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Short communication

Olive fruit pulp and pit growth under differing nutrient supply

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ABSTRACT

The objetive of this work was to study if the addition of nutrients to the irrigation water modified 'Manzanilla de Sevilla' olive pulp and pit growth. The experiment was carried out during the 2003 fruit-growth period in an irrigated orchard near Seville, southern Spain. Fruit samples were taken in July and September, at 12 and 21 weeks after full bloom (AFB) respectively, in trees irrigated with (T1) or without (T0) the addition of nutrients (N–P–K). The nutrient availability of T1 fruits increased the fruit fresh and dry weight, longitudinal and equatorial diameters, and the pulp-to-pit ratio, characteristics particularly appreciated for table olives. The balance of growth between the fruit mesocarp (pulp) and endocarp (pit) was modified because those two tissues were affected differently. Mesocarp fresh weight was significantly higher at both 12 and 21 weeks AFB in the fertilized treatment, as was mesocarp dry weight at 12 weeks AFB. Neither the endocarp fresh and dry weight nor shape (the ratio of the equatorial and longitudinal diameters) was altered at either of the two studied dates. These results emphasize the importance of an appropriate fertilization management in irrigated olive orchards, particularly for table olives, and also confirm the olive endocarp as a strong sink tissue that competes with the mesocarp during early development.

1. Introduction

The olive fruit is a drupe composed of three distinct tissues: the thin protective exocarp, the fleshy mesocarp (pulp or flesh) and the stony endocarp (pit or stone) (King, 1938). The mesocarp is the edible portion of table olives and the tissue where oil is accumulated. A high mesocarp:endocarp (pulp-to-pit) ratio is considered desirable, particularly for table olives (Garrido et al., 1997). Also, in the case of pitted table olives, it makes pit removal easier, reducing processing costs. Potential cultural management to improve the pulp-to-pit ratio is complex, however, as the growth and development of these two tissues are closely interrelated due to their common origin in the ovary pericarp and their overlapping activity as competing sinks (Rallo and Rapoport, 2001).

A number of authors (Lavee et al., 1990; Michelakis et al., 1995; d'Andria et al., 2004) have demonstrated the positive effect of irrigation on final olive fruit size and a high mesocarp:endocarp (pulp-to-pit) ratio. However, to our knowledge there are few studies which consider the effect of nutrients on mesocarp and endocarp growth. Lavee (1986) indicated that N deficiency may lead to a decrease in both fruit set and size, while B deficiency may alter fruit shape because of modified lignification of the mesocarp. Also, K deficiency may cause a decreased in fruit size, particularly in conditions of low availability of soil water (Fernández-Escobar, 2007).

In a recent study, Rapoport et al. (2004) suggested that endocarp growth has a higher sink priority than mesocarp growth. They observed that the mesocarp and endocarp of young 'Leccino' trees responded in different ways to an early water deficit: during the water stress period, equatorial transverse areas were reduced for both tissues, but after the resumption of irrigation, the endocarp of the stressed plants but not the mesocarp grew and reached a similar size to that of the continuously irrigated plants. Thus the irrigation regime may affect both the absolute and relative growth of mesocarp and endocarp, as well as the timing of development of those two tissues.

In this report we examined whether the addition of nutrients to the irrigation water modifies the development of the mesocarp and endocarp of the olive fruit. An intermediate date (12 weeks after full bloom, AFB) and mature harvest (21 weeks AFB) were evaluated to determine the effect of adding nutrients depending on the timing of growth and development, to better understand those processes and in view of optimizing cultivation strategies. These are two critical stages in olive fruit development: endocarp (stone) expansion and the major part of massive endocarp sclerification is complete at 12 weeks in this cultivar (Rallo and Rapoport, 2001), while fruit

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expansive growth is completed at 21 weeks. The study was carried out in 'Manzanilla de Sevilla', a popular cultivar in many olive growing countries which is appreciated for table olive production because of its size and pulp quality.

2. Material and methods

The experiment was carried out during the 2003 growing season in an orchard near Alcalá de Guadaíra (Seville) in southern Spain (37°18′N, 5°54′W). The trees were 14-year-old and planted at 7 m × 7 m, giving a plant density of 204 trees ha^{-1}, in a sandy–clay–loam soil. Fruit samples were taken from two treatments belonging to an experiment established in the orchard in 1999: T0, in which the trees were irrigated but not fertilized, and T1, in which the trees were irrigated with the same amounts of water than in T0, and each tree received 600 g N, 150 g P and 450 g K during the irrigation period of 2003, from 16 May to 22 September; in 2002 doses were similar to that of 2003, but from 1999 to 2001 each tree received 400 g N, 100 g P and 300 g K only, because they were smaller. The nutrient proportions correspond to those commonly used (under fertigation) in the region and the amounts were base on previous studies (Martín-Aranda and Troncoso, 1986; Troncoso et al., 1997).

A randomised complete block design (six blocks and four trees per elementary plot) was used. The trees were irrigated daily to satisfy crop water needs, calculated with the crop coefficient approach, as described by Fernández et al. (2006). We used a lateral per tree row with four 8 L h^{-1} compensating drippers per tree, 1 m apart. A complex N–P–K liquid fertilizer was injected daily towards the end of each irrigation event in T1 trees, allowing for a 15 min rinse of the laterals. Equal daily doses were applied throughout the whole period. N was derived from urea, NH_4 and NO_3 (2:1:1 mixture), P from H_3PO_4 and K from KCl. All trees of both treatments received an additional dose of approximately 60 g N due to nitrate content in the irrigation water. The 2003 rainfall was 531 mm, with no summer rains.

Five fruits were sampled randomly from each tree, around the canopy, at a height of about 1.7 m, both at 12 and 21 weeks after full bloom (AFB), that occurred on 1 May. For both dates, we measured the following parameters for each fruit: weight; fresh and dry weights of the mesocarp; fresh and dry weights of the endocarp; mesocarp to endocarp ratio; longitudinal and equatorial diameters of both pulp and stone, and fruit and stone shapes, that is the ratio of the equatorial and longitudinal diameters. For dry weight, fruits were dried at 70 °C to constant weight. At 21 weeks AFB, the number of fruits per tree was also determined. Data were processed using the analysis of variance and mean separations were obtained by the least significant differences (LSD) test. The coefficients of variation were determined by the error mean square.

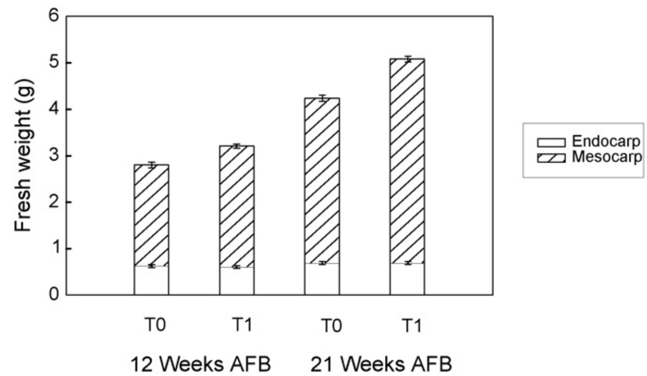

Fig. 1. Fruit, mesocarp and endocarp fresh weight in T0 and T1 trees at 12 and 21 weeks after full bloom (AFB). Fruit weight is the sum of mesocarp and endocarp weights. Bars represent standard errors for each tissue. See text for details on the treatments.

3. Results and discussion

The addition of nutrients to the irrigation water improved the number of fruits per tree at 21 weeks AFB (Table 1), as well as the fresh weight of both fruit and mesocarp at 12 and 21 weeks AFB (Fig. 1). It also increased the mesocarp dry weight at 12 weeks AFB (Table 1), but not at the end of fruit growth. The mesocarp dry

Table 1
Fruit number per tree, mesocarp and endocarp weight (g) and growth (accumulation % per period), and mesocarp:endocarp ratio in T0 and T1 trees at 12 and 21 weeks after full bloom (AFB)

Fruit weight and growth	Date and treatment							
	12 weeks AFB				21 weeks AFB			
	T0	T1		C.V. (%)	T0	T1		C.V. (%)
No. Fruit $tree^{-1}$	–	–	–	–	970	1719	*	19.3
Mesocarp weight								
f.w.	2.17	2.60	**	5.9	3.55	4.39	***	8.2
d.w.	0.55	0.63	**	6.4	0.98	1.10	ns	10.0
d.w.:f.w. ratio	0.30	0.28	**	3.0	0.31	0.28	*	4.5
Endocarp weight								
f.w.	0.63	0.61	ns	4.6	0.69	0.69	ns	8.9
d.w.	0.47	0.45	ns	4.5	0.53	0.52	ns	8.7
d.w.:f.w. ratio	0.74	0.74	ns	1.5	0.77	0.76	ns	1.3
Mesocarp:endocarp ratio (pulp-to-pit)								
f.w.	3.47	4.26	***	12.0	5.22	6.43	***	11.7
d.w.	1.18	1.38	****	10.8	1.88	2.10	***	9.2
Mesocarp growth (% of final)								
f.w	61.13	59.23	–	–	(100)	(100)	–	–
d.w.	56.12	57.27	–	–	(100)	(100)	–	–
Endocarp growth (% of final)								
f.w.	91.30	88.41	–	–	(100)	(100)	–	–
d.w.	88.68	86.54	–	–	(100)	(100)	–	–

See text for details on the treatments. CV = coefficient of variation; d.w. = dry weight; f.w. = fresh weight. ns = non-significant.
Asterisks indicate significant differences within each date at $P < 0.05$ (*), 0.01 (**), 0.001 (***) or 0.0001 (****).

Table 2
Longitudinal and equatorial diameters and shape of fruit and endocarp in T0 and T1 trees at 12 and 21 weeks after full bloom (AFB)

Date and treatment	Fruit			Endocarp		
	Longitudinal diameter (mm)	Equatorial diameter (mm)	Shape	Longitudinal diameter (mm)	Equatorial diameter (mm)	Shape
12 weeks AFB						
T0	1.89	1.61	1.17	1.32	0.91	1.45
T1	1.99	1.69	1.12	1.32	0.88	1.50
	*	**	ns	ns	ns	**
CV (%)	1.4	2.2	1.3	0.8	1.6	0.9
21 weeks AFB						
T0	2.18	1.88	1.16	1.38	0.91	1.52
T1	2.33	2.01	1.16	1.38	0.90	1.54
	*	***	ns	ns	ns	ns
CV (%)	1.9	3.3	2.3	2.9	3.4	3.2

Shape refers to the ratio of the diameters. See text for treatment details. CV = coefficient of variation. ns = non-significant.
Asterisks indicate significant differences within each date at $P < 0.05$ (*), 0.01 (**) or 0.001 (***).

weight:fresh weight ratio was, on the contrary, less in T1 than T0 fruits at both sampling times (Table 1). This means that water content was greater in the T1 fruits, which positively affected the final fruit weight. The increase in fruit weight, together with the increase of fruit number, led to higher fruit yield in T1, which is economically important to the farmer.

The highest nutrient availability in the T1 trees also improved the mesocarp:endocarp ratio on both dates, which was approximately 19% greater than in T0 fruits (Table 1). This was due to the different growth responses of endocarp and mesocarp. In fact, there were no differences between treatments in the fresh and dry weight of the endocarp, at any of the two studied stages of the fruit growth (Table 1). Differences in the timing of growth of both mesocarp and endocarp were also non-significant. When expressed both as fresh and dry weight, approximately 60% of mesocarp growth, and 90% of endocarp growth, occurred between 0 and 12 weeks AFB, both in T1 and T0 (Table 1). These results contrast with previous observations on the effect of other environmental factors, such as effect of an early water deficit, on the timing of growth of the olive fruit tissues (Lavee et al., 1996; Rapoport et al., 2004).

According to Lavee et al. (1996), the endocarp size can be reduced when a water deficit occurs at the beginning of fruit growth, therefore leading to a greater mesocarp:endocarp ratio at maturity as compared to fruits from fully irrigated trees. This strategy can be of interest for improving the proportion of fruit pulp in table olive fruits, as well as in other stone crops, if total fruit size is not reduced too much. Under our conditions, with varied fertilization, we found weak and negative correlations between the mesocarp:endocarp ratio (fresh weight) and the endocarp fresh weight ($r^2 = -0.418$ and $r^2 = -0.449$, $P < 0.0001$, at 12 and 21 weeks AFB, respectively) in T0 only, as well as between the mesocarp:endocarp ratio (dry weight) and endocarp dry weight ($r^2 = -0.385$ and $r^2 = -0.431$, $P < 0.0001$, at 12 and 21 weeks AFB, respectively). This means that under varied fertilization, a change in the mesocarp:endocarp ratio could occur without fruit or mesocarp size necessarily suffering. Further experimentation is required to test this.

No significant differences were found in fruit shape (ratio of longitudinal and equatorial diameters) at any of the two stages of growth, although fruit diameters always tended to be greater in T1 than in T0 (Table 2). With respect to the endocarp, a small but significant difference in the shape was observed at 12 weeks AFB (Table 2), but not at 21 weeks AFB. No differences were observed in the stone longitudinal and equatorial diameters, at any of the two dates of observation.

In summary, our results emphasize the importance of an appropriate fertilization management in irrigated olive orchards, particularly for table olives, in which fruit size, pulp-to-pit ratio and pulp quality are important characteristics, and indicate the added experimental value when different fruit component tissues are measured. By examining intermediate and final stages of growth, our results also confirm that the olive endocarp is a strong sink tissue that competes with the mesocarp during early development for water and nutrients. On the other hand, the fertigation practice may also affect the balance of growth of mesocarp and endocarp, although it seems that the timing of growth of both tissues is independent of nutrient availability.

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