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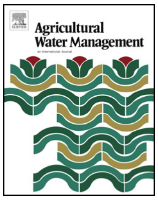

# Jujube fruit water relations at fruit maturation in response to water deficits

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## ABSTRACT

The fruit maturation stage is considered the optimal phenological stage for implementing water deficit in jujube (*Zizyphus jujuba* Mill.), since a low, moderate or severe water deficit at this time has no effect on yield, fruit volume or eating quality. However, no information exists at fruit water relations level on the mechanisms developed by *Z. jujuba* to confront drought. The purpose of the present study was to increase our understanding of the relationship between leaf and fruit water relations of jujube plants under different irrigation conditions during fruit maturation, paying special attention to analysing whether fruit size depends on fruit turgor. For this, adult jujube trees (cv. Grande de Albatera) were subjected to five irrigation treatments. Control plants (T0) were irrigated daily above their crop water requirements in order to attain non-limiting soil water conditions in 2012 and 2013. T1 plants were subjected to deficit irrigation throughout the 2012 season, according to the criteria frequently used by the growers in the area. T2 (2012), T3 and T4 (2013) were irrigated as T0 except during fruit maturation, in which irrigation was withheld for 32, 17 and 24 days, respectively. The results indicated that the jujube fruit maturation period was clearly sensitive to water deficit. During most of this stage water could enter the fruits via the phloem rather than via the xylem. From the beginning of water withholding to when maximum water stress levels were achieved, fruit and leaf turgor were maintained in plants under water deficit. However, a direct relation between turgor and fruit size was not found in jujube fruits, which could be due to an enhancement of a cell elasticity mechanism (elastic adjustment) which maintains fruit turgor by reducing fruit cells size or to the fact that jujube fruit growth depends on the fruit growth-effective turgor rather than just turgor pressure.

## 1. Introduction

Jujube tree (*Zizyphus jujuba* Mill), is native to temperate Asia and is mostly cultivated in China, India, Central Asia and southwest Asia (Williams, 2006b). Although considered as a multipurpose plant, its fruits are the major focus of interest (Bowe, 2006). *Z. jujuba* is considered a minor crop, but is an integral part of the culture and way of life for millions of Asians and has also become so for large regions of Africa (Williams, 2006a). This growing interest on jujube fruit is due to its presumed health-promoting effects, and it is now considered a functional food, since it has nutritional as well as medicinal uses (Heo et al., 2003; Huang et al., 2007; Li et al., 2007; Zhao et al., 2008; Mahajan and Chopda, 2009; Choi et al., 2011; Collado-González et al., 2013, 2014). For all this, the International Centre for Underutilized Crops has identified *Z. jujuba* as a crop with substantial growth potential (Williams et al., 2006c).

Jujube tree is admired for its multiple uses, easy management, early bearing and wide adaptations to environmental conditions. In this sense, it is tolerant to saline irrigation water, low winter temperatures during dormancy and severe drought during the growing season (Dahiya et al., 1981; Ming and Sun, 1986; Jain and Dass, 1988). In this last respect, Cruz et al. (2012) showed that *Z.*

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*jujuba* is able to withstand severe water deficits, while maintaining leaf turgor, which allows good gas exchange rates and, as a consequence, good leaf productivity. This leaf turgor maintenance was mainly due to two simultaneous and complementary mechanisms: decreased leaf conductance and a shorter period of maximum stomatal opening in order to control water loss via transpiration (stress avoidance mechanisms). The gradual recovery of leaf conductance after rewatering can also be considered as a mechanism for promoting leaf rehydration. In addition, from the beginning of the stress period, active osmotic adjustment operated, which can contribute to the maintenance of leaf turgor (stress tolerance mechanism). The high relative apoplastic water content levels and the possibility of increasing the accumulation of water in the apoplasm in response to water stress, supporting a steeper gradient in water potential between the leaf and the soil, which can be considered another drought tolerance characteristic in pear-jujube leaves.

According to Cui et al. (2008), the phenological periods of jujube tree can be divided into bud burst to leafing (stage I, early April–early May), flowering to fruit set (stage II, mid May–late June), fruit growth (stage III, late June–late July), fruit maturation (stage IV, early August–early September) and dormancy (stage V, this October–next March) stages. Also, these authors indicated that the fruit maturation stage is the optimal stage for implementing water deficit in jujube, because low, moderate and severe water deficits have no effect on the fruit weight and volume, the fruits taste sweeter and eating quality is improved. In addition, the fruit maturation period is shortened, raising the market price of the fruit, fruit firmness is enhanced and the percentage of rotten fruit after storage is reduced. Despite the importance of the maturation period on jujube fruit quality, to the best of our knowledge no information exists on jujube fruit water relations. For these reasons, the aim of this study was to increase our understanding of the relationship between leaf and fruit water relations of jujube plants under different irrigation conditions during fruit maturation, paying special attention to analysing whether fruit size depends on fruit turgor.

## 2. Materials and methods

### 2.1. Plant material, experimental conditions, and treatments

Two different but complementary experiments were performed with the common goal of investigating if jujube fruit maturation period was clearly sensitive to water deficit. In the first experiment (2012) control plants were compared with plants subjected to moderate water deficit and with plants under severe water deficit. In order to verify the results obtained in the first experiment, in the second experiment (2013) control plants were compared with other plants subjected to different water stress conditions.

Both experiments were carried out at a farm near the city of Albatera (Alicante, Spain) (38°12′N, 0°51′W). The plant material consisted of 8-year-old jujube trees (*Zizyphus jujuba* Mill), cv. Grande de Albatera), planted at 2 m × 6 m. The soil of the orchard is a Torrifluvent with a sandy loam texture, very low electrical conductivity (109 μS/cm, 1:10 w:v), high lime content (570 g/kg), very low organic matter content (3 g/kg), low exchangeable potassium (40 mg/kg) and available phosphorus (20 mg/kg) levels. The irrigation water had an electrical conductivity of between 1.7 and 2.2 dS/m and a $Cl^-$ concentration ranging from 36 to 48 mg $l^{-1}$. Pest control and fertilization practices were those usually used by the growers, and no weeds were allowed to develop within the orchard.

Jujube plants were drip-irrigated every night, using one lateral pipe parallel to the tree row and 2 emitters per tree, each delivering 8 l $h^{-1}$. In-line water meters were used to measure the water supplied to each experimental unit.

#### 2.1.1. Experiment 1 (2012)

During the 2012 experimental period (DOY 93–230), control plants (treatment T0) were irrigated in order to guarantee non-limiting soil water conditions (41% daily crop reference evapotranspiration (ETo) during bud burst and leafing (DOY 93–121), 52% ETo during flowering and fruit set (stage I, DOY 122–167), 69% ETo during fruit growth (stage II, DOY 168–197) and 106% ETo during fruit maturation (stage III, DOY 198–230). Such percentages were applied according to the water needs obtained in previous results. T1 plants were subjected to deficit irrigation throughout the season, according to the criteria frequently used by the growers in the area (23% ETo during bud burst and leafing (DOY 93–121), 30% ETo during flowering and fruit set (stage I, DOY 122–167), 40% ETo during fruit growth (stage II, DOY 168–197) and 61% ETo during fruit maturation (stage III, DOY 198–230). T2 treatment was irrigated as T0 except during 32 days before harvest, in which irrigation was withheld (from day of the year (DOY) 198 to 230). Total seasonal water amounts applied were 440, 252 and 274 mm for T0, T1 and T2 treatments, respectively.

#### 2.1.2. Experiment 2 (2013)

During the 2013 experimental period (DOY 101–242), control plants (treatment T0) were irrigated with a similar criterion to that used in 2012 (42% ETo during bud burst and leafing (DOY 101–126), 53% ETo during flowering and fruit set (stage I, DOY 127–169), 76% ETo during fruit growth (stage II, DOY 170–198) and 110% ETo during fruit maturation (stage III, DOY 199–242). T3 and T4 plants were irrigated as T0 except during the last 17 and 24 days before harvest in which irrigation was withheld (from day of the year (DOY) 225 (T3) and 218 (T4) to 242), respectively. Total seasonal water amounts applied were 441, 360 and 322 mm for T0, T3 and T4 treatments, respectively.

### 2.2. Measurements

Meteorological data, namely air relative humidity, air temperature, solar radiation, rainfall and wind speed 2 m above the soil surface, were collected by an automatic weather station located near the experimental site. Mean daily air vapour pressure deficit ($VPD_m$) and daily crop reference evapotranspiration (ETo) were calculated according to Allen et al. (1998).

The water relations of the leaves and fruits were measured at midday (12 h solar time). Fruits and fully expanded leaves from the south facing side and middle third of the tree of four trees per treatment were selected for measurements. Leaf conductance ($g_{leaf}$) was measured with a porometer (Delta T AP4, Delta-T Devices, Cambridge, UK) on the abaxial surface of two leaves per tree. Leaf water potential ($\Psi_{leaf}$), and stem water potential ($\Psi_{stem}$) were measured in a similar number and type of leaves as used for $g_{leaf}$ using a pressure chamber (PMS 600-EXP, PMS Instruments Company, Albany, USA) (Greenspan et al., 1994; Nobel and de la Barrera, 2000). Leaves for $\Psi_{stem}$ measurements were enclosed in a small black plastic bag covered with aluminium foil for at least 2 h before measurements. Fruit water potential ($\Psi_{fruit}$) was measured with the pressure chamber (PMS 600-EXP, PMS Instruments Company, Albany, USA) in two fruits per tree as described by McFadyen et al. (1996) and Gelly et al. (2004).

Midday leaf ($\Psi_{\pi\ leaf}$) and fruit ($\Psi_{\pi\ fruit}$) osmotic potentials were determined in the same leaves and fruits as used for $\Psi_{leaf}$ and $\Psi_{fruit}$ measurements, respectively. Leaves and fruits were covered with aluminium foil and immediately frozen in liquid nitrogen and stored at −80 °C. The osmotic potential was measured after thawing the samples and expressing the sap, using a vapour pressure osmometer (Wescor 5600, Logan, USA). Estimated midday leaf ($\Psi_{p\ leaf}$) and fruit ($\Psi_{p\ fruit}$) turgor potentials were derived as the dif-

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