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Effect of deficit irrigation on olive and olive oil quality during fruit storage

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Abstract. We evaluated the effects of deficit irrigation on olive fruit and olive oil quality. Mature 'Konservolea' olive trees were deficit irrigated during August (10% of control). Control trees received in total around 5600 m^3/ha. Total water savings in deficit irrigated trees were around 3000 m^3/ha. Quality parameters, as skin colour, flesh firmness, dry matter and total phenols, were evaluated on green olives harvested in late September, both at harvest and after 1 and 2 weeks of storage at 5ºC including. In early November, ripe olives were harvested and quality was evaluated on fruit and olive oil at harvest and after 11, 17 and 24 days at 5ºC. At harvest, ripe fruit size and shape, density, oil and water content, respiration rate, skin colour, firmness, and chlorophyll content were evaluated. The last five quality parameters were also evaluated during fruit storage, while acidity, peroxide value and spectrophotometric oxidation indexes were measured on olive oil. Deficit irrigation did not affect green olive fruit quality at harvest and after storage. Ripe fruit from deficit irrigated trees were slightly bigger and of more advanced maturity with lower oil content than control fruit. Olive oil extracted from fruit harvested from deficit irrigated trees was similar to olive oil obtained from control fruit at harvest, but, during fruit storage, the extracted olive oil quality deteriorated rapidly due to increased acidity and K270 index.

Keywords. *Olea europaea* – Phenols – Firmness – Colour – Acidity.

Effets de l'irrigation déficitaire sur la qualité de l'olive et de l'huile d'olive pendant le stockage des fruits

Résumé. *Nous avons évalué les effets de l'irrigation déficitaire sur la qualité de l'olive et de l'huile d'olive pendant le stockage des fruits. Des oliviers adultes de la variété 'Konservolea' subirent un traitement d'irrigation déficitaire durant le mois d'août (10% du traitement contrôle, dont les arbres reçurent 5600 m^3/ha). L'économie d'eau fut de 3000 m^3/ha. La qualité des fruits verts, récoltés fin Septembre, fut évaluée à la récolte et après 1 et 2 semaines à 5ºC. Début Novembre, les olives mûres furent récoltées et leur qualité évaluée (fruit et huile d'olive) à la récolte et après 11, 17 et 24 jours à 5ºC. Les cinq derniers critères furent aussi évalués durant le stockage des fruits, ainsi que l'acidité, le niveau de peroxydes et les indices spectrophotométriques d'oxydation de l'huile d'olive. L'irrigation déficitaire n'a pas affecté la qualité du fruit. Les fruits mûrs des arbres du traitement déficitaire furent légèrement plus gros et de maturité plus avancée, avec un contenu en huile inférieur a ceux du traitement contrôle. L'huile d'olive extraite des fruits du traitement déficitaire fut similaire a celle obtenue du traitement contrôle à la récolte, mais la qualité de l'huile extraite s'est détériorée rapidement pendant le stockage, due à l'augmentation de l'acidité et de l'indice K270.*

Mots-clés. *Olea europaea – Phénols – Fermeté – Couleur – Acidité.*

I – Introduction

Olive is an important crop in the Mediterranean region that has traditionally been cultivated with no irrigation and is known to attain acceptable production even under dry farming. Nevertheless, the last decade irrigated olive orchards proved to be more productive with increased shoot growth, flowering, fruit set and reduced biennial bearing and fruit drop (Inglese *et al.*, 1996; Proietti and Antognozzi, 1996). Water availability also improved the commercial value of table olives by increasing fruit size (Proietti and Antognozzi, 1996).

Despite the fact that water is beneficial to olive cultivation, we must keep in mind that water scarcity is a global problem that concerns everybody, especially in the Mediterranean region. Agriculture is still the greatest consumer of the water in the Mediterranean region, as more than 80% of available water resources are allocated to irrigation with relatively high losses exceeding 50% (Laraus, 2004). Most of olive growers apply water inefficiently, with lower or higher than required quantities. The efficient management of the limited water resources in the Mediterranean agriculture scientifically proven irrigation scheduling techniques and deficit irrigation. There are several cases of successful application of regulated deficit irrigation in the xerothermic regions like many Mediterranean areas (Fereres and Soriano, 2007). Studies have shown that there are advantages in reducing irrigation to olive trees at the time of slow fruit growth (pit hardening). Regulated deficit irrigation after pit hardening has been recommended replacing only the 66% of crop evapotranspiration at least in deep soils with good water retention (Tognetti *et al.*, 2006).

The optimisation of irrigation management practices requires more research to be done on olive tree response to water stress through regulated deficit irrigation and efficient irrigation management programmes. Thus, the aim of this work was to study the effect of deficit irrigation on the quality of olive fruit and olive oil from cv. Konservolea, a major Greek olive cultivar, at harvest and after fresh fruit storage.

II – Materials and methods

'Konservolea' olive trees from an olive farm located in Anchialos, Central Greece, were used. The soil is relatively heavy with many stones and around 5% slope facing south. Irrigation is done by low volume sprinklers with good water quality (conductivity <700 μS/cm). The trees are planted 5m x 5m and pruned yearly. The fruit is used for table olives (green or black) or for olive oil extraction. Six trees were the experimental units – replications per treatment: control**,** irrigated from the end of May to the end of July for a total of 5.76 m^3 of water per tree and from early August to mid September for a total of 8 m^3/tree and deficit, irrigated as the control until the end of July, and then irrigated just once in August receiving 0.32 m^3/tree. That is around 3000 m^3/ha water savings.

In this experiment we harvested by hand in two different periods:

First harvest occurred in late September for green table olives: fruit quality was evaluated immediately and after 1 and 2 weeks cold storage at 5°C plus 1 day shelf-life at the Lab. of Pomology, Univ. of Thessaly. Quality evaluation included skin color, flesh firmness, dry matter and total phenols. Skin color was measured using a colorimeter (Hunter Lab, MiniScan XE Plus, Reston, VA, USA), flesh firmness was measured, after careful removal of fruit skin on opposite sides of the fruit, with fruit firmness tester (Turoni Slr, Italy) equipped with a 4mm plunger without touching the pit. The % dry matter of olives was calculated after weighing the fresh mass of flesh pieces, drying them at 100°C until no further changes in mass and final dry mass measurement. For measuring total phenol content we used the Folin-Ciocalteau method expressed as gallic acid equivalents per 100 g fresh mass. Analysis of variance (ANOVA) was performed on raw data in order to detect statistical differences between treatments, and means separation was assessed with Tukey test.

Second harvest occurred in early November with ripe olives for olive oil extraction: four plastic boxes containing 25 kg olives each were harvested from each treatment. All boxes were left in a shaded well aerated place for two days until they were transported by car to the Postharvest Laboratory at the University of Foggia. Upon arrival, each treatment was divided in three replicates and the following attributes were determined on 35 fruit per replicate: fruit size (perimeter, major and minor axis, and projected area), and shape (roundness), bulk density, true density, seed ratio as percent of weight, moisture content and oil content (expressed as percentage on fresh and dry weight).

Then, the olives of each treatment were stored in 3 boxes (one for each replicate) in a humidified cold room at 5°C. Initially and after 11, 17 and 24 days, the following attributes were determined: colour, evaluated on 35 olives for each sample using a scale from 1 to 5, with 1= full green, 2 = partially black (less than 50%), 3= partially black (more than 50%) black, 4= not completely black, and 5 = completely black; firmness, as the load (in N) required to have a 3-mm deformation on the minor axis with a speed of 120 mm/minute, measured with an Instron Universal Testing machine, model 3340; and chlorophyll, with 20-ml pure methanol added to 5 g of frozen olive fruit samples and kept in the dark at room temperature for 24 hours, followed by measurements of absorbance at 666 and 653 nm and chlorophyll calculations as following (in mg/100g of fresh weight):

chlorophyll a= $(15.65*A_{666})-(7.34*A_{653})$ and chlorophyll b= $(27.05*A_{653})-(11.21*A_{666})$

In order to measure respiration rate, 1 kg of olives for each replicate, were stored in individual 9,42 L jars (three replicates for each treatment) for the entire duration of the experiment and all jars were connected to a continuous flow of humidified-air. Respiration rate (in ml CO_2/kg/h) was measured using a dynamic system; air samples of 0.5 ml were collected with a syringe from the inlet and the outlet tubings and differences in CO_2 concentration were detected with a gas chromatograph (Shimadzu, model 17A ATF, Japan) equipped with a TCD detector, and then referred to the sample weight and air flow.

At each evaluation time, from about 6 kg of olives from each lot, oil samples were mechanically extracted using a laboratory scale olive oil extraction plant constituted of a hammer crusher, a mixer, and a vertical open-centrifuge.

The following attributes were determined on oil samples according to the analytical methods described in Regulations EEC2568/91 and EEC1429/92 of the European Union Commission (EUC, 1991): titratable acidity (% of oleic acid), determined by titration of a solution of oil dissolved in ethanol/ether (1:1) with ethanolic potash; peroxide value (in meq of active oxygen per kilogram of oil) with a mixture of oil and chloroform/acetic acid left to react with potassium iodide solution in darkness, followed by titration of free iodine with sodium thiosulfate solution; K232 and K270 extinction coefficients were calculated from absorption at 232 and 270 nm, respectively, with a UV spectrophotometer using a 1% solution of oil in cyclohexane and 1 cm path length.

The statistical design was a CRD (Completely randomized design) and the data analyzed with a one-way ANOVA with irrigation regime as factor. Data on samples after harvest were treated alone and together with pooled data from all evaluation times. The first results give information about the state of the fruit and oil initially before storage, while the second allows evaluating the overall differences between treatments during storage.

III – Results and discussion

Skin color of green Konservolea olives, although found to be statistically dependent on storage duration, did not change profoundly in all color parameters evaluated (L*, a*, b*, C* and hue angle) as these fruit did not ripen to substantially lose green color and did not develop chilling injury (appearing as dull skin color developing with time to brown-black areas on the skin) (data not shown).

Fruit weight of green Konservolea olives was not negatively affected from deficit irrigation or time (data not shown). Deficit irrigation did not affect green fruit flesh firmness. The percentage of fruit dry matter of green Konservolea olives slightly decreased with storage duration and somewhat increased due to deficit irrigation compared to control (Figure 1). Total phenols in green Konservolea fruit were not affected from deficit irrigation but decreased with storage time (Table 1).

The effect of irrigation treatment on ripe olives at harvest was observed on fruit size, color and fruit flesh firmness, as deficit irrigated fruit were bigger (possibly due to variation in total fruit load per tree) than control fruit, despite to what was expected. Similarly, area, perimeter and major axis were significantly higher in deficit irrigated ripe fruit (Table 2). Color score of deficit irrigated ripe olives was significantly higher, indicating faster color changes from green to black and therefore a more advanced maturity stage, than control fruit. As a consequence, firmness was lower for deficit irrigated ripe olives than for control (well-irrigated) ones. This is in agreement with work on table olives irrigated or not, where non-irrigated olives ripened (softened and changed colour) faster than irrigated ones (Inglese *et al.*, 1996; Proietti and Antognozzi, 1996). No other differences in ripe olive fruit quality at harvest were observed (Table 2). Olives had a moisture content of about 53%, a true density of 0.88 and 0.97 g/ml for control and deficit irrigated fruit, respectively, and seed ratio at 20% by weight. Respiration rate ranged from 12 to 15 ml CO_2/kg/h, and total chlorophyll content was 1-2 mg/100 g of fresh weight at harvest (Table 2).

The irrigation regime didn't seem to affect quality parameters and respiration rate of ripe Konservolea olives during storage at 5°C except colour score, which was significantly higher in deficit irrigated olives (Table 3).

At harvest, ripe olives from control treatment had higher oil percent per fresh weight basis than deficit irrigated olives, i.e. 17 and 16%, respectively, but no significant difference was detected between the two treatments when oil content was expressed per dry weight basis (Table 4). Similarly irrigation increased oil content per fresh weight basis (and per dry weight basis) in Carolea olives compared to non-irrigated control (Inglese *et al.*, 1996). Regarding oil quality obtained from olives at harvest, the only significant difference between irrigation regimes was detected for K_{270} extinction coefficient, which was significantly higher for oil obtained from deficit irrigated olives, 0.2 versus 0.1, indicating a more advanced oxidation process, but oils from both treatments remaining within the range of extra virgin olive oil fixed at 0.22 (Table 4).

After storage, quality of oil extracted from deficit irrigated olives declined. Acidity increased to 1.2%, reaching above 1% even after 11 days of storage, thus over-passing the limit of extra-virgin olive oil fixed at 0.8% (Table 5), while oil obtained from well-irrigated olives did not show changes and remained stable during storage at around 0.5% (Table 5). Extinction coefficient at 270 was also significantly higher in oil obtained from deficit irrigated olives with average value over-passing the limit for extra-virgin oil, and indicating a more advanced oxidation process, while ΔK was about zero for both treatments.

IV – Conclusions

According to the experimental results green Konservolea olive fruit quality didn't change significantly with storage except of a slight reduction in total phenols.

The effect of irrigation treatment on ripe Konservolea olives at harvest was observed on fruit size, color and firmness, as fruit irrigated with deficit treatment were bigger, had higher color score and lower firmness than well irrigated olives. Thus, it seems that deficit irrigation advanced olive maturity at harvest. Deficit irrigation treatment also advanced skin color changes during fruit storage at 5°C, with no other differences detected concerning olive fruit quality.

Ripe olives from control treatment had higher oil content (on fresh weight basis) compared to olives from deficit treatment. Oil quality at harvest was similar between treatments except for K270 extinction coefficient, which was significantly higher for oil obtained from deficit irrigated olives, but both remaining within the range of extra virgin olive oil fixed in 0.22. Finally, oil quality after storage declined in deficit irrigated olives based on oil acidity and K270 extinction coefficient.

Table 1. Effect of deficit irrigation on total phenols of green Konservolea olives at harvest and after 1 and 2 weeks storage at 5°C.

	Total Phenols (mg Gallic acid/100g FW)	
Time of storage	Control	Deficit
Harvest	106 ± 7,1	102± 5,1
1 week	110 ± 5,6	107± 3,5
2 week	79 ± 12	83± 11

Table 2. Effect of deficit irrigation on quality parameters of ripe Konservolea olives at harvest.

Parameter	Control	Deficit
Moisture content (%)	55.3 a	54.5 a
True density (g/ml)	0.88 a	0.97 a
Bulk density (g/ml)	0.5 a	0.5 a
Seed ratio (%w)	22.1 a	20.1 a
Area (pixel^2)	32073 b	32201 a
Perimeter (pixel)	682 b	720 a
Major axis (pixel)	229 b	242 a
Minor axis (pixel)	178 a	187a
Roundness	0.78 a	0.77a
Respiration Rate (ml CO_2/Kg/h)	15.6 a	12.6 a
Color score	3.6 b	4.4 a
Firmness (N)	17.9 a	12.4 b
Chl a (mg/100g)	0.4 a	0.6 a
Chl b (mg/100g)	0.9 a	1.6 a
Chl Total (mg/100g)	1.3 a	2.2 a

Within each row, values followed by different letters are significantly different for P<0.05

Table 3. Effect of deficit irrigation on quality parameters of ripe Konservolea olives during storage at 5°C, mean values for all storage evaluations are shown.

Parameter	Control	Deficit
Respiration Rate (ml CO_2/Kg/h)	12.5 a	11.1 a
Firmness (N)	13.1 a	11.3 a
Weight loss (%)	1.4 a	1.4 a
Color score	3.8 b	4.3 a
Chl a (mg/100g)	0.66 a	0.44 a
Chl b (mg/100g)	1.57 a	2.19 a
Chl Total (mg/100g)	2.23 a	3.17 a

Within each row, values followed by different letters are significantly different for P<0.05

Table 4. Effect of deficit irrigation on quality parameters of olive oil extracted from ripe Konservolea olives at harvest.

Parameter	Control	Deficit
Oil content (% FW)	17.1 a	15.7 b
Oil content (% DW)	40.0 a	37.3 a
Acidity (% oleic acid)	0.5 a	0.7 a
Peroxide value (meq O_2/ Kg)	7.6 a	7.5 a
K_{232}	1.2 a	2.4 a
K_{270}	0.1 b	0.2 a

Within each row, values followed by different letters are significantly different for P<0.05

Table 5. Effect of deficit irrigation on quality parameters of olive oil extracted from ripe Konservolea olives after storage at 5°C, mean values for all storage evaluations are shown.

Parameter	Control	Deficit
Acidity (% oleic acid)	0.5 b	1.2 a
Peroxide value (meq O_2/ Kg)	6.7 a	8.5 a
K_{232}	1.4 a	2.1 a
K_{270}	0.1 b	0.3 a

Within each row, values followed by different letters are significantly different for P<0.05

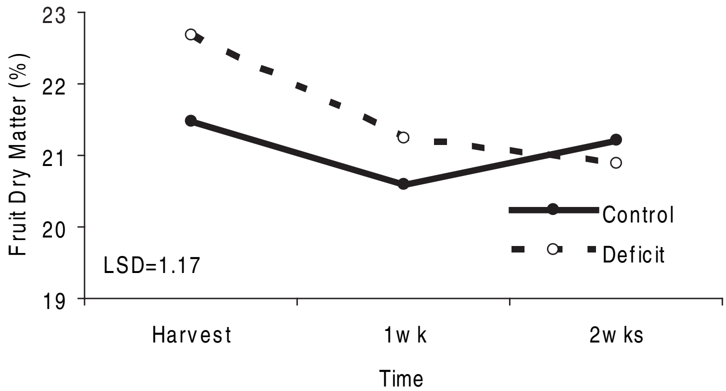

Figure 1. Effect of deficit irrigation on fruit dry matter (%) from Konservolea olives at harvest and after 1 and 2 weeks storage at 5°C.

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