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Short communication

Bruising susceptibility of Manzanilla de Sevilla table olive cultivar under Regulated Deficit Irrigation

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ABSTRACT

The olive tree (*Olea europaea* L.) is a Mediterranean tree adapted to drought conditions and traditionally rainfed. For irrigated olive groves, there is extensive knowledge about the effects of Regulated Deficit Irrigation (RDI) scheduling on the sensibility of different phenological stages and about the importance of rehydration in the last part of the fruit growth stage. Water stress in this period could reduce the fruit size, but the exact extent of this reduction is still unknown. Additionally, table olive varieties may be damaged during harvesting or processing. This results in *bruising*, superficial browning injuries that progress through the mesocarp. Bruising susceptibility is an important quality parameter in table olives, however it has been little studied in RDI research. Hand-harvested fruits of 'Manzanilla de Sevilla' for green processing, treated with two types of RDI and full irrigation, were bruise-induced with a standardized drop to evaluate bruising susceptibility. Bruising index (BI) and external (BA_E) and internal (BA_I) bruising damage were measured 3 and 24 h after the bruising treatment. A full irrigation treatment was set up in order to maintain the Ψ_h values higher than −1.2 MPa before pit hardening and −1.4 MPa until harvest. RDI-1 and RDI-2 were irrigated with a full irrigation treatment until 2 and 4 weeks before harvest, respectively. Then, water was withheld until −2.5 MPa. RDI-2 can save 50% of the water applied without affecting the fruit weight, volume or pulp-to-pit ratio (fresh and dry). Fruits under RDI treatments are less susceptible to bruising than fruits with a full irrigation treatment, as evidenced by the lower bruising index and the smaller external and internal damaged area. As for the bruising time line, 3 h after the bruise inducement, the bruising index and external damaged area had already developed, whereas internal bruising damage continued increasing up to 24 h after the bruising treatment.

1. Introduction

Olea europaea L. is a typical Mediterranean rainfed tree. Traditionally, olive groves have been cultivated in non-irrigation conditions due to their drought tolerance, but at the beginning of the 90 s there was a big increase in the surface of irrigated olive orchards particularly in Spain (MAGRAMA, 2016). Currently, water scarcity in arid and semi-arid regions and the decrease of the water available for agricultural uses have propitiated the expansion of the Regulated Deficit Irrigation (RDI) system. RDI is an irrigation scheduling method that imposes water deficits in specific phenological stages, which have been found to be less sensitive to drought, without significant effects on yield and fruit quality (Behboudian and Mills, 1997). In olive trees, the pit hardening has been commonly reported as the more resistant phenological stage (i.e. Goldhamer, 1999; Moriana et al., 2003; Iniesta et al., 2009). However, severe water restrictions during this period reduce the fruit yield, albeit at a lower level than with the water saving (Goldhamer, 1999). Girón et al. (2015b) reported that a midday trunk water potential below −2.0 MPa during pit hardening increases the fruit drop and reduces the fruit size, though rehydration resumes the fruit growth and no differences are found at harvest. Rehydration is necessary during the last part of the fruit growth, when the pit hardening finishes. The rehydration period usually involves a significant volume of water, in a period of low rainfall. From the literature, it is not possible to find any references to the adequate level of water-stress before harvesting or the effect on fruit quality.

Olive trees are grouped into table and oil cultivars according to their final use. Table olives are classified, for commercial purposes, according to different quality attributes such as size and shape, colour, texture, pulp-to-pit ratio and physical defects,

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e.g. bruising. Bruises consist of a rupture of the cellular tissue by external forces that release intracellular fluid, leading to the oxidation of phenolic compounds (Mohsenin, 1986). This results in the subsequent formation of more or less extensive superficial browning damage at different depths (Gambella et al., 2013). The studies related to bruising in table olives focus on measuring the bruised area (Saracoglu et al., 2011), non-destructive determination of the impact of bruising using NIR spectroscopy (Jiménez-Jiménez et al., 2012), evaluating the table olive cultivar susceptibility (Jiménez-Jiménez et al., 2013) and the anatomical and histological description of damage (Jiménez et al., 2016). 'Manzanilla de Sevilla', one of the most appreciated table olive varieties because of its high yield and fruit quality (Rejano et al., 2010), is considered susceptible to bruising damage by all these authors.

Most of the irrigation works in table olive mainly consider size, colour and pulp-to-pit ratio, but little is known about the effect of the water status in the bruising. Research on fruit has shown that factors such as fruit size, shape, water status, fruit turgidity and firmness could influence the bruising susceptibility (Opara and Pathare, 2014). Table olives obtained after RDI treatments were characterised by different fruit weight, higher dry matter and oil contents (Cano-Lamadrid et al., 2016, 2015) and these aspects could be related to a different incidence of bruising.

The aim of this work is to study the effect of different RDI strategies on the bruising incidence of 'Manzanilla de Sevilla' table olive cultivar as this could help to establish an RDI threshold in olive orchard management.

2. Materials and methods

2.1. Plant material

The experiment was carried out on adult olive trees (45 years old) Manzanilla de Sevilla cv, from the Consejo Superior de Investigaciones Científicas (CSIC) experimental farm 'La Hampa' in Coria del Río, Seville (Spain), cultivated under an irrigation system in a well-established olive grove in full production.

2.2. Experiment design

Two types of RDI and a fully irrigated treatment were evaluated during 2014. The fully irrigated treatment was established in order to maintain the Ψ_h values higher than −1.2 MPa before pit hardening and −1.4 MPa until harvest, as recommended by Moriana et al. (2012). The beginning of the pit-hardening period was determined according to Rapoport et al. (2013). RDI-1 and RDI-2 were fully irrigated until 2 and 4 weeks before harvest, respectively, when water was withheld until −2.5 MPa. No rehydration was performed in these two latter treatments and two different levels of stress were reached before harvesting. The amount of water applied in the irrigation treatments is shown in Table 1.

The plot had an area of 0.5 ha and a randomized complete-block design was used, with three plots per treatment and two control trees per plot. Thus irrigation scheduling was controlled with the measurements of six trees per treatment throughout the growing season.

2.3. Measurements

Fruits were hand harvested at the ripening stage for green processing (Maturity Index = 1, Ferreira (1979)). A sub-sample of 20 fruit per RDI treatment was used to determine the average fruit weight (g), fruit volume (mL) and pulp-to-pit ratio (fresh and dry).

To determine the effect of RDI on bruising susceptibility, a sub-sample of 100 fruits per irrigation treatment (Fully Irrigated, RDI-1 and RDI-2) were bruise-induced with a standardized drop from a height of one meter, according to Jiménez et al. (2016). The sample was compared with a sub-sample of 100 fruits only, hand-harvested and not subjected to dropping (control fruits). Fruits were classified into three categories according to the severity of the bruising on the skin (non-bruised, low damage (less than 25%) or severe damage (25–100%)) and the bruising incidence (BI) was evaluated 3 and 24 h after impact. The bruising incidence was determined as follows: $BI = [1(N_L) + 2(N_S)]/(N_0 + N_L + N_S)$ being N_0 = number of fruits with no damage; N_L = number of fruits with low damage; N_S = number of fruits with severe damage, according to Morales-Sillero et al. (2014). In addition, the bruising damage was estimated by evaluating both the external (BA_E) and the internal (BA_I) bruised area (mm^2). BA_E was assumed to be elliptical (Lewis et al., 2007) and was determined as follows: $BA_E = \pi/4(W_1 W_2)$ where W_1 and W_2 are the length (mm) of the main axes. BA_I was measured in damaged mesocarp portions of 12 bruise-induced fruits and 12 control fruits per RDI with a Leica Qwin (Leica, Cambridge, UK) image analysis system connected to a binocular microscope (Leica Mz12) according to Jiménez et al. (2016).

The data were subjected to a variance analysis to determine the effect of irrigation treatments, bruise induction and time after bruise induction. The Tukey's test ($P < 0.05$) was used to discriminate among the mean values. 'StatGraphics Plus' software (Version 5.1, Manugistics Inc., USA) was used for the calculations. When necessary, data were previously transformed using Box-Cox power transformations (Box and Cox, 1964) to achieve normality and homogenize the variance.

3. Results and discussion

Fruit quality, measured as fruit weight, fruit volume, and pulp-to-pit ratio (fresh and dry) was not significantly affected by the irrigation treatment (Table 1) even with reductions of 50% of the volume of water applied (RDI-2 compared to Fully Irrigated). Similar results were obtained for quality attributes of table olives by Cano-Lamadrid et al. (2015).

The bruise-inducing treatment significantly increased the bruising incidence in fruits (BI = 1.43) to values approaching severe damage (BI = 2) (Table 2). The external and internal bruised area also increased compared to control fruits (Table 2). The bruise-inducing treatment performed by Jiménez et al. (2016) and Jiménez-Jiménez et al. (2013) also increased the amount of bruised fruits in 'Man-

Table 1
Water applied in irrigation treatments and the effect on fresh fruit parameters (mean values ± sd). Different letters within the same parameter indicate significant differences according to the Tukey's test at $P < 0.05$.

Irrigation Treatment	Water applied (mm)	Fruit weight (g)	Fruit volume (ml)	Pulp-to-pit ratio (fresh)	Pulp-to-pit ratio (dry)
Full irrigation	278 ± 22	4.35 ± 0.01	4.38 ± 0.04	4.56 ± 0.43	2.05 ± 0.21
RDI-1	242 ± 54	4.15 ± 0.22	4.18 ± 0.25	4.57 ± 0.78	2.23 ± 0.27
RDI-2	143 ± 13	4.24 ± 0.15	4.30 ± 0.14	4.43 ± 0.69	2.19 ± 3.43

Irrigation treatment: the fully irrigated treatment was established in order to maintain Ψ_h with values higher than −1.2 MPa before pit hardening and −1.4 MPa until harvest. RDI-1 and RDI-2 were fully irrigated until 2 and 4 weeks, respectively, before harvest when water was withheld until −2.5 MPa.