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Effect of fruit load on oil yield components and dynamics of fruit growth and oil accumulation in olive (*Olea europaea* L.)

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ABSTRACT

Olive oil yield and its components (fruit number, average fruit weight and fruit oil concentration) depend on crop load and source–sink ratios as affected by environmental conditions, management and the alternate bearing typical of the species. The aims of this work were to: (i) establish quantitative relationships between oil yield and its components as affected by fruit load in a high-yielding production system, (ii) analyse the dynamics of fruit weight and fruit oil concentration in terms of rates and durations, and (iii) explore the relationships between the dynamics of oil and water in fruit. In a fully irrigated olive orchard in Mendoza (32° S), Argentina, cv. Arbequina trees with similar crown volume and three fruit loads (3-fold range) were monitored during two seasons. Oil yield was positively associated with both fruit number and fruit fresh weight, but not with fruit oil concentration. Across seasons and fruit loads, fruit yield increased linearly with fruit number at ~1.5 kg per thousand fruit and reached a maximum ~60 kg tree^{-1} (or 25 t ha^{-1}) at a fruit load of 32,700 fruit tree^{-1}. The fruit filling rate was affected by fruit load, while the duration of fruit growth and the dynamics of oil and water concentration were unaffected by fruit load. Fruit water concentration reached a minimum at the onset of Stage III of fruit growth, which was marked by a rapid increase in oil concentration. Fruit fresh weight and oil weight increased with source–sink ratio from ~0.5 up to a threshold ~2 m^3 crown per thousand fruit. In contrast, a 8-fold range of source–sink ratio did not affect fruit oil concentration.

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1. Introduction

In common with other species, fruit number is the main yield component in olive (Baratta et al., 1986; Patumi et al., 1999). Oil production is thus, in principle, a direct function of fruit load. Two trade-offs, however, can alter the correlation between fruit number and oil yield. Firstly, fruit number and size are often negatively correlated (Lavee and Wodner, 1991; Barone et al., 1994; Gucci et al., 2007). Importantly from the viewpoint of oil yield, this negative correlation is mostly accounted by changes in fresh weight of the epicarp (i.e. main oil accumulating tissue), while pit weight is not so much affected by fruit load (Lavee and Wodner, 2004; Rapoport et al., 2004). Secondly, fruit oil concentration can decrease with high crop load (Barone et al., 1994; Gucci et al., 2007) but this relationship is far from universal (Lavee and Wodner, 2004; Lavee et al., 2007).

Peak fruit oil concentration has been proposed as an estimator of physiological maturity in olive (Ayton et al., 2001; Mickelbart and James, 2003). However, oil accumulation rate is affected by the environment (Mailer et al., 2007), fruit load (Gucci et al., 2007), and cultivar (Lavee and Wodner, 1991; Mailer et al., 2007). Here we propose that the simultaneous characterisation of oil and water dynamics will help understanding the influence of fruit load on the dynamics of fruit ripening and oil accumulation in olive. Indeed, the simultaneous characterisation of the dynamics of water and reserves has illuminated the processes of seed and fruit maturity in a range of species including cereals (Slafer et al., 2009), sunflower (Rondanini et al., 2007) and grapevine (Sadras et al., 2008; Thomas et al., 2008). In addition, the relationship between oil and water in olive fruit is important from an industrial viewpoint as high water concentration in fruit produces emulsions called “difficult pastes” (De la Rosa et al., 2008) with reduced oil extractability (Motilva et al., 2000; Alegre et al., 2002; Grattan et al., 2006).

Olive trees have a biennial pattern of fruit production; usually crop load is not controlled by fruit thinning as in other species. Recently, the causes of biennial bearing in olives have attracted considerable attention (Lavee and Avidan, 1994; Baktir et al., 2004; Ulger et al., 2004; Fernández Escobar et al., 2004; Lavee, 2006; Al-Shdiefat and Qrunfleh, 2008), while studies on crop load have

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mostly focused on the effect of water supply (Patumi et al., 1999; Moriana et al., 2003; Tognetti et al., 2006; Gucci et al., 2007; Iniesta et al., 2009). Understanding the effects of fruit load on yield and its components is fundamental to generate management strategies to reduce biennial bearing and to achieve early estimates of oil yield.

The aims of this work were to: (i) establish quantitative relationships between oil yield and its components as affected by fruit load in a high-yield, intensive production system, (ii) analyse the dynamics of fruit weight and fruit oil concentration in terms of rates and durations, and (iii) explore the relationships between the dynamics of oil and water in fruit.

2. Materials and methods

2.1. Site and orchard

The experiment was carried out during the 2007–2008 and 2008–2009 seasons in an intensive olive (cv. Arbequina) orchard at Lavalle (32°43′ S, 68°36′ W, 920 m.l.s.), Mendoza, Argentina. The region has an average annual temperature of 15.8 °C, a frost-free period between October and March, and average annual rainfall of 165 mm concentrated during summer. The orchard was planted in 1997 with 4 m × 6 m spacing (417 trees ha^{-1}). The soil was a clay-loam (Typic entisol torrifluvent, Abraham and Martínez, 1996) with a pH of 7.5. Trees were irrigated with microjets to restore 100% of the estimated crop evapotranspiration during the whole growing season, according to the model of Pizarro (1996) and a crop coefficient, Kc = 0.68 (Girona et al., 2002).

2.2. Treatments and experimental design

Three treatments, i.e. low, medium and high fruit load, were established in a randomised complete block design with four replications. Fruit load was defined in two steps. First, 200 trees were inspected and classified in the three nominal categories of fruit load during the flowering stage in mid November. From this set, four plants with similar crown volume (determined with a spherical cap equation; Del Río et al., 2005), were selected for each category. Second, the assignment of plants to load levels was confirmed through direct estimation of fruit number at harvest. The same trees were evaluated in both years. This scheme aimed at a broad range of source–sink ratios calculated as the ratio between crown volume (m^3) and actual fruit number per tree.

2.3. Fruit traits

From early December; 25, 20 and 15 fruits were extracted fortnightly from high, medium and low fruit load trees, respectively. The samples were taken at 1.5 m high and around the canopy. The fruits were packed and placed in a portable refrigerator until processing, usually carried out within the following 4 h.

Fruit fresh weight (FFW) was measured in five fruits, which were then dried at 60 °C during 48 h to determine dry weight. Percent water concentration (WC) was calculated as 100 × (fresh wt − dry wt)/fresh wt. A sample of five fruits was manually separated into pulp and pit to determine pulp/pit ratio. Fruit oil concentration was determined using the method of Avidan et al. (1999). Briefly, 5 g pulp samples were dried during 48 h at 60 °C. The dried pulp was macerated in 15 ml of petroleum ether (60–80°) and shaken during 12 h in darkness. Then, the samples were filtered and transferred into previously weighed tubes. During the filtering process, tubes and filter paper were washed with 5 ml of solvent. The tubes were exposed at 60 °C until constant weight. Oil concentration was then estimated as the quotient, in percentage, of oil weight and pulp weight on fresh (OC_{FP}) and dry basis (OC_{DP}).

2.4. Oil yield and its components

In both seasons, crops were manually harvested on May 27 when at least 80% of the fruit were starting veraison. From a 2 kg sample, 100 fruits were weighed to determine their average weight. The maturity index (MI) was determined by classifying the fruits from 0 to 7, according to skin and pulp colour (Beltrán et al., 2004). The total number of fruit from each tree was estimated from the average fruit weight. Oil yield (kg oil $tree^{-1}$) was calculated as:

$$\text{Oil yield} = (FFY) \times \left(\frac{P}{F}\right) \times \left(\frac{DW}{FW}\right) \times (OC_{DP}) \quad (1)$$

where *FFY* is fruit fresh yield, *P*/*F* is pulp/fruit fresh weight ratio, *DW*/*FW* is the relation between dry and fresh fruit weight, and OC_{DP} is pulp oil concentration on a dry-weight basis.

2.5. Statistical analysis

Models used to characterise the dynamics of sugars and water in grapevine berries (Sadras et al., 2008) were used to characterise the dynamics of oil (Eq. (2)) and water (Eq. (3)) in olive fruit.

Fruit oil concentration dynamics were analysed fitting the following transition function:

$$OC_{DP} = \frac{OC_{DP\max}}{1 + e^{[(-x-x_0)/b]}} \quad (2)$$

where OC_{DP} is fruit oil concentration on a dry-weight basis; $OC_{DP\max}$ is the highest oil concentration; x is time (days); x_0 is the transition centre, i.e. the time when OC_{DP} reaches half $OC_{DP\max}$ and b is transition width × 2.197^{-1}. The transition width is the time it takes oil concentration to raise from 0.25 to 0.75 of maximum (Sadras et al., 2008).

Fruit water concentration dynamics were analysed fitting the following function:

$$WC = WC_{\min} + \frac{WC_{\max} - WC_{\min}}{1 + (x/x_{50})^b} \quad (3)$$

where x is time (days), WC is fruit water concentration, and subscripts max and min indicate maximum and minimum, x_{50} is the time when WC is halfway between maximum and minimum and b is the Hill slope.

A bilinear with plateau model was fitted to describe the relationships fruit yield vs. fruit number, fruit fresh weight vs. time, and fruit oil concentration vs. fruit fresh weight. The general form of the model is (Table Curve non-linear routine):

$$y = a + bx \quad \text{for } x < c \quad (4a)$$

$$y = z \quad \text{for } x \geq c \quad (4b)$$

where a is the intercept and b is the slope of the linear phase, c is the breakpoint over which y is maximised.

3. Results

3.1. Mean temperature and frost

Average temperature during the oil biosynthesis period (i.e. January until harvest) was similar in both growing seasons, i.e. 20.2 °C vs. 20.4 °C (Fig. 1). The main difference between seasons was the early onset of frost, i.e. April 14th (minimum temperature = −3.2 °C) in 2007–2008, compared to May 13th (minimum temperature = −1.2 °C) in 2008–2009. The early onset of frost likely accounts for the reduced oil yield in 2007–2008 (Table 1).