Influence of the Site of Cultivation on Chétoui Olive (*Olea europaea* L.) Oil Quality

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Abstract: A comparative study was conducted to evaluate the effect of location on the chemical composition and quality of monovarietal virgin olive oils obtained from the Chétoui cultivar in relation to the fruit ripening stages. Three sites representative of two Tunisian olive growing regions were examined, Selten (region I (RI): original site of plantation of Chétoui variety in the north of the country), Ousletia and Jelma (region II (RII): in the central part of the country away from the original plantation site). In this study, Chétoui olive cultivar was found to have different responses to environmental conditions. Chétoui olive oils showed lower values in phenol and *o*-diphenol contents and were less stable to oxidation (weaker oxidative stability and antioxidant activity levels) when the olive trees were cultivated away from the original plantation site. These Chétoui olive oils are also characterized by decreased oil content and higher values of quality parameters such as free acidity, peroxide value and UV absorbance due probably to the drought during the flowering and olive ripening periods. Furthermore, many analytical parameters, i.e., chlorophyll pigments, carotenoids, oleic acid contents, total phenol and *o*-diphenol amounts, oxidative stability, antioxidative capacity and quality parameters showed nearly the same changes during fruit ripening but in different degrees depending on the site of the plantation.

Key words: Chétoui olive oil, Fatty acids, Locations, Olive maturity, Oxidative stability.

Virgin olive oil, extracted from fresh and healthy olive fruits (*Olea europaea* L.) and properly processed, is characterized by an elevated stability and unique aroma highly appreciated by consumers. Virgin olive oil is a natural juice, in contrast to other edible oils with a similar fatty composition, namely, sunflower and soybean oils, which must be refined before consumption, thus losing their original composition during this process. Virgin olive oil represents a typical lipid source of the Mediterranean diet, and its consumption has been associated with a low incidence of cardiovascular diseases, neurological disorders, and breast cancer (Medeiros, 2001; Gimeno et al., 2002; Kelly et al., 2004). The oxidative stability, sensory quality and health properties of virgin olive oil stem from its prominent and well-balanced chemical composition (Bendini et al., 2007). In fact virgin olive oil is a source of healthy unsaturated fatty acids and many micronutrients, especially antioxidants, such as phenol compounds, vitamin E and carotenoids which may act, by different mechanisms, as an effective defence against reactive oxygen species (Warhrburg et al., 2002; Morelló et al., 2005).

The chemical and quality characteristics of a virgin olive oil are influenced by the site of cultivation and the olive ripening stage (Rotondi et al., 2004; Tura et al., 2007). Morello et al. (2006) reported that the levels of pigments and phenols in olive oil or pulp from olive trees frost-damaged during winter were lower as a consequence of faster ripening. Ben Témime et al. (2006) showed that the climatic conditions, in particular the rainfall during the growing and the ripening of the olive fruits, influence the concentration of phenolic compounds. According to Osman et al. (1994) phenols, unsaturated fatty acids, oxidative stability and free acidity are negatively correlated with altitude. Pannelli et al. (1993) showed that rainfall was correlated positively with total volatiles. Servili et al. (1990) found that the skeleton percentage of soil was correlated positively with the phenol content of oils (possibly because it influences negatively the moisture of soil). Ranalli et al. (1999) reported that fruitiness, the contents of oleic and linoleic acids, sensory score, and total sterol content could be negatively correlated with the limestone percentage of the soils.
During ripening, several metabolic processes take place in olives with subsequent variations in profiles of some compounds such as fatty acids, polyphenols, tocopherols, pigments. These changes are reflected on the sensorial characteristics, and oxidative stability and nutritional value of the obtained product and, obviously, on its quality grade.

Nevertheless, there is scarce information available on the influence of the site of cultivation of olive trees in relation to the fruit ripening in the Tunisian cultivars. Tunisia is the largest African exporter and fourth largest exporter in the world after Spain, Italy and Greece with an annual average export over 100 000 tons (IOOC, 2004). The Chétoui cultivar, used in this study, is the second main variety cultivated in Tunisia. It is widespread in the north of the country, occurring in plains as well as in mountainous regions. The production area of this variety covers 176 000 ha and accounts for more than 20% of the olive oil produced in Tunisia. To increase the production and to evaluate the genetic plasticity of the Chétoui cultivar under various environmental conditions such as arid climate, we examined the chemical composition of oils as well as the oxidative stability and anti-oxidative activity in relation to the olive maturity process. This study aimed also to define the optimum harvesting period for the tested oils.

**Materials and Methods**

1. **Sampling**

   Experiments were carried out with monovarietal virgin olive oils from the second main Tunisian cultivars (cv. Chétoui). Three sites representative of two Tunisian olive growing regions were investigated, the first (Selten) was in the north of the country (original region of plantation (RI)) of Chétoui variety and the two others (Ousletia and Jelma) were in central Tunisia (away from original region of plantation (RII)). The location and the environmental particularities of the three locations are shown in Fig. 1.

   Fig. 1. Localization and description of the three Tunisian sites.

   - **Site: Selten**
     - Original region of plantation (RI)
     - Latitude: 36° 41’ 34.7” N
     - Longitude: 10° 24’ 55.7” E
     - Altitude: 17 m
     - Annual mean temperature: 20°C
     - Annual mean rainfall: 438 mm
     - Soil type: silty sand

   - **Site: Ousletia**
     - Away from original region of plantation (RII)
     - Latitude: 35° 51’ 26.6” N
     - Longitude: 09° 36’ 27.6” E
     - Altitude: 472 m
     - Annual mean temperature: 21.5°C
     - Annual mean rainfall: 281 mm
     - Soil type: silty clay

   - **Site: Jelma**
     - RI
     - Latitude: 35° 26’ 00.4” N
     - Longitude: 09° 25’ 41.0” E
     - Altitude: 410 m
     - Annual mean temperature: 19.5°C
     - Annual mean rainfall: 189.4 mm
     - Soil type: silty clay
throughout April. After harvest, olive fruits were immediately transported to the laboratory and carefully blended. One hundred olives were randomly taken from each harvest date, and the maturation index (MI) was determined. This parameter is the function of fruit color in both skin and pulp and was determined according to the method developed by the Agronomic Station of Jaén (Uceda and Hermoso, 1998). MI values range from 0 (100% intense green skin) to 7 (100% purple flesh and black skin).

2. Oil Extraction

Oil was extracted under the conditions similar to the industrial extraction procedures using an Abencor analyzer (MC2 Ingenierias y Sistemas, Sevilla, Spain). After determination of their ripeness indices, olives were washed and crushed with a stainless steel hammer crusher mill and malaxed for 30 min at 25°C. The paste so obtained was centrifuged without addition of water. The oil was separated by decanting, transferred into amber glass bottles without headspace, and stored in the dark at 4°C.

3. Analytical methods

Free acidity, peroxide value, UV spectrophotometric indices (K232, K270) and fatty acid composition were evaluated according to the official methods described in the European Union Commission Regulations EEC/2568/91 and EEC/1429/92.

Free acidity, expressed as percent of oleic acid (% C18:1), was determined by titration of the solution of oil dissolved in ethanol/ether (1:1, v/v) with 0.1 M potassium hydroxide ethanolic solution. Peroxide value, given in milliequivalents of active oxygen per kilogram of oil (meq O₂ kg⁻¹), was determined as follows: a mixture of oil and chloroform/acetica acid (10:14, v/v) was left to react in darkness in a saturated potassium iodide solution; the free iodine was then titrated with a sodium thiosulfate solution.

K232 and K270 extinction coefficients were calculated from absorptions at 232 and 270 nm, respectively, using a 1% solution of oil in cyclohexane with 1 cm path length.

For the determination of fatty acid composition, the methyl-esters were prepared from olive oil, and after cold saponification by vigorous shaking of a solution of oil in methyl-esters were prepared from olive oil, and after cold saponification by vigorous shaking of a solution of oil in ethyl acetate (10%, w/v), 1 mL was added to 4 mL of a freshly prepared DPPH solution (10⁻⁴ M in ethyl acetate) in a screwcapped 10 mL test tube. The reaction mixture was then shaken vigorously for 10 s in a Vortex apparatus, and the tube was maintained in the dark for 30 min, after which a steady state was reached. The absorbance of the mixture was measured at 515 nm against a blank solution. The radical scavenging activity (RSA) toward [DPPH] was expressed as the % reduction in DPPH concentration (% [DPPH]red) by the constituents of the oils:

% [DPPH]red = 100 - (1 × [DPPH]₃₀/[DPPH]₀), where [DPPH]₀ and [DPPH]₃₀ were the concentrations of DPPH in the control sample (t = 0) and in the test mixture after the 30 min reaction, respectively.

4. Statistical analysis

The results are expressed as means ± SD of the mean values. In addition, Duncan’s multiple range tests were used to determine significant differences among data. Statistical Analysis was performed using the Statistica 5.0 package (StatSoft '97 edition).
Results and Discussion

The olives picked from each site and used for oil extraction had the following maturation indices: RI (Selten): 1.02, 2.03, 3.07, 4.17, 5.09; RII: Jelma: 1.4, 2.1, 3.01, 4.22; Ousletia: 1.08, 2.01, 3.13, 4.33.

Free acidity has been exclusively used as a traditional criterion for classifying olive oil. The percentage of free acidity of studied oils, increased as ripening progressed as shown in Table 1. This trend was confirmed by the high positive correlation between maturation index (MI) and free acidity (Table 2). The same behaviour has been shown in Table 1. This trend was confirmed by the high positive correlation between maturation index (MI) and peroxide value (Table 2). The same behaviour has been shown in Table 1. This trend was confirmed by the high positive correlation between maturation index (MI) and peroxide value (Table 2). The same behaviour has been shown in Table 1. This trend was confirmed by the high positive correlation between maturation index (MI) and peroxide value (Table 2). The same behaviour has been shown in Table 1. This trend was confirmed by the high positive correlation between maturation index (MI) and peroxide value (Table 2). The same behaviour has been shown in Table 1. This trend was confirmed by the high positive correlation between maturation index (MI) and peroxide value (Table 2). The same behaviour has been shown in Table 1. This trend was confirmed by the high positive correlation between maturation index (MI) and peroxide value (Table 2). The same behaviour has been shown in Table 1. This trend was confirmed by the high positive correlation between maturation index (MI) and peroxide value (Table 2). The same behaviour has been shown in Table 1. This trend was confirmed by the high positive correlation between maturation index (MI) and peroxide value (Table 2). The same behaviour has been shown in Table 1. This trend was confirmed by the high positive correlation between maturation index (MI) and peroxide value (Table 2).

The peroxide value and UV characteristics are two main parameters that represent the progress of the stages that lead to oil rancidity. As indicated in Table 1, the changes in peroxide value were nearly the same in the different locations; they decreased during the ripening process. High negative correlations were found between the maturation index (MI) and peroxide value (Table 2). The Chétoui olive oils obtained from different locations at

| Geographical region | MI | Oil content (% dry weight) | Acidity (% C18:1) | PV (meq O₂ kg⁻¹) | K292 | K270 | Chlorophylls (mg kg⁻¹) | Carotenoids (mg kg⁻¹) |
|---------------------|----|---------------------------|------------------|-----------------|------|------|------------------------|---------------------|
| RI Selten           | 1.02 | 43.26±2.29 a | 0.24±0.01 c | 6.53±0.63 a | 1.67±0.00 a | 0.17±0.00 a | 9.17±0.32 a | 3.82±0.14 a |
|                     | 2.03 | 56.97±0.08 a | 0.24±0.01 c | 5.75±0.43 a | 1.60±0.01 a | 0.13±0.01 bc | 6.11±0.23 b | 2.67±0.10 b |
|                     | 3.07 | 57.45±2.06 a | 0.26±0.02 c | 4.29±0.26 b | 1.61±0.01 a | 0.14±0.00 b | 4.62±0.10 c | 2.16±0.07 c |
|                     | 4.17 | 55.19±0.39 a | 0.30±0.03 b | 3.50±0.25 c | 1.53±0.08 b | 0.13±0.01 c | 4.30±0.34 cd | 2.08±0.10 cd |
|                     | 5.09 | 52.60±0.58 b | 0.34±0.01 a | 3.00±0.25 a | 1.43±0.04 c | 0.11±0.01 d | 3.84±0.28 d | 1.90±0.09 d |
| Jelma               | 1.40 | 42.93±0.20 c | 0.28±0.05 b | 8.00±0.50 a | 1.65±0.04 ab | 0.19±0.00 ab | 6.18±0.65 a | 2.77±0.30 a |
|                     | 2.10 | 46.60±1.48 b | 0.31±0.02 b | 7.33±0.52 a | 1.61±0.04 a | 0.19±0.01 a | 5.16±0.25 b | 2.80±0.18 b |
|                     | 3.01 | 49.22±2.53 a | 0.35±0.00 b | 6.17±0.29 b | 1.48±0.03 b | 0.18±0.00 b | 4.74±0.45 b | 2.14±0.02 c |
|                     | 4.22 | 46.85±2.68 b | 0.44±0.03 a | 5.17±0.38 b | 1.48±0.07 ab | 0.18±0.00 a | 3.11±0.27 a | 1.70±0.19 a |
| RII                 | 1.08 | 41.27±1.60 c | 0.25±0.02 c | 8.83±0.38 a | 1.60±0.05 a | 0.11±0.00 ab | 6.12±0.29 a | 2.46±0.22 a |
|                     | 2.01 | 45.47±2.06 b | 0.28±0.03 bc | 8.75±0.25 a | 1.50±0.04 a | 0.10±0.01 b | 4.73±0.27 b | 2.09±0.15 b |
|                     | 3.13 | 49.96±0.18 a | 0.30±0.02 b | 7.17±0.52 a | 1.33±0.06 b | 0.12±0.01 ac | 3.63±0.29 a | 1.67±0.13 c |
|                     | 4.33 | 47.16±1.09 b | 0.38±0.03 a | 5.58±0.38 c | 1.36±0.06 b | 0.12±0.01 a | 3.41±0.10 c | 1.59±0.17 c |

Extra virgin olive oil | - | ≤0.80% | ≤20.00 | ≤2.50 | ≤0.22 | - | - |

Data are expressed as mean values ± SD of three independent experiments. Duncan’s test has been used to assess significance (Duncan’s test, p ≤ 0.05). Values followed by the same letters within column are not significantly different.

MI: maturation index.

Table 2. Regression coefficients between: (A): several analytical parameters and maturation index; (B): total phenols, α-diphenols and oxidative stability; (C): total phenols, α-diphenols and RSA of the Chétoui olive oils obtained from RI and RII.

| RI       | Ousletia | Jelma |
|----------|----------|-------|
| A        |          |       |
| Acidity  | 0.95**   | 0.97**| 0.99** |
| PV       | -0.90**  | -0.98**| -0.99** |
| K292     | -0.95**  | -0.94**| -0.90** |
| K270     | -0.90**  | 0.73 NS| 0.68 NS |
| Chlorophylls | -0.91** | -0.94**| -0.98** |
| Carotenoids | -0.90**| -0.96**| -0.96** |
| MUFA/PUFA | -0.90**  | -0.97**| -0.97** |
| C18:1/C18:2 | -0.90** | -0.97**| -0.97** |

| B        |          |       |
| Total Phenols | 0.99**   | 0.90**| 0.94** |
| α-diphenols | 0.89**   | 0.90**| 0.99** |

| C        |          |       |
| Total Phenols | 0.93**   | 0.90**| 0.97** |
| α-diphenols | 0.93**   | 0.90**| 0.97** |

*: significant at p ≤ 0.05; **: significant at p ≤ 0.01; NS: not significant. C18:1: oleic acid; C18:2: linoleic acid.
more advanced stages of maturity showed lower peroxide values. This behaviour can be explained by a decrease in the activity of lipoxygenase. These results are in accord with the finding of other authors (Guitérrez et al., 1999; Salvador et al., 2001; Baccouri et al., 2007). As observed in free acidity, the oil in Jelma and Ousletia (RII) showed higher peroxide values than that in Selten as ripening progressed. All studied oil samples showed lower peroxide values ranging from 3.00 to 8.83 meq O₂ kg⁻¹, which belong to extra virgin olive oil category.

UV spectrophotometric characteristics were expressed by measuring the specific extinction coefficients at 232 and 270 nm. The change in spectrophotometric absorption at 232 nm (K₂₃₂) was similar to that in the peroxide index in the different locations with a decrease at a later maturation stage, whereas, the absorbance at 270 nm (K₂₇₀) decreased only in the Chétoui oils obtained from Selten (RI), and remained practically constant in the oils from Jelma and Ousletia during the ripening (Table 1). Salvador et al. (2001) and Matos et al. (2007) also reported that UV absorbance of olive oil diminished during fruit maturation. The low values of K₂₃₂ and K₂₇₀ also confirmed the good overall quality of these oils at each olive ripening stage. In no case in either sample did these parameters exceed 2.50 and 0.22, the limits for “Extra virgin olive oil” category, for K₂₃₂ and K₂₇₀, respectively.

The quality parameters such as free acidity, peroxide value and specific ultraviolet absorbance are generally influenced by processing and storage conditions, as well as fruit quality, and determine the classification of the oil. However, all olive samples used for oil extraction were in a good healthy state without any kind of infection or physical damage and the difference in these quality parameters between the RI (Selten) and RII (Jelma and Ousletia) may be due to the differences in the climatic conditions between the two regions. The higher free acidity and peroxide values observed in Jelma and Ousletia olive oils were probably the consequence of drought during the flowering and ripening periods. The cumulative rainfall during the flowering period (March-April) was 110, 91.8 and 45.5 mm in Selten, Ousletia and Jelma, respectively, and that during the ripening phase (October-January) was 185.4, 56.65 and 34.5 mm, respectively. In addition, although the temperature during these periods was similar in these regions, it was higher during the summer period in RII than in RI (Fig. 2). In fact, flowering and ripening are two critical phases during which provision of water is critical for the development of olive fruit, and the water deficit during these periods might damage the yield and oil composition (Moriana et al., 2003, 2007). Rainfall, particularly during the growing and ripening of the olive fruit, is one of the most important environmental factors affecting chemical properties of virgin olive oils (Pannelli et al., 1993; Salvador et al., 1998, 2001; Beltrán et al., 2005). According to Salvador et al. (2003), the high free acidity and peroxide values observed in Cornicabra virgin olive oil
were probably the consequence of drought followed by heavy rainfall shortly before harvesting in December.

In addition to their antioxidant activities, pigments are responsible for the oil color, which is important to the consumer. The change in the chlorophyll and carotenoid contents at different ripening stages are shown in Table 1. In all samples studied, a decrease in the chlorophyll content was detected as ripening progressed. In fact, all analyzed samples showed high negative correlations between the chlorophyll concentrations and the MI (Table 2). The pigment concentration in olive oils is generally decreases during ripening (Salvador et al., 2001; Beltran et al., 2005; Criado et al., 2007; Baccouri et al., 2008). The color change in olive oils during the maturity process was explained not only by the reduction in these pigment concentrations, but also by the formation of other colored compounds, such as anthocyanins (Baccouri et al., 2008). A similar change in the pigment contents during the maturation process in different locations suggest that the climatic conditions in the two Chétoui growing regions do not seem to have a great influence on these parameters. Other studies showed that irrigation treatments did not influence the chlorophyll and carotenoid contents of the Spanish oils (Tovar et al., 2003).

Table 1 shows the change in oil content on the basis of dry weight of olives at different ripeness stages. In each region, the oil content generally increased during ripening until it reached a maximum at mid-maturity and then slightly decreased. This indicates the maintenance of other triglyceride-forming biosynthetic processes which, according to Sánchez (1994), end 30 weeks after flowering while the fruit weight continues to increase. Thus, the oil content, on the basis of dry fruit weight, could decline at more advanced stages of fruit maturity. In addition, at the end of the season (higher maturation index) these compounds probably undergo degradation which may be correlated with the increased activity with fruit maturation of the hydrolytic enzymes such as lipases, lipoxygenases and hydroperoxide lyases leading to the decrease of oil content (Luaces et al., 2007; Yousfi et al., 2009). The oil content increases dramatically during early fruit ripening and declines slightly as fruit becomes ripe (Salvador et al., 2001; Baccouri et al., 2007). The olives harvested in RII (Jelma and Ousletia) had a lower oil content than those harvested in RI (Selten). This reduction in the oil content can be attributed to the dry climatic conditions in RII. During the ripening period (from October to January) the olive trees in Ousletia and Jelma (RII) had a total amount of rainfall of only 56.65 and 34.5 mm, respectively, as compared to 185.4 mm in RI. These results agree with the reports that the oil accumulation process was sensitive to water stress and the increase in the seasonal water volume led to an increase in the size of olives and oil content (Lavee and Wodner, 1991; Tognetti et al., 2007). Milella

Table 3. Fatty acid composition of the Chétoui olive oils from RI and RII at various stages of olive maturity (results expressed as % of total fatty acid fraction).

| Geographical region | MI   | C16:0 | C16:1 | C18:0 | C18:1 | C18:2 | C18:3 | C20:0 | MUFA/PUFA | C16:1/18:2 |
|---------------------|------|-------|-------|-------|-------|-------|-------|-------|------------|-------------|
| Selten              | 1.02 | 11.44 | 0.16   | 3.22  | 71.88 | 12.19 | 0.54  | 0.50  | 0.44       | 5.68 ±0.23  |
|                     | 2.05 | 11.84 | 0.17   | 3.37  | 70.19 | 13.12 | 0.47  | 0.56  | 0.42       | 5.14 ±0.11  |
| Jelma               | 3.07 | 10.38 | 0.18   | 3.37  | 68.53 | 16.01 | 0.87  | 0.58  | 0.46       | 4.15 ±0.24  |
|                     | 4.17 | 10.62 | 0.17   | 3.42  | 66.56 | 17.83 | 0.35  | 0.70  | 0.54       | 3.60 ±0.06  |
|                     | 5.09 | 9.97  | 0.20   | 3.19  | 65.83 | 19.45 | 0.35  | 0.63  | 0.38       | 3.29 ±0.12  |
| Ousletia            | 1.40 | 9.45  | 0.37   | 3.25  | 69.41 | 16.26 | 0.51  | 0.62  | 0.55       | 4.14 ±0.17  |
|                     | 2.10 | 9.79  | 0.37   | 2.88  | 68.57 | 17.71 | 0.47  | 0.69  | 0.55       | 3.75 ±0.13  |
|                     | 3.01 | 9.50  | 0.38   | 2.81  | 68.00 | 18.11 | 0.21  | 0.72  | 0.49       | 3.63 ±0.10  |
|                     | 4.22 | 9.92  | 0.39   | 2.70  | 64.30 | 21.27 | 0.73  | 0.40  | 0.40       | 2.94 ±0.15  |
| RII                 | 1.08 | 10.79 | 0.42   | 3.26  | 68.02 | 16.24 | 0.21  | 0.67  | 0.53       | 4.04 ±0.05  |
|                     | 2.01 | 11.23 | 0.39   | 3.09  | 67.82 | 16.40 | 0.85  | 0.54  | 0.51       | 4.03 ±0.27  |
|                     | 3.13 | 11.53 | 0.39   | 2.99  | 64.24 | 19.63 | 0.62  | 0.68  | 0.48       | 3.18 ±0.09  |
|                     | 4.35 | 11.86 | 0.48   | 2.96  | 60.82 | 22.41 | 0.53  | 0.88  | 0.54       | 2.63 ±0.09  |

Data are expressed as mean values ± SD of three independent experiments. Duncan’s test has been used to assess significance (Duncan’s test, p = 0.05). Values followed by the same letters within column are not significantly different.

MI: maturation index; C16:0: palmitic acid; C16:1: palmitoleic acid; C18:0: stearic acid; C18:1: oleic acid; C18:2: linoleic acid; C18:3: linolenic acid; C20:0: arachidic acid; MUFA: monounsaturated fatty acid; PUFA: polyunsaturated fatty acid.
and Dettori (1986) reported that the climatic conditions of a particular year can influence the productive response of an olive grove. Lavee and Wodner (1991) observed 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. In contrast, Gomez-Rico et al. (2007) reported that the irrigation treatment apparently did not affect the oil accumulation in the Cornicabra fruit. Berenguer et al. (2006) and Aganchich et al. (2008) showed that the oil content was even greater under deficit irrigation. Differences in oil yield (t ha\(^{-1}\)) are usually associated with fruit production and not with oil production itself (Mangliulo et al., 2003; Moriana et al., 2003), though the oil accumulation process has been reported as sensitive to water stress (Lavee and Wodner, 1991).

The major fatty acids involved in Chétoui olive oil are oleic (C\(_{18:1}\)), linoleic (C\(_{18:2}\)), palmitic (C\(_{16:0}\)), and stearic acid (C\(_{18:0}\)). Palmitoleic (C\(_{16:1}\)), linolenic (C\(_{18:3}\)) and arachidic (C\(_{20:0}\)) acids were also detected in small amounts (Table 3). In all the samples of Chétoui oils from different locations, it can be seen that with the exception of oleic and linoleic acids, the fatty acid content did not change during the maturation process. The oleic acid which contributes to the oil stability and its quality, is the main monounsaturated fatty acid in all the samples and is present in higher concentrations; never less than 60% of the total fatty acid. The highest percentage of linoleic acid, which is much more susceptible to oxidation than monounsaturated fatty acids, was observed at the last ripening stage. In the course of fruit ripening, oleic and linoleic acids showed the opposite trend in studied samples. Oleic acid contents decreased gradually, whereas, linoleic acid levels increased as the fruit ripened. Hence, the oleic/linoleic acid ratio (C\(_{18:1}/C_{18:2}\)) tended to decrease during the maturation process, which was also confirmed by a high negative correlation between this ratio and the MI of Chétoui oils obtained from RI and RII (Table 2). The ratio of monounsaturated to polyunsaturated fatty acids (MUFA/PUFA) also decreased during the olive

![Fig. 3. Total phenol (A), \(\alpha\)-diphenol (B), oxidative stability (C) and radical scavenging activity (D) of the Chétoui olive oils from RI (Selten) and RII (Jelma and Ousletia) at various stages of olive maturity.](image_url)
maturation process (Table 3). This trend was confirmed by the high negative correlation between this ratio and the MI in Chétoui olive oils obtained from RI and RII (Table 2). This behaviour could be explained by the activity of olate desaturase that transforms oleic acid into linoleic (Gutiérrez et al., 1999). Furthermore, it can be noted that the palmitic acid content slightly decreased as fruit ripened solely in the Chétoui oils from Selten, possibly as a result of a dilution effect (Gutiérrez et al., 1999). Generally, the fatty acid composition is not influenced by the site of cultivation. The increase in the major and minor fatty acid levels during the ripening period was nearly the same in all locations with the exception of linoleic acid which showed a higher content in RII (Ousletia and Jelma). Consequently, the oleic/linoleic acid and MUFA/PUFA ratios were slightly lower in oils obtained from these regions. Many others reported that the irrigation regime barely affected the oil fatty acid ratios or composition (Patumi et al., 2002; Aganchich et al., 2008).

Polyphenols are not only associated with the nutritional and sensory qualities of olive oil, but also play a beneficial role in human health by showing anticarcinogenic, antiatherogenic, antimicrobial and antioxidant activities (Servili et al., 2004; Bendini et al., 2007). Concentrations of total phenol found in Chétoui olive oils from Selten, Jelma and Ousletia regions at different MI are shown in Fig. 3A. In each region and during the olive ripening, total phenols increased until the maturity index reached 2 – 3.5, after which it decreased. These results coincide with those observed in the Cornicabra variety (Salvador et al., 2001). In each region, o-diphenols, the main antioxidant phenolic compound, changed similarly to the total phenol during maturity process; it increased at the early stages of maturity followed by a diminution at the advanced ripening stage (Fig. 3B), which is in agreement with the report by Baccouri et al. (2008). Chétoui olive oils in Jelma and Ousletia (RII) which are characterized by an arid climate had a generally lower total phenol and o-diphenol contents than those of the original plantation (Selten) which it decreased as was observed in total phenol and o-diphenol content. This decrease at the later stage of ripening could be explained by the loss of natural antioxidants particularly the biophenols, as shown previously. These results are in accord with the finding of Salvador et al. (2001) and Baccouri et al. (2008). Oils originating in RI are relatively less stable than those of original plantation. That can be the consequence of their lower content of biophenols compared with those of Selten. The same trend observed on the level of stability and total phenols in all oils of the three areas can confirm the close relation between these two parameters. It is well known that the high oxidative stability of virgin olive oil is primarily due to o-diphenols such as hydroxytyrosol and its oleosidic forms (Bendini et al., 2007). Various antioxidant compounds (both phenolic and non-phenolic) and the lipid composition can also contribute to the oil stability. The high positive correlation observed between total phenol and o-diphenol with oxidative stability confirms their active part in the oil stability (Table 2).

Further experimentation on the radical scavenging activity (RSA) of the studied virgin olive oils verified the relation between the oil stability and antioxidant compounds discussed above. It can be seen from Fig. 3D that the RSA of Chétoui olive oil from the Selten region (RI) was much higher than that from Jelma and Ousletia, probably due to the higher phenol and o-diphenol contents in Selten oil. Other minor biomolecules such as phytosterols, and tocopherols might have contributed to the increase of RSA (Perez-Jimenez, 2005). The high positive correlations of total phenol and o-diphenol with the RSA confirm their contribution to the oil stability (Table 2). The change in RSA was similar to that in total phenol, o-diphenols and oxidative stability during maturity; it increased at the early stages of ripening until a maximum at MI 2 – 3.5 followed by a diminution in the advanced...
Comparative study of the effect of the maturation process of the olive fruit on the chlorophyll and carotenoid fractions of drupes and virgin oils from Arbequina and Farga cultivars. Food Chem. 100: 748-755.

Garcia, J.M., Seller, S. and Pérez-Camino, M.C. 1996. Influence of fruit ripening on olive oil quality. J. Agric. Food Chem. 44: 3516-3520.

Gimeno, E., Fito, M., Lamuela-Raventos, R.M., Castellote, A.L., Covas. M. and Farré, M. 2002. Effect of ingestion of virgin olive oil on human low-density lipoprotein composition. Eur. J. Clin. Nutr. 56: 114-120.

Gomez-Rico, A., Salvador, M.D., Moriana, A., Pérez, D., Olmedilla, N., Ribas, F. and Fregapane, G. 2007. Influence of different irrigation strategies in a traditional Cornicabra cv. olive orchard on virgin olive oil composition and quality. Food Chem. 100: 508-578.

Gutfinger, T. 1981. Polyphenols in olive oils. J. Am. Oil. Chem. Soc. 58: 966-968.

Gutiérrez, F. 1989. Determinacion de la establezda oxidativa de acetes de oliva virgenes: Comparacion entre el metodo A.O.M. y el metodo Rancimat. Grasas. Aceites 40: 1-5.

Gutiérrez, F., Jimenez, B., Ruiz, A and Albi, M.A. 1999. Effect of olive ripeness on the stability of virgin olive oil extracted from the varieties Pical and Hojiblanca and on different components involved. J. Agric. Food Chem. 47: 121-127.

International Olive Oil Concil (IOOC) 2004. Olive oil exportation. [Online]. http://www.internationaloliveoil.org.

Kalantzakis, G., Blekas, G., Pegklioudou, K. and Boskou, D. 2006. Stability and radical scavenging activity of heated olive oil and other vegetable oils. Eur. J. Lipid Sci. Technol. 108: 329-335.

Kelly, C.N.M., Miller, G.J. and Williams, C.M. 2004. Olive oil and haemostasis. Grasas. Aceites 55: 52-65.

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

Luaces, P., Gutiérrez, F., Romero, C., Sanz, C. and Pérez, A.G. 2007. Contribution of olive seed to the phenolic profile and related quality parameters of virgin olive oil. J. Sci. Food. Agric. 87: 2721-2727.

Manghulo, V., D’Andria, R., Lavini, A., Morelli, G. and Patumi, M. 2003. Yield and quality of two rainfed olive cultivars following shifting to irrigation. J. Hort. Sci. Biotech. 78: 15-23.

Matos, L.C., Cunha, S.C., Amaral, J.S., Pereira, J.A., Andrade, P.B., Seabra, R.M. and Oliveira, B.P.P. (2007). Chemometric characterization of three varietal olive oils (Cvs. Cobrancosa, Madural and Verdeal Transmontana) extracted from olives with different maturation indices. Food Chem, 102: 406-414.

Medeiros, M.D. 2001. Olive oil and health benefits. In R.E.C. Wildman ed., The Handbook of Nutraceuticals and Functional Foods. CRC Press, Boca Raton. 261-267.

Milella, A. and Dettori, S. 1986. Three cultural coefficients for table olive irrigation. Riv. Ortofrutticoltura Ita. 70: 231-240.

Minguez-Mosquera, M.I., Rejano, L., Gandul, B., Sanchez, A.H. and Fernández-Gutiérrez, A. 2005. Influence of fruit ripening process on the natural antioxidant content of Hojiblanca virgin olive oils. Food Chem. 95: 289-296.

Milella, A. and Dettori, S. 1986. Three cultural coefficients for table olive irrigation. Riv. Ortofrutticoltura Ita. 70: 231-240.

Minguez-Mosquera, M.I., Rejano, L., Gandul, B., Sanchez, A.H. and Fernández-Gutiérrez, A. 2005. Influence of fruit ripening process on the natural antioxidant content of Hojiblanca virgin olive oils. Food Chem. 95: 289-296.

Milella, A. and Dettori, S. 1986. Three cultural coefficients for table olive irrigation. Riv. Ortofrutticoltura Ita. 70: 231-240.
Morelló, J.R., Romero, M.P. and Motilva, M.J. 2006. Influence of seasonal conditions on the composition and quality parameters of monovarietal virgin olive oils. *J. Am. Oil. Chem. Soc.* 83: 683-690.

Moriana, A., Orgaz, F., Pastor, M. and Fregapane, G. 2007. Irrigation scheduling for traditional, low-density olive orchards: Water relations and influence on oil characteristics. *Agr. water manag.* 87: 171-179.

Osman, M., Metzidakis, I., Girasopoulos, G. and Kiritsakis, A. 1994. Quantitative changes in olive oil of fruits collected from trees grown at two altitudes. *Riv. Ital. Sostanze Grasse* 71: 187-189.

Pannelli, G., Famiani, R, Servili, M. and Montedoro, G.R. 1993. Agro-climatic factors and characteristics of the composition of virgin olive oil. Presented at the 2nd International Symposium on Olive Growing, Jerusalem, Israel, September 6-10.

Patumi, M., D’Andria, R., Marsili, V., Fontanazza, G., Morelli, G. and 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.

Perez-Jimenez, F. 2005. International conference on the healthy effect of virgin olive oil. *Eur. J. Clin. Invest.* 35: 421-424.

Ranalli, A., De Mattia, G., Patumi, M. and Proietti, P. 1999. Quality of virgin olive oil as influenced by origin area. *Grasas Aceites* 50: 249-259.

Rotondi, A., Bendini, A., Cerretani, L., Mari, M., Lercker, G. and Gallina Toschi, T. 2004. Effect of olive ripening degree on the oxidative stability and organoleptic properties of *cv* Nostrana di Brisighella extra virgin olive oil. *J. Agric. Food. Chem.* 52: 3649-3654.

Salvador, M.D., Aranda, F. and Fregapane, G. 1998. Chemical composition of commercial cornicabra virgin olive oil from 1995/96 and 1996/97 crops. *J. Am. Oil Chem. Soc.* 75: 1305-1311.

Salvador, M.D., Aranda, F. and Fregapane, G. 2001. Influence of fruit ripening on Cornicabra virgin olive oil quality: a study of four crop seasons. *Food Chem.* 73: 45-53.

Salvador, M.D., Aranda, F., Gomez-Alonso, S. and Fregapane, G. 2003. Influence of extraction system, production year and area on Cornicabra virgin olive oil: A study of five crop seasons. *Food Chem.* 80: 359-366.

Sánchez, J. 1994. Lipid photosynthesis in olive fruit. *Prog. Lipid Res.* 33: 97-104.

Servili, M., Montedoro, G.R, Pannelli, G. and Famiani, R. 1990. Influence of pedoclimatic, technological and genetic factors on the quality of virgin olive oil. Presented at the meeting: Qualitative Problems of Olive Oil. Sassari, Italy, November 6.

Servili, M., Scavaglini, S., Esposto, A., Tacchini, G., Montedoro, G.F. and Morozi, G. 2004. Health and sensory properties of virgin olive oil hydrophilic phenols: Agronomic and technological aspects of production that affect their occurrence in the oil. *J. Chromatogr. A* 1054: 113-127.

Tognetti, R., D’Andria, R., Sacchi, R., Lavini, A., Morelli, G. and Abino, A. 2007. Deficit irrigation affects seasonal changes in leaf physiology and oil quality of *Olea europaea* (cultivars Frantoio and Leccino). *Ann. Appl. Biol.* 150: 169-186.

Tovar, M.J., Romero, M.P., Alegre, S., Girona, J. and Motilva, M.J. 2003. Composition and organoleptic characteristics of oil from Arbequina olive (*Olea europaea* L.) trees under deficit irrigation. *J. Sci. Food Agric.* 82: 1755-1763.

Tura, D., Gigliotti, C., Pedo Sa, Failla, O., Bassi, D. and Serraiocco, A. 2007. Influence of cultivar and site of cultivation on levels of lipophilic and hydrophilic antioxidants in virgin olive oils (*Olea Europaea* L.) and correlations with oxidative stability. *Sci. Hortic.* 112: 108-119.

Uceda, M. and Hermoso, M. 1998. La calidad del aceite de oliva In D. Barranco, R. Fernandez-Escobar and L. Rallo eds., El Cultivo del Olivo. Junta de Andalucía Ediciones, Mundi-Prensa: Madrid, Spain. 547-572.

Warhrburg, U., Kratz, M. and Cullen, P. 2002. Mediterranean diet, olive oil and health. *Eur. J. Lipid Sci. Technol.* 104: 675-698.

Yousfi, K., Cavuela, J.A. and Garcia, J.M. 2009. Effect of temperature, modified atmosphere and ethylene during olive storage on quality and bitterness level of the oil. *J. Am. Oil Chem. Soc.* 86: 291-296.