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Influence of Irrigation Regimes on Quality Attributes of Olive Oils from Two Varieties Growing in Lebanon

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***Abstract*—** *An increasing interest on supplemental irrigation is observed in modern olive orchards because of its effect in increasing yield. In this study, the effect of three irrigation regimes (0, 60 and 100% ETC) on quality and chemical composition of olive oil is assessed in Baladi and Edlbi varieties planted in Lebanon. Significant differences ($p<0.05$) between varieties were observed for the majority of studied traits. Meanwhile, the response to irrigation regimes was strongly different between varieties. In Baladi variety, irrigation regimes resulted in increasing fresh fruit weight together with slight effects on oil yield, quality and composition. Only oleacein content showed significant decrease with irrigation (50.35 mg/kg for 0% ETC, 28.25 for 60% and 34.60 for 100%). On the contrary, in Edlbi variety, irrigation resulted in a strong decrease of total phenols (509.91 mg GAE/kg for 0% ETC, 385.87 for 60% and 365.74 for 100%) and chlorophylls (20.83 mg/kg for 0% ETC, 14.54 for 60% and 14.81 for 100%). Curiously, 60% ETC showed high content of the majority of individual phenols, including higher than 0% ETC.*

***Keywords*— Fatty acid profile, Monovarietal olive oil, Olea europaea L., Oxidative stability, Olive oil quality, Phenolic compounds, Supplemental irrigation.**

I. INTRODUCTION

The olive tree (*Olea europaea* L.) has a long history in Mediterranean countries where there is evidence of human cultivation from as far back as 5,000–6,000 years ago [1]. It is considered as one of the best adapted species to the Mediterranean climate characterized by limited water availability and high evaporative demand [2]. Therefore, it has been traditionally cultivated under dry-land conditions where trees were spaced widely to take full advantage of the stored soil water from winter rains for spring and summer growth. More recently, olive cultivation is progressively expanding in many countries in response to increased oil consumption, and many agricultural practices have been changed for improving production, productivity and quality of olive oil [3–5]. One of the most important changes in olive cultivation is the expansion of high-density irrigated olive orchards.

The substantial increase in olive oil and table olives consumption is due not only to its nutritional properties and potential role in protecting against cardiovascular and neurodegenerative diseases [6]; but also to its organoleptic attributes [7]. These outstanding properties are attributed to the high oleic acid percentage of olive oil and to the presence of several minor components endowed with antioxidant activity such as phenolic compounds, pigments, tocopherols, etc. However, this peculiar chemical composition is the result, besides the fundamental genetic basis, of a complex interaction between several factors clustered into four main groups: environmental (soil, climate), agronomic (irrigation, fertilization), cultivation (ripeness harvesting) and technological factors (fruit storage, extraction procedures) [8].

Among these factors, irrigation can have large impact on both the production of the olive tree and the composition of the olive fruits [4], even with small amounts of water [9]. In fact, several studies showed increased fruit and oil yield with irrigation, but conflicting results were observed regarding relative oil content of the fruits. For instance, Lavee and Wodner [10] showed a decrease in relative oil content as a function of increased amounts of applied water. However, Moriana et al. [4] indicated an increase in oil content with irrigation; and, Costagli et al. [11] reported no effect. In addition, it is relevant to state that any irrigation regime employed in the olive orchard must take into

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account the ultimate effect on olive oil as several researches have shown variations in oil quality and composition between rainfed and different irrigation managements. Indeed, Stefanoudaki et al. [12] revealed that the irrigation regimes had little or no effect on free acidity, peroxide value, or fatty acid composition of olive oil. Conversely, Tognetti et al. [13] and Berenguer et al. [14] stated that irrigation influences the oil quality parameters, fatty acid composition, phenolic content, volatile profile and sensorial characteristics of the olive oil. It is worth mentioning that, an inverse relationship between the amount of water applied to the olive trees and the phenolic content, the oxidative stability and the bitterness of the oil has been previously reported [5, 15–17].

In Lebanon, olive growing is widespread from the coast until around 1000 m a.s.l. It represents around 23.43% of the total cultivated land with more than 58000 ha [18]. The Lebanese groves are dominated by the variety Baladi; although, other varieties are also present such as Souri, Ayrouni, Edlbi, Nabali, Manzanilla de Sevilla, Fantoio and Picholine. Only 8% of the olive cultivated areas are irrigated, the rest is rainfed. This is mainly due to the lack of information on the performance of local varieties under different irrigation regimes. On the other hand, the Lebanese olive oil industry consists of around 544 mills among which 85% still traditional [19]. The main obstacle facing the modernization of the Lebanese olive oil industry is the fact that the modern continuous systems provide oils with a bitter taste not preferred by local consumers who are familiar with sweetie oil tastes generated by traditional systems. Thus, irrigation may provide a solution for decreasing bitterness attribute of olive oil obtained by continuous systems. Therefore, the main goal of this study was to investigate the effect of different irrigation regimes on fresh fruit weight, oil yield, quality and composition of olive oil from Baladi and Edlbi varieties planted in Lebanon.

II. MATERIALS AND METHODS

2.1 Experimental site and irrigation regimes

The study was carried out during 2012-2013 olive crop season in an experimental field maintained by the Lebanese Agricultural Research Institute (LARI), and located in Jezzine city (South of Lebanon) at 351 a.s.l, 33°32'33'' N and 35°27'11'' E. The annual precipitation recorded in Jezzine in 2012 was 810 mm, the minimum registered temperature was 3.1 °C below zero and the maximum was 34.9 °C. Olive trees from the two varieties Baladi and Edlbi were planted since 1996 at a distance of 4 m between trees. The orchard is characterized by a calcareous soil to which 3 kg per tree of 17-17-17 NPK complex were added in December of each year.

The irrigation was done by using a localized irrigation system consisting of 2 mini sprinklers of 32 L/hour/tree. Three irrigation regimes were adopted: I0: without irrigation (rainfed), I60: 60% of crop ETC, and I100: 100% of crop ETC calculated from climatic data registered in the weather station located close to the orchard (for calculating reference evapotranspiration, ET0) and using the Penman–Monteith–FAO method [20], with an estimated crop coefficient (Kc=0.75 in spring and 0.55 in summer) [21], and a coverage coefficient (Kr = 0.5) [22] where:

$$ETc = Kr \times Kc \times ET0 \quad (1)$$

2.2 Plant material and olive oil extraction

For each variety and each irrigation regime, four fruit samples of 700 g each were collected from four trees at 6 harvesting times. The ripening index (RI) was calculated according to the fruit skin color as proposed by Frías et al. [23]. The weight of the 100 fruits from each sample was also recorded. Then, oils were extracted using an Abencor system (Mc2 Ingenieria y Sistemas, Seville, Spain) equipped with a hammer mill, a thermobeater and a centrifuge. After crushing the olives, the paste underwent malaxation at 28 °C for 30 min, and then centrifuged at 3500 rpm for 2 min. When stopped, the oil will separate from the paste and will be collected in graduated cylinders. After decantation, the oil samples were separated from the vegetable water, transferred into glass bottles, and stored in the dark at -20 °C until analysis. The oil yield was calculated according to the following formula:

$$\text{Oil yield} = \text{Volume of extracted oil} \times 0.915 \times 100 / \text{Mass of the olive paste} \quad (2)$$ [24]

2.3 Analytical determination in olive oil

2.3.1 Quality indices

Free acidity, peroxide value and UV absorbance at 232 and 270 nm (conjugated dienes (K_{232}) and conjugated trienes (K_{270}), respectively) were determined following the methods described in the European Union Commission Regulation EEC No 2568/91 [25]. All parameters were performed in triplicate for each sample.

2.3.2 Fatty acid composition

Fatty acid methyl esters (FAMEs) were prepared by vigorously shaking, for 1 min, 0.1 g of oil dissolved in 2 mL of *n*-hexane with 200 µL of a methanolic solution of KOH (2 M). After settling for 5 min, an aliquot of 975 µL of the upper phase containing *n*-hexane and FAMEs were transferred to a test tube containing 25 µL of C19:0 as external standard [26]. The resulting mixture was injected by duplicate into a Shimadzu GC-2010 Plus coupled to a

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flame ionization detector (FID) (280 °C), and equipped with a fused silica capillary column (DB-wax; Agilent Technologies, Wilmington, DE; 30 m length x 0.25 mm i.d. and 0.25 µm of film thickness). Nitrogen was used as carrier gas at 1.69 mL/min with split injector system (Split ratio: 1:50, 250 °C). The initial oven temperature program was kept at 165 °C for 15 min, then increased from 165 °C to 200 °C at a rate of 5 °C/min, and maintained at 200 °C for 2 min, then raised from 200 °C to 240 °C at a rate of 5 °C/min, and finally held at 240 °C for 5 min. Peak identification was achieved by reference to authentic commercial standards. The concentrations of EFAs were expressed as relative percent of total area.

2.3.3 Phenolic profile

The phenolic compounds were isolated by double extraction of a solution of oil (3 g) in *n*-hexane (2 mL) with a methanol-water mixture (60:40, v/v) [27]. A solution of the internal standard (250 µL of 15 mg/kg of syringic acid in methanol) with 1.75 mL of methanol-water mixture was used for the first extraction and 2 mL of methanol-water mixture for the second one. The extracts from both extractions were combined and placed in the dark at -20 °C for further determinations.

Total phenols content was determined calorimetrically using the Folin-Ciocalteu method [28]. The absorbance was measured at 765 nm by a jenway UV/Vis spectrophotometer (Staffordshire, ST15 OSA, UK). The results were expressed as mg gallic acid equivalent (GAE)/kg of oil.

The extracted phenolic fraction was analyzed in triplicate by a Shimadzu HPLC equipped with an automatic injector, a column oven and a diode array UV detector (using 280 nm as quantification wavelength). Separation of individual phenols was achieved on a Microsorb-MV 100 C18 column (250 × 4.6 id mm, 5µ particle size), maintained at 40 °C. The injection volume was 20 µL and the flow rate 1.0 mL/min. Mobile phases were 0.2 % *o*-phosphoric acid in water (mobile phase A) and a mixture methanol-acetonitrile (50:50, v/v) (B). The initial concentrations were 96% of A and 4% of B and the gradient was changed as follows: the concentration of B was increased to 50% in 40 min, increased to 60% in 5 min, and to 100% in 15 min, and maintained for 10 min. Initial conditions were reached in 7 min. The identification of olive phenols was performed on the basis of their maximum absorption and retention times compared to those of commercial standard compounds. Standards of oleocanthal and oleacein were acquired from Prof. P. Magiatis (University of Athens). Results were elaborated by Shimadzu LabSolution software. Phenolic compounds quantification was achieved using syringic acid as internal standard and 9 points calibration curves of authentic standards. Results were expressed as mg of the target analyte per kg of oil.

2.3.4 Pigments

Total chlorophyll, chlorophyll a and chlorophyll b were determined according to the Official Methods of Analysis [29]. The method consists of measuring the absorbance of a solution of oil (0.5 g) in *n*-hexane (10 mL) at 642.5 ($A_{642.5}$) and 660 nm (A_{660}) using a UV/Vis spectrophotometer (Jenway Scientific Instruments, Staffordshire, ST15 OSA, UK). The results are given by the following formulas:

$$\text{Total chlorophyll} = 7.12 \times A_{660} + 16.8 \times A_{642.5} \quad (3)$$

$$\text{Chlorophyll a} = 993 \times A_{660} - 0.777 \times A_{642.5} \quad (4)$$

$$\text{Chlorophyll b} = 17.6 \times A_{642.5} - 2.81 \times A_{660} \quad (5)$$

The concentration of *β*-carotene was obtained using 6 points calibration curve of corresponding commercial standard and the readings were achieved at 436 nm.

The results of chlorophylls and *β*-carotene were expressed in mg/kg of oil

2.3.5 Oil oxidative stability

Oil oxidative stability was evaluated by the Rancimat method [30]. Stability was expressed as the induction time (h) measured with the Rancimat 892 model (Metrohm SA, Herisau, Switzerland). An oil sample of 3 g was warmed to 120 °C under a constant air flow of 20 L/h. The analytical determinations were carried out in duplicate and the results were expressed in hours.

2.4 Statistical analysis

Analysis of variance (ANOVA) was performed for testing differences in olive oil quality and composition between varieties and irrigation regimes. Tukey´s test ($p<0.05$) was used to discriminate among the mean values. Multivariate analysis based on principal component analysis (PCA) was also performed from a set of 32 studied variables (fatty acids: 11, sums and ratios of fatty acids: 6, total and individual phenols: 10, chlorophylls: 3, *β*-carotene and induction time) after standardization. Statistical analyses were carried out using Statistix 8.0 (Analytical Software, Tallahasse, FL, USA) and Unscrambler (CAMO A/S, Trodheim, Norway) statistical packages.

III. RESULTS AND DISCUSSION

3.1 Harvesting time and ripening index (RI)

Analysis of variance revealed significant differences in RI between varieties ($p=0.0000$). As Fig. 1 shows, the evolution of ripening process in Edlbi variety was faster than in Baladi variety. On the other hand, the difference

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between irrigation regimes was not significant in both varieties, although it was remarkable that the trees under I0 regime showed higher RI (1.44 in Baladi and 2.88 in Edlbi variety). A positive relationship between RI and the amount of water applied was observed as I100 regime provided olives with higher RI than I60 regime (1.21 in Baladi and 2.75 in Edlbi variety for I100, and 1.13 in Baladi and 2.42 in Edlbi variety for I60). These results are partially in agreement with those described by Berenguer et al. [14] who indicated higher RI in rainfed trees, but a negative relationship between RI and the amount of applied water.

3.2 Fruit fresh weight

The mean fruit fresh weight ranged from 1.43 to 3.20 g in Baladi variety and from 2.22 to 5.23 g in Edlbi variety with statistically significant difference between varieties (p=0.0000). Besides, irrigation in both varieties yielded higher fruit fresh weight than under rainfed conditions, although the difference was only significant in Baladi variety. These results are in agreement with previous studies in which irrigation has been shown to increase fruit size, especially in dry years [5, 31].

3.3 Oil yield

Oil yield obtained through Abencor system showed highly significant differences between varieties (p<0.0001). The oil yielded by Edlbi variety (197.1 g/kg) was significantly higher than Baladi variety (176.4 g/kg). Apart, oil yield was not significantly affected by irrigation regimes in both varieties (p=0.7218 for Baladi and p=0.1581 for Edlbi), albeit the highest oil yield was recorded for I0 (183.8 g/kg for Baladi and 214.0 g/kg for Edlbi variety), followed by I60 (177.6 g/kg for Baladi and 194.7 g/kg for Edlbi variety) and I100 (167.8 g/kg for Baladi and 182.7 g/kg for Edlbi variety). The low extractability of irrigated olives could belong to the higher water content accumulated in the fruits of the irrigated regimes [31].

3.4 Quality indices

The free acidity was highly significantly affected by the variety (p=0.0000), where Edlbi showed higher values than Baladi variety (Table 1). It is agreed that oil quality indices are less affected by the olive variety; however, in this study, Edlbi variety recorded very high free acidity levels in the last two harvesting (21 October and 04 November) as it ripened earlier than Baladi variety. A positive relationship between ripening and free acidity was previously recorded [32]. In opposite, no statistically significant differences were obtained between studied varieties for peroxide value, K_{232} and K_{270}.

Regarding the influence of different irrigation regimes on quality indices, only K_{232} and K_{270} showed significant differences in both varieties, with higher values in oils obtained from I0. Similar results were obtained by Gómez-Rico et al. [5] who reported slight effects of irrigation on free acidity and peroxide value, and a decrease in K_{232} and K_{270} with increasing irrigation amounts. According to the same authors, this decrease could result from the interference of phenolic compounds (higher content in rainfed), which absorbs in the UV region in these analytical determinations. Opposite results were found by Dabbou et al. [33] who indicated significant effects of irrigation regimes on free acidity, peroxide value and K_{232} of oils from Coratina variety. This discrepancy is probably due to the interaction between the experimental conditions and the genetic characteristics of each variety that might induce different effects on the oxidative reactions of the oil during the extraction process.

3.5 Fatty acid composition

Great differences were found between Baladi and Edlbi varieties with regard to their fatty acid composition (Table 2). While Baladi variety recorded significantly higher percentages of C16:0, C18:0, C18:1, C18:3, C20:0, C20:1, C22:0 and C24:0, Edlbi variety presented significantly higher C14:0, C16:0 and C18:2. Moreover, the studied fatty acid sums and ratios revealed highly significant differences between varieties with Baladi exhibiting higher SFA, MUFA, MUFA/PUFA and C18:1/C18:2 and Edlbi higher PUFA and UFA/SFA.

The fatty acid composition was strongly affected by irrigation regimes (Table 3). In both varieties, C14:0, C16:0, C16:1, C18:1, C18:3, C24:0, SFA, MUFA and UFA/SFA were the most affected. Besides, C18:0, C20:0 and C22:0 presented inconsistent differences between varieties. Regarding the major fatty acids, significant differences were observed mainly between rainfed and irrigated trees. In fact, the percentages of C16:0 and C18:3 in oils from irrigated trees were significantly higher than in oils from rainfed ones. However, the percentage of C18:1 was higher in oils from rainfed trees than in oils from irrigated ones. Conversely, the percentage of C18:2 didn't show any significant difference with irrigation regimes. Regarding C18:0, significant difference between irrigation regimes was observed only in Edlbi variety with higher percentages in oils obtained from rainfed trees. The results of this study are partially in agreement with those obtained by Gómez-Rico et al. [5] and Dabbou et al. [34] who reported higher C18:1 in rainfed trees, but also higher C16:0 and C18:2 in irrigated trees. Conflicting results

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indicating slight effects of irrigation on fatty acid composition are also present [17].

In addition, irrigation increased significantly the sum of saturated fatty acids (SFA) while decreasing the sum of monounsaturated fatty acids (MUFA). In fact, it is well known, that a higher percentage of MUFA is considered as one of the main characteristics of a good quality olive oil. Moreover, the ratio of unsaturated to saturated fatty acids was influenced by different irrigation regimes with higher ratios in oils from rainfed trees.

It is worth to note that the differences in fatty acid profiles were significant but at slight levels of difference. These observations are in accordance with the results of Gómez-Rico et al. [5] who reported higher ratios of MUFA in oils from rainfed trees but at difference levels that don't have any nutritional relevance.

3.6 Total and individual phenols

Statistical analysis showed that individual phenols, except tyrosol and vanillic acid, revealed significant differences between Baladi and Edlbi varieties. Higher contents of *p*-coumaric acid, oleocanthal and luteolin were found in oils from Baladi variety, and of hydorxytyrosol, oleacein and apigenin in oils from Edlbi variety (Table 4). It was relevant that *o*-coumaric acid was only detected in oils from Edlbi variety. The genetic variability of the phenolic profile has been widely described in national and international olive collections, with most varieties displaying a particular phenolic composition [35].

As shown in Table 5, the influence of irrigation regimes on oil phenolic composition appears to be strongly dependent on the olive variety. Regarding total phenols, the content was significantly higher only in oils form Edlbi variety in rainfed conditions. This behavior is consistent with several varieties showing reduction of total phenols with irrigation [36, 37]. In contrast, Baladi variety showed a prominent behavior with no significant reduction in total phenols with irrigation. This is very relevant since the phenolic compounds contribute to nutritional and organoleptic characteristics of olive oil [38]. As per individual phenols, the effect of irrigation was also more pronounced in Edlbi than in Baladi variety. In fact, the contents of hydroxytyrosol, tyrosol, vanillic acid, *p*-coumaric acid, *o*-coumaric acid, oleacein and luteolin in oils from Edlbi variety showed the same trend with higher amounts observed in I60 irrigation regime. Higher irrigation level negatively affected these compounds. However, oleocanthal and apigenin showed higher amounts in oils from Edlbi variety under rainfed conditions; although, for oleocanthal the difference between I0 and I60 was negligible. These results are partially in agreement with those obtained by Patumi et al. [39] and Tovar et al. [40] who reported higher concentrations of phenols in oils from olive trees exposed to a certain level of water deficit. These higher concentrations can be attributed to changes in the activity of the enzymes responsible of the biosynthesis of phenolic compounds, such as L-phenylalanine ammonia-lyase whose activity is greater under water stress conditions Tovar et al. [41]. Regarding Baladi variety, the effect of irrigation on individual phenols was only significant for oleacein content. Previous studies stated that the content of oleacein and oleocanthal significantly increases in oils from the most stressed irrigation regimes [17]. In the present study, this was observed only for oleacein content of oils from Baladi variety, and for oleocanthal content of oils from Edlbi variety. It is worth mentioning that oleacein is a compound that plays an important role in the intensity of the oil bitterness [33]. Accordingly, the irrigation of Baladi olives may induce a reduction in the bitterness of the oil without significant effect on the contents of total and other individual phenols.

3.7 Pigments

Oils from Baladi variety showed significantly higher contents of total chlorophyll, chlorophyll a and *β*-carotene than oils from Edlbi variety (Table 4). These pigments are relevant for the consumers because they play a key role as hedonistic factor and affect the sensorial acceptability of the oil [42].

Similarly to phenolic compounds, the effect of irrigation regimes on pigments was more marked in Edlbi varieties. In fact, the contents of total chlorophyll, chlorophyll a and chlorophyll b in oils from Edlbi variety decreased significantly with irrigation (Table 5) as previously described by Romero et al. [43]. Conversely, Gómez-Rico et al. [5] reported that pigments are not influenced by irrigation, in concordance with results obtained in this study for oils from Baladi variety.

3.8 Oil oxidative stability

The oil oxidative stability expressed as induction time presented significantly higher values for oils from Edlbi (11.89 h) than from Baladi variety (9.46 h) (Table 4). In fact, strong correlation was previously reported between oil oxidative stability and oleacein content. The latter (higher content in oils from Edlbi variety) has been shown to extend the storage time of the oil due to its antioxidant activity [44].

In both varieties, the oils obtained from rainfed trees showed the highest oxidative stability, although the difference was only significant in Edlbi variety (Table 5).

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The significant decrease of oxidative stability with irrigation can be explained by the parallel decrease in total phenols, in accordance with findings of previous studies [45, 46].

3.9 Multivariate analysis

Principal components analysis (PCA) revealed that the first two principal components explained 59% of total variance and showing groupings and subgroupings. The first PC accounted for 40% of total variance, with a high positive correlation with C18:0, C20:0, C20:1, luteolin, *p*-coumaric acid and vanillic acid, and negative with C16:1, tyrosol and hydroxytyrosol. The second PC accounted for 19% of total variance and was positively correlated with total phenols, induction time and chlorophyll b. Along the PC2, oil samples were differentiated in two groups: the first one belong to Baladi variety and the second one to Edlbi variety, independently from the irrigation regimes. In addition, PCA allowed the discrimination of the oil samples from irrigated and rainfed trees in each variety as oils from rainfed trees showed a considerable grouping (Fig. 2).

IV. CONCLUSIONS

This work is the first evaluation of the performance of olive varieties growing in Lebanon under different irrigation regimes. The response of olive trees to different irrigation regimes showed strong varietal differences, mainly between rainfed and irrigated trees. The most relevant is that in Baladi variety, irrigation increased fruit fresh weight with limited effect on oil content, fatty acid composition, total and individual phenols, pigments and oil oxidative stability. The only significant decrease in individual phenols was in oleacein content that was described to have a positive relationship with olive oil bitterness attribute. A premise of this work was that Baladi variety may provide high production, high quality and less bitter oil, if small amounts of water are applied during the dry season. This issue may increase the local demand for oils from Baladi variety grown under deficit irrigation conditions and processed with continuous system characterized by strong bitter oils. Interestingly, in Edlbi variety, deficit irrigation of olive trees with 60% ETC appears to be beneficial as it increased fruit fresh weight, maintained high oil content, showed the highest content of all individual phenols except apigenin; nevertheless, it decreased total phenols and oil oxidative stability. Finally, more work is necessary in order to confirm the results obtained for Baladi variety, and further experiments with more severe deficit irrigation strategies (lower than 60% ETC) must be explored in case of Edlbi variety to improve the quality of the olive oil produced from this variety.

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http://dx.doi.org/10.22161/ijeab/2.2.43 *ISSN: 2456-1878*

FIGURES

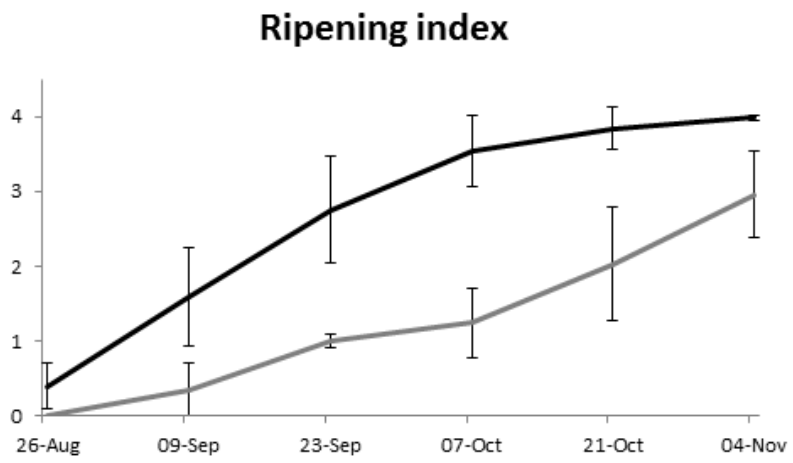

Fig.1: *Evolution along harvesting dates of ripening indexes in 'Baladi' (grey) and 'Edlbi' (Black) varieties. Error bars represent means ± Standard deviation.*

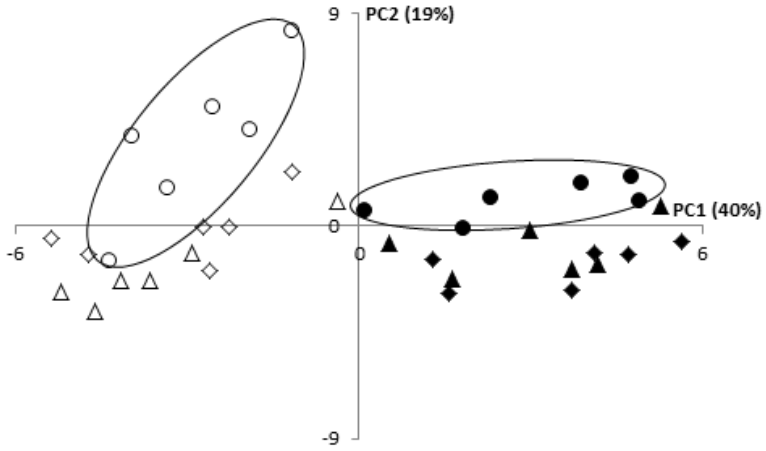

Fig.2: *Distribution of the olive oil samples in the axes of the first and the second principal components. Baladi I0: ●, Baladi I60: ◆, Baladi I100: ▲, Edlbi I0: ○, Edlbi I60: ◇, Edlbi I100: △.*

TABLES

Table.1: Quality indices of olive oil from 'Baladi' and 'Edlbi' varieties, as affected by irrigation regimes.

	'Baladi'				'Edlbi'			
	I0	**I60**	**I100**	**Sig.**	**I0**	**I60**	**I100**	**Sig.**
Free acidity (g/kg of oleic acid)	2.8a	3.0a	2.4a	NS	7.3x	4.5x	6.3x	NS
Peroxide value (meq O_2/kg of oil)	8.06a	7.93a	7.57a	NS	9.42x	7.47x	8.30x	NS
K_{232}	1.52a	1.40b	1.33b	***	1.52x	1.30y	1.39xy	***
K_{270}	0.10a	0.09ab	0.08b	*	0.10x	0.07y	0.08y	***

I0: rainfed; I60: irrigated with 60% ETC; I100: irrigated with 100% ETC; Sig.: significance; RI: ripening index; FFW: fresh fruit weight; NS: statistically not significant; *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0$. Means followed by different letters within the same row and variety (a–b or x–y, resp.) differ significantly by Tukey's test ($p<0.05$) with respect to the irrigation level.

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Table.2: Fatty acid composition (g/kg) of olive oil from 'Baladi' and 'Edlbi' varieties.

	'Baladi'	'Edlbi'	Significance
C14:0	0.114b	0.133a	***
C16:0	130.2a	126.6b	*
C16:1	4.7b	6.9a	***
C18:0	35.3a	31.7b	***
C18:1	718.5a	700.2b	***
C18:2	93.2b	119.0a	***
C18:3	6.9a	6.0b	***
C20:0	5.4a	4.8b	***
C20:1	3.3a	2.6b	***
C22:0	1.4a	1.3b	***
C24:0	0.9a	0.8b	*
SFA	173.5a	165.3b	***
MUFA	726.5a	709.7b	***
PUFA	100.1b	125.0a	***
UFA/SFA	47.7b	50.6a	***
MUFA/PUFA	74.8a	58.7b	***
C18:1/C18:2	80.0a	61.1b	***

*: $p < 0.05$; ***: $p < 0.001$. Means followed by different letters within the same row (a–b) differ significantly by Tukey's test ($p<0.05$).

Table.3: Fatty acid profile (g/kg) of olive oil from 'Baladi' and 'Edlbi' varieties, as affected by irrigation regimes.

	'Baladi'				'Edlbi'			
	I0	**I60**	**I100**	**Sig.**	**I0**	**I60**	**I100**	**Sig.**
C14:0	0.106b	0.123a	0.114ab	***	0.128xy	0.126y	0.144x	*
C16:0	125.7b	133.7a	131.2a	***	118.3y	129.7x	131.6x	***
C16:1	4.1b	5.1a	4.9a	***	5.8y	7.2x	7.8x	***
C18:0	35.8a	35.6a	34.7a	NS	35.8x	29.6y	29.7y	***
C18:1	726.2a	710.8b	719.1ab	**	712.1x	700.0xy	688.4y	**
C18:2	91.0a	96.8a	91.8a	NS	113.0x	117.7x	126.3x	NS
C18:3	6.2b	7.4a	7.1a	***	5.4y	6.2x	6.4x	***
C20:0	5.3b	5.6a	5.4ab	*	5.0x	4.7x	4.8x	NS
C20:1	3.3a	3.3a	3.3a	NS	2.6x	2.6x	2.6x	NS
C22:0	1.40b	1.49a	1.45ab	*	1.25x	1.27x	1.27x	NS
C24:0	0.8b	1.0a	0.9ab	*	0.7y	0.9x	0.9x	**
SFA	169.2c	177.4a	173.8b	***	161.1y	166.3x	168.4x	***
MUFA	733.6a	718.5b	727.3ab	*	720.5x	709.8xy	698.9y	**
PUFA	97.2a	104.2a	98.9a	NS	118.4y	123.9xy	132.7x	NS
UFA/SFA	49.1a	46.5b	47.6b	***	52.1x	50.2y	49.4y	***
MUFA/PUFA	77.0a	71.3a	76.2a	NS	62.3x	59.3x	54.5x	NS
C18:1/C18:2	81.8a	76.3a	81.8a	NS	64.7x	62.0x	56.7x	NS

I0: rainfed; I60: irrigated with 60% ETC; I100: irrigated with 100% ETC; Sig.: significance; NS: statistically not significant; *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$. Means followed by different letters within the same row and variety (a–c or x–y, resp.) differ significantly by Tukey's test ($p<0.05$) with respect to the irrigation level.

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Table.4: Phenolic profile, pigments and oxidative stability of olive oils from 'Baladi' and 'Edlbi' varieties.

	'Baladi'	'Edlbi'	Significance
Hydroxytyrosol (mg/kg)	6.59b	9.78a	*
Tyrosol (mg/kg)	3.10a	3.29a	NS
Vanillic acid (mg/kg)	2.46a	2.24a	NS
***p*-coumaric acid (mg/kg)**	3.47a	1.43b	***
***o*-coumaric acid (mg/kg)**	N.D	1.13	-
Oleacein (mg/kg)	37.74b	71.26a	***
Oleocanthal (mg/kg)	36.98a	29.11b	*
Luteolin (mg/kg)	27.42a	2.09b	***
Apigenin (mg/kg)	4.24b	9.88a	***
Total phenols (mg GAE/kg)	411.95a	420.51a	NS
Total chlorophyll (mg/kg)	18.84a	16.72b	*
Chlorophyll A (mg/kg)	9.70a	7.54b	***
Chlorophyll B (mg/kg)	9.16a	9.20a	NS
***B*-carotene (mg/kg)**	16.13a	10.45b	***
Induction time (hours)	9.46b	11.89a	***

N.D: not detected; NS: statistically not significant; *: $p < 0.05$; ***: $p < 0.001$. Means followed by different letters within the same row (a–b) differ significantly by Tukey's test ($p<0.05$)

Table.5: Phenolic profile, pigments and oxidative stability of olive oils from 'Baladi' and 'Edlbi' varieties, as affected by irrigation regimes.

	'Baladi'				'Edlbi'			
	I0	**I60**	**I100**	**Sig.**	**I0**	**I60**	**I100**	**Sig.**
Hydroxytyrosol (mg/kg)	7.22a	5.19a	7.35a	NS	8.25y	14.33x	6.77y	**
Tyrosol (mg/kg)	2.82a	2.65a	3.83a	NS	2.90xy	4.40x	2.57y	*
Vanillic acid (mg/kg)	2.24a	2.41a	2.72a	NS	1.56z	3.03x	2.14y	***
***p*-coumaric acid (mg/kg)**	3.46a	3.35a	3.60a	NS	1.11y	1.87x	1.31y	**
***o*-coumaric acid (mg/kg)**	N.D	N.D	N.D	-	1.03y	1.42x	0.95y	**
Oleacein (mg/kg)	50.35a	28.25b	34.60ab	*	72.48xy	85.68x	55.61y	NS
Oleocanthal (mg/kg)	42.46a	35.51a	32.97a	NS	33.22x	33.11x	21.01x	*
Luteolin (mg/kg)	31.72a	23.83a	26.70a	NS	1.52y	2.80x	1.98y	***
Apigenin (mg/kg)	5.62a	3.42a	3.67a	NS	14.788x	8.66y	6.20y	***
Total phenols (mg GAE/kg)	454.81a	376.94a	404.09a	NS	509.91x	385.87y	365.74y	**
Total chlorophyll (mg/kg)	19.18a	19.99a	17.38a	NS	20.83x	14.54y	14.81y	**
Chlorophyll A (mg/kg)	10.09a	10.17a	8.83a	NS	9.15x	6.88y	6.60y	**
Chlorophyll B (mg/kg)	9.08a	9.83a	8.56a	NS	11.70x	7.68y	8.23y	***
***B*-carotene (mg/kg)**	16.29a	17.43a	14.68a	NS	11.39x	10.90x	9.07x	NS
Induction time (hours)	10.18a	9.22a	8.97a	NS	15.28x	10.43y	9.99y	***

I0: rainfed; I60: irrigated with 60% ETC; I100: irrigated with 100% ETC; N.D: not detected; Sig.: significance; NS: statistically not significant; *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$. Means followed by different letters within the same row and variety (a–b or x–z, resp.) differ significantly by Tukey's test ($p<0.05$) with respect to the irrigation level.