academicJournals

Vol. 8(48), pp. 6291-6299, 12 December, 2013
DOI: 10.5897/AJAR2013.7972
ISSN 1991-637X ©2013 Academic Journals
http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Oil quality and aroma composition of 'Chemlali' olive trees (*Olea europaea* L.) under three irrigation regimes

Hechmi Chehab[1]*, Manel Issaoui[2], Guido Flamini[3], Beligh Mechri[2], Faouzi Attia[4], Cioni Pier Luigi[3], Dalenda Boujnah[1] and Mohamed Hammami[2]

[1]Institute of Olivier of Sousse, Tunisia.
[2]Laboratoire de Biochimie UR 'Nutrition Humaine et Altérations Métaboliques' Faculté de Médecine, Rue Avicenne, 5019 Monastir, Tunisie.
[3] Dipartimento di Chimica Bioorganica e Biofarmacia, via Bonanno 33, 56126 Pisa, Italy.
[4]Agronutrition Parc Activestre-3 avenue de l'Orchidée 31390 carbonne- France.

Accepted 21 November, 2013

The present work focused on the chemical composition of monovarietal virgin olive oil from the cultivar *Chemlali* cultivated in the South of Tunisia: sub-arid zone under three different irrigation regimes: stressed, moderate and well irrigation treatment with the restitution of 50, 75 and 100% of crop evapotranspiration (ETc), respectively. Quality characteristics (acidity and peroxide value) and chemical data (antioxidant compound, fatty acids volatile compounds and oxidative stability) were studied in addition to the pomological characteristic of olive fruit. Results show that there were significant differences observed in oil composition according to the irrigation regime applied. Total phenols, bitterness intensity and LOX products content showed the highest values for low irrigation regime, whereas polyunsaturated fatty acid and oxidative susceptibility values had highest values for olive oil from well irrigated trees. Analytic characteristic of fruits showed the highest values of pulp/stone ratios from olive trees irrigated by the highest amount of water.

Key words: Virgin olive oil, phenols, volatile compounds, oxidative stability.

INTRODUCTION

World-wide production of olive oil during the last 20 years increased by almost 70% (from 1.7 to 2.8 million tons) (Zampounis, 2006). Olive oils makes up a small proportion (<3.5%) of the volume in the world vegetable oil market. However, in terms of product value, only olive oil has a 15% share of world trade (Luchetti, 2000). The price of olive oil can be two to five times higher than that of other vegetable oils depending on the country, category of the oil and year of production (Luchetti, 2000). Spain is the primary world producer of olive oil, followed by Italy, Greece, Tunisia and Turkey. World consumption generally follows a parallel path to the production rate. This enormous growth is due to several factors, which are the acknowledgements of olive oil's health-promoting potential as a part of the Mediterranean diet and the global promotional campaigns initiated by the International Olive Council (Dag et al., 2008).

In Tunisia 'Chemlali' is the main cultivar; 1.3 million ha are grown in South and Central, and accounts for 80% of Tunisia's oil production (Baccouri et al., 2008). The chemical and organoleptic characteristics of olive oil depend on several factors (Salvador et al., 2001).

*Corresponding author. E-mail: cheheb2003@yahoo.fr.

According to Aparicio and Luna (2002), these factors are clustered into four main groups: environmental (soil, climate), cultivation (ripeness, harvesting), technological (fruit storage, extraction procedure), and agronomic factors (fertilisation, irrigation). Among these factors irrigation is a major determinant of olive oil quality (Gomez-Rico et al., 2007). High quality olive oil cannot be obtained from fruit that have suffered a severe water stress (Gomez-Rico et al., 2007). As water supplies decrease and better quality water supplies are reserved for more sensitive crops to drought conditions than olive tree (Palese et al., 2006). In fact, studies have shown that irrigation can increase olive production (Grattan et al., 2006; Samish et Spiegel, 1961; Moriana et al., 2003) thereby increasing total fruit yield and oil production per tree (Grattan et al., 2006). However, studies differ regarding their overall performance to applied water. Chemical and sensory characteristics, however, allow distinguishes clearly between virgin olive oils from irrigated and non-irrigated olive trees (Gomez-Rico et al., 2006; Patumi et al., 2002; Bedbabisa et al., 2010).

Thus, total content of polyphenols, which contribute to the oil bitter taste, is lower in the virgin olive oil harvested from irrigated zones (Gomez-Rico et al., 2006; Patumi et al., 2002). This is of great importance for varieties characterised by high values of astringent, throat-catching or bitter sensory descriptors. This paper presents the first investigation on the characterization of virgin olive oils from *Chemlali* cultivar implanted in the South of the country submitted to different irrigation regimes by fresh water using a localized irrigation in high density olive orchard. In this study, we describe the composition of Tunisian virgin olive oils through classical quality indexes, fatty acids composition and minor components, which are related to both oxidative stability and oil purity.

MATERIALS AND METHODS

Plant material and growing areas selected

The study was carried out on monovarietal virgin olive oils from the main Tunisian cultivar, *Chemlali*. The orchard is localized in the South, trees are planted at a density of 6mx6m (278 trees ha^{-1}) since 2002. The soil is sandy-loam with alkaline pH. The mean precipitation and temperature registered were 250 mm $year^{-1}$ and 30°C, respectively. In the olive orchard, water was delivered three times each week (from Juin to September) using a localized irrigation system with four drip nozzles of 8 l/h each per tree (two per side), set in a line along the rows at a distance of 0.5 m from the trunk.

Olive *Chemlali* cultivars were tested in a factorial combination with three irrigation levels well irrigated (T3), moderate (T2) and stressed (T1) receiving a seasonal water irrigation amount equivalent to 100, 75 and 50% of crop evapotranspiration (ETc) calculated using the Penman–Monteith (Allen et al., 1998) with a single estimated crop coefficient (Kc = 0.6) and a coverage coefficient (Kr = 0.5).(D'Andria et al., 2004). ETc = Kc.Kr.ET0, when ET0 is the reference evapotranspiration calculated by Penman–Monteith equation (Allen et al., 1998).

Morphological study

Immediately before harvest during 2008, 100 fruits were randomly sampled from around the canopy of each tree to determine the maturation index (MI) according to a 0 to 7 scale (Boskou, 1996) and the fruit fresh weight. The variety characterization was realized according to the method adopted by the International Olive Oil Council (IOOC) called 'methodology for the characterization of olive tree varieties'. The mean average weight of 40 fresh fruits was measured for each sample. Then, olives were de-stoned and the flesh (pulp) was separated in order to measure the pulp to stone ratio. The moisture content was determined from 40 g of olive fruits which were dried in an oven at 80°C to constant weight. Oil content, expressed as a percentage of dry weight, was determined by extracting dry material with hexane at 68°C using a *Soxhlet* apparatus, following the procedure described in AOCS Regulation Official Method (A.O.C.S, 1995). The fruit ripeness index of was attributed by qualitative evaluation of the olive skin and flesh colours (Uceda, 1975). This system is routinely used by the olive oil industry to characterize the degree of ripeness of olives arriving at their facilities. This evaluation was performed in triplicate.

Reagents and standards

The (*p*-hydroxyphenyl) ethanol (*p*-HPEA) was obtained from Janssen Chemical Co. (Beerse, Belgium). Pure analytical standards of volatile compounds were purchased from *Fluka* and *Aldrich* (Milan, Italy).

Analytical methods

Quality parameters

Determinations of free acidity and peroxide value were carried out following analytical methods described in the EEC 2568/91 and EEC 1429/92 European Union Regulation (European Union Commission Regulation 1991).

Fatty acid methyl esters (FAMEs) analysis

The FAMEs were prepared as described by EU official method. The chromatographic separation was carried out using a Hewlett-Packard (HP 5890) chromatograph, a split/splitless injector, and a flame ionization detector (FID) linked to an HP Chemstation integrator. A fused silica capillary column HP-Innowax (30 m x 0.25 mm x 0.25 µm) was used with nitrogen as the carrier gas at a flow rate of 1ml min^{-1}; flame-ionization detection temp. 280°C; injector temperature 250°C and an oven temperature programmed from 180 to 250°C. Results were expressed as relative percent of total area (Issaoui et al., 2007).

Total phenols

These were determined colorimetrically as previously reported (Montedoro et al., 1992) and the results are expressed as 3, 4-DHPEA equivalents. Evaluation of the intensity of bitterness was carried with the procedure described by Beltranet al. (2007).

Rancimat assay

Rancimat assay oxidation stability was evaluated by the Rancimat apparatus (Mod. 743, Metrohm Ω, Switzerland) using an oil sample of 3 g warmed to 120°C and an air flow of 20 L h^{-1}. Stability was

Table 1. Influence of irrigation regimes on maturity index, pomological parameters of *Chemlali* olive fruit.

Parameter	*Chemlali* olive oil		
	T1	T2	T3
Maturity index	2.9^{b}	2.6^{b}	3.1^{a}
Fesch fruit weight (g)	0.7^{bc}	0.8^{b}	1.4^{a}
Stone weight (g)	0.20^{b}	0.21^{b}	0.25^{a}
Pulp/stone ratio	2.5^{c}	2.8^{b}	4.6^{a}
Fruit damage (%)	2^{c}	3^{b}	24^{a}
*Oil content Soxhlet (%)	29.7^{a}	24.2^{b}	24.8^{b}

T1, T2 and T3, irrigated treatments with 50, 75% and 100% of ETc, respectively. Mean values (n = 3). Values in each row with different superscript letters present significant differences (p<0.05) between the different irrigation strategies for each parameter. *Expressed as dry matter.

expressed as induction time (h).

Volatile compound analyses

Extraction: Solid phase micro extraction was used as a technique for headspace sampling of virgin olive oils. Sampling was performed with Supelco SPME with film thickness of 100m; 75m carboxen/polydimethylsiloxane (CAR/PDMS) were used to sample the headspace of 2 ml of virgin olive oil inserted into a 5 ml glass vial and allowed to equilibrate for 30 min after the equilibration time, the fiber was exposed to the headspace for 50 min at 25°C room temperature. Once sampling was finished, the fiber was withdrawn into the needle and transferred to the injection port of the GC and GC-MS system (Campeol et al., 2001).

Identification: GC analyses were accomplished with an HP-5890 series II instrument equipped with a HP-5 capillary column (30 m x 0.25 mm, 0.25 µm film thickness), working with the following temperature programme: 60°C for 10 min, ramp of 5°C min^{-1} to 220°C; injector and detector temperatures, 250°C; carrier gas, nitrogen (2 ml min^{-1}); detector FID; split ratio, 1:30; injection, 0.5 µl. the identification of the components was performed by comparison of their retention times with those of pure authentic samples and by means of their linear retention indices (LRI) relative to the series of *n*-hydrocarbons. The relative proportions of the constituents were obtained by FID peak area normalization.

GC-EIMS analyses were performed with a Varian CP 3800 gas-chromatograph equipped with a DB-5 Capillary column (30m x 0.25 mm; coating thickness= 0.25µm) and a Varian Saturn 2000 ion trap mass detector. Analytical conditions were as follows: injector and transfer line temperature at 250 and 240°C, respectively; oven temperature was programmed from 60 to 240°C at 3°C min^{-1}; carrier gas, helium at 1 ml min^{-1}; splitless injection. Identification of the constituents was based on comparison of the retention times with those of pure standards of volatile compounds comparing their linear retention indices relative to the series of *n*-hydrocarbons, and on computer matching against commercial (NIST 98 and Adams 1995) and homemade library mass spectra built from pure substances and components of known oils and MS literature data (Stenhagen et al., 1974; Adams, 1995). Moreover, the molecular weights of all the identification substances were confirmed by GC-CIMS, using MeOH as CI ionizing gas (Flamini et al., 2003).

Statistical analysis

All parameters analyzed were carried out in triplicate. Significant differences among varieties studied were determined by an analysis of variance which applied a Student test, using the Statistical Package for the Social Sciences (SPSS) programme, release 11.0 for Windows.

RESULTS AND DISCUSSION

Pomological parameters

Table 1 lists the olive fruit characteristics and composition, as affected by the different irrigation treatments studied and the fruits ripening index for the *Chemlali* cultivar. Infect, ripening index was affected by the irrigation level (Table 1). In the same ripening date, the average level was 2.9 for olives produced from trees submitted to 50% ETc. The average level of fruits obtained from trees submitted to a restitution of 75 and 100% ETc were 2.6 and 3.1, respectively. Individual fruit size increased proportionally with applied water (r=0.924). As a consequence, the pulp stone ratio increased two times at well irrigated treatment. The irrigation treatment apparently did affect the oil accumulation in the *Chemlali* fruit since statistically significant differences in the oil yield were observed in the present study only at a volume of irrigation more than 50% ETc. In fact, Lavee and Wodner (1991) and Motilva et al. (1999) did not observe a slight delay in oil accumulation in fruits from non-irrigated olive trees as a consequence of water stress at the end of the summer season.

Quality indices

The quality parameters evaluated in the olive oil samples from the *Chemlali* olive oil of different irrigation percentage are shown in Table 2. A trend of increasing free acidity (FFA) of virgin olive oil with increased irrigation levels was observed in the analyzed samples. Fatty acid content of 0.8% as oleic acid divides the categories ‘virgin’ and ‘extra virgin’ olive oil according to

Table 2. Influence of irrigation regimes on analytical parameters, fatty acid profiles and oxidative stability of *Chemlali* olive oil.

Parameter	Chemlali olive oil		
	T1	T2	T3
Acidity (%)	0.2^{c}	0.4^{b}	1.6^{a}
Peroxide value (meqO$_2$ kg^{-1})	10.6^{c}	13.5^{b}	20.0^{a}
Category	Extra Virgin	Extra Virgin	Virgin
C16 :0 (%)	18.1^{a}	16.9^{b}	12.0^{c}
C16 :1	2.1^{a}	2.1^{a}	0.4^{b}
C18 :0	2.4^{b}	2.5^{a}	2.7^{a}
C18 :1	58.7^{b}	60.9^{a}	55.1^{c}
C18 :2	16.2^{b}	15.9^{c}	28^{a}
C18 :3	1.0^{a}	1.1^{a}	1.0^{a}
SFA	20.5^{a}	19.0^{b}	14.7^{c}
PUFA	17.1^{b}	17.1^{b}	29^{a}
MUFA	60.8^{b}	63.0^{a}	55.5^{c}
UFA/SFA	3.8^{c}	4.2^{b}	5.7^{a}
MUFA/PUFA	3.5^{b}	3.7^{a}	1.9^{c}
O/L	3.6^{a}	3.8^{a}	1.9^{b}
IV	87.0^{b}	82.8^{c}	102.9^{a}
OS	887.4^{b}	898.2^{b}	1415.7^{a}
Oxidative stability (h)	10.5^{a}	10.0^{a}	4.8^{b}
Oxidative stability (day kg^{-1})	145.9^{a}	139.4^{b}	67.3^{c}
Oxidative stability (year kg^{-1})	0.4^{a}	0.4^{a}	0.2^{b}

T1, T2 and T3, Irrigated treatments with 50, 75 and 100% of ETc, respectively. Mean values (n = 3). Values in each row with different superscript letters present significant differences ($p<0.05$) between the different irrigation strategies for each parameter. *Expressed as dry matter.

EU-legislated standards (European Union Commission Regulation 2003). Consequently, the oil from olives submitted to 50 and 75% ETc were categorized as ‘extra virgin’ olive oil, while the oil produced from olive tress submitted to 100% ETc fell into the ‘virgin’ category. These results suggest that free acidity increased during the short period (several hours at most) between the time the fruit was removed from the trees and the time the oil was extracted and collected. The positive correlation between irrigation level and FFA content could be due to increased sensitivity of fruit with higher water content, a thinner cuticle layer to mechanical injury (Table 1). Such relative sensitivity of olive fruit from high irrigated compared to rain-fed trees was reported previously in Spain for the *Cornicabra* cultivar (Gomez-Rico et al., 2006). Olive oil quality indices observed in the most irrigated olives was probably due to the relatively high fruit damage produced by an olive fly attack that affected mainly the well irrigated olive trees (Gomez-Rico et al., 2007). The same behaviour was observed with the peroxide value for *Chemlali* virgin olive oil submitted to the different irrigation levels (Table 2).

Fatty acid composition

Table 2 reports the level of fatty acids in the *Chemlali* olive oils subjected to three irrigation regimes (50, 75 and 100% Etc, respectively). The oleic acid level exhibited a clear variation in relation to the irrigation level. Hence, virgin olive oil from trees submitted to 50% ETc had 58.7% of oleic acid. The level of this compound increased proportionally with water restitution of about 75% ETc until 60.9%. However, we noticed a significant decrease when 100% ETc was applied to olive trees (Table 2). The linoleic acid showed significant increase when amount of water exceeded 75% ETc. Moreover, the palmitic acid content had values varied from 18.1 to 12% which were higher in oils from tress submitted to low irrigation regimes than those reported in virgin olive oils from tress subjected to high irrigation volume (Table 2). There was a negative linear relationship between *Kc* and the palmitic acid rate (r = -0.944). Another important saturated acid is the stearic acid; its content (2.4%) was barely affected by irrigation regimes (Table 2). With regard to the effect produced in the fatty acid composition by the irrigation regime, we noticed that, the oleic linoleic acid ratio decrease of about the half when 100% of water was used. Similarly, the MUFA/PUFA and SFA/UFA ratios were practically unaffected by the irrigation regimes of 50% ETc and 75% ETc. However, statistically a significant difference was established between the later analyzed samples and virgin olive oils from high irrigation regimes. As a consequence, the MUFA/PUFA ratios

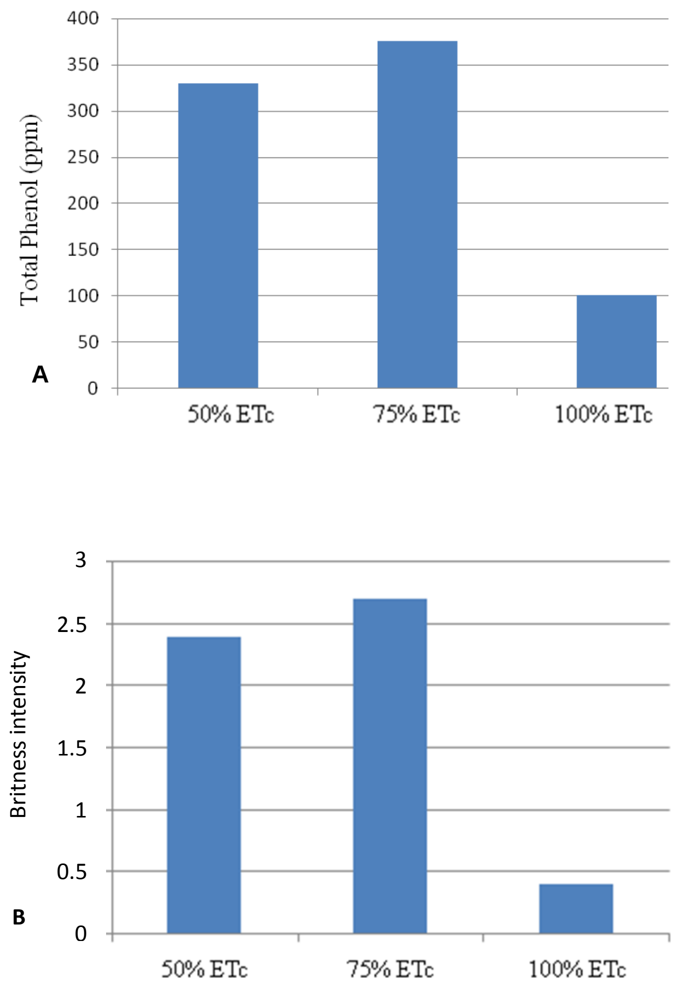

Figure 1. Influence of irrigation regimes on total phenols and bitterness intensity category.

obtained in virgin olive oil obtained from olive trees submitted to 100% ETc were about 2 fold less important than other samples. The irrigation regime superior to 75% ETc, affected significantly the oil fatty acid ratio influences the organoleptic characteristics of the oil because oil with a high content of saturated fatty acids could influence the organoleptic characteristics of the oil. This gives rise to the defect defined as a "fatty sensation" (Patumi et al., 2002; Solinas, 1990). The potential oxidative susceptibility is therefore much higher in the virgin olive oil produced from the well irrigated trees than other VOO (Table 2). Gomez-Rico et al. (2007) and Salas et al. (1997) found that irrigation induces an increase in palmitic and linoleic acids and a decrease in oleic and linolenic acid content in virgin olive oil. Other investigations observed contrast trends in *Arbequina* virgin olive oil obtained by a young super high density orchard, where different regulated deficit irrigation was applied. Moreover, Ingelese et al. (1996) and Patumi et al. (1999) found that the fatty acid composition of different Italian varieties was affected mainly by cultivar and not by irrigation practices.

Phenols

Figure 1 reports the concentration of the phenolic compounds (mg kg^{-1}) found in virgin olive oils obtained from *Chemlali* olives subjected to the different irrigation managements studied. Our results showed that an irrigation regime higher than 75% ETc is very detrimental to the concentration of total phenols. Hence, we noticed a sharp decrease of about 3.5 times in *Chemlali* virgin olive oil obtained from olives well irrigated with 100% ETc. In fact, phenolic biosynthesis in plants is known to be highly sensitive to environmental conditions. Several investigations (Patumi et al., 1999; Tovar et al., 2002) have reported that different water status of olive trees under different irrigation strategies, implied changes in the activity of enzymes responsible for phenolic compounds synthesis in drupes, such as L-phenylalanine ammonia lyase (PAL), whose activity is grater under higher water stress conditions, leading to superior phenolic contents in the olive flesh and therefore in the virgin olive oils obtained.

Intensity of bitterness

The bitterness intensity of virgin olive oils from the different irrigation strategies are depicted in Figure 1. Bitter taste is one of the characteristic attributes of virgin olive oil. Its intensity varies greatly and influences consumer attraction and acceptance. Our results showed that an irrigation volumes superior to 75% ETc decrease the bitterness intensity of the oils from 2.8 to 0.4. The same volume of water transforms *Chemlali* virgin olive oils from bitter oils to non bitter oils. The decrease in bitterness due to the irrigation technique used, though very low in the oils studied, is indeed relevant from a marketing point of view. Oils with a high level of bitterness are less preferred by consumers and therefore the descent of this attribute could be desirable in rich phenol virgin olive oil such as the *Chétoui* olive oil (Issaoui et al., 2010). On the contrary, the same effect could negatively affect *Chemlali* virgin olive oil sensory profile, in fact due to its natural low phenolic content, a descent of these compounds would lead to a virgin olive oil which is too mild and flat, and moreover its reduced oxidative stability could reduce significantly the shelf-life of this product (Gomez-Rico et al., 2006; Patumi et al., 2002 ; Aparicio et Luna 2002).

Volatile compounds

From the biochemical point of view, the volatile compounds are considered as direct metabolites produced in plant organs by intracellular biogenic pathways (Aparicio and Luna, 2002). The increased activity and synthesis of enzymes can lead to an accumulation of metabolites that influence the biogenesis of volatiles. This explains why the biochemical pathways are responsible for the particular profiles of the monovarietal virgin olive oils although external parameters (climate, soil, harvesting and extraction conditions) modulate the final sensory profile (Aparicio and Luna, 2002). Table 3 shows the level of these individual volatile compounds in *Chemlali* virgin olive oils as influenced by different irrigation managements. Because of the importance of the green perception in the virgin olive oil flavour, the C6 compounds- also called "green volatiles" (Aparicio and Morales, 1998) were quantified in all the analyzed samples. Virgin olive oil obtained from olive trees submitted at 50% ETc had the highest level of C6 aldehydes (59.0%), flowed by samples of olive trees treated by 75% Etc (14.0%), whereas the oil obtained from trees submitted to 100% ETc had the lowest level (11.6%). It is also noteworthy that the content of (*E*)-2-hexenal, which gives the typical "green note" to extra virgin olive oil, is by far the major C6 aldehyde compound in studied oils of trees submitted to irrigation treatments T1 and T2 (Table 3). Hence, we found that, the rate of (*E*)-2-hexenal decreased from 54.4 (in oils produced from olive trees submitted to 50% ETc) to 7.2% (in oils produced from olive trees submitted to 100% ETc) with increasing irrigation volumes (Table 3). The hexanal content (related to apple, green, and cut grass sensory notes) seems to be barely affected by the irrigation management. In terms of C6 alcohols, we identified only the 1-hexanol in virgin olive oil analyzed the value of this compounds ranged between traces to 11.2%. They have less sensory significance than aldehydes because of their higher odour threshold values and their sensory descriptions being associated with fruity, soft green and aromatic sensory notes (Luna et al., 2006). Our results showed that irrigation had a great influence on the level of this compound; hence we noticed that the level of this compound is the highest in sample T2 when irrigation treatment 75% of Etc is applied (Table 3).

Esters, compounds associated with sweet, fruity and green leaves notes (Aparicio and Luna, 2002; Luna et al., 2006) as hexyl acetate and (*Z*)-3-hexenyl acetate, were present in aroma of all studied virgin olive oils (Table 3). Our results showed that esters were very influenced by the irrigation regimes applied. Hence, we noticed an increase in both hexyl acetate and (*Z*)-3-hexenyl acetate from 1.6 and 2.3% to 21.2 and 4.3% when we increased irrigation volumes until 75% ETc. The hydrocarbons of olive oils have been studied by different authors as possible markers to distinguish virgin olive oil from different olive varieties or different geographic origins (Aparicio and Luna, 2002 ; Issaoui et al., 2010; Ben Temime et al., 2006; Issaoui et al., 2009). The hydrocarbons 1-nonene, 3-methyl -4-heptanone, 5-methyl-3-heptanone, 1-heptanol, 3-octanone, 3-octanol, myrcene, limonene, phenyl acetaldehyde, (*E*)-β-ocimene, (*E*)-2-octenal, phenylethylalcohol, borneol, *E*)-2-hexenyl butyrate, ethyl octanoate, decanal, (*E*, *Z*)-2,4-decadienal, valencene and (*E*, *E*)-α-farnesene have been detected in the aroma fraction of the tested oils. The contents of limonene did exceeded 10% in *Chemlali* virgin olive oils. Our results showed that their level was dependent to the irrigation regimes applied because their response to the irrigation was quite high. It seems that the high volume of water decrease the abundance of limonene in the virgin olive oils (Table 3). This component could play a very important role in the fragrance of this precious food as indicated by Vichi et al. (2003) and Baccouri et al. (2008). In contrast, the (*E*)-β-ocimene showed an inverse behaviour to the limonene. Hence, *E*)-β-ocimene increased with increasing irrigation volume (Table 3). We noticed also a positive correlation between the

Table 3. Influence of irrigation regimes on aromatic composition (%) of *Chemlali* olive oil.

Parameter	Chemlali olive oil		
	T1	T2	T3
Hexanal	4.6^{b}	5.7^{a}	4.4^{b}
(E)-2-hexenal	54.4^{a}	8.3^{b}	7.2^{b}
1-hexanol	tr	11.2^{a}	7.2^{b}
1-nonene	ND	7.2^{a}	4.3^{b}
3-methyl -4-heptanone	1.4	ND	ND
5-methyl-3-heptanone	0.9	ND	ND
1-heptanol	0.7^{a}	tr	0.5^{a}
3-octanone	0.4^{a}	tr	0.9^{a}
3-octanol	0.7	ND	ND
Myrcene	1.2^{a}	tr	1.3^{a}
(Z)-3-hexenyl acetate	2.3^{b}	4.3^{a}	4^{a}
1-hexyl acetate	1.6^{b}	21.2^{a}	17.4^{a}
Limonene	10.8^{a}	2.6^{b}	3.3^{b}
Phenyl acetaldehyde	ND	ND	0.5
(E)-β-ocimene	1.4^{c}	7.6^{b}	11.5^{a}
(E)-2-octenal	1.2	ND	1.5
Nonanal	0.5	ND	ND
Phenylethylalcohol	1.0^{b}	2.2^{a}	1.4^{b}
Borneol	tr	5.0^{a}	2.8^{b}
(E)-2-hexenyl butyrate	ND	0.4	ND
Ethyl octanoate	ND	1.0	ND
Decanal	5.0^{c}	10.9^{b}	15.3^{a}
(E, Z)-2,4-decadienal	ND	1.4	0.9
Valencene	5.8^{a}	tr	1.5^{b}
(E, E)-α-farnesene	3.7^{b}	6.9^{a}	7.5^{a}
Total (%)	97.2^{a}	95.9^{a}	94.0^{a}

T1, T2 and T3, Irrigated treatments with 50, 75 and 100% of ETc, respectively. Mean values (n = 3). Values in each row with different superscript letters present significant differences (p<0.05) between the different irrigation strategies for each parameter. *Expressed as dry matter. Tr, Traces; ND, not detected.

appearance of decanal and the irrigation volumes applied to the olive tress (r = 0.996) and also a positive correlation between decanal and the percentage of the fruit damage (r = 0.843). In fact, decanal is the result of autoxidation of oleic acid, for that reason it was more abundant in oils rich in free fatty acid (r = 0.889), peroxide value (r = 0.955) and oxidative susceptibility (r = 0.831).

The sum of the products of lipoxygenase oxidation (LOX) pathways, which generally are the major components of the olive oil volatile fraction, were higher in *Chemlali* virgin olive oils produced from tress submitted to a low irrigation volumes (50%), than in higher ones (75 and 100% ETc). This value decreased from 62.9 (at a restitution of 50% of crop evapotranspiration) and 50.7 (at a restitution of 75% of crop evapotranspiration) to 40.2% (at a restitution of 100% of crop evapotranspiration). It became clear that the changes in the volatiles of *Chemlali* virgin olive oils under the different irrigation practices applied in the orchards. Hence, the volatile compounds most affected by the water status of olive trees were (*E*)-2-hexenal, hexanal, limonene, 1-hexanol, (*Z*)-3-hexenyl acetate, 1-hexyl acetate and (*E*)-β-ocimene. *Chemlali* virgin olive oils obtained from olive trees under stress due to deficit irrigation are characterized by high green and citrus like sensory notes than those from high irrigated trees.

Oxidative stability

The observed decrease of oxidative stability does affect markedly the *Chemlali* olive oil shelf life or quality when the amount of water added is more than 75% ETc (*Table 2*). In fact, as a consequence of antioxidant compounds decrease we showed also an oxidative stability (OSI) decrease. Hence, a positive correlation was established between total phenols and OSI (r = 0.97), also between oleic linoleic acid ratio and OSI (r = 0.985) and with (*E*)-2-hexenal (r = 0.584). In contrast, the potential oxidative susceptibility is therefore much higher in the *Chemlali* virgin olive oil produced from the well irrigated trees by 100% ETc (lower oxidative stability) than other VOO. In fact, as the irrigation volumes increased, oxidative susceptibility and iodine value increased (r = -0.998 and r = -0.961, respectively).

Conclusion

The analysis of *Chemlali* virgin olive oils has shown that there were quantitative differences among the chemical profiles of oils tested, in spite of issued from the same cultivar. Then, as the harvesting period and extraction conditions were similar for the samples analyzed, these results confirmed that irrigation practices is responsible for some of the differences observed in olive oil quality since, for the same raw material, different final products are obtained. Increased irrigation quantity increased the free acidity level of the oil and decreased the total phenol content and the aromatic compounds produced through LOX pathway of VOO. A restitution of 75% of crop evapotranspiration was sufficient to achieve good quality of *Chemlali* olive oil, while higher water volumes gave low quality. Moreover, additional studies are necessary to confirm normal composition values for *Chemlali* olive oils cultivated in other irrigation conditions for more than one year.

ACKNOWLEDGEMENTS

This research was supported by the Tunisian Ministry of Enseignement Superieur, Scientific Research and Technology (UR03/ES-08). Part of this work was carried out at the Dipartimento di Chimica Bioorganica e Biofarmacia, Universita` di Pisa, Italy. We wish to thank the personnel of the laboratory of ‘‘Human Nutrition and Metabolic Disorder" Faculty of Medicine of Monastir, Institute of Olivier of Sousse’’

Abbreviations: FAMEs, Fatty acid methyl esters; **FID,** flame ionization detector; **PAL,** L-phenylalanine ammonia lyase; **LOX,** lipoxygenase oxidation.

REFERENCES

Adams RP (1995). Identification of Essential Oil Components by Gas ChromatographyMass Spectroscopy, Allured Publ. Corp, Carol Stream, IL.

Allen RG, Pereira LS, Raes D, Smith M (1998). Crop evapotranspiration. Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Rome P. 56.

AOCS (1995). American Oil Chemists Society: Official and Recommended Practices of the AOCS. 4th Edn. AOCS Press, Champaign, IL (USA) 1995, Official Method Aa pp. 4-38.

Aparicio R, Luna G (2002). Characterisation of monovarietal virgin olive oils. Eur. J. Lipid Sci. Technol. 104:614-627.

Aparicio R, Morales MT (1998). Characterization of olive ripeness by green aroma compounds of virgin olive oil. J. Agric. Food Chem. 46:1116-1122.

Baccouri O, Bendini A, Cerretani L, Guerfel M, Baccouri B, Lercker G, Zarrouk M, Daoud Ben Miled D (2008). Comparative study on volatile compounds from Tunisian and Sicilian monovarietal virgin olive oils. Food Chem. 111:277-296.

Bedbabisa S, Ben Rouinab B, Boukhrisa M (2010). The effect of waste water irrigation on the extra virgin olive oil quality from the Tunisian cultivar Chemlali. Sci. Hortic. 125:556-561.

Beltran G, Ruona MT, Jimenez A, Uceda M, Aguilera MP (2007). Evaluation of virgin olive oil bitterness by total phenol content analysis. Eur. J. Lipid Sci. Technol. 108:193-197.

Ben Temime SE, Campeol E, Cioni PL, Daoud D, Zarouk M (2006). Volatile compounds from chatoui olive oil and variations induced by growing area. Food Chem. 99:315-325.

Boskou D (1996). Olive oil: Chemistry and technology. AOCS Press, Champaign, IL, USA. P. 85.

Campeol E, Flamini G, Chericoni S, Catalano S, Cremonini R (2001). Volatile compounds from three Cultivars of *Olea europea* from Italy. J. Agric. Food Chem. 49:5409-5411.

D'Andria R, Lavini A, Morelli G, Patumi M, Tiranziani S, Calandrelli D, Fragnito F (2004). Effects of water regimes on five pickling and double aptitude olive cultivars (*Olea europaea* L.). J. Hort. Sci. Biotechnol. pp. 79-18.

Dag A, Ben-Gal A, Yermiyahu U, Basheer L, Nir Y, Kerem Z (2008). The effect of irrigation level and harvest mechanization on virgin olive oil quality in a traditional rain-fed ‘Souri’ olive orchard converted to irrigation. J. Sci. Food. Agric. 88:1524-1528.

European Union Commission Regulation (1989/2003). Characteristics of olive and olive pomace oils and their analytical methods. Off. J. Eur. Commun. L295:57.

European Union Commission Regulation (2568/1991). Characteristics of olive and olive pomace oils and their analytical methods. Off. J. Eur. Commun. L248, 1991, P. 1.

Flamini G, Cioni PL, Morelli I (2003). Volatiles from leaves, fruits and virgin oil from *Olea europaea* Cv. *Olivastra Seggianese* from Italy. J. Agric. Food Chem. 51:1382-1386.

Gomez-Rico A, Salvador MD, Fregapane G (2007). Virgin olive oil and olive fruit minor constituents as affected by irrigation management based on SWP and TDF as compared to ETc in medium-density young olive orchards (*Olea europaea* L. cv. Cornicabra and Morisca). Food Res. Int. 42:1067-1076.

Gomez-Rico A, Salvador MD, Moriana A, Perez D, Olmedilla N, Ribas F, Fregapane G (2006). Influence of different irrigation strategies in a traditional Cornicabra cv. olive orchard on virgin olive oil composition and quality. Food Chem. 100:568-578.

Grattan SR, Berenguer MJ, Connell JH, Polito US, Vossen PM (2006). Olive oil production as influenced by different quantities of applied water. Agric. Water Manage. 85:133-140.

Issaoui M, Ben Hassine K, Flamini G, Brahmi F, Chehab H, Aouni Y, Hammai M (2009). Discrimination of some monovarietal olive oils according to their oxidative stability, volatiles compounds and sensory analysis. J. Food Lipids 16:164-186.

Issaoui M, Dabbou S, Echbili A, Rjiba I, Gazzah N, Trigui A, Hammami M (2007). Biochemical characterisation of some Tunisian Virgin Olive Oils obtained from different cultivars growing in Sfax National Collection. J. Food Agric. Environ. 5:17-21.

Issaoui M, Flamini G, Brahmi F, Dabbou SB, Hassine K, Taamali A, Zarrouk M, Hammami M (2010). Effect of the growing area conditions on differenciation between Chemlali and Chétoui olive oils. Food Chem. 119:220-225.

Lavee S, Wodner M (1991). Factors affecting the nature of oil accumulation in fruit of olive (*Olea europaea* L.) cultivar. J. Hort. Sci. 66:583-591.

Luchetti F (2000). Introduction: In Handbook of Olive Oil: Analysis and Properties (Eds, Harwood, J. Aparicio, R.) Aspen Publishers, Inc., Gaithersburg, MD, USA, pp. 1-16.

Luna G, Morales MT, Apaaricio R (2006). Characterization of 39 varietal virgin olive oils by their volatile compositions. Food Chem. 98:243-252.

Montedoro GF, Servili M, Baldioli E, Miniati E (1992). Simple and hydrolyzable phenolic compounds in virgin olive oil.1.1. Their extraction, separation and quantitative and semiquantitative. Afr. J.

Agric. Res. 40:1571-1576.

Moriana A, Orgaz F, Fereres E, Pastor M (2003). Yield responses of mature olive orchard to water deficits. J. Am. Soc. Hortic. Sci. 128:425-431.

Motilva MJ, Romero MP, Alegre S, Girona J (1999). Effect of regulated deficit irrigation in olive oil production and quality. Acta Horticulturae., 474:377-380.

Palese AM, Celano G, Masi S, Xiloyannis C (2006). Treated wastewater for irrigation of olive trees: effects on yield and oil quality. In: Olivebioteq 2006, November 5-10 Mazara del Vallo, Marsala (Italy), II, pp. 123-129.

Patumi M, d´Andria R, Fontanazza G, Morelli G, Giori P, Sorrentino G (1999). Yield and oil quality of intensively trained trees of three cultivars of olive under different irrigation regimes. J. Hortic. Sci. Biotechnol. 74:729-737.

Patumi M, d'Andria R, Marsilio G, Fontanazza G, Morelli G, Lanza B (2002). Olive and olive oil quality after intensive monocone olive growing (*Olea europaea* L., cv. Kalamata) in different irrigation regimes. Food Chem. 77:27-34.

Salas J, Pastor M, Castro J, Vega V (1997). Influencia del riego sobre la composicion y caracterısticas del aceite de oliva. Grasas Aceites 48:74-82.

Samish RM, Spiegel P (1961). The use of irrigation in growing olives for oil production. Israel J. Agric. Res. 11:87-95.

Salvador MD, Aranda F, Gomez-Alonso S, Fregapane G (2001). Cornicabra virgin olive oil: a study of five crops seasons. Composition, quality and oxidative stability. Food Chem. 74:267-274.

Solinas M (1990). Olive oil quality and its determining factors. In proceedings of problems on olive oil quality congress. Sassari, Italy. pp. 23-55.

Stenhagen E, Abrahamsson SMc, Lafferty FW (1974). Registry of mass spectral data. John Wiley and Sons, New York. P. 3136.

Tovar MJ, Romero MP, Alegre S, Girona J, Motilva MJ (2002). Composition and organoleptic characteristics of oil from Arbequina olive (*Olea europaea* L.) trees under deficit irrigation. J. Sci. Food Agric. 82:1755-1763.

Uceda M, Frias L (1975). Harvest dates. Evolution of the fruit of content, oil composition and oil quality. In Proceedings of II Seminario Oleicola International; International Olive-oil Council: Cordoba, Spain. P. 125.

Vichi S, Pizzale L, Conte LS, Buxaderas S, López-Tamames E (2003). Solidphase microextraction in the analysis of virgin olive oil volatiles fraction: Characterisation of virgin olive oils from two distinct geographical areas of northern Italy. J. Agric. Food Chem. 57:6572-6577.

Zampounis V (2006). In Olive oil: Chemistry and Technology, 2nd add. (Ed, Boskou, D.) Champaign: AOCS Press, pp. 21-40.