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Original Research Article

Effect of regulated deficit irrigation on commercial quality parameters, carotenoids, phenolics and sugars of the black cherry tomato (*Solanum lycopersicum* L.) 'Sunchocola'

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ABSTRACT

In this preliminary study, the effect of regulated deficit irrigation (RDI) on the commercial quality (size, weight, soluble solids, firmness and colour), content of carotenoids, phenolics and sugars of black tomato (*Solanum lycopersicum* L.) 'Sunchocola' was studied. Two water irrigation treatments were applied: regulated deficit irrigation (RDI) and control with 82,7 and 398 mm of water supplied, respectively. Tomato of the first cluster harvested at three stages of maturity were studied. The size and weight of the tomato did not present significant differences regarding the RDI and maturity. In both groups the concentration of carotenoids and phenolics increased with the degree of maturity (on average 57 % and 8 % respectively). On the other hand, in most cases, the content of carotenoids, phenolics and sugars showed significant differences between irrigation treatments ($p < 0.1$). In conclusion, with the application of the RDI, it was possible to maintain the size and weight and increase the carotenoid levels of the fruits.

1. Introduction

Tomato is one of the most consumed vegetables worldwide. It is recognized as a source of fiber, protein, carbohydrates, potassium, phosphorus, calcium, magnesium, sugars, organic acids, vitamins C, E, B1, B2, and B6, niacin and pantothenic acid (Perveen et al., 2015). It is also a source of health-promoting bioactives including several carotenoids and phenolic compounds (Coyago-Cruz et al., 2018; Perveen et al., 2015), which are thought to contribute to reduce the risk of developing conditions such as several types of cancer, metabolic disorders or cardiovascular disease, among others (Ignat et al., 2011; Meléndez-Martínez, 2019). Tomato is widely used for the obtaining of lycopene as an additive and for the development of innovative products such as novel foods or nutricosmetics (Meléndez-Martínez et al., 2021a). Apart from lycopene, it is now well known that many common tomato varieties are also good sources of the colourless carotenoids phytoene and phytofluene, which are attracting much interest in health-promotion through the diet and nutricosmetics (Dias et al., 2018; Meléndez-Martínez et al., 2019). The extraction of carotenoids from tomatoes as well as strategies to increase their levels not only by agronomic practices but

Abbreviations: E.T.S.I.A., Escuela Técnica Superior de Ingeniería Agronómica; a.s.l., above sea level; RDI, regulated deficit irrigation; ETc, crop evapotranspiration; FAO, Food and Agriculture Organization of the United Nations; M1, M2, M3, ripening stages; ED, equatorial diameter; LD, longitudinal diameter; SS, soluble solids; CIELAB, the Commission International of IEclairage (CIE), defined colour spaces that includes CIE L*a*b*; UV–vis, ultraviolet-visible; RRLC, rapid resolution liquid chromatography; UHPLC, ultra performance liquid chromatography; TCC, total carotenoids content; TPCC, total phenolic content; TSC, total sugars content; DAT, days after transplant; A^b, significance of differences between the RDI and control samples; AM^b, significance of differences between ripening stages; ns, not significant.

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Fig. 1. Pthotographs of ripening stages of the 'Sunchocola' tomato. M1, 25 % red; M2, 50 % red; M3, 75 % red (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

also by means of post-harvest treatments continues to be an important research topic (Meléndez-Martínez et al., 2021b).

Due to its importance, several studies have focused on improving the genetic characteristics of new cultivars, which are attractive to the consumer, industry and farmers (Vergani, 2002). In virtue of this, numerous improvement programs have generated a great variety of hybrids with different sizes and colours and with different characteristics to resist diseases, high temperatures, drought processes or to improve their nutritional characteristics (Bergougnoux, 2014). Although most tomato varieties are red, there are also yellow, orange and green commercial varieties (Coyago-Cruz et al., 2019b). In addition, in recent years, dark tomato varieties characterized by having higher lycopene contents and/or accumulating other compounds (for instance anthocyanins), are attracting increased interest (Borghesi et al., 2011; Park et al., 2018).

The tomato crop production is affected by environmental and agronomic factors and by the geographic location of the crop (Dannehl et al., 2014). On the other hand, the needed amount of irrigation of the crop depends on the species, the variety and the edaphoclimatic conditions. An important part of the horticultural cultivation areas has been located in zones with warm climates, as the optimal light conditions and high temperatures favor crops. The main problem is that those zones have high water requirements (Patanè et al., 2011). In addition, climate change has reduced the availability of fresh water, so that it is increasingly necessary to improve water-use efficiency in agriculture (Chai et al., 2016; Patanè et al., 2011). One of the water saving techniques is the regulated deficit irrigation (RDI), which was developed in the early eighties especially in woody crops (Chai et al., 2016). This system of irrigation programming is based on the existence of phenological states of the plant that are more resistant to water stress conditions and that, therefore, would allow the reduction of the amount of water to be applied without affecting production or, decreasing it very little (Carbonell-Barrachina et al., 2015; Nangare et al., 2016). Thus, RDI can be considered a hydro-sustainable, and hence environmentally friendly technique (Cano-Lamadrid et al., 2015). In addition, RDI can lead to an increase in the content of bioactive compounds and in the intensity of some sensory attributes in fruits and vegetables (Shao et al., 2008). The usefulness of RDI has not been yet extensively studied in horticultural species and only few studies, mainly in tomatoes, can be found in the scientific literature. There are few RDI studies conducted in tomato, which are mainly focused on tomato industry. One of these studies indicate that the application of RDI in the stage of fruit set of the first fruits produce precocity in the change of colour to red and can improve the content of the soluble solids in the harvest without a significant decrease in the yield (Quadir et al., 2006). Recent studies in diverse red-coloured tomato cultivars indicated that RDI in the most resistant phenological stages of the crop can also be a suitable hydrosustainable approach that does not affect negatively tomato yield and can in some cases increase their content in health-promoting phytochemicals (Coyago-Cruz et al., 2017b).

The main aim of this study was to determine the effect of a regulated deficit irrigation treatment and the degree of maturity on quality

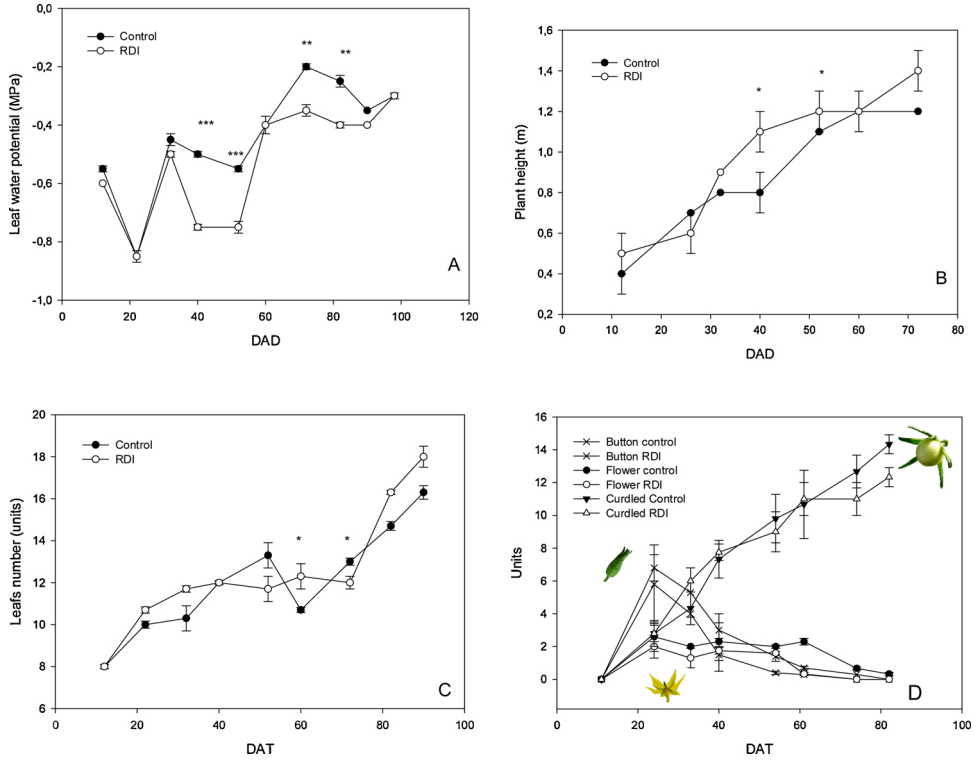

Fig. 2. Parameters measured to evaluate the growth of the plants (RDI and control treatments) A) Leaf water potential; B) Plant height; C) Number of leaves; D) Floral development in the first cluster.

parameters (size, weight, firmness, soluble solids, colour, carotenoids, phenolics and sugars) of the fruits. For this purpose, an emerging and little studied cultivar, the dark green-red coloured 'Sunchocola' tomato was considered.

2. Materials and methods

2.1. Reagents and standards

Chemical compounds studied in this article: Methanol (PubChem CID: 887), trichloromethane (PubChem CID: 6212) and hydrochloric acid (PubChem CID: 313) were of analytical grade and purchased from Labscan (Dublin, Ireland). HPLC-grade methanol, HPLC-grade acetonitrile (PubChem CID: 6342), HPLC-grade ethyl acetate (PubChem CID: 8857), and formic acid (PubChem CID: 284) were obtained from Panreac (Barcelona, Spain). Water was purified in a NANOpure Diamond™ system (Barnsted Inc., Dubuque, IO). β-Carotene (PubChem CID: 5280489) was purchased from Sigma-Aldrich (Steinheim, Germany) and lutein, phytoene and lycopene were obtained from appropriate sources as described elsewhere (Meléndez-Martínez, Vicario, & Heredia, 2007; Meléndez-Martínez, Stinco, Liu, & Wang, 2013). Quercetin (PubChem CID: 5280804), *p*-coumaric acid (PubChem CID: 637542), gallic acid (PubChem CID: 370) and chlorogenic acid (PubChem CID: 1794427) were purchased from Sigma-Aldrich (Madrid, Spain). The standards corresponded to major carotenoid and phenolic compounds in tomatoes (Coyago-Cruz et al., 2018, 2017a, 2017c).

2.2. Plant materials

Medium-sized, round, black cherry tomato (*S. lycopersicum*) of the 'Sunchocola' variety with indeterminate growth was preliminarily studied. The tomatoes were grown in a greenhouse at *Escuela Técnica Superior de Ingeniería Agronómica* (E.T.S.I.A.) of the *Universidad de Sevilla* (Seville, South Spain, 37º21'09.71'' Lat. N, 5º56'19.13'' Long. W, 33 m a. s.l.) during autumn of 2015. The experimental greenhouses were made up of plastic with 75 % transmissibility of the radiation, and furthermore they were provided with a ventilation window. The seeds were provided by W. Atlee Burpee (Warminster, USA). As this was a preliminary study due to the lack of bibliography in this regard, just a block of 30 plants with 2 repetition were sown for each treatment (RDI and control) and 14 plants of were analysed. Each elementary plot consisted of 30 plants, 3 lines with 10 plants. The seeds were grown for 30 days in a nursery seedling and they were transplanted into soil when the seedlings had developed three or four true leaves with a distance between plants of 50 cm and 1 m between lines. The measurements were taken in 7 central plants of the plot, the rest were considered border. Plants were trained and pruned, especially secondary stems and leaves, by using the common practices for tomato crop in greenhouse. Flowers were biologically pollinated with bumblebees (BioSur, Spain). The irrigation was done by dripping, with two daily cycles of irrigation that depended to crop evapotranspiration (ETc) of the plant. The RDI was applied two weeks after transplantation. Irrigation treatments were: RDI, with a threshold of −1 MPa of leaf water potential, and a control treatment with irrigation requirements determined according to daily ETc calculated with the FAO Penman-Monteith method (Allen et al., 2006). This treatment considered two periods: 1) vegetative development in which 100 % Etc was applied and 2) RDI: in which an irrigation threshold was maintained at −1 MPa a leaf water potential, Leaf water potential at midday was measured weekly using a pressure chamber (PMS Instrument Company, USA). The plants were irrigated when the crop reached this threshold (−1 MPa). If the reduction was less than 10 %, an irrigation dose of 25 % of control irrigation was applied and between 10 and 30 % the reduction an irrigation dose of 50 % of control treatment was provided. Thus, water was applied at 82.7 and 398 mm for the RDI and the control treatments, respectively. The irrigation of the plants was done by dripping, with 2 drippers per square meter, with two daily irrigations (Coyago-Cruz et al., 2019b).

To evaluate the growth of the plants the following parameters were measured: leaf water potential, plant height, number of leaves and flowers development. The leaf water potential was measured with a pressure chamber (PMS Instrument Company, USA). Harvesting of the tomatoes was made in January 2016. Three fruits in three different degrees of maturity of fourteen plants were sampled for the analyses at the same time. Thus, six samples were analysed (two irrigation treatments, three stage of maturity) and each sample consisted in a mix of twenty-one tomatoes (three fruits of seven plants). The different degrees of maturity for harvesting were determined visually by considering their colour. The development stages corresponded to fruits with 25 % red (M1), 50 % red (M2) and 100 % red (M3) (Fig. 1). First of all, the fresh fruits were characterized (analysis of size, weight, SS, firmness and colour). Then, each group of twenty-one tomatoes was divided into two samples for the quantification of carotenoids, phenolics compound and sugars. The placenta and seed were removed, and the pulp was cut and freezed-dried with a Cryodos system (Telstar, Japan). The samples were stored under nitrogen atmosphere in a freezer at -21 °C until their analysis.

2.3. Commercial quality assessments

The equatorial diameter (ED) and longitudinal diameter (LD) (in cm), weight (in g), soluble solids (SS, in ºBrix), firmness (in kg/cm^2) and CIELAB colour coordinates (L*, a*, b*, C^*_{ab} and h_{ab}) were measured in fresh tomatoes as described elsewhere (Coyago-Cruz et al., 2018). A Hand-refractometer RHC-200ATC (Huake, China), a PCE-PTR 200 Forge Gauce penetrometer (PCE-Inst., Spain), and CM-700d colourimeter (Minolta, Japan) were used to measure SS, fruit firmness, and fruit colour, respectively.

2.4. Analysis of carotenoids

Individual carotenoids were extracted in triplicated as described by Elena Coyago-Cruz et al. (2017b). Approximately 20 mg of homogenized freeze-dried sample were mixed with 250 μL of methanol, 500 μL of trichloromethane and 250 μL of Milli-Q water. The mixture was vortexed, sonicated for 2 min and centrifuged at 14 000 × *g* for 3 min. After centrifugation the aqueous phase was removed and again extracted with 500 μL of trichloromethane. This operation was repeated until colour exhaustion. The organic phase was evaporated at 30 °C and stored under nitrogen atmosphere at -20 °C until HPLC analysis.

For injection into the RRLC system, the dried extract was dissolved in 40 μL of ethyl acetate. The RRLC analysis was carried out using the method reported by Stinco et al. (2014) in an Agilent 1260 system equipped with a diode-array detector and a C_{18} Poroshell 120 column (2.7 μm, 5 cm × 4.6 mm) (Agilent, Palo Alto, CA). Each sample was injected in the system twice. Total carotenoids content (TCC) was calculated as the sum of the content of the individual carotenoids. Carotenoids were identified by comparison of their chromatographic and UV–vis spectroscopic characteristic with those of standards. The quantification of the carotenoids was performed by external calibration from the areas of the chromatographic peaks obtained by UV detector at the following wavelengths: 285 nm for phytoene, 350 nm for phytofluene and 450 nm for lutein, lycopene, and β-carotene.

2.5. Analysis of phenolic compounds

Individual phenolic compounds were extracted in triplicate as described by Coyago-Cruz, Corell, Stinco, et al. (2017). Approximately 0.5 g of freeze-dried material were mixed with 15 mL of acidified methanol (0.1 %). The mixture was vortexed, sonicated for 15 min, and centrifuged at 4190 × *g* for 7 min at 4 °C. After centrifugation the solid phase was extracted twice with 5 mL of acidified methanol (0.1 %). The extract was stored at -20 °C until UHPLC analysis.

For injection into the UHPLC system, the extract was filtered through Millipore membranes (0.45 μm pore, 15 mm diameter) (Agilent Technologies, Spain). The UPLC analysis was carried out using the method reported by Coyago-Cruz et al. (2018) in an Agilent 1290 system equipped with a diode-array detector and an Eclipse Plus C_{18} column (1.8 μm, 2.1 × 5 mm) (Agilent, Palo Alto, CA). Each sample was injected in the system twice. Total phenolic compounds content (TPCC) was calculated as the sum of the content of the individual phenolics. The identification of phenolics was achieved by comparison of their spectra and retention times with those of appropriate standards, their levels being determined by external calibration considering the following wavelengths: 280 nm for *p*-hydroxibenzoic acid, *p*-coumaric acid, caffeic acid, chlorogenic acid, ferulic acid, naringin and crisin; and 320 nm for quercetrin and quercetin.

2.6. Analysis of sugars

Individual sugars were extracted in triplicate as described by Kasim and Kasim (2015). Approximately 200 mg of freeze-dried material were mixed with 5 mL of Milli-Q water. The mixture was vortexed, sonicated for 5 min, and centrifuged at 4190 × *g* for 7 min at 4 °C. For injection into the HPLC system, the extract was filtered through Millipore membranes (0.45 μm pore, 15 mm diameter) (Agilent Technologies, Spain). The HPLC analysis was carried out using an Agilent 1200 chromatograph equipped with a RID-detector (Agilent Technologies, Palo Alto, CA, USA) and a Zorbax Carbohydrate column (4.6 mm × 150 mm). Each sample was injected in the system twice. Total sugars content (TSC) was calculated as the sum of the content of the individual sugars. These were identified by comparison of their retention times with those of appropriate standards and internal standard. The quantification of the individual sugars was performed by external calibration from the areas of the chromatographic peaks obtained by refractive index (IR) detector.

2.7. Statistical analysis

Results are provided as the mean ± standard deviation. The means were compared by one-way ANOVA followed by the post hoc Tukey's test ($\alpha = 0.01$). Pearson's test with 99 % confidence level was used to estimate the possible significance of the effect of regulated deficit irrigation and ripening stages. The STATGRAPHICS Centurion XVII software was used for the statistical analyses.

3. Result and discussion

3.1. Water potential changes

In Fig. 2A, leaf water potential, plant height, leaves number, and button, flower and curdled number are shown. These parameters present similar behaviors both in control and RDI with some significant differences. Twenty days after transplant (DAT), i.e. at the beginning of the vegetative development, the leaf water potential of the crop decreased for RDI and control to -0.8 MPa, while at the end of this stage, it reached values of -0.5 MPa for the two treatments. On the other hand, at harvest time, i.e. 100 DAT, this potential reached values of -0.3 MPa (Fig. 2-A). These data keep relationship with those obtained by other authors, who suggested that the water requirements in the crop are dependent on the phenological phases, growing season and variety (Coyago-Cruz et al., 2019b; Patanè et al., 2011; Zerrano, 2014). On the other hand, significant differences in leaf water potential between RDI and control were observed at 40, 52, 72 and 82 DAT. Thus, the leaf water potential did not reach the threshold of -1.0 MPa, which means that the crop did not reach severe conditions of water stress, as suggested by other authors (Fortes et al., 2013), thus, achieving a water saving of 70 %.

The growth of the plant (Fig. 2-B), leaves (Fig. 2-C) and button, flower and curdled flowers (Fig. 2-D) in control and RDI followed an exponential growth and in indeterminated tomato cultivar the flower development is a continuous process for the plant. Thus, significant differences ($p < 0.1$) in plant height were showed at 40 and 52 DAT (Fig. 2-B) and in leaves number at 60 and 72 DAT (Fig. 2-C), while the buttons, flowers and curdled flowers did not show statistical differences during the development of the tomato crop (Fig. 2-D). There are no references in the bibliography relative to black tomato with which to compare but from these results if it can be observed that the RDI would seem to have no important effect on the vegetative development of the plant in this variety with similar number of curdled fruits in control and RDI, as can be in previous research on red cherry tomato varieties (Coyago-Cruz et al., 2019b, 2018).

3.2. Commercial quality

The commercial quality of the tomato is a sum of several attributes that depend on the agronomic, environmental and cultivation conditions, in addition to the preferences of the consumer (Coyago-Cruz et al., 2017a, 2017c; Patanè et al., 2011; Vinha et al., 2014). The mean values of size, weight, SS, firmness and colour parameters are summarized in Table A1. The weight, size and colour parameters of the fruits were similar to those obtained for the same variety in a previous study (Coyago-Cruz et al., 2019a) and the SS values of our tomatoes were comparable with those obtained by other authors in 'Hei' tomatoes of dark varieties, i.e. 5.4°Brix (Seo et al., 2013) and 5.28°Brix in immature and 4.94°Brix in mature tomatoes (Park et al., 2018).

In relation to the RDI, the weight, size, firmness, L* and h_{ab} did not show significant differences between the control and the RDI in all the maturity stages. These results are satisfactory in terms of weight and size, since in several studies it has been found that water deficiency in the plant causes stress and a decreased crop yield (Coyago-Cruz et al., 2017a, 2017c; Lichtenthaler and Burkart, 1999). In addition, the results were not in accordance with the results obtained by other authors, who pointed out that the lack of water causes a decrease in the size of the fruit (Ozbahce and Tari, 2010). On the other hand, the colour coordinates a*, b* and C^*_{ab} in M2 and the SS in M3 showed significant differences between the two treatments. Thus, decreasing the water at the end of the crop is a common practice to improve the amount of SS in the tomato (Coyago-Cruz et al., 2017b).

Regarding the effect of the degree of maturity, as expected in fruits, the firmness decreased with the degree of maturity. Concerning colour, the increase in the values of a* with the increasing in the degree of maturity observed in our study, concomitant with the increased biosynthesis of carotenoids, was also expected and also in concordance with that found by other authors (Meléndez-Martínez et al., 2010). The SS in the tomatoes grown in RDI, increased (15.8 %) with the degree of maturity, while in control plants did not show significant differences when the three stages of maturity were compared. In this sense, this can occur because by reducing the water supply to the plant, the availability of water in the fruit decreases, which causes an increase in SS, as

suggested by other studies (Beckles, 2012). At the same time, the firmness decreased (23.8 % and 27.3 %) with respect to the degree of maturity in the tomatoes grown in RDI and control, respectively. This decrease in firmness is typical of the maturation process, as suggested by other authors (Park et al., 2018). On the other hand, in the two treatments, in most cases, a*, b* and C^*_{ab} increased with the degree of maturity, while h_{ab} decreased, typical changes observed over the ripening of red tomatoes (Meléndez-Martínez et al., 2010).

3.3. Carotenoids

The content of carotenoids (phytoene, lutein, lycopene, β-carotene and total carotenoids) for both treatments (RDI and control) and at different degrees of maturity is shown in Table A2. The content of the carotenoids (individual and TCC) was higher in the RDI group compared to control. The major carotenoids in RDI-treated tomatoes were phytoene and lycopene, in this order in M1 and M2, and lycopene and phytoene, in this order, in M3. In control samples, the predominant carotenoid was phytoene, followed by lutein, except in M3, where lycopene was the second most abundant carotenoid to phytoene, as seen in other commercial varieties (Coyago-Cruz et al., 2019a). Notably, the difference in the lycopene levels between treated and control samples was 7.9-fold. Thus, it would appear that these dark varieties are susceptible to stress produced by different factors such as storage time (Park et al., 2018), type of light used in storage (Liu et al., 2009) and in our study to decrease of water in the crop, causing considerable increases in the concentration of lycopene. Taken together, this seems to indicate that the RDI tested in this study leads to important changes in the regulation of carotenoid biosynthesis leading to an enhanced accumulation of lycopene. Although RDI is known to have an impact on the levels of carotenoids and other secondary metabolites, which is in some cases dependent on factors including genotype or fruit position (Coyago-Cruz et al., 2018, 2017a, 2017c) (Sánchez-Rodríguez et al., 2012), more studies (for instance carotenogenic gene expression studies) are needed to gain further insight into this fact.

The water reduction treatment had an important positive effect on the total carotenoid content. Thus, the TCC increased with the RDI treatment 2.3-fold, 2.4-fold and 3.0-fold in the degrees of maturity M1, M2 and M3, respectively. The behavior of this cultivar towards the application of RDI was analogous to that observed for red common and cherry tomato cultivars studied recently (Coyago-Cruz et al., 2018, 2017b). However, the direct extrapolation of these results to other genotypes is not possible as the effect of the treatment can be largely dependent on the genotype, as suggested by other authors (Sánchez-Rodríguez et al., 2012).

With respect to the degree of maturity (M1 vs M3) in the tomatoes grown in plants under RDI there was an increase of 62.6 %, 78.0 %, 25.9 % and 62.7 % in the content of phytoene, lycopene, β-carotene and TCC, respectively. On the other hand, in the tomatoes grown with irrigation control it was observed increases of 51.3 %, 86.9 %, 25.7 % and 51.9 % in the content of phytoene, lycopene, β-carotene and TCC, respectively. Lutein level increased from M1 to M2 and then decreased in M3 in both RDI and control.

3.4. Phenolic compounds

The content of individual phenolic compounds and the TPCC is presented in Table A3. Irrigation treatment (RDI vs. control) caused a decrease in the content of individual and total phenolic compound in all cases. Thus, the TPCC decreased 1.2, 1.3- and 1.2-fold in the degrees of maturity M1, M2 and M3, respectively. These data keep relationship with other studies which suggested that the stress of plant causes a decrease in the phenolic compounds (Lule and Xia, 2005).

In both treatments, the TPCC increased from M1 to M3. The levels of *p*-hydroxybenzoic acid increased from M1 to M3, both in tomato grown in RDI (1.6-fold) and control (1.6-fold). Similar results were obtained on red cherry varieties (Coyago-Cruz et al., 2018). In turn, in the control samples, the *p*-coumaric acid decreased (1.7-fold) as did the caffeic acid in RDI (1.4-fold).

In addition, for both RDI and control, in the degree of maturity M1, the predominant phenolic compounds were *p*-hydroxybenzoic acid, *p*-coumaric and quercetin, in that order; in the degree of maturity M3 the predominant carotenoids were *p*-hydroxybenzoic acid, quercetin and *p*-coumaric acid, in that order. On the other hand, in this study the content of chlorogenic acid in the tomatoes grown with the control treatment, did not change significantly as a function of the degree of maturity. These results were different from those reported by other authors who observed decreases of this compound with the degree of maturity of red tomato (Meléndez-Martínez et al., 2010; Verheul et al., 2015).

3.5. Sugars

The content of individual sugars and TSC are shown in Table A4. The RDI treatment had a significant effect on the concentration of fructose, glucose and TSC in the maturity stages M1 and M2. In particular, in the degree of maturity M1, RDI caused a decrease in the content of fructose, glucose and TSC of 13.6 %, 13.0 % and 12.0 %, respectively, while in the M2, RDI led to an increase of 9.0 %, 6.7 % and 7.3 %, respectively. The application of low dosages of water in later stages of ripening is a very common practice in tomato crops. The treatment can increase the sugar content and improve the flavour, enhancing the quality of the product characteristics and therefore the consumer's preferences (Kasim and Kasim, 2015; Zerrano, 2014).

With respect to the degree of maturity, the content of individual and total sugars showed significant differences, except for the sucrose in the tomatoes grown in control plants. Comparing M1 and M2, the content of fructose, glucose, sucrose and TSC increased by 27.5 %, 32.1 %, 25.5 % and 30.5 % in the tomatoes grown in plants under RDI, respectively. In the control samples these contents increased by 9.0 %, 18.0 %, 36.0 % and 17.0 %, respectively.

On the other hand, in the three degrees of maturity studied and in both groups of samples (RDI and control), glucose showed the highest concentration followed by fructose and sucrose, in that order. These data agreed well with those reported elsewhere, indicating that fructose and glucose are major sugars in cherry red tomato fruits (Coyago-Cruz et al., 2017a, 2017c; Gómez et al., 2009) and that in mature tomato the sucrose content is low due to the high activity of acid invertase (Figàs et al., 2015), as shown in previous studies (Coyago-Cruz et al., 2019a).

4. Conclusions

In general, the RDI did not lead to important changes in the commercial quality parameters. The colour coordinates a*, b* and C^*_{ab} and the SS showed significant differences between the two treatments in M2 and M3. On the other hand, in the two treatments, in most cases, a*, b* and C^*_{ab} increased with the degree of maturity. On the other hand, the degree of maturity caused an increase in the SS and a decrease in the firmness in tomato of plants grown in RDI and control, respectively.

Interesting changes in the carotenoid profile were observed between treatments. Notably, the major carotenoids in RDI-treated tomatoes in the last stage of maturity (M3) were lycopene and phytoene, in this order. In control samples, the predominant carotenoid in the M3 stage was phytoene followed by lycopene. These results indicate that the RDI favors the biosynthesis of this carotenoid considerably. The content of carotenoids (both individual and TCC) was higher in the treated group in all the maturity stages. Specifically, the TCC increased with the RDI

treatment 2.3-fold, 2.4-fold and 3.0-fold in the degrees of maturity M1, M2 and M3, respectively, which clearly indicates that deficit irrigation is a very good approach to increase the carotenoid levels of this cultivar.

Contrastingly, the treatment caused a slight decrease in the content of individual and total phenolic compounds. Specifically, the TPCC decreased 1.2-, 1.3- and 1.2-fold in the degrees of maturity M1, M2 and M3, respectively.

As usual, the sugar levels increased with the maturity stages. The treatment eventually led to slight increases in the levels of fructose, glucose and TSC (9.0 %, 6.7 % and 7.3 %, respectively in M3).

CRediT author statement

Elena Coyago-Cruz: Analyses, data processing, writing of original draft.

Mireia Corell: Conceptualization, resources, methodology, validation, supervision.

Dolores Hernanz: Methodology, writing, revision of drafts.

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Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A

Diameter equatorial (DE) and longitudinal (DL) in mm; weight (W) in g; soluble solid (SS) in ºBrix; firmness (F) in kg/cm^2; Colour parameters L*, a^*_{ab} and b^*_{ab}, C^*_{ab}, h_{ab}; [a] Mean value ± SD (n = 63). [b] Significance of differences between the RDI and control samples (A^b) and significance of differences between ripening stages (A_M^b) is given: ns, not significant; *, $p < 0.1$; **, $p < 0.01$; ***, $p < 0.001$.

[a]Mean values ± SD (n = 63). DW, dry weight; [b] Significance of differences between the RDI and control samples (A^b) and significance of differences between ripening stages (A_M^b) is given: ns, not significant; *, $p < 0.1$; **, $p < 0.01$; ***, $p < 0.001$.

[a]Mean values ± SD (n = 63). DW, dry weight; [b] Significance of differences between the RDI and control samples (A^b) and significance of differences between ripening stages (A_M^b) is given: ns, not significant; *, $p < 0.1$; **, $p < 0.01$; ***, $p < 0.001$.

[a]Mean values ± SD (n = 63). DW, dry weight; [b] Significance of

Table A1
Average values of parameters related to the commercial quality.

Commercial quality		M1			M2			M3			A_M^b	
		RDI	Control	A^b	RDI	Control	A^b	RDI	Control	A^b	RDI	Control
DE		47.2 ± 2.3	46.9 ± 1.9	ns	45.9 ± 2.1	45.1 ± 2.1	ns	45.6 ± 2.2	45.5 ± 1.3	ns	ns	ns
DL		39.7 ± 1.4	41.6 ± 3.8	ns	39.6 ± 2.0	39.8 ± 2.0	ns	39.6 ± 2.0	39.4 ± 1.0	ns	ns	ns
Weight		51.0 ± 4.1	51.2 ± 5.9	ns	52.2 ± 8.7	48.8 ± 8.7	ns	52.3 ± 9.1	48.5 ± 3.6	ns	ns	ns
SS		5.3 ± 0.9	4.9 ± 0.5	ns	5.6 ± 0.8	5.2 ± 0.8	ns	6.3 ± 0.2	4.9 ± 0.8	***	*	ns
Firmness		4.2 ± 0.4	4.4 ± 0.4	ns	3.4 ± 0.7	3.4 ± 0.7	ns	3.2 ± 0.5	3.2 ± 0.4	ns	ns	*
Colour	L*	34.9 ± 0.7	34.9 ± 3.0	ns	34.4 ± 1.2	34.2 ± 1.2	ns	34.4 ± 1.0	33.8 ± 0.9	ns	ns	ns
	a*	2.8 ± 0.2	3.0 ± 0.6	ns	5.2 ± 0.9	6.5 ± 0.9	*	8.8 ± 1.7	8.8 ± 1.6	ns	***	***
	b*	12.8 ± 1.2	12.3 ± 0.9	ns	13.0 ± 1.1	15.1 ± 1.1	*	14.2 ± 1.0	14.7 ± 1.5	ns	*	**
	C^*_{ab}	13.1 ± 1.3	12.7 ± 0.9	ns	14.0 ± 1.2	16.5 ± 1.2	*	16.7 ± 1.6	17.2 ± 1.9	ns	***	***
	h_{ab}	78.0 ± 5.2	76.4 ± 2.7	ns	68.3 ± 2.9	66.8 ± 2.9	ns	58.3 ± 4.5	59.1 ± 3.2	ns	***	***

Table A2
Average values of parameters related to carotenoids content.

Carotenoid content (μg/ g DW)																				
	M1							M2							M3						A_M[b]	
	RDI			Control			A^b	RDI			Control			A^b	RDI			Control			A^b	RDI	Control
Phytoene	64.2	±	0.8	49.0	±	3.8	*	71.5	±	4.4	66.5	±	0.4	ns	171.8	±	1.0	100.7	±	3.4	***	***	***
Lutein	22.9	±	0.6	12.4	±	0.9	***	55.9	±	4.2	14.7	±	0.5	***	19.5	±	0.2	14.5	±	1.0	ns	***	ns
Lycopene	50.3	±	1.8	3.8	±	0.3	***	71.5	±	4.8	5.8	±	0.1	***	228.7	±	14.1	28.9	±	2.0	***	***	***
β-carotene	38.6	±	0.4	11.3	±	0.5	***	38.3	±	1.9	13.1	±	0.3	***	52.1	±	1.7	15.2	±	0.9	***	***	*
TC	176.0	±	0.0	76.5	±	5.4	***	237.2	±	2.0	100.1	±	0.3	***	472.1	±	21.0	159.2	±	7.4	***	***	***

Table A3
Average values of parameters related to phenolic compounds.

Phenolic compounds (μg/ g DW)																				
	M1							M2							M3						A_M[b]	
	RDI			Control			A^b	RDI			Control			A^b	RDI			Control			A^b	RDI	Control
p-Hydroxy	666.3	±	0.0	816.0	±	0.2	**	761.7	±	48.5	998.7	±	15.3	***	1060.6	±	59.9	1270.8	±	30.8	**	***	***
p-Coumaric	358.1	±	19.7	433.8	±	17.4	**	199.7	±	19.9	261.5	±	5.4	**	215.5	±	1.1	258.5	±	9.6	***	***	***
Caffeic	274.7	±	24.6	332.6	±	24.9	*	256.5	±	22.0	336.0	±	2.3	**	194.5	±	2.2	233.3	±	10.2	**	**	***
Chlorogenic acid	53.9	±	4.8	65.3	±	4.9	*	48.5	±	2.9	63.6	±	1.2	***	53.0	±	0.6	63.6	±	2.8	**	*	ns
Gallic acid	176.6	±	10.0	214.0	±	9.0	**	173.8	±	5.3	228.1	±	11.1	***	174.0	±	3.7	208.7	±	2.2	***	ns	*
Quercetin	311.0	±	1.1	377.0	±	6.9	***	296.3	±	20.0	388.4	±	4.5	***	309.5	±	2.0	371.2	±	9.6	***	*	*
TPC	1840.6	±	58.2	2238.6	±	49.3	***	1736.4	±	11.8	2276.2	±	24.4	***	2007.2	±	61.8	2406.0	±	3.5	***	**	***

Table A4
Average values of parameters related to sugar content.

Sugars content (mg/g DW)	M1					M2					M3					A_M^b	
	RDI			Control		A^b	RDI		Control		A^b	RDI		Control		A^b	RDI	Control
Fructose	78.0	±	0.2	90.3	±	2.8	*	111.2	±	1.9	101.2	±	0.7	**	80.6	±	7.4	92.1	±	4.1	ns	**	*
Glucose	248.7	±	10.4	285.8	±	8.1	*	339.7	±	2.7	317.1	±	0.9	**	230.7	±	11.7	261.5	±	5.2	*	***	**
Sucrose	28.5	±	0.8	27.4	±	1.1	ns	36.5	±	1.6	33.7	±	1.4	ns	27.2	±	2.0	21.4	±	0.8	ns	***	ns
TS	355.2	±	19.2	403.5	±	11.9	*	487.4	±	6.4	452.0	±	3.1	**	338.5	±	35.1	375.0	±	15.1	ns	***	**

differences between the RDI and control samples (A^b) and significance of differences between ripening stages (A_M^b) is given: ns, not significant; *, $p < 0.1$; **, $p < 0.01$; ***, $p < 0.001$.

References

Allen, R., Pereira, L., Raes, D., Smith, M., 2006. Evapotranspiración del cultivo. Guías para la determinación de los requerimientos de agua de los cultivos, FAO. FAO.

Beckles, D.M., 2012. Factors affecting the postharvest soluble solids and sugar content of tomato (Solanum lycopersicum L.) fruit. Postharvest Biol. Technol. 63, 129–140. https://doi.org/10.1016/j.postharvbio.2011.05.016.

Bergougnoux, V., 2014. The history of tomato: From domestication to biopharming. Biotechnol. Adv. 32, 170–189. https://doi.org/10.1016/j.biotechadv.2013.11.003.

Borghesi, E., González-Miret, M., Escudero-Gilete, M., Malorgio, F., Heredia, F., Meléndez-Martínez, A., 2011. Effects of salinity stress on carotenoids, anthocyanins, and color of diverse tomato genotypes. J. Agric. Food Chem. 59, 11676–11682. https://doi.org/10.1021/jf2021623.

Cano-Lamadrid, M., Girón, I., Pleite, R., Burló, F., Corell, M., Moriana, A., Carbonell-Barrachina, A., 2015. Quality attributes of table olives as affected by regulated deficit irrigation. LWT - Food Sci. Technol. 62, 19–26. https://doi.org/10.1016/j.lwt.2014.12.063.

Carbonell-Barrachina, Á., Memmi, H., Noguera-Artiaga, L., Gijón-López, M., Ciapa, R., Pérez-López, D., 2015. Quality attributes of pistachio nuts as affected by rootstock and deficit irrigation. J. Sci. Food Agric. 95, 2866–2873. https://doi.org/10.1002/jsfa.7027.

Chai, Q., Gan, Y., Zhao, C., Xu, H.-L., Waskom, R., Niu, Y., Siddique, K., 2016. Regulated deficit irrigation for crop production under drought stress. A review. Agron. Sustain. Dev. 36, 1–21. https://doi.org/10.1007/s13593-015-0338-6.

Coyago-Cruz, Elena, Corell, M., Moriana, A., Hernanz, D., Stinco, C., Meléndez-Martínez, A., 2017a. Effect of the fruit position on the cluster on fruit quality, carotenoids, phenolics and sugars in cherry tomatoes (Solanum lycopersicum L.). Food Res. Int. 100, 804–813. https://doi.org/10.1016/j.foodres.2017.08.002.

Coyago-Cruz, Elena, Corell, M., Stinco, C., Hernanz, D., Moriana, A., Meléndez-Martínez, A., 2017b. Effect of regulated deficit irrigation on quality parameters, carotenoids and phenolics of diverse tomato varieties (Solanum lycopersicum L.). Food Res. Int. 96, 72–83. https://doi.org/10.1016/j.foodres.2017.03.026.

Coyago-Cruz, Elena, Corell, M., Meléndez-Martínez, A., 2017c. Estudio sobre el contenido en carotenoides y compuestos fenólicos de tomates y flores en el contexto de la alimentación funcional. Universidad de Sevilla. ed. Punto Rojo Libros, S.L. Sevilla.

Coyago-Cruz, E., Corell, M., Moriana, A., Hernanz, D., Benítez-González, A., Stinco, C., Meléndez-Martínez, A., 2018. Antioxidants (carotenoids and phenolics) profile of cherry tomatoes as influenced by deficit irrigation, ripening and cluster. Food Chem. 240, 870–884. https://doi.org/10.1016/j.foodchem.2017.08.028.

Coyago-Cruz, E., Corell, M., Moriana, A., Mapelli-Brahm, P., Hernanz, D., Stinco, C.M., Beltrán-Sinchiguano, E., Meléndez-Martínez, A.J., 2019a. Study of commercial quality parameters, sugars, phenolics, carotenoids and plastids in different tomato varieties. Food Chem. 277, 480–489. https://doi.org/10.1016/j.foodchem.2018.10.139.

Coyago-Cruz, E., Meléndez-Martínez, A., Moriana, A., Girón, I., Martín-Palomo, M., Galindo, A., López-pérez, D., Torrecillas, A., 2019b. Yield response to regulated de fi cit irrigation of greenhouse cherry tomatoes. Agric. Water Manag. 213, 212–221. https://doi.org/10.1016/j.agwat.2018.10.020.

Dannehl, D., Josuttis, M., Huyskens-Keil, S., Ulrichs, C., Schmidt, U., 2014. Comparison of different greenhouse systems and their impacts on plant responses of tomatoes. Gesunde Pflanz. 66, 111–119. https://doi.org/10.1007/s10343-014-0322-0.

Dias, M., Olmedilla-Alonso, B., Hornero-Méndez, D., Mercadante, A.Z., Osorio, C., Vargas-Murga, L., Meléndez-Martínez, A., 2018. Comprehensive database of carotenoid contents in Ibero-American foods. A valuable tool in the context of functional foods and the establishment of recommended intakes of bioactives. J. Agric. Food Chem. 66, 5055–5107. https://doi.org/10.1021/acs.jafc.7b06148.

Figàs, M., Prohens, J., Raigón, M., Fita, A., García-Martínez, M., Casanova, C., Borràs, D., Plazas, M., Andújar, I., Soler, S., 2015. Characterization of composition traits related to organoleptic and functional quality for the differentiation, selection and enhancement of local varieties of tomato from different cultivar groups. Food Chem. 187, 517–524. https://doi.org/10.1016/j.foodchem.2015.04.083.

Fortes, R., Prieto, M., González, J., Campillo, C., 2013. Estrategias de riego deficitario controlado en el cultivo de tomate de industria. Vida Rural 20, 14–19.

Gómez, P., Ferrer, M., Fernández-Trujillo, P., Calderón, A., Artés, F., Egea-Cortines, M., Weiss, J., 2009. Structural changes, chemical composition and antioxidant activity of cherry tomato fruits (cv. Micro-Tom) stored under optimal and chilling conditions. J. Sci. Food Agric. 89, 1543–1551. https://doi.org/10.1002/jsfa.3622.

Ignat, I., Volf, I., Popa, V., 2011. A critical review of methods for characterisation of polyphenolic compounds in fruits and vegetables. Food Chem. 126, 1821–1835. https://doi.org/10.1016/j.foodchem.2010.12.026.

Kasim, M., Kasim, R., 2015. Postharvest UV-B treatments increased fructose content of tomato (Solanum lycopersicon L. cv. Tayfun F1) harvested at different ripening stages. Food Sci. Technol. 35, 742–749. https://doi.org/10.1590/1678-457X.0008.

Lichtenthaler, H.K., Burkart, S., 1999. Photosynthesis and high light stress. Bulg. J. Plant Physiol. 25, 3–16.

Liu, L., Zabaras, D., Bennett, L., Aguas, P., Woonton, B., 2009. Effects of UV-C, red light and sun light on the carotenoid content and physical qualities of tomatoes during post-harvest storage. Food Chem. 115, 495–500. https://doi.org/10.1016/j.foodchem.2008.12.042.

Lule, S., Xia, W., 2005. Food phenolics, pros and cons: a review. Food Rev. Int. 21, 367–388. https://doi.org/10.1080/87559120500222862.

Meléndez-Martínez, A., 2019. An overview of carotenoids, apocarotenoids and vitamin A in agro-food, nutrition, health and disease. Mol. Nutr. Food Res. 1–43. https://doi.org/10.1002/mnfr.201801045.

Meléndez-Martínez, A., Fraser, P., Bramley, P., 2010. Accumulation of health promoting phytochemicals in wild relatives of tomato and their contribution to in vitro antioxidant activity. Phytochemistry 71, 1104–1114. https://doi.org/10.1016/j.phytochem.2010.03.021.

Meléndez-Martínez, A., Stinco, C., Mapelli-Brahm, P., 2019. Skin carotenoids in public health and nutricosmetics. The emerging roles and applications of the UV light-absorbing colourless carotenoids phytoene and phytofluene. Nutrients 11, 1093–1133.

Meléndez-Martínez, A., Böhm, V., Borge, G., Cano, M., Fikselová, M., Gruskiene, R., Lavelli, V., Loizzo, M., Mandić, A., Mapelli-Brahm, P., Mišan, A., Pintea, A., Sereikaitė, J., Vargas-Murga, L., Vlaisavljević, S., Vulić, J., O'Brien, N., 2021a. Carotenoids: considerations for their use in functional foods, nutraceuticals, nutricosmetics, supplements, botanicals and novel foods in the context of sustainability, circular economy and climate change. Annu. Rev. Food Sci. Technol.

Meléndez-Martínez, A., Mandić, A., Bantis, F., Böhm, V., Borge, G., Brnčić, M., Bysted, A., Cano, M., Dias, M., Elgersma, A., Fikselová, M., García-Alonso, J., Giuffrida, D., Gonçalves, V., Hornero-Méndez, D., Kljak, K., Lavelli, V., Manganaris, G., Mapelli-Brahm, P., Marounek, M., Olmedilla-Alonso, B., Periago-Castón, M., Pintea, A., Sheehan, J., Tumbas Šaponjac, V., Valšíková-Frey, M., Meulebroek, L., O'Brien, N., 2021b. A comprehensive review on carotenoids in foods and feeds: status quo, applications, patents, and research needs. Crit. Rev. Food Sci. Nutr. 1–51. https://doi.org/10.1080/10408398.2020.1867959.

Nangare, D., Singh, Y., Kumar, P., Minhas, P., 2016. Growth, fruit yield and quality of tomato (Lycopersicon esculentum Mill.) as affected by deficit irrigation regulated on phenological basis. Agric. Water Manag. 171, 73–79.

Ozbahce, A., Tari, A., 2010. Effects of different emitter space and water stress on yield and quality of processing tomato under semi-arid climate conditions. Agric. Water Manag. 97, 1405–1410. https://doi.org/10.1016/j.agwat.2010.04.008.

Park, M., Sangwanangkul, P., Baek, D., 2018. Changes in carotenoid and chlorophyll content of black tomatoes (Lycopersicone sculentum L.) during storage at various temperatures. Saudi J. Biol. Sci. 25, 57–65. https://doi.org/10.1016/j.sjbs.2016.10.002.

Patanè, C., Tringali, S., Sortino, O., 2011. Effects of deficit irrigation on biomass, yield, water productivity and fruit quality of processing tomato under semi-arid Mediterranean climate conditions. Sci. Hortic. (Amsterdam). 129, 590–596. https://doi.org/10.1016/j.scienta.2011.04.030.

Perveen, R., Rasul, H., Muhammad, F., Sadiq, M., Pasha, I., Ahmad, S., 2015. Tomato (Solanum lycopersicum) carotenoids and lycopenes chemistry; metabolism, absorption, nutrition, and allied health claims—a comprehensive review. Crit. Rev. Food Sci. Nutr. 55, 919–929. https://doi.org/10.1080/10408398.2012.657809.

Quadir, M., Hickey, M., Boulton, A., Hoogers, R., 2006. Effect of deficit irrigation on TSS in tomatoes. IREC Farmers Newsl. 172, 36–37.

Sánchez-Rodríguez, E., Leyva, R., Constán-Aguilar, C., Romero, L., Ruiz, J.M., 2012. Grafting under water stress in tomato cherry: improving the fruit yield and quality. Ann. Appl. Biol. 161, 302–312. https://doi.org/10.1111/j.1744-7348.2012.00574.x.

Seo, J., Shin, G., Jang, M., Lee, Y., 2013. Breeding of black tomato 'Hei' for protected cultivation. Korean J. Hortic. Sci. Technol. 31, 833–836.

Shao, G., Zhang, Z., Liu, N., Yu, S., Xing, W., 2008. Comparative effects of deficit irrigation (DI) and partial rootzone drying (PRD) on soil water distribution, water use, growth and yield in greenhouse grown hot pepper. Sci. Hortic. (Amsterdam). 119, 11–16. https://doi.org/10.1016/j.scienta.2008.07.001.

Stinco, C., Benítez-González, A., Hernanz, D., Vicario, I., Meléndez-Martínez, A., 2014. Development and validation of a rapid resolution liquid chromatography method for the screening of dietary plant isoprenoids: carotenoids, tocopherols and chlorophylls. J. Chromatogr. A 1370, 162–170. https://doi.org/10.1016/j.chroma.2014.10.044.

Vergani, R., 2002. Lycopersicum esculentum: una breve historia del tomate. Horticultura 1–9.

Verheul, M., Slimestad, R., Tjøstheim, I., 2015. From producer to consumer: greenhouse tomato quality as affected by variety, maturity stage at harvest, transport conditions, and supermarket storage. J. Agric. Food Chem. 63, 5026–5034. https://doi.org/10.1021/jf505450j.

Vinha, A., Alves, R., Barreira, S., Castro, A., Costa, A., Oliveira, M., 2014. Effect of peel and seed removal on the nutritional value and antioxidant activity of tomato (Lycopersicon esculentum L.) fruits. LWT - Food Sci. Technol. 55, 197–202. https://doi.org/10.1016/j.lwt.2013.07.016.

Zerrano, Z., 2014. Prontuario del cultivo de tomate. Junta de Andalucía.