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# Effect of sustained and regulated deficit irrigation on fruit quality of pomegranate cv. 'Mollar de Elche' at harvest and during cold storage

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ABSTRACT

The effect of several irrigation strategies on fruit quality at harvest and during cold storage at 5 °C of 'Mollar de Elche' pomegranates (*Punica granatum* L.) was studied for three seasons. Irrigation treatments consisted of a control irrigated at 100% of crop evapotranspiration (ETc), a sustained deficit irrigation (SDI) where trees were irrigated at 50% of the ETc during the entire season, and three regulated deficit irrigation (RDI) treatments. In the RDI regimes, severe water restrictions (25% ETc) were applied during one of three phases: flowering and fruit set ($RDI_{fl.-fr.set}$), fruit growth ($RDI_{fr.gr}$) or the final phase of fruit growth and ripening ($RDI_{ripe}$). Results showed that after 8 or 19 weeks at 5 °C plus 7 days of shelf life at 20 °C, some fruit quality attributes such as the soluble solids content (SSC), anthocyanins and fruit colour were enhanced by deficit irrigation. Higher SSC and more reddish colouration in the fruit peel were noted at harvest and during cold storage in pomegranates from SDI and $RDI_{ripe}$. On the other hand, higher juice anthocyanins content were obtained in the $RDI_{fr.gr.}$ fruit. Control fruit showed greater susceptibility to physiological disorders manifested as peel pitting, blemishes and sinking, and to weight loss with respect to deficit irrigation samples. Weight loss increased with storage time and SDI and $RDI_{ripe}$ showed lower weight loss compared to the control treatment. Deficit irrigation, depending on the phenological period when water shortage is applied, can be then used as a field practice to control fruit ripening timing, enhance pomegranate fruit composition and improve fruit postharvest performance.



## 1. Introduction

Pomegranate is a popular fruit of tropical and subtropical regions that is gaining great interest as a result of the beneficial effects on health (Lansky and Newman, 2007). Spain is the main producer and exporter in Europe. In Spain, the pomegranate cultivation area is located in the south-eastern part, 'Mollar de Elche' being the most important pomegranate cultivar of the area due to its soft seeds and outstanding organoleptic properties.

Pomegranate is fairly drought resistant but require regular watering to produce high yield and large fruit weight (Holland et al., 2009). In Israel, under common conditions, the amount of water applied annually ranges between 5000 and 6000 $m^3\,ha^{-1}$, but may reach up to 12,000 $m^3\,ha^{-1}$ in desert areas (Schwartz et al., 2009). In Spain, pomegranate trees are irrigated with about 4500–5500 $m^3\,ha^{-1}$ (Intrigliolo et al., 2011). However, water resources in the area are limited, and it is very important to encourage water saving, while safeguarding fruit yield and quality. For this reason, regulated deficit irrigation (RDI) strategies, which impose water deficits during phenological stages when trees are less sensitive to water stress (non-critical period), have been proposed to reduce the amount of applied water (Ruiz Sánchez et al., 2010). RDI has been applied with successful results in many woody perennial crops such as peach, pear, plum, almond and citrus trees (Mitchell and Chalmers, 1982; Ebel et al., 1993; Egea et al., 2009; Intrigliolo and Castel, 2005; González-Altozano and Castel, 1999).

In addition to the possible water savings, some investigations have also shown that deficit irrigation during fruit growth period might have a positive effect on fruit quality by improving fruit taste, associated with an increase in soluble solids content (SSC) (Li et al., 1989; Crisosto et al., 1994; Mpelasoka et al., 2001) and quality attributes, such as colour (Torrecillas et al., 2000; Pérez-Pastor et al., 2007). Alternatively, excessive watering may have adverse effects on fruit quality, since it increases tree vegetative growth, which promotes a nutritional imbalance and decreases fruit dry mass (Herrero and Guardia, 1992). In peaches the overwatering can

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also cause decrease in cuticle thickness, which resulted in higher fruit water losses during storage, more shrivelling symptoms and vulnerability to fungal attacks (Crisosto et al., 1994).

In the case of pomegranate, little research has been carried out on irrigation requirements and tree physiological and production responses to water stress or nutritional aspects (Holland et al., 2009). Only recently some field studies have been conducted in south-eastern Spain that have determined the effects of different deficit irrigation practices on yield performance (Intrigliolo et al., 2013) and on some fruit composition characters during fruit growth (Mellisho et al., 2012). The present experiment was designed to determine the effects of several deficit irrigation strategies on fruit quality attributes, physiological disorders and decay of 'Mollar de Elche' pomegranate during prolonged cold storage and shelf life.

## 2. Materials and methods

### 2.1. Experimental conditions and irrigation treatments

The field experiment was conducted from 2009 to 2011 on a commercial pomegranate tree orchard (*Punica granatum* L) cv. 'Mollar de Elche' in Elche, Alicante, Spain, (38° North, elevation 97 m). The entire orchard was of about 15 ha, and the experiment was performed in a 0.8 ha block. The soil was a typical calcaric fluvisol sandy-loam with an effective depth over 120 cm. Trees were planted in 2000 at a spacing of 5 × 4 m and, at the beginning of the experiment, the average tree shaded area was 53%. The irrigation water had a moderate risk of salinization with an average electrical conductivity, EC at 25 °C of 2.63 dS $m^{-1}$ and an average $Cl^-$ and Na concentration of 43.5 and 326.3 mg $L^{-1}$, respectively. However, pomegranate trees are considered moderately tolerant to salinity (Holland et al., 2009). Trees received 140, 60 and 170 kg $ha^{-1}$ $year^{-1}$ of N, $P_2O_5$, and $K_2O$, respectively. Agricultural practices followed were those common for the area. More details about the orchard characteristics can be found in the companion paper by Intrigliolo et al. (2013).

Weather was recorded at an automated weather station equipped with: a datalogger CR1000 (Campbell Scientific, Logan, UT, USA), an air humidity and temperature sensor 1.1005.54 (Thies clima, Göttingen, Germany), a wind speed sensors 4.3519.00 (Thies clima), a solar pyranometer CMP·(Kipp & Zonen Delft, The Netherlands) and a rain gauge ARG 100 (Campbell Scientific). The weather station was located at 5 km distance from the orchard. Precipitation and reference evapotranspiration (ETo) during the experimental period (April to October) are reported in Table 1. Drip irrigation was applied with eight emitters per tree delivering 4.0 L $h^{-1}$ and were located in a single line parallel to the tree row. Irrigation treatments tested were based on either applying different irrigation regimes throughout the growing seasons, or severe water restrictions limited during certain given phenological periods (regulated deficit irrigation, RDI). The five treatments were:

Control: irrigation was scheduled in order to replace 100% of the estimated crop evapotranspiration (ETc). Crop ETc was estimated as product of ETo and crop coefficient (Kc). ETo was calculated with hourly values by the Penman-Monteith formula as in Allen et al. (1998). The Kc values employed were based on results reported by Intrigliolo et al. (2011).

Sustained deficit irrigation (SDI): water was constantly applied at 50% of control regime.

$RDI_{fl.-fr.set}$: severe water restrictions (25% of the control irrigation amount) were imposed during May and June, coinciding with flowering, fruit set and early fruit growth, while during the rest of the season 100% of control irrigation amount was applied.

$RDI_{fr.gr}$: severe water restrictions (25% of the control irrigation amount) were imposed during July to end of August (linear fruit growth phase), while during the rest of the season 100% of control irrigation amount was applied. Fruit growth seasonal variations were studied in all three seasons, and those results are reported in Intrigliolo et al. (2013).

$RDI_{ripe}$: severe water restrictions (25% of the control irrigation amount) were imposed from the end of August until the end of the season (last part of fruit growth and ripening period) while during the rest of the season 100% of control irrigation amount was applied.

The reductions in the amount of water applied during the deficits were achieved by reducing irrigation duration, while frequency of irrigation was always the same for all treatments. Irrigation frequency changed over the season with all treatments irrigated once a week in early spring and autumn and six-seven times a week during summer. The experimental design was a randomized complete block, with four replicates per treatment. Each plot had three rows, with 6–8 central trees per row. Midday stem water potential ($\Psi$s) was measured with a pressure chamber (Soil Moisture Equip. Corp. mod. 5100A, Santa Barbara, CA, USA), following procedures described by Intrigliolo et al. (2013).

### 2.2. Postharvest storage conditions

Pomegranates were harvested at commercial maturity. A sample of about 125 fruit per treatment was taken and transported to the IVIA where pomegranates were selected for absence of physical damage. Sound fruit were kept at 5 °C and 90–95% RH until the next day, when fruit were randomly divided into three replicates of 17 fruit each per treatment and stored at 5 °C and 90–95% RH for two different storage periods (8 and 19 weeks). Then the fruit were transferred to shelf life conditions (7 days at 20 °C and 70–75% RH) to evaluate the quality attributes.

### 2.3. Physico-chemical fruit quality

Fruit quality evaluations were performed at harvest and after storage and shelf life simulation. The fruit diameter at harvest was measured on 20 fruit per treatment using an electronic digital caliper (0–150 ± 0.01 mm; Comecta, Barcelona, Spain).

During storage, weight loss was determined in 51 fruit per treatment and results were expressed as percentage loss of initial weight.

External rind colour was assessed in 30 fruit per treatment on opposite cheeks of healthy pomegranates using standard CIELab colour space coordinates and expressed as $L^*$, $a^*$, $b^*$, and hue colour values provided by a colorimeter (Minolta, model CR-400, Osaka, Japan). The maximum value for $L^*$ is 100, which represents a perfect reflecting diffuser. The minimum for $L^*$ is zero, which represents black. Positive $a^*$ values represents red colour, while negative is green. Positive $b^*$ is yellow. Negative $b^*$ is blue.

Juice quality was determined in three replicates of 5 fruit each per treatment. For juice yield, pomegranates were hand-peeled and the arils weighed. The arils were then homogenized in a commercial blender, the juice weighted, and the yield was expressed as percentage. SSC of the juice was measured using a digital refractometer (model PR1; Atago Co. Ltd, Japan) and values were expressed as °Brix. The titratable acidity (TA) of the fruit juice was determined by titrating 5 mL of juice sample with 0.1 mol $L^{-1}$ sodium hydroxide to an end point of pH 8.1 and expressed as percentage of citric acid. The maturity index (MI) was calculated as the SSC/TA ratio.

### 2.4. Bioactive compounds

For anthocyanins analysis, the juice sample (1 mL) was centrifuged (3 min at 7000 rpm) and the supernatant was filtred