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Effects of deficit irrigation applied during fruit growth period of late mandarin trees on harvest quality, cold storage and subsequent shelf-life

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ABSTRACT

The quality traits of fruit harvested from 'Fortune' mandarin trees (*Citrus clementina* Hort. Ex. Tanaka × *C. reticulata* Blanco) subjected to different irrigation strategies was studied at harvest, during cold storage (33 d at 5 °C), and after an additional shelf-life period of 5 d at 25 °C. Plant water status was also determined in the pre-harvest period. Irrigation treatments consisted of a control irrigated at 100% of crop evapotranspiration throughout the season, and two deficit irrigation treatments irrigated during the fruit growth period to maintain the ratio between the fruit growth rate (FGR) of the control trees and those of the water deficit treatment (signal intensity, SI_{FGR}) at two different water stress levels: (i) Severe (DI_{10}) when this ratio was around 1.1 (SI_{FGR}), and (ii) moderate (DI_5) when it was around 1.05. The amount of water applied in DI_{10} and DI_5 represented a reduction of 40% and 29%, respectively, compared with the control. No negative effects on the yield parameters studied were observed. During the second fruit growth stage, differences in stem water potential at midday of around 0.4 and 0.9 MPa in DI_5 and DI_{10} treatments, respectively, respect control promoted a significant decrease in FGR. Overall, both DI treatments improved fruit quality at harvest due to increased total soluble solids and juice proline content, fruit maintained their quality longer during storage than the control. Cold stored fruit of both DI treatments presented similar fruit hardness values but a higher juice proline content, total soluble solids and titratable acidity, and, as a consequence, a lower maturity index than the control. At the end of storage, DI fruit showed a thicker skin and lower commercial losses due to chilling injury.

1. Introduction

In recent years mandarin trees have become one of the most important crops in south-eastern Spain, and now represent about 35% of the national production of citrus fruit, most of which is exported. 'Fortune' and 'Nova' are the most important hybrid mandarins and are destined to fresh consumption with or without refrigeration (Pagán et al., 2009). In south-eastern Spain, water is one of the main limiting factors for fruit production due to the scarcity of water available to farmers in many seasons, which has led to increasing research into irrigation systems, technologies and strategies to increase the productivity of the irrigation water used (Ginestar and Castel, 1996).

Regulated deficit irrigation strategies (RDI) allow water to be applied below the water needs of the crop during phenological periods in which the deficit does not affect the production or crop quality (Chalmers, 1989; Naor and Cohen, 2006). RDI improve the efficiency of water use, yield and fruit quality in citrus (González-Altozano and Castel, 1999, 2003; Pérez-Pérez et al., 2009; García-Tejero et al., 2010; Ruiz-Sánchez et al., 2010) and in stone fruit (Pérez-Pastor et al., 2007). In 'Fortune' mandarins, irrigation scheduling is usually based on climatic data and plant water stress indicators such as stem water potential or maximum daily trunk shrinkage (Pagán et al., 2012), but irrigation scheduling based on fruit growth has received no attention in Citrus so far.

Abbreviations: FI, full irrigation; DI, deficit irrigation; SI, signal intensity; FGR, fruit growth rate; FGR_{FI}, fruit growth rate of FI treatment; FGR_{DI}, fruit growth rate of DI treatment; ϕ, fruit equatorial diameter; DI_5, moderate regulated deficit irrigation treatment; DI_{10}, severe regulated deficit irrigation treatment; SI_{FGR}, signal intensity calculated from fruit growth rate; RGR, relative growth rate; ETo, crop reference evapotranspiration; ETc, crop evapotranspiration; $\Psi_{s,md}$, stem water potential at midday; PE, production efficiency; IWP, irrigation water productivity; L^*, lightness; C^*, chrome; H^*, hue angle; CI index, skin chilling injury index; TSS, total soluble solids content; TA, titratable acidity; MI, maturity index; L-proline, juice proline content; WL, weight loss.

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In this study, we proposed irrigation scheduling based on one simple parameter (fruit equatorial diameter), the parameter that most interests citrus exporters. The purposes of this study can be summarized as: (i) to evaluate irrigation scheduling based on fruit growth, and (ii) to evaluate the effect of this irrigation scheduling on fruit quality at harvest and after cold storage. The transfer of any knowledge gained to commercial situations is also discussed.

2. Materials and methods

2.1. Plant material and experimental field conditions

The trial was conducted during 2012 in a commercial orchard of 22-year-old drip-irrigated 'Fortune' mandarin trees (Dancy tangerine × Clementine (*Citrus clementine Hort. Ex Tanaka* × *Citrus reticulata Blanco*)), grafted onto Cleopatra mandarin (*Citrus reshni Hort. Ex. Tanaka*). The orchard was located in La Palma (Cartagena, SE Spain). The soil with a bunk density of 1.31 g cm^{-3} had a clay loam texture (11.45%, 30% and 58.55% sand, silt and clay particle size, respectively) with a medium level of organic matter (1.8%). Trees were spaced at 6 m × 4 m, and irrigated by a drip irrigation system with two lines per row of trees. Each tree was irrigated with 4 emitters of 4 L h^{-1} and 2 emitters of 2 L h^{-1}. Irrigation water was a mixture of desalinized underground water with water from the Tajo-Segura aqueduct, reaching an electrical conductivity of 1.42 dS m^{-1} and a pH around 8. Climatic data were recorded at an automated weather station near the grove. The climate is Mediterranean, with total annual rainfall of 475 mm mainly concentrated during the autumn–winter season, and a total annual reference evapotranspiration (ET_0) of 1244 mm. Maximum temperatures were above 36 °C during summer and the minimum temperature was −1.1 °C (recorded in January).

2.2. Irrigation treatments

A full irrigation treatment (control or FI) with 100% irrigation of estimated seasonal crop evapotranspiration (ETc) throughout the season served as the control. Two deficit irrigation (DI) treatments were applied: (i) severe regulated deficit irrigation treatment (DI_{10}), irrigated to maintain the signal intensity (SI) at around 1.1 during the three fruit growth stages, and full irrigation applied during the rest of the season; (ii) moderate regulated deficit irrigation treatment (DI_5), irrigated to maintain SI at around 1.05 during the three fruit growth stages. The DI treatments started with identical scheduling to FI, according to the FAO methodology for ETc (Allen et al., 1998), but later irrigation volumes were adjusted to maintain SI at values close to the thresholds. To maintain the desired signal intensity, doses were increased or decreased every two weeks of irrigation by 5% or 10%, depending on the treatment (DI_5 or DI_{10}, respectively). Both DI treatments were irrigated as the control until the fruit diameter reached 10 mm approximately (Fig. 1). All trees received the same quantity of nutrient elements through the irrigation system. The signal intensity (SI) was calculated from fruit set until harvest with the equation:

$$SI_{FGR} = \left(\frac{FGR_{FI}}{FGR_{DI}}\right) = \left(\frac{\phi_{FI,1} - \phi_{FI,0}}{\phi_{DI,1} - \phi_{DI,0}}\right),$$

where SI is the signal intensity, FGR_{DI} is the fruit growth rate of the DI treatment and FGR_{FI} is the growth rate of FI. FGR was calculated as the difference between equatorial diameter (ϕ) of the current measurement (day 1) and the diameter measured two weeks ago (day 0).

Every fortnight, 75 fruits per irrigation treatment were measured in the field and the FGR was obtained for each treatment; ETc was determined weekly from the Penman-Monteith equation

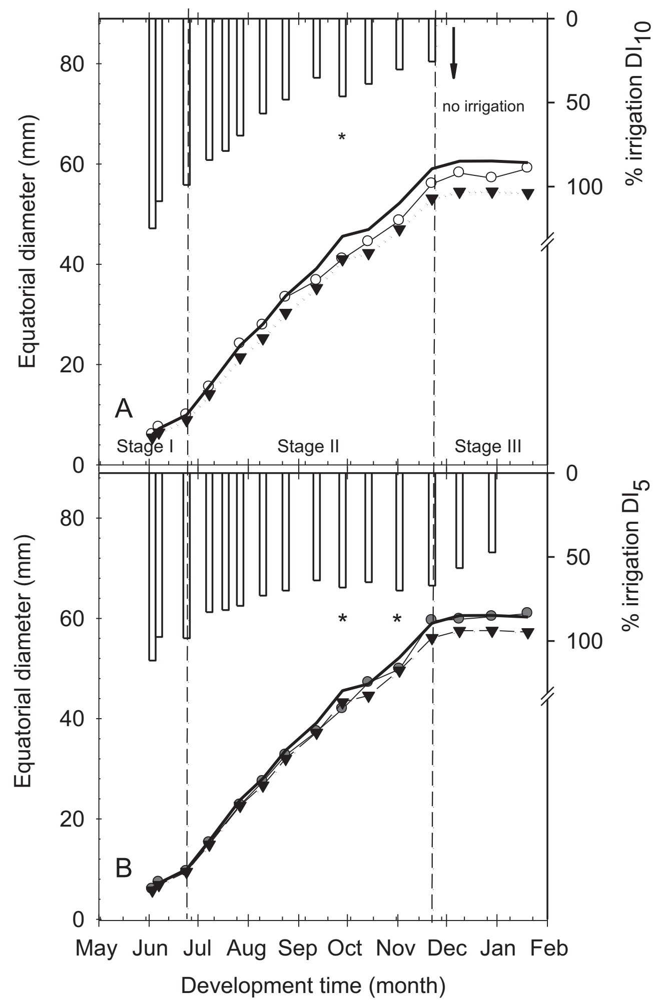

Figure 1. Irrigation scheduling based on fruit growth during the study period. The vertical bar (▭) indicates the percentage of irrigation applied in DI_{10} (A) and DI_5 (B) compared with control (FI). The continuous black lines (—) indicate the values of the equatorial diameter of control. The grey circles (—●—) indicate the average values of DI_5 measured in the field (= current DI_5). The white circles (—○—) indicate the average values of DI_{10} measured in the field (= current DI_{10}). The black triangles (···▼···) refer to the threshold values estimated to maintain signal strength for the treatments proposed (DI_5 and DI_{10} thresholds). Asterisks indicate the days when irrigation was increased in DI_{10} and DI_5, respectively. The arrow indicates the time when the irrigation in DI_{10} was suppressed. Each measurement is the average of 75 fruits per treatment: control, (fully irrigated treatment or FI), DI_{10} (severe deficit irrigation) and DI_5 (moderate deficit irrigation).

based on ET_0 (Allen et al., 1998), the crop coefficient (Doorenbos and Pruitt, 1986) and the correction factor *versus* the shaded area (Fereres et al., 1981). The experimental design consisted of three replicates per treatment, randomly distributed within the orchard. Each replicate had three adjacent tree rows and 6 trees per row. Measurements were taken only in the 5 trees of the central row, the other trees serving as borders.

2.3. Experimental design for cold storage

Fruits were harvested on 22 February 2012 and stored at 5 °C and 75 ± 5% relative humidity for 33 d. A subsequent shelf-life period of 25 °C for 5 d at 70 ± 5% relative humidity was applied. Fruit quality was determined in 30 fruits per treatment (ten fruit for each replicate) at harvest, at different cold storage times (14, 28 or 33 d at 5 °C), and at the end of the additional shelf-life period. Fruit weight loss and fruit equatorial diameter were determined in three