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Olive oil quality response to irrigation cut-off strategies in a super-high density orchard

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ABSTRACT

An increase in olive oil consumption has occurred worldwide in the last decades and has resulted in more land area being dedicated to olive orchards in several southern hemisphere countries. In order to achieve sustainable productivity under the increasing water scarcity, optimal water use is essential. Thus, a field experiment was conducted during four consecutive growing seasons (2010–2011 to 2013–2014) to evaluate olive oil quality in response to irrigation cut-off strategies applied after fruit set using midday stem water potential (Ψ_{stem}) thresholds in a super-high density olive orchard (cv. Arbequina) located in the Pencahue Valley, Maule Region, Chile. The experimental design was completely randomized with four treatments and four replicates. In treatment T_1 (control), Ψ_{stem} was between -1.4 and -2.2 MPa (100% of actual evapotranspiration) throughout the season, while the T_2, T_3 and T_4 treatments did not receive irrigation from fruit set until they reached a Ψ_{stem} threshold of approximately -3.5, -5.0, and -6.0 MPa, respectively. Once these thresholds were reached, irrigation was reestablished and maintained as T_1 in all treatments until olives were harvested. Fruit oil and water content (%) at harvest were not affected by the different treatments. Free acidity was also not affected, while peroxide and extinction coefficients only showed minor differences between treatments that were within the limits established for commercial extra virgin oil quality. Total polyphenols at harvest were much higher in the water deficit treatments and showed a significant linear relationship each year with the water stress integral. The percentages of the main fatty acids were not affected by the treatments. However, they were significantly different between seasons. Sensory tests indicated that the higher total polyphenol content positively contributed to more pronounced bitter and pungent attributes of olive oil from trees with higher water deficit. Thus, the irrigation cut-off strategies evaluated at our four-year study can be an excellent management tool to both improve the oil quality of cv. Arbequina and reduce water use in super-high density orchard.

1. Introduction

In recent years, the consumption of olive oil has increased worldwide, even in countries that do not have a long-standing tradition of olive growing (Morello et al., 2006). This is due in part to olive oil being linked to lower incidences of cardiovascular and neurodegenerative diseases, type 2 diabetes and even cancer (Guasch-ferre et al., 2015; Mateos et al., 2013; Pérez-Jiménez et al., 2007). In order to meet the new demand for olive oil, new plantations have been established in many parts of the world including South American countries such as Chile and Argentina (García-González et al., 2010; Rondanini et al., 2011). Irrigation application is common in these new orchards, which are increasingly being planted in higher densities (≥1000 trees ha^{-1}) and trained as hedgerows to allow for a more efficient use of mechanical harvesters (Fernandes-Silva et al., 2013; Gómez del Campo, 2013a, 2013b). Under this scenario, the cultivar that best adapts to mechanical harvesting is 'Arbequina', due to its small size, precocity and branch flexibility (Gómez del Campo, 2013b; Torres and Maestri, 2006).

The application of irrigation water has become common in olive orchards because several studies have proven the benefits of water supply on olive yield (Lodolini et al., 2014; Martín-Vertedor et al., 2011; Moriana et al., 2003; Patumi et al., 1999, 2002; Tognetti et al., 2007). However, the increasing water scarcity globally and the increased water demand for other uses in our society has caused pressure to reduce the water used in irrigation (Fereres and Soriano, 2007). For

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this reason, regulated deficit irrigation (RDI) has been suggested for optimizing water application in super-high density olive orchards (Fernández et al., 2013; Gómez del Campo, 2013a, 2013b). In this regard, cutting-off irrigation until reaching a predetermined water potential threshold can be used as a management tool to save water without affecting fruit and oil yields (Dell'Amico et al., 2012; Trentacoste et al., 2015).

Irrigation does not often affect the oil concentration in the fruit (on a dry weight basis). Therefore, the oil yield is mostly affected by RDI strategies when fruit number and subsequent yield are reduced (García et al., 2013; Gómez-Rico et al., 2007; Iniesta et al., 2009; Patumi et al., 2002). Based on this information, RDI strategies may have an advantageous effect since water use efficiency for olive oil production increases (Iniesta et al., 2009). Moreover, trees grown under RDI strategies often have similar, or even better, olive oil quality compared to trees that are well irrigated (Fernandes-Silva et al., 2013). García et al. (2013) found that irrigation strategies do not significantly affect parameters of oil quality such as free acidity, peroxide value, and extinction coefficients (K_{232}, K_{270}). Moreover, Motilva et al. (2000) observed that the application of RDI strategies applied to cv. Arbequina induced a significant increase in polyphenol concentration and oil stability. Fernandes-Silva et al. (2013) also observed that total polyphenols were strongly related to the water stress integral. Furthermore, Gómez del Campo and García (2013) observed that the application of RDI in summer caused a significantly higher oxidative stability, which coincided with a significantly higher content of phenol derivatives. These compounds are of great interest because they influence the quality and the palatability of olive oils and increase their shelf life by slowing the formation of polyunsaturated fatty acid hydroperoxides (Abaza et al., 2005).

Moreover, olive oil fatty acid composition is often not affected by RDI strategies (Motilva et al., 2000), although other studies indicate that irrigation strategies cause small variations in the oleic and palmitic acids (Dabbou et al., 2010; Fernandes-Silva et al., 2013). Genotype (i.e., cultivar) and environmental conditions appear to have a stronger effect on the oil's fatty acid composition, especially for palmitic and oleic acids (Borges et al., 2017; Rondanini et al., 2011). Among the environmental factors, temperature can play an essential role in fatty acid composition (Hernández et al., 2011). In this context, García-Inza et al. (2014) indicated that high temperatures increase polyunsaturated fatty acid content (linoleic and linolenic acids).

Deficit irrigation can also influence the sensory attributes of olive oil. In cultivars such as 'Arbequina', which normally has low phenolic concentrations, deficit irrigation is beneficial due to the greater polyphenol concentrations. More phenolics contribute to better balanced oils with a more sophisticated pungent and bitter flavor (Fernandes-Silva et al., 2013). Deficit irrigation can also reduce hay-like and greasy defects in olive oils (Dabbou et al., 2010).

In the literature, it has been reported that irrigation cut-off strategies in olive trees (cv. Morisca) have caused decreased shoot growth using a Ψ_{stem} threshold value of -2.0 MPa (Moriana et al., 2012). Also, this strategy with a Ψ_{stem} threshold value of -2.5 MPa increased water productivity twofold with respect to the control (Ψ_{stem} around -1.2 MPa). However, oil yield may not necessarily be reduced with such strategies. While Moriana et al. (2012) observed that oil yield (cv. Morisca) decreased using a Ψ_{stem} threshold of -2.0 MPa, Trentacoste et al. (2015) indicated that oil yield (cv. Frantoio) was not significantly affected using a Ψ_{stem} threshold of -2.5 MPa. Finally, Ahumada-Orellana et al., 2017 indicated that oil yield (cv. Arbequina) was also not reduced when irrigation was cut-off from fruit set until reaching a Ψ_{stem} threshold $= -3.5$ MPa, but it was significantly decreased with Ψ_{stem} thresholds < -5.0 MPa. Despite these assessments of oil yield, there is little information about the effect of irrigation cut-off on the olive oil quality. For this reason, the objective of this study was to evaluate the effect of irrigation cut-off strategies on quality attributes of monovarietal extra virgin olive oil from cv. Arbequina.

2. Materials and methods

2.1. Site description and experimental design

The site description and experimental design are described in detail by Ahumada-Orellana et al. (2017) who evaluated the yield and water productivity responses to irrigation cut-off strategies applied after fruit set using Ψ_{stem} thresholds in a super-high density olive orchard. Briefly, an experiment was conducted during four consecutive growing seasons (2010–2011 to 2013–2014) in a 6-year-old drip-irrigated olive orchard (*Olea europaea* L. cv. Arbequina) located in the Pencahue Valley, Maule Region, Chile (35°, 232′ L.S; 71° 442′ W; 96 m altitude). The olive trees were trained under a hedgerow system with a planting density of 1333 tree ha^{-1} (1.5×5.0 m) and irrigation was performed using two 2.0 $L\,h^{-1}$ drippers per tree using good quality water pumped from a nearby river. At the experimental site, the climate is Mediterranean with rainfall occurring mostly during the winter months, and the soil has a clay-loam texture with a field capacity and wilting point of 31 and 16 $cm^3\,cm^{-3}$, respectively.

The olive water requirements were calculated according to the standard FAO56 approach for crop evapotranspiration ($ETc = ETo \times Kc$) where ETo is the reference evapotranspiration (mm day^{-1}) and Kc is the crop coefficient. Climate data for calculating ETo were collected from an automated weather station installed over a reference grass and located about 2 km from the experimental site. Values of ETo were estimated using the Penman–Monteith equation (Allen et al., 1998; Ortega-Farías et al., 1995) while those of Kc were between 0.56 and 0.42 (see López-Olivari et al., 2016).

The experimental design was completely randomized with four treatments (T_1, T_2, T_3 and T_4) and four replications (five trees per replication). T_1 was irrigated with 100% of ETc during the growing season (from September to April). For T_2, T_3 and T_4, the irrigation was cut-off from fruit set (about 20 days after full bloom) until reaching Ψ_{stem} thresholds of approximately -3.5, -5.0 and -6.0 MPa, respectively. Upon reaching these thresholds, the irrigation was restored and maintained as T_1 in all treatments until olives were harvested. It is important to indicate that the period after fruit set always coincides with high atmospheric demands for water vapor and pit hardening which is the least sensitive to water deficit (Goldhamer, 1999; Gómez del Campo and García, 2013).

2.2. Plant water status measurements

The midday stem water potential (Ψ_{stem}) was measured weekly to monitor plant water status. These measurements were performed between 12:30 and 14:00 h (Gómez del Campo et al., 2008; Moriana and Fereres, 2002) using two apical twigs per plot from the current year (with at least 10 leaves), located in the middle of the canopy (Rousseaux et al., 2008; Secchi et al., 2007). These twigs were covered in the canopy with a plastic bag and aluminum foil for 1–2 h before the measurements (Meyer and Reicosky, 1985). Thereafter, the twigs were removed from the tree for measurement using a Scholander-type pressure chamber (PMS Instrument Company, Model 1000 Pressure Chamber Instrument) (Scholander et al., 1965).

Lastly, in order to describe the accumulated effect of the irrigation cut-off strategies, the water stress integral (SΨ) was calculated (Myers, 1988) as:

$$S_{\Psi} = \left|\sum (\overline{\Psi}_{stem} - c)n\right| \qquad (1)$$

where Ψstem is the average of stem water potential for any interval (MPa), c is the value of the maximum stem water potential during the season, and n is the number of the days in each interval (Ahumada-Orellana et al., 2017; Moriana et al., 2007).