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Effect of regulated deficit irrigation on quality parameters, carotenoids and phenolics of diverse tomato varieties (*Solanum lycopersicum* L.)

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ABSTRACT

This study aims to evaluate the effects of regulated deficit irrigation (RDI) and of cluster position (CI: first and second cluster; CII: third and fourth cluster; CIII: fifth and sixth cluster) on fruit quality parameters, carotenoids and phenolics in tomatoes. Three common ('Tigerella', 'Palamós' and 'Byelsa') and two cherry varieties ('Lazarino' and 'Summerbrix') were studied. The results showed that the regulated deficit irrigation with reduction of 40 and 50% in the leaf water potential in common and cherry tomatoes did not affect greatly the organoleptic quality of common tomatoes and 'Summerbrix', while cherry varieties were significantly affected with the cluster position. In most case, significant changes in the levels of carotenoids were observed depending on the treatment and the cluster position in all varieties. Significant changes with the treatment and no change with the cluster position were observed in phenolic compounds. Thus, in general, increased total carotenoid levels and reduced the content of phenolic compounds were observed. Considering the significance of changes in the levels of these groups of compounds it was concluded that 'Lazarino' was more susceptible to water deficit, whereas 'Summerbrix' and 'Palamós' were more resistant. On the other hand, the organoleptic and functional quality changed with the variety.

1. Introduction

The tomato (*Solanum lycopersicum* L.) is one of the most important crops and widely consumed either fresh or processed as food. Tomato is a source of fibre, potassium, phosphorous, vitamin C, B and E, carotenoids and phenolic compounds (Ripoll, Urban, Brunel, & Bertin, 2016).

The functional quality of the tomato regarding carotenoids and phenolic compounds levels is affected by agronomical factors, such as maturation in the plant, post–harvest treatment (Centeno et al., 2011), collection period, light intensity, temperature of cultivation (Dorais, 2007), CO_2, vapour pressure deficit, air quality and pollutants (Torres, Adrews, & Davies, 2006). Carotenoids of tomatoes are of great interest for different reasons, thus, these are in general the primary source of lycopene in the human diet (Rao & Rao, 2007). These are also one of the best dietary sources of the colourless carotenoids phytoene and phytofluene (Meléndez-Martínez, Mapelli, Benítez, & Stinco, 2015) whose study is attracting increasing interest very recently (Meléndez-Martínez, Paulino, Stinco, Mapelli-Brahm, & Xiang-Dong, 2014; Stinco, Heredia, Vicario, & Meléndez, 2016) as they may provide health benefits (Meléndez-Martínez et al., 2013; Meléndez-Martínez et al., 2015). On the other hand, phenolics have been shown to exhibit antioxidant properties in vitro, and are thought to provide health benefits (Shadini & Ambigaipalan, 2015).

The tomato quality is a sum of several factors. The market quality change with water and environmental stress, these can affect the fruit size and sugar content (Vinha, Alves, Barreira, Castro, & Costa, 2014), because they can generate varied responses in the plant, such as the reduction of water potential, turgor, water content, growth and crop productivity (Shao, Chu, Abdul, & Zhao, 2008). Deficit irrigation can be used to save water. This is characterized by watering the root zone with less water and can be useful to improve the quality of some products by enhancing the characteristic sensory attributes, which leads to a greater level of satisfaction among international consumers (Cano-Lamadrid et al., 2015).

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On the other hand, the increase of the population has provoked greater agricultural demand, with decrease of the available water. Water stress can cause changes in the fruit quality and increase soluble solids content in late growing seasons. It is a usual agronomical techniques for improving quality in the fruit ripening phase (Johnstone, Hartz, LeStrange, Nunez, & Miyao, 2005). However, high levels of water deficit irrigation in sensitive phenological phases (such as flowering) may reduce the sugar, acid and carotenoid content (Ripoll et al., 2016). Plant measurements have been considered very efficient tools for irrigation scheduling (Turner, 1990). Deficit irrigation based on plant water status (especially leaf water potential) are increasingly used for scheduling deficit irrigation (Corell et al., 2016). However, there are few studies on deficit irrigation techniques based on plant water status and cluster position, and its effect on the commercial and functional tomato quality.

In this regard, the main aim of the study was to determine the effect of a regulated deficit irrigation treatment (based on crop water status, with physiological measurements, and compared with well-irrigated plants) and the cluster position (CI: first and second cluster; CII: third and fourth cluster; CIII: fifth and sixth cluster) on fruit quality parameters (diameter, weight, soluble solids and colour) as well as in carotenoids and phenolics levels. For this purpose 5 tomato genotypes (three common 'Daniella' type and two cherry varieties) were considered. The controlled deficit irrigation, consisted in reducing the water amount applied in the more resistant phases of the crop, so as not to affect the production and yield. In this particular case, this technique is based on measures of water status to optimize production, increasing the efficiency of water use. Measures of water status, with thresholds of stress that in theory do not affect the production of the crop were used. This deficit irrigation schedule is devised so as not cause a water stress in the plant that affects negatively the production.

2. Materials and methods

2.1. Reagents and standards

Methanol, trichloromethane and hydrochloric acid were of analytical grade and purchased from Labscan (Dublin, Ireland). HPLC-grade methanol, HPLC-grade acetonitrile (PumChemCID: 6342), HPLC-grade ethyl acetate (PumChemCID: 8857) and formic acid (PumChemCID: 284) were obtained from Panreac (Barcelona, Spain). Water was purified in a NANOpureDlamond™ system (Barnsted Inc., Dubuque, IO). β-carotene (PumChem CID: 5,280,489) was purchased from Sigma-Aldrich (Taufkirchen, Germany) and lutein, lycopene, phytoene and phytofluene were obtained from appropriate sources as described elsewhere (Meléndez-Martinez, Stinco, Liu, & Wang, 2013; Meléndez-Martínez, Vicario, & Heredia, 2007). Quercetin (PumChem CID: 5,280,804), ferulic acid, caffeic acid, p-coumaric acid (PumChem CID: 637,542), were purchased from Sigma-Aldrich (Madrid, Spain).

2.2. Plant materials

Five tomato (*S. lycopersicum*) varieties with indeterminate growth were studied, specifically three 'Daniella' type varieties (Palamós, Tigerella and Byelsa) and two cherry varieties (Summerbrix and Lazarino). These were provided by Fitó from Spain. All varieties have a red colour except 'Tigerella' that is a striped round medium to small variety. 'Palamós' is a round medium to big variety, 'Byelsa' is a pear type of tomato, 'Summerbrix' is a pear small variety and 'Lazarino' is a round variety. They were tested in a greenhouse production at Escuela Técnica Superior de Ingeniería Agronómica (E.T.S.I.A.) in the Universidad de Sevilla (Sevilla, South Spain, 37°21′09.71″ Lat. N, 5°56′19.13″ Long. W, 33 m a.s.l.). They were tested during spring 2015 (23rd February to 15th June). The varieties studied were germinated in seedlings and, when they developed three or four true leaves, they were transplanted and secondary plant stems were pruned. Pest control was performed with insecticides and acaricides specific for tomatoes. The irrigation of the plants was done by dripping, with two daily cycles of irrigation that depended to crop evapotranspiration (ETc) of the plant. The irrigation treatments were: Regulated deficit irrigation (RDI), with a water stress threshold of −1 MPa of leaf water potential (55.1 mm of applied water) from flowering, and a control treatment with irrigation requirements determined according to ETc calculated with the FAO Penman-Monteith method (Allen, Pereira, Raes, & Smith, 2006) (532.2 mm of applied water). The RDI was applied fifteen days after transplantation. Each parcel was made up of 3 rows; tomatoes samples were collected at central rows plants. All the clusters were harvest at the same time. Fruit harvest for the analysis was performed at full red ripening on June 21st.

Samples included fruits representative of the three different clusters. The first and second clusters corresponded to position I (CI), the third and fourth clusters corresponded to position II (CII), and the fifth and sixth clusters corresponded to position III (CIII). Three fruits of seven plants for cherry varieties and one fruit of seven plants for common varieties were collected at each position. These were selected from different parts of the cluster. In most cases, fruit in the CI position was selected from the distal part, CII from medium part and CIII proximal part of the cluster. Samples included a mix of fruits of each level previously characterized. This mix was divided into two samples for the quantification of functional quality. The seeds and inside locular tissues were removed, cut and quickly frozen at −80 °C, before being freeze-dried with a Cryodos system (Telstar, Japan). The water content was determined by weighing the sample before and after freeze-drying.

The dried samples were ground in a basic IKA A 11 mill, then stored in a dark glass bottle and hermetically sealed under nitrogen atmosphere. The samples were stored in a freezer at −21 °C until their analysis.

2.3. Measurements performed on the fruits

The measurements performed on the fresh tomato quantified equatorial and longitudinal diameter (cm), weight (g), soluble solids (°Brix) and colour. The soluble solids were measured using a Hand-refractometer RHC-200ATC (Huake, China), and the fruit colour was analysed using a CM-700d colorimeter (Minolta, Japan). For this purpose the whole visible spectrum (380–770 nm) was recorded with a bandwidth of 1 nm. The colour parameters corresponding to the uniform colour space CIELAB were obtained directly from the apparatus. Illuminant D65 and 10° observer were considered as reference.

2.4. Carotenoid analysis

2.4.1. Sample preparation

Individual carotenoids were determined as described by Borghesi et al. (2011) with slight modifications. Approximately 20 mg of homogenized freeze-dried powder were used for the extractions. The powder was mixed with 250 μL of methanol, 500 μL of trichloromethane and 250 μL of MiliQ-water and then vortexed, sonicated for 2 min and centrifuged to remove the aqueous phase at 14 000 × *g* for 3 min. After recovering the coloured fraction, 500 μL of trichloromethane were added, and then the mixture was vortexed, sonicated and centrifuged again. These operations were repeated until the solids did not have colour. The organic coloured fractions were evaporated to dryness at a temperature below 30 °C in a vacuum concentrator and stored under N_2 at −20 °C until the analysis.

2.4.2. RRLC chromatography

The dry residue was re-dissolved in 40 μL of ethyl acetate prior to their injection in the RRLC system. The RRLC analysis was carried out using the method reported by Stinco et al. on an Agilent 1260 system equipped with a diode-array detector, C_{18} Poroshell 120 column (2.7 μm, 5 cm × 4.6 mm) (Agilent, Palo Alto, CA), 2.5 μL of the