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Fruit and oil quality of mature olive trees under partial rootzone drying in field conditions

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RESUMEN

Calidad de fruto y aceite de olivos maduros en condiciones de cultivo de secado parcial de la zona radical.

Este estudio fue realizado para evaluar los efectos cuantitativos y cualitativos de la irrigación de olivos por secado parcial de la zona radical (PRD) sobre la calidad de su fruto y de su aceite. Los olivos de la variedad marroquí Picholine fueron cultivados en condiciones áridas en Marrakech, y expuestos a cuatro tratamientos de irrigación: Control (irrigado con el 100 % de la evapotranspiración de la cosecha, en los dos lados del sistema radical), PRD1 (irrigado con el 50 % del control, en sólo un lado del sistema radical, cambiando cada dos semanas), PRD2 (irrigado con el 50 % del control, en un lado del sistema radical, cambiando cada cuatro semanas) y PRD3 (irrigado con la misma cantidad del agua que el control aplicado en un lado del sistema radical, cambiando cada dos semanas). El peso individual del fruto, sus dimensiones y el contenido en aceite fueron generalmente mayores bajo PRD que en el control. Mientras que, el contenido de agua de la aceituna fue inferior en PRD1 y PRD2 que en el control y en PRD3. La acidez del aceite no se afectó por el régimen de irrigación, mientras que el contenido total de polifenoles, que afecta a la estabilidad oxidativa y a las características sensoriales del aceite, aumentó en respuesta a la irrigación mediante PRD, sobre todo con los tratamientos PRD1 (246.0 ppm) y PRD2 (278.5 ppm), frente a los 148.4 ppm y 101.8 ppm de PRD3 y el control, respectivamente. Este aumento podría explicar el amargor del aceite obtenida con PRD1 y PRD2. La composición de ácidos grasos no fue afectada por PRD1 Y PRD2. La calidad del aceite basada en los coeficientes de absorción UV (K_{232} y K_{270}) disminuyó considerablemente con PRD2. El contenido de clorofila resultó antagonista del índice de madurez, y éste último se desarrolló más precozmente en los tratamientos de irrigación PRD que en el control.

PALABRAS CLAVE: Irrigación de déficit – Composición de ácidos graso – 'Picholine Marocaine' – PRD.

SUMMARY

Fruit and oil quality of mature olive trees under partial rootzone drying in field conditions.

This study was conducted to evaluate the quantitative and qualitative effects of partial rootzone drying (PRD) irrigation on olive trees and their fruit and oil quality. Olive trees of the Moroccan Picholine variety were grown under arid conditions in Marrakech, and exposed to four irrigation treatments: Control (irrigated with 100 % of the crop evapotranspiration, on the two sides of the root system), PRD1 (irrigated with 50 % of the control, on one side of the root system, switching every two weeks), PRD2 (irrigated with 50 % of the control, on one side of the root system, switching every four weeks) and PRD3 (irrigated with the same amount of water as the control applied on one side of the root system, switching every two weeks). The individual fruit weight, dimensions and oil contents were generally greater under PRD than the control. Whereas, the fruit water content was lower under PRD1 and PRD2 than the control and PRD3. Oil acidity was not affected by irrigation, while the total polyphenol content, which affects the oxidative stability and sensory characteristics of the oil, increased in response to the PRD irrigation, especially under PRD1 (246.0 ppm) and PRD2 (278.5 ppm) treatments, against 148.4 ppm and 101.8 ppm for PRD3 and the control respectively. This increase could explain the oil bitterness observed under PRD1 and PRD2. The fatty acid composition was not affected by PRD1 and PRD2. The oil quality based on UV absorption coefficients (K232 and K270) decreased significantly under PRD2. Chlorophyll content and maturity index were antagonistic, and olive ripeness was found to be precocious under PRD irrigation treatments compared to the control.

KEY-WORDS: Deficit irrigation – Oil fatty acid composition – Picholine marocaine – PRD.

1. INTRODUCTION

Morocco is a traditional, Mediterranean producer of olives with an average annual production of 600,000 tons of olive fruit and 60,000 tons of oil (MADRPM/DPV, 2005). Based on the volume of olive exportation (63,000 tons/year), Morocco ranks second after Spain (MADRPM/DPV, 2005). However, intensive olive growing is barely feasible without irrigation especially in the southern Mediterranean countries suffering from little or no rainfall during the most critical phonological phases for yield production. To increase or at least maintain crop production in these countries, with less water available for irrigation, will be a great challenge for the coming decades (Alvino *et al*., 1994; Centritto *et al*., 2000; Fereres and Soriano, 2007). More attention should be focused on defining the optimum water requirement that will ensure efficient water use and avoid waste. In Europe, studies on irrigation have generally pointed towards the necessity of full irrigation to maximize olive production (d'Andria *et al*., 1999). However, work by Goldhamer (1999) suggested that mild water deficits can be imposed without any significant loss of oil yield.

Substantial benefits in olive yield and quality can be gained from careful management of irrigation during fruit development and ripening periods (d'Andria *et al*., 1999; Goldhamer, 1999; Motilva *et al*., 1999; Tovar *et al*., 2002). Partial Rootzone Drying (PRD), derived from split-root research, is a well documented technique of water saving irrigation (Dry *et al*., 1996; Loveys *et al*., 2000). The technique was developed based on knowledge of the physiological mechanisms controlling plant transpiration and root-shoot signalling under water deficits. It consists in irrigating only one side of the rootzone, so that the plant can be simultaneously exposed to both wet and dry soils. PRD was tested first on grapevines in southern Australia resulting in *a*) a large increase in water use efficiency without any decrease in crop yield, *b*) a significant reduction in vegetative growth and better balance between vegetative and reproductive development in the grapevine and *c*) an improvement in grape quality (Dry *et al*., 1996; Loveys *et al*., 2000). This technique was also successfully tested on several horticultural crops and fruit trees, including tomato (Davies *et al*., 2002; Mingo *et al*., 2003; Tahi *et al*., 2007), soybean (Bahrun, 2003), common bean (Wakrim *et al*., 2005), citrus (Hutton, 2000), pear (Kang *et al*., 2002), and olive (Centritto *et al*., 2005; Wahbi *et al*., 2005; Fernàndez *et al*., 2006; Aganchich *et al*., 2007).

In previous works (Wahbi *et al*., 2005; Centritto *et al*., 2005) we showed that PRD increased water use efficiency of mature olive trees grown in the field under arid conditions in southern Morocco. The PRD treatments significantly affected plant water relationships, starting with a decrease in stomatal conductance (Gs), and subsequently leaf water potential (Ψ), with an insignificant effect on leaf relative water content (RWC). The PRD treatments also induced a slight reduction in the average shoot length, which was comparable to the fruit yield reduction. A yield reduction in olives under PRD was mainly due to a decrease in fruit numbers, whereas the average fruit diameter was slightly higher under PRD than the control (Wahbi *et al*., 2005). The potential benefit of PRD on WUE was demonstrated in olives, and the hypothesis of a PRD-induced chemical signal was supported by the observation that stomatal closure was similar in all PRD treatments, including PRD3, which had exactly the same level and evolution of leaf water potential as the control (Wahbi *et al*., 2005).

More recently, PRD-treated plants of both varieties Picholine Marocaine and Picholine Languedoc exhibited lower Gs, and higher Ψ and RWC when compared with those exposed to regulated deficit irrigation (RDI), although both treatments received the same amount of water (Aganchich *et al*., 2007). Plant vegetative growth was substantially reduced under both PRD and RDI compared with the control, as expressed by lower values of shoot length, leaf number and total leaf area (Aganchich *et al*., 2007). However, there is little information on the consequences of PRD and deficit irrigation techniques on fruit and oil quality.

The aim of the present work was to investigate the qualitative and quantitative effect of PRD irrigation on olive fruit and olive oil quality parameters.

2. MATERIAL AND METHODS

2.1. Field conditions and plant material

This research was conducted during two consecutive seasons (2000-2002) in an experimental orchard at the Office Régional de la Mise en Valeur Agricole (ORMVA), Station Saada (20 km West of Marrakech city), Latitude: 31°38′ N, Longitude: 8° 04′ W, Altitude: 411,6 m). The climate is of the Mediterranean type with hot and dry summers and mild winters when the reference evapotranspiration is generally about 1,600 mm, as estimated by the FAO– Penman –Monteith equation (Allen, 2000). The average annual rainfall is 250 mm. The soil is silty clay with an average CaCO3 content varying between 2.6% and 5.2%, poor in organic matter, with an organic matter content varying between 1.39 and 1.47% in the top soil surface layer (0-30 cm). The soil pH is slightly alkaline (pH between 8.1 and 8.5), the soil is also moderately saline (average EC around 0.73 mmho.cm^{-1} in the top 60 cm).

The olive orchard used consisted of 100 trees (*Olea europaea*, cv, Picholine marocaine) planted in 1989 on 0.36 Ha, and spaced 6m x 6m. Standard cultural practices in the region were applied (Wahbi *et al*., 2005); trees were well fertilized each year in the beginning of January with 200 kg ha^{-1} potassium phosphate (45%), 138 kg ha^{-1} potassium sulfate (48%), and 350 kg ha^{-1} ammonium sulfate. N was applied thrice, with 200 kg ha^{-1} NH_4NO_3 during pre- and post-flowering stages, and 180 kg ha^{-1} during fruit growth. Olive trees were pruned each year in the end of December, to eliminate higher stumps. Plants were treated against olive leaf spot (*Cycloconium Oleaginum* Cast.) in December-January by aerial spraying of a fungicide (copper oxychloride 50%), and against pests in June by application of Decis 50 (Deltamethrin). Weed control was done by a combination of cultivation and a single hand weeding.

2.2. Irrigation treatments and experimental design

Before the beginning of the experiment, all the plants were irrigated with the same amount of water based on the crop evapotranspiration (ETc), estimated from the potential evapotranspiration (ETo), calculated from class A pan evaporation and using the Penman-Monteith crop coefficients (Kc= 0,7) proposed by FAO. The experiment started in March 2000 with the application of four irrigation treatments: Control, irrigated with 100% of Etc on 2 sides of the trees every 2 weeks, PRD1, irrigated with 50% of the Control on one side, the other one kept dry, and switching every irrigation (2 weeks), PRD2, irrigated with 50% of the control on one side switching sides every 2 irrigations (4 weeks), and PRD3, irrigated with 100% of the control on one side, switching sides every irrigation. Watering was done every two weeks from March until October, corresponding to flowering and fruit ripening stages, respectively. Each tree was surrounded by a 3 m x 3 m basin divided in two parts by a small ridge. Irrigation was conducted by filling the two sides of the basin with drip emitters placed on the two sides of the trees, at 1 m distance from the trunk, the discharge rate was 8 litres per hour, with two emitters per tree, one emitter per side per tree for the control, PRD1 and PRD2 and 4 emitters per tree, 2 emitters per side for PRD3. The experimental design was a split-plot, with 4 blocks and 4 treatments, each individual plot constituted 4 trees, the total number of trees (100) which included 64 trees in the trial, and the remaining 36 trees used as surrounding borders. Full details about the experimental set up were described by Wahbi *et al*. (2005)

2.3. Olive sampling

The olive fruits were harvested by hand in the beginning of January 2004, a period during which the farmers of the region usually harvest their olives.

2.4. Olive fruit characterization

- Fruit weight and size: 100 olives from each sample were randomly selected and weighed. Fruit dimensions (individual length and width) were also measured in the same sample.
- Ripeness index: fruit ripeness was determined on 100 olives randomly selected in each sample (the same for the fruit weight) according to the method proposed by Uceda and Frias (1975), based on the evaluation of the olive skin and pulp colors. Ripeness index values range from 0 (100 % intense green skin) to 7 (100 % black pulp flesh and skin).

2.5. Oil extraction

Approximately 1 kg/tree/treatment of fruits was ground to a paste using a hammer mill, the sample was thoroughly mixed and approximately 700 g of the paste were placed into a mixing jar for 20 min stirring. 100 ml of boiling water was added to the sample, and it was further stirred for 10 min. The sample was then centrifuged for 1 min to allow oil separation from the water. The oil was collected in a graduate cylinder and decanted overnight.

2.6. Olive oil analyses

- Oil content was determined by extracting dry olive paste with hexane using a Soxhlet apparatus (A.F.NOR, 1984).
- The water content of the olive paste was determined by desiccation according to the normalized method (A.F.NOR, 1984). Approximately 30 g of paste was placed into a Petri dish, and dried at 80° C in a fan forced oven for 48 hours. The difference in weight was calculated as water content.
- Oil bitterness (K_{225}) was determined according to the method described by Gutiérrez *et al*. (1992), which consists of the extraction of the bitter components from an oil sample passed through a C18 column (Bakerbond spe, J.T. Baker, Phillipsburg, NJ, USA). The absorbance of the extract was measured at 225 nm against methanol/water (1:1).
- The chlorophyll content was measured using the method of Wolff (1968). The absorbance of the oil sample was measured at 630, 670 and 710 nm, using carbon tetrachloride as control. The chlorophyll content was then calculated according to the method and reported in ppm.
- Total phenol content in oil was determined according to the Folin-Ciocalteu procedure, as Vázquez Roncero *et al*. (1973) described.
- Oil acidity given as % of oleic acid was determined according to the A.F.NOR T, 60-204 method (A.F.NOR, 1984). The free fatty acid content was estimated after titration of an oil ethanol mixture with a potassium hydroxide solution.
- Specific extinction coefficient at 232 nm and 270 nm was determined following the analytical methods described in A.F.NOR T60-223 (A.F.NOR, 1984).
- Total fatty acids: methyl esters were prepared according the A.F.NOR method NF.T. 60-233 (A.F.NOR., 1984). Gas liquid chromatography (GLC) analysis was carried out using a Girdel-3000 Chromatograph, equipped with a FID detector and a spectra-physics 4 100 calculator. A CP-Wax 52 CB column was used (25 m length x 0.25 mm id x 0.20 μm thickness). Nitrogen was used as a carrier gas with 1 ml/min as column flux. Temperatures of the injector and detector were set at 230°C and oven temperature at 180°C. Data treatment was performed by the Star interface.

2.7. Statistical analysis

Significant differences between treatments were determined using one-way ANOVA followed by the LSD test ($p < 0.05$), carried out on the SPSS 10.0 for Windows.

3. RESULTS AND DISCUSSION

3.1. Fruit analyses

3.1.1. Biometric parameters

Weight and dimensions of olive fruits are of great importance for trade value and to determine their use for oil production or as table olives (Kiritsakis and Marakakis 1987). These parameters were found to be dependent on irrigation treatments (Table 1). The fruit fresh weight (FW) was improved by PRD irrigation, relative to the control. FW was consistently higher under the PRD treatments (270.7, 284.5 and 287.8 g for PRD1, PRD2 and PRD3, respectively) compared to the control (232.2 g) ($p<0.05$) but differences between PRD treatments were not significant.

Stone weight did not differ among PRD1, PRD3 and the control (Table 1), while significant differences were observed among these three treatments and PRD2, which had the highest value (46.3 g). This increase in stone weight under PRD2 was related to the increase in fruit FW under this treatment. Moreover the stone / fruit ratio was significantly higher in the control in comparison with the PRD treatments (Table 1); this means that the olives under treatments PRD1, PRD2 and PRD3 contained 83.9%, 83.7% and 85.6% flesh, respectively; against 81.6% for the control. The fruit width was increased under PRD2 and PRD3, whereas PRD1 values were similar to those of the control. The fruit length was slightly affected by PRD1; but under PRD3 fruit length was greater than the control and the other PRD treatments. Since PRD3 treatment brings the same amount of water as the control but only on one side of the root system, we can assume that partial rootzone drying must be responsible for the increase in weight and dimensions of the olive fruits. This increase was probably due to a slightly lower olive production. Indeed our previous work showed that olive yield under PRD treatments was 78.7 (PRD1), 74.5 (PRD2) and 88.9 (PRD3) kg/tree against 92.8 kg/tree for the control (Wahbi *et al*., 2005). In fact, it was previously reported that the size of the fruit diminishes as olive tree production increases (Lavee and Wodner, 2004; Gomez-Rico *et al*., 2005). El Antari *et al*. (2002) reported that under deficit irrigation, low olive yields correlated with an increase in individual weight and dimensions of the fruit.

Table 1

Olive fruit characteristics, under different irrigation treatments. Values are means ± SE of four replicates. Different letters within a column indicate statistically significant differences ($p<0.05$).

Irrigation treatments	Olives weight (g)	Stone weight (g)	Stone / olive	Length (cm)	Width (cm)
PRD1	270.7 ± 8.0 a	43.6 ± 3.6 ab	0.16 ± 0.02 ab	1.86 ± 0.12 a	1.41 ± 0.08 a
PRD2	284.5 ± 16.9 a	46.3 ± 1.4 a	0.16 ± 0.01 a	1.93 ± 0.13 b	1.46 ± 0.11 b
PRD3	287.8 ± 14.0 a	41.5 ± 1.7 b	0.14 ± 0.01 b	2.03 ± 0.17 c	1.49 ± 0.12 c
Control	232.2 ± 5.2 b	42.8 ± 1.2 b	0.18 ± 0.01 c	1.94 ± 0.15 b	1.41 ± 0.11 a

3.1.2. Ripeness index

Olive ripening, estimated by fruit color, showed differences among the irrigation treatments; all PRD treatments had higher values of ripeness index (RI), compared to the control (Table 2). The highest RI values were obtained under PRD2 and PRD1 (3.61 and 3.41 respectively) which were both supplied with only 50% water compared to the control. The olive ripeness seems to be precocious under PRD irrigation, which was probably due to the low yield induced by the water deficit (El Antari *et al*., 2002). In fact, in the same experiment we found that PRD

Table 2

Olive ripeness index, under different irrigation treatments. Values are means ± SE of four replicates. Different letters within a column indicate statistically significant differences ($p<0.05$).

Irrigation treatments	Olive ripeness index
PRD1	3.41 ± 0.21 a
PRD2	3.61 ± 0.04 a
PRD3	2.62 ± 0.05 b
Control	2.16 ± 0.16 c

treatments induced a slight yield reduction (15-20%) compared to the control, which was achieved with a 50% reduction in the total amount of water applied. This has resulted in an increase in water use efficiency by 60-70% under PRD1 and PRD2 treatments, compared to the control and PRD3 (Wahbi *et al*., 2005). The irrigation of the half root system could also be responsible for the precociousness of olive ripeness, since RI was significantly elevated even under PRD3 which received the same amount of water as the control, but applied on one side of the root system.

There is general agreement that high quality oil requires the precise harvest timing of good quality fruit although in-field determination of when to harvest can be difficult. Numerous studies in the Mediterranean basin have shown that during the ripening period, oil percentage increases dramatically during early fruit ripening (Salvador *et al*., 2001; Beltran *et al*., 2004). It then slows down as full ripeness approaches and declines slightly as fruits become over-ripe. Fruit detachment force declines steadily as fruit ripens. It then drops sharply when fruit reaches full ripeness and fruit drop increases.

Other studies (Caponio and Gomes, 2001) indicated that fruit maturity influences the organoleptic characteristics of the oil and the ultimate oil stability. It has been reported that an early harvest gives less oil content, with low acidity, green in color, with fruity flavor, burning, and more herbaceous taste. A late harvest gives generally more abundant oil, with higher acidity, yellow in color, and with a less fruity flavor (Berger, 2006).

3.2. Oil analyses

3.2.1. Oil content

The results in Table 3 show that olive fruit water content is closely related to the water supply. Under PRD1 and PRD2, which both reduced water supply by 50% compared to the control, the mean value of fruit water content was lower than the control and PRD3 which were irrigated with 100% of the ETc (Table 3). No significant difference was observed between PRD1 and PRD2 and between PRD3 and the control.

In contrast to the olive water content, oil content was greater under PRD1 and PRD2, whereas PRD3 and the control had the lowest values (Table 3). This antagonistic effect between fruit water and oil contents could be explained by their opposite polarity and their competition in the occupation of cellular spaces (Mazliak, 1968; Gianfranco, 1989). As mentioned before, the greater oil content in PRD1 and PRD2 could be the result of the precocious effect of these treatments on olive ripeness. Under a similar irrigation scheme, Motilva *et al*. (2000) reported that for olives subjected to regulated deficit irrigation, the oil content increased when the water content decreased.

Table 3

Olive water and oil contents under different irrigation treatments. Values are means ± SE of four replicates. Different letters within a column indicate statistically significant differences ($p<0.05$).

Irrigation treatments	Olive water content (%)	Olive oil content (%)
PRD1	55.16 ± 0.63 ab	42.28 ± 0.76 ab
PRD2	54.52 ± 0.51 a	43.03 ± 0.95 a
PRD3	58.15 ± 2.2 bc	41.15 ± 0.74 bc
Control	59.29 ± 3.57 c	40.73 ± 0.67 c

3.2.2. Acidity

Oil acidity was similar in all irrigation treatments (Table 4), all values were below 0.4%. According to the International Olive Oil Council (IOOC, 2001) these oils can be considered as extra-virgin. Several other authors reported that olive oil acidity does not change with the irrigation strategy and frequency (Dettori and Russo, 1993; Stefanoudaki *et al*., 2001; El Antari *et al*., 2002; Patumi *et al*., 2002).

3.2.3. Chlorophyll content

As expected, chlorophyll content was higher in the immature olives and rapidly decreased with time as the color changed from green to black. Under all PRD treatments the oil had lower values of chlorophyll content than the control (Table 4). PRD2 had the lowest level of chlorophyll content, i.e., 0.00 ppm, whereas PRD1 and PRD3 had 0.28 ppm and 0.34 ppm, respectively. Similarly, Gomez-Rico *et al*., (2005) reported that chlorophyll content of virgin olive oil from Cornicabra olive cultivar was not influenced by irrigation, however an important decrease in pigment content during fruit ripening was observed (Gomez-Rico *et al*., 2005). In our study, chlorophyll oil content under PRD irrigation was related with our finding that the maturity index was greater under PRD1 and PRD2 (Table 2). Similarly, the finding of Tovar *et al*. (2001) on young olive trees (cv. Arbequina) grown under linear irrigation strategies showed that pigment content (chlorophylls and carotenoïds) was negatively related to the amount of water applied. However these authors did not report any effect of irrigation on the olive oil chlorophyll content under RDI strategy (Tovar *et al*., 2002).

3.2.4. UV absorption coefficients

Oil quality estimated by specific extinction coefficient at 232 nm and 270 nm was not affected by PRD1, PRD3 and control treatments (Table 4) whereas under PRD2 both coefficients decreased significantly. Similar results were reported by Nanos

Table 4
Acidity, chlorophyll content and organoleptic evaluation of oil, under different irrigation treatments. Values are means ± SE of four replicates. Different letters within a line indicate statistically significant differences ($p<0.05$).

Irrigation treatments	PRD1	PRD2	PRD3	Control
Acidity (%)	0.37 ± 0.05 a	0.35 ± 0.04 a	0.33 ± 0.01 a	0.35 ± 0.06 a
Chlorophyll content (ppm)	0.28 ± 0.07 a	0.00 ± 0.00 b	0.34 ± 0.12 a	0.54 ± 0.10 c
K232	1.51 ± 0.07 a	1.21 ± 0.08 b	1.42 ± 0.21 a	1.57 ± 0.07 a
K270	0.17 ± 0.01 a	0.13 ± 0.01 b	0.15 ± 0.02 a	0.16 ± 0.01 a
Total phenols (ppm)	246.00 ± 18.54 a	278.51 ± 28.44 a	148.35 ± 31.64 b	101.79 ± 4.44 c
K225	1.11 ± 0.09 a	0.9 ± 0.27 a	0.38 ± 0.04 b	0.37 ± 0.06 b

et al. (2002) on almond oil. In contrast, Gomez-Rico *et al*. (2005) found that K_{232} and K_{270} of virgin olive oil decreased with water increase. This effect is probably caused by the interference of the content in phenolic compounds, which also absorb in the UV region in these analytical determinations (Gomez-Rico *et al*., 2005). This could possibly explain the significant decrease in these coefficients in PRD2. The observed decrease in K_{232} and K_{270} indexes could also be explained by the long period of irrigation switch between the dry and the wet sides of the root system under PRD2 (28 days). It could be concluded that under PRD2 treatment, the oil quality was improved, since the K_{232} and K_{270} coefficients are negatively related to oil quality (Nanos *et al*., 2002).

3.2.5. Total phenol content

Phenolic substances in the olive oil were significantly and positively affected by the PRD irrigation treatments (Table 4). Our results confirm the negative relationship previously observed between phenol content and irrigation levels and frequency (Patumi *et al*., 1999; Tovar *et al*., 2001; El Antari *et al*., 2002; Patumi *et al*., 2002; Tovar *et al*., 2002; Gomez-Rico *et al*., 2005). The increase in oil phenol content under PRD1 and PRD2 could be a consequence of water stress, since both these treatments were irrigated with only 50% of the water supplied to the control. It is well established that water stress induces changes in the enzyme activities responsible for the synthesis of phenolic compounds, such as L-phenylalanine amonia-lyase (PAL). It has been previously demonsrtaed that PAL activity was greater under water stress conditions (Patumi *et al*., 1999; Tovar *et al*., 2002). This could also be a reason for the highest level of phenol contents obtained in PRD2 which was the most drought-stressed treatment (period of irrigation switch between sides was 28 days). The irrigation of one side of the root system could also be a reason for the increase in the polyphenol contents, as a stress signal in response to the drying part of the root system. This effect was further confirmed by significant differences in phenol contents between PRD3 and the control, although they have both received a similar amount of irrigation water.

Phenols have a wide range of biochemical and pharmaceutical effects, including anticarcinogenic, antiatherogenic, antimicrobial and antioxidant activities (Kohyama *et al*., 1997; Visioli and Galli, 1998). The phenols were also found to be closely associated with the organoleptic characteristics of the oil. They are largely responsible for the attributes pungency and bitterness. Such compounds are of great interest because they influence the quality and the palatability of the olive oil and prolong its shelf-life by slowing down the formation of hydroperoxides of polyunsaturated fatty acids (Salas *et al*., 1997).

3.2.6. Oil bitterness (K225)

Oil bitterness is an important parameter to evaluate olive oil quality (Gutiérrez *et al*., 1992). Our data showed that oil bitterness increased as the water amount applied to the olive trees decreased (Table 4). But no significant differences were observed between PRD3 and the control or between PRD1 and PRD2. This increase in bitterness could be explained by the elevation of phenolic compounds content which affects the oxidative stability and sensory bitterness in the oils (d'Andria *et al*., 1996; Motilva *et al*., 1999; Motilva *et al*., 2000; Tovar *et al*., 2001; Gomez-Rico *et al*., 2005).

3.2.7. Total fatty acids

The oleic and palmitic acids contents were similar in all irrigation treatments applied, except for PRD3 where a slight decrease and increase was observed for oleic (73.76%) and palmitic (9.23%) acids, respectively (Table 5). Linoleic acid content decreased significantly under PRD treatments. But the contents in other minor fatty acids were similar under all irrigation treatments. These results contrasted with those of Patumi *et al*. (2002), who reported that the irrigation regime did not cause any variation the fatty acid composition of oil.

Table 5

Oil fatty acid composition under different irrigation treatments. Saturated acids: C:16 palmitic, C:17 heptadecanoic, C:18 stearic, C:20 eicosanoic ; unsaturated acids: C16:1 palmitoleic, C17:1 heptadecenoic, C18:1 oleic, C18:2 linoleic, C18:3 linolenic eicosenoic, C20:1 eicosenoic. Uns/sat= unsaturated saturated acids ratio. Values are means ± SE of four replicates. Different letters within a column indicate statistically significant differences (p<0.05).

Irrigation treatments	C16:0 (%)	C16:1 (%)	C17:0 (%)	C17:1 (%)	C18:0 (%)	C18:1 (%)	C18:2 (%)	C18:3 (%)	C20:0 (%)	C20:1 (%)	Uns/sat
PRD1	7.04± 0.71 a	0.63± 0.06 a	0.10± 0.01 a	0.34± 0.06 b	2.91± 0.34 a	76.01± 0.72 a	11.22± 0.37 b	0.95± 0.09 ab	0.39± 0.03 a	0.42± 0.04 a	8.67± 1 ab
PRD2	6.87± 0.7 a	0.62± 0.04 a	0.10± 0.01 a	0.45± 0.04 c	2.84± 0.33 a	75.86± 1.30 a	11.62± 0.49 ab	0.92± 0.05 b	0.8± 0.03 a	0.40± 0.02 a	8.90± 0.93 a
PRD3	9.23± 0.36 b	0.62± 0.07 a	0.10± 0.00 a	0.36± 0.07 bc	2.82± 0.26 a	73.76± 1.05 b	11.18± 0.34 b	0.94± 0.07 b	0.38± 0.02 a	0.39± 0.03 a	7.43± 0.76 b
Control	7.29± 0.84 a	0.69± 0.03 a	0.10± 0.00 a	0.58± 0.02 a	2.56± 0.09 a	75.32± 0.55 a	11.85± 0.32 a	1.05± 0.06 a	0.38± 0.04 a	0.40± 0.02 a	8.71± 0.69 ab

The unsaturated/saturated acid ratio was around 8, and did not appear to be influenced by PRD irrigation (Table 5). However, for PRD3 we observed a small decrease in this acid ratio. This effect could possibly be explained by an increase in palmitic acid and decrease in oleic acid. The unsaturated/saturated acid ratio influences the organoleptic characteristics of the oil because an oil with a high content of saturated fatty acids is more viscous and persistent in the mucous of the oral cavity. This gives rise to the defection defined as a “fatty sensation” (Solinas, 1990).

Overall, according to the criteria of IOOC, the oil obtained under all irrigation treatments in terms of fatty acid composition is of good quality (IOOC, 2001).

4. CONCLUSION

The results of this study indicated that in addition to saving 50% of water irrigation on olive trees, PRD irrigation provides a favorable condition for the two olive uses either as table olives, as the olive biometric parameters are positively affected by PRD, and for oil production since the olive oil content is greater and fruit ripeness is precocious under PRD. This last effect may also permit a good recovery of the olive trees for the following year. Moreover, the oil extracted is extra virgin and the oil phenol content increases, which could have great importance for improving oil organoleptic characteristics and oil oxidative stability. The assessment of stability is an important component of olive oil which must remain at a high quality during storage and prior to consumption.

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