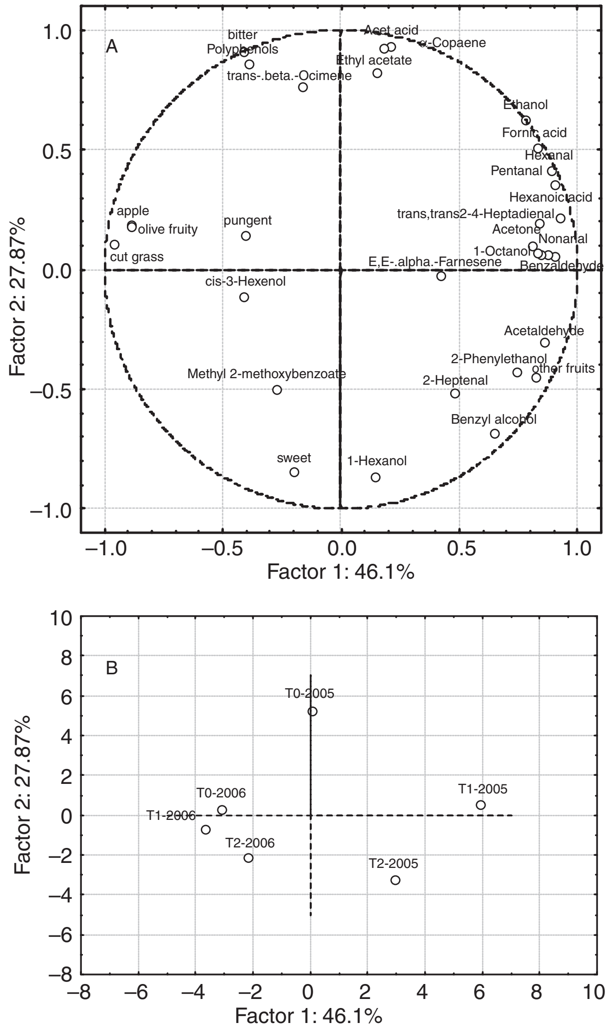

Figure 3
Projection of the variables (A) and of the oil samples (B) on the plane defined by the first and second principal components.

and hexyl acetate concentrations were higher in olive oils from the north than those from south Tunisia.

3.3. Volatile compounds and sensory attributes

A univariate analysis was applied to sensory attribute intensities and, to concentrations of polyphenols (Fernandes-Silva, *et al.*, 2013) and the volatile compounds described in Table 1. Some correlations were observed among the considered variables (Table 2).

The highest positive correlation (0.95) was found between polyphenols and the bitter attribute. These findings agree with previous results found in cvs. Leccino (Servilli *et al.*, 2007) and Koroneiki (Stefanoudaki *et al.*, 2009). Conversely, the bitter attribute is negatively correlated with 1-hexanol (–0.83) and benzyl alcohol (–0.89). It is well accepted that the C6 and C5 aromatic volatile compounds are chiefly responsible for the green perceptions of the unique aroma of VOO (Olías *et al.*, 2003), while bitterness and pungency have to be mainly related to secoiridoid compounds (Angerosa *et al.*, 2000). The green sensations, like reminiscent of leaves, freshly cut grass and green fruits such as apple are identified as "green" odor notes, and typify the flavor of oils extracted from unripe olives. They are considered as freshness and liveliness characteristics of good quality VOO by consumers (Angerosa *et al.*, 2002). In our study, the cut grass sensation was negatively correlated with hexanal (–0.84), a compound from the LOX pathway, which is in agreement with previous works by Angerosa et al. (2002). Similarly, in our study, a negative correlation was observed among this descriptor and 1-octanol (–0.81), acetaldehyde (-0.86) and hexanoic acid (–0.92). These two latter compounds are identified as responsible for the sensations of pungent, sweet, and floral (Angerosa et al., 2004). The sensory descriptor apple displayed a significant negative correlation with hexanoic acid (–0.82),) hexyl acetate (–0.82) and benzaldehyde (–0.83). Similarly, this latter compound and 2-Phenylethanol showed a negative relation with the sensory attribute of olive fruity (–0.84 and –0.80, respectively). For the attribute "other fruits" we observed a positive correlation with benzyl alcohol (0.95), 2-phenylethanol (0.96), hexyl acetate (0.83), *trans*-2-hexenal (0.89) and with

Table 2
Regression coefficients (r) of examined variables for each sensory attribute

	Sensory attribute						
	Bitter	**Pugent**	**Olive fruity**	**Apple**	**Other fruits**	**Sweet**	**Cut grass**
Acetaldehyde	–0.63	–0.17	–0.78	–0.65	0.75	–0.02	–0.86
Hexanal	0.01	–0.22	0.51	–0.73	0.51	–0.59	–0.84
Pentanal	–0.04	–0.44	–0.73	–0.77	0.66	–0.39	–0.78
Benzaldehyde	–0.30	–0.72	–0.84	–0.83	0.84	0.01	–0.77
Nonanal	–0.31	0-12	–0.65	–0.71	0.71	–0.32	–0.78
2-Heptenal	–0.69	0.08	–0.57	–0.28	–0.57	–0.64	–0.65
trans,trans-2,4-Heptadienal	–0.17	–0.58	–0.78	–0.65	0.69	–0.15	–0.73
Trans-2-Hexenal	–0.71	–0.73	–0.65	–0.66	0.89	0.64	–0.48
Ethanol	0.24	–0.29	–0.60	–0.57	0.37	–0.65	–0.68
1-Hexanol	–0.83	–0.09	–0.15	–0.43	0.56	0.67	–0.16
cis-3-Hexenol	0.08	0.47	0.50	0.62	–0.33	0.10	0.51
rans-2-hexenol	–0.43	–0.59	–0.06	–0.31	0.48	0.79	0.14
1-Octanol	–0.29	0.14	–0.57	–0.66	0.53	–0.48	–0.81
Benzyl alcohol	–0.89	0.59	–0.74	–0.76	0.95	0.60	–0.65
2-Phenylethanol	–0.69	–0.73	–0.80	–0.78	0.96	0.45	–0.68
Acetic acid	0.77	0.27	0.11	0.02	–0.27	–0.93	–0.05
Hexanoic acid	–0.19	–0.25	–0.77	–0.82	0.61	–0.45	–0.92
Octanoic acid	–0.28	0.15	–0.56	–0.67	0.51	–0.49	–0.80
trans-β-Ocimene	0.74	–0.11	0.04	0.38	–0.52	–0.51	0.12
α-Copaene	0.76	–0.24	–0.09	–0.02	–0.18	–0.65	–0.07
E,E-α-Farnesene	–0.19	0.64	–0.10	–0.17	0.13	–0.49	–0.40
Hexyl acetate	–0.28	–0.56	0.75	–0.82	0.83	–0.08	–0.74
Ethyl acetate	0.70	–0.34	–0.03	–0.09	–0.06	–0.47	0.03
Ethyl 2-methylbutanoate	0.42	–0.71	–0.24	–0.26	0.10	–0.09	–0.07
Methyl 2-methoxybenzoate	–0.37	0.52	0.14	0.32	–0.28	0.15	0.04
Polyphenols	0.95	0.43	0.59	0.43	–0.73	–0.74	0.46

See Figure 1.

benzaldehyde (0.84). According to Angerosa *et al.,* (2004), theses latter volatile compounds were associated with the sensation of almond, which confirms the results found by Gouveia (1985) that the aromas of almond and nuts are characteristic of VOO from the cv. "Cobrançosa".

4. CONCLUSIONS

Principal components analysis (PCA) clearly separates the three olive oils from 2005, the driest year, and aggregates the three samples from 2006 into a single group, indicating no effect of irrigation on volatile compounds in years with a rainy spring and a marked effect in years with severe drought.

The descriptors pungent and bitter were more pronounced in olive oils from stressed treatments (T0 and T1), which had higher polyphenolic concentrations, with a strong positive relation with this variable and the bitter attribute. Olive oil from the cv. "Cobrançosa" has a typical nutty sensory attribute which is confirmed by a strong positive relation between benzaldehyde and the sensory note "other fruits" (like almond and nuts) observed in the driest year (2005).

Continuous deficit irrigation strategy with only 30% of maximum ET_c may have a beneficial effect, as it doubles the oil yield compared to the rainfed conditions (Fernandes-Silva, 2010) while VOO quality is similar. Nevertheless, additional studies of different deficit irrigation strategies are still needed for the cv. "Cobrançosa" to develop an efficient irrigation strategy in circumstances where full irrigation supply is not possible, taking into account the balance between oil yield and olive oil quality.

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