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Study of commercial quality parameters, sugars, phenolics, carotenoids and plastids in different tomato varieties

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Abstract

The aim of this study was to assess commercial quality parameters, sugars, phenolics, carotenoids and plastid in diverse and little studied tomato varieties to gain insight into their commercial and functional quality and reveal possible noticeable differences. Five cherry tomato varieties and six common (i.e., non-cherry) tomatoes were evaluated. The highest levels of lycopene were detected in ʿTigerella’ and ʿByelsa’, and those of phytoene in ʿOrangeˀ, those of phenolics in ʿGreen Zebra’, all of them common tomatoes.The levels of sugars in both groups of tomatoes were comparable. Interesting differences in plastid carotenoid-accumulating sub-structures as a function of the carotenoid profile were observed. Given the importance of chromoplasts in the deposition of carotenoids in plants and their release during digestion, this information can be valuable in investigations on the regulation of the biosynthesis and the bioavailability of tomato carotenoids.

Keywords: Functional foods; chromoplasts; phytoene; phytofluene; ultrastructure, transmission electron microscopy (TEM)

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the vegetables more consumed in the world and the basis of other food products. They provide important compounds like sugars, minerals, vitamins, carotenoids and phenolics, whose levels can vary markedly as a function of genetics, physiological, agronomic, technological or other factors (Coyago-Cruz, Corell, Stinco, et al., 2017; Antonio J. Meléndez-Martínez, Fraser, & Bramley, 2010). Given the economic and nutritional importance of tomato and derivatives, it is not surprising that their study from different perspectives, including composition (Cichon, Riedl, & Schwartz, 2017; R. M. Schweiggert & Carle, 2017), sustainable production approaches (Borghesi et al., 2011; Coyago-Cruz et al., 2018; Coyago-Cruz, Corell, Stinco, et al., 2017) release of components during digestion (Mapelli-Brahm, Corte-Real, Meléndez-Martínez, & Bohn, 2017; Talens, Mora, Bramley, & Fraser, 2016) and possible health benefits derived from their intake (Cooperstone et al., 2015), continue featuring in the latest scientific literature.

Apart from weight, size and total soluble contents (related to sugar content), colour is one of the key parameters evaluated in the context of commercial quality and food acceptability. Although traditionally red tomatoes have been marketed and are usually preferred by consumers; varieties with other colours (including green, yellow, orange, purple) are not as commonly found in the market and have been less studied (Borghesi et al., 2011; Cooperstone et al., 2017; Antonio J. Meléndez-Martínez et al., 2010; Yuan, Li, & Wilson, 2008) . The red colour of tomatoes is mainly due to their carotenoid profile while in darker varieties, this attribute can be due mainly to the retention of chlorophyll and the accumulation of lycopene (Park, Sangwanangkul, & Baek, 2018) or even the accumulation of both carotenoids and anthocyanins (Borghesi et al., 2011). In non-green tomatoes, carotenoids are accumulated in a type of plastid named chromoplast, whose biogenesis is associated with chlorophyll degradation (Li & Yuan, 2013). There are different classes of chromoplasts with different carotenoid accumulating structures such as,crystals or globules, among others, which depends on the carotenoid profile of the part of the plant (root, fruit, petal, etc.) in question (R. M. Schweiggert & Carle, 2017). The study of the types of chromoplasts is relevant as theyare key organelles for the deposition of carotenoids and also important in relation to the release of carotenoids during digestion, one of the key factors governing their bioavailability (R. M. Schweiggert & Carle, 2017).

Taking all these facts together, the goal of this study was to assess commercial quality parameters (equatorial and longitudinal diameter, weight, soluble solids and colour), sugars, phenolics and carotenoids contents as well as chromoplast morphology in diverse and little studied tomato varieties in order to gain further insight into their commercial and functional quality and reveal possible noticeable differences.

2. MATERIALS AND METHODS

2.1 Reagents and standards

Analytical grade reagents, specifically methanol (PumChem CID: 887), trichloromethane (PumChem CID: 6212) and hydrochloric acid (PunChem CID: 313) were purchased from Labscan (Dublin, Ireland). HPLC grade reagents, like methanol, acetonitrile (PumChem CID: 6342) and ethyl acetate (PumChem CID: 8857) were obtained from Panreac (Barcelona, Spain). Ultra-pure water was obtained by means of a NANOpure Dlamond^{TM} system (Barnsted Inc., Dubuque, IO). Lutein, lycopene, phytoene and phytofluene were obtained from appropriate sources as described elsewhere (Melendez-Martinez, Stinco, Liu, & Wang, 2013; Antonio J. Meléndez-Martínez, Vicario, & Heredia, 2007), β-carotene (PumChem CID: 5280489) was purchased from Sigma-Aldrich (Taukirchen, Germany), and quercetin (PumChem CID: 370), ferulic acid, caffeic acid, *p*-coumaric acid (PumChem CID: 637542), and gallic acid (PumChem CID: 1794427) were from Sigma-Aldrich (Madrid, Spain). Glutaraldehyde, formaldehyde and buffer sodium cacodylate were acquired from Ted Pella, Inc. (Redding, USA).

2.2. Plant materials

Eleven tomato (*Solanum lycopersicum* L.) varieties were studied. Five cherry varieties of Granada La Palma Company, i.e. ‘Cherry amarillo’ (A), ʽCherry pera clásico’ (B), ʽCherry pera naranja’ (C) and ʽMinichocmato pera’ (D) (corresponding to 4 Mixcherrys) and ʽCherry cereja’ (E), were selected and obtained from a local market in Sevilla. ʽCherry amarillo’ and ʽCherry cereja’ were round varieties with yellow and red colour, respectively, while ʽCherry pera clásico’, ʽCherry pera naranja’ and ʽMinichocmato pera’ were pear varieties with red, orange and green-red colour, respectively. Forty fruits of each cherry variety were considered for the commercial quality analyses. On the other hand, six “common” (that is, non-cherry) tomato varieties, i.e. ʽGreen Zebra’(F), ʽSunchocola’(G), ʽTigerella’ (H), ʽByelsa’ (I), ʽPalamós’ (J), and ʽOrange’ (K), were grown in a greenhouse at *Escuela Técnica Superior de Ingeniería Agronómica* (E.T.S.I.A.) of *Universidad de Sevilla* (Sevilla, South Spain, 37º21'09.71" Lat. N, 5º56'19.13" Long. W, 33 m a.s.l.) during spring of 2015 (23rd February to 15th June), exceptʽSunchocola’, which was grown during autumn of 2015 (23rd September to 15th December). The seeds of the varieties ʽByelsa’ and ʽPalamós’ were provided by Fitó (Almería, Spain), ʽSunchocola’ and ʽOrange’ or ʽOrange Wellington’ by W. Atlee Burpee (Warminster, USA) and ʽGreen Zebra’ and ʽTigerella’ by Magic Garden Seeds (Regensburg, Germany). ʽGreen Zebra’ and ʽTigerella’ were striped round medium to small varieties with green-yellow and red-yellow colour, respectively. ʽSunchocola’ is a round medium to small variety**,** which has a green-red colour. ʽByelsa’ and ʽPalamós’ are red medium to large tomatoes, with a pear and round form, respectively. ʽOrange’ is a very large variety with orange colour. Three ripe fruits of seven plants (21 samples of tomato) of each common tomato variety were sampled for the analyses of commercial quality. The optimum degree of maturity for harvesting was determined visually by considering their colour.

The measurements of size, weight, soluble solids, humidity, and colour as well as the microscopic analyses were performed on the fresh fruit. Afterwards, the seeds and inside locular tissues were removed and the remaining parts of the fruits of each variety were mixed. Afterwards, the mixtures were divided into two halves, which were ground in a basic A 11 IKA mill, frozen at -80°C and freeze-dried (Cryodos system). The freeze-dried samples were stored under a nitrogen atmosphere in dark glass bottles hermetically sealed. These were kept at -21 °C until the analyses.

2.3. Commercial quality assessments

Equatorial and longitudinal diameter (cm), weight (g), soluble solids (° Brix), humidity and colour were measured on the fresh tomatoes. Analyses were performed with 40 replicates for the cherry varieties and 21 replicates for the common varieties. The soluble solids (SS) were quantified with a Hand-Refractometer RHC-200ATC (Huake, China) using a drop of tomato juice. The colour parameters corresponding to the uniform colour space CIELAB (L^*, a^*, b^*, C^*_{ab} and h_{ab}) were obtained directly from a CM-700d colorimeter (Minolta, Japan) as described elsewhere Coyago-Cruz et al. (2017).

2.4 Analysis of sugars, phenolic compounds and carotenoids

2.4.1 Analysis of sugars

Sugars were extracted and analyzed as described by Kasim & Kasim, (2015) with slight modifications. The two homogenized freeze-dried powder were extracted in triplicate. Approximately 200 mg of the freeze-dried sample was extracted with 5 mL of water. The mixture was vortexed, sonicated for 5 min, and centrifuged at 4190 *g* for 7 min at 4 ºC. The extracts were filtered through Millipore membranes (0.45 µm pore, 15 mm diameter) (Agilent Technologies, Spain) prior to their injection in the HPLC system. All the extracts were injected twice. The HPLC analyses were carried out on 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) kept at 30 ºC. The injection volume was 5 µL and the flow rate was 1 mL/min. The mobile phase consisted of acetonitrile/water (70:30). The open lab ChemStation software was used. Sugars were identified by comparing their retention time with those of standards. Fructose, glucose and sucrose were identified with standards by comparing their retention times and the total sugar content (TSC) were calculated as the sum of individual sugars.

2.4.2 Analysis of phenolic compounds

The extractions and analyses were carried out as described by Coyago-Cruz, *et al.* (2017). The two homogenized freeze-dried powder were extracted in triplicate. Briefly, approximately 0.5 g of homogenized freeze-dried powder was vortexed and sonicated for 15 min with 15 mL of 75% aqueous methanol (v/v) containing HCl 0.1% (v/v). The mixture was centrifuged at 4190 g for 7 min at 4 ºC; the supernatant was collected and the residue subjected to the same process twice, using only 5 mL of aqueous methanol. The extract was stored at - 20 °C until analysis. The extracts were filtered through Millipore membranes (0.45 µm pore, 15 mm diameter) (Agilent Technologies, Spain) for injection in the UHPLC system. One mL of the extract obtained was dissolved in 4 mL of 0.01% formic acid in water or injection in the UHPLC system. All the extracts were injected twice. The UHPLC analyses were carried out on an Agilent 1290 chromatograph equipped with a diode-array detector (Agilent Technologies, Palo Alto, CA. USA) and an Eclipse Plus C18 column (1.8 um, 2.1 × 5 mm) at 30 °C. The mobile phase consisted of 1 mL/min of 0.01% of formic acid in water (solvent A) and acetonitrile (solvent B) with the linear gradient elution: 100% A, 0 min; 95% A + 5% B + 20% C, 5 min; 50% A + 50% B, 20 min; washing and re-balancing of the column, 22 min. The open lab ChemStation software was used and the chromatograms were monitored at 280, 320 and 370 nm for the quantification of *p*-hydroxybenzoic acid, *p*-coumaric acid, caffeic acid, chlorogenic acid, gallic acid, ferulic acid, naringin, crisin, quercetrin and quercetin, respectively. Phenolics were identified with standards by comparing their retention time and UV-vis spectra. Total phenolic content was calculated as the sum of individual phenolics.

2.4.3 Analysis of carotenoids

Carotenoids were extracted and analyzed as described by Coyago-Cruz, *et al*. (2017). The two homogenized freeze-dried powder samples were extracted in triplicate. In brief, approximately 20 mg of homogenized freeze-dried powder were mixed with 250 μL of methanol, 500 μL of trichloromethane and 250 μL of Milli-Q water. The coloured organic fractions were evaporated and stored under a nitrogen atmosphere at -20 °C until the chromatographic analysis. The dry residue was re-dissolved in 40 μL of ethyl acetate prior to their injection in the RRLC system. All the extracts were injected twice. These were carried out on an Agilent 1260 system equipped with a diode-array detector. A C_{18} Poroshell 120 column (2.7 μm, 5 cm x 4.6 mm) (Agilent, Palo Alto, CA) at 30 ºC was used for the separations. The mobile phase consisted of 1 mL/min of acetonitrile (solvent A), methanol (solvent B) and ethyl acetate (solvent C) with the linear gradient elution: 85% A + 15% B, 0 min; 60% A + 20% B + 20% C, 5 min; 60 % A + 20% B + 20% C, 7 min; 85% A + 15% B, 9 min; 85% A + 15 % B, 12 min. The open lab ChemStation software was used and the chromatograms were monitored at 285, 350 and 450 nm for the quantification of phytoene, phytofluene and the rest of the carotenoids, i.e. lutein, lycopene and β-carotene respectively. Carotenoids were identified by comparing their retention times and UV-vis spectra with those of standards. Total carotenoids contents were calculated as the sum of all main individual carotenoids.

2.5 Plastid morphologyobservation by transmission electron microscopy (TEM)

All the samples were observed under the microscope, except the Orange variety, which was not available at the time of this analysis. A small amount (about 1 g) of thin sheets of mesocarp was covered with 1 mL of Karnovsky (0.5 % glutaraldehyde, 2.5 % formaldehyde in 0.1 M sodium cacodylate, pH 7.4) and the sample was allowed to fix in the dark for 4 h at room temperature. This mixture was then centrifuged and the supernatant was discarded. The sample was washed twice with 1 mL of 0.1 M sodium cacodylate. Afterwards, the sample was embedded in 1 mL of cacodylate and stored in refrigeration for no more of 9 h. Osmium tetraoxide and 1 % aqueous uranyl acetate were used for post-fixed (1 h, 25 ºC) and stained the sample (2 h, 25 ºC), respectively. Dehydration was made through an acetone series. Then, the sample was embedded in Spurr resin. Lastly, the sample was polymerized overnight at 70 °C. Ultrathin sections (70 nm) were examined with a Zeiss Libra 120 transmission electron microscope (Oberkochen, Germany) equipped with a SSCCD digital camera.

2.6 Statistical analyses

Results are provided as the mean ± standard deviation. Statistical differences were determined by analysis of variance (simple ANOVA). The mean separation was made via a Tukey’s test with 0.01 significant differences. Correlations were carried out by Pearson test with 95% confidence level in order to estimate the possible significance of the effect. The STATGRAPHICS Centurion XVII software was used for statistical analyses.

3. RESULT AND DISCUSSION

3.1. Commercial quality assessments

Data on the values of commercial fruit quality parameters (size, weight, soluble solids, humidity and colour) are summarized in Table 1 and Table 2. Overall, statistically significant differences in quality parameters were observed both in cherry and common varieties.

3.1.1. Size

Fruit equatorial diameter (ED) values for cherry and common varieties, ranged from 3.6 (ʽCherry pera clásico') to 4.3 cm (ʽCherry cereja') and from 4.6 (ʽSunchocola') to 13.7 cm (ʽOrange') (ca. 3-fold difference) respectively. The smaller size of ʽSunchocola' could be due to the fact that this is a small-medium variety and the larger size in ʽOrange' may be because this is a large variety, as described in the methodology section. In some cases, there were not statistically significant differences between some varieties, as ʽCherry pera clásico', ʽCherry pera naranja' and ʽMinichocmato pera' among the cherry varieties, or ʽGreen Zebra' and ʽPalamós' as well as ʽTigerella' and ʽByelsa' among the common varieties. The particularity in cherry pear varieties could be due to the fact that the tomatoes packed in rations, in most cases, are classified by size (calibre), which allows for a higher homogeneity of the product sold. On the other hand, longitudinal diameter (LD) values for cherry and common varieties, ranged from 2.6 (ʽCherry amarillo') to 3.6 cm (ʽCherry pera clásico') and from 3.9 (ʽSunchocola') to 7.0 cm (ʽOrange') (ca. 2-fold difference) respectively. In some cases, there were not statistically significant differences in the LD values among varieties, like in the cases of ʽMinichocmato pera' and ʽCherry cereja' among the cherry varieties, or ʽGreen Zebra' and ʽPalamós' as well as ʽSunchocola' and ʽTigerella’ among the common varieties. The homogeneity of sizes among some common varieties could be due to the similar agronomic and environmental conditions, which did not cause major changes in the size of the fruit.

Noticeably, the ʽOrange’ common variety showed a substantially higher size than other varieties as this can be classified as a “large variety” instead of a common one.

3.1.2 Weight

Cherry varieties showed weight values between 7.9 (ʽMinichocmato’) and 11.5 g (ʽCherry cereja’) (ca. 1.5-fold difference). These values were in general lower than those reported in other studies, ranging from 14 to 28 g for several round cherry varieties and from 11 to 21 g for several pear varieties (Choi et al., 2014; Flores, Sánchez, Fenoll, & Hellín, 2017). This may be, at least in part, because the cherry tomatoes under study did not , at least in part, reach physiological maturity, causing the gelatinous mass did not fully develop and failed to fill the interior of the locules, causing a lower weight, as indicated in a FAO publication (Lopéz Camelo, 2003). In general, the weights of the common varieties, which ranged from 45.6 (ʽTigerella’) to 274.9 g (ʽOrange’) (ca. 6-fold difference), were similar to those reported in several other studies, which reported values ranging from 37 to 69 g for the small to medium samples, from 73 to 103 g for the medium to large samples and from 162 to 250 g for the large samples (Flores et al., 2017). ʽOrange’ was by far the variety with the highest weight (ca. 275 g) among the varieties categorized as common, followed by Palamós (ca. 103 g). There were not statistically significant differences in the weights of ʽCherry amarillo’, ʽCherry pera clásico’ and ʽCherry pera naranja’ among the cherry varieties. This agrees well with the premise that the cherry varieties prior to their sale were classified according to size causing homogeneity in the weight. Likewise, there were not statistically significant differences between ʽGreen Zebra’ and ʽPalamós’, nor among ʽSunchocola’, ʽTigerella’, and ʽByelsa’ among the common tomatoes.

3.1.3 Soluble solids

Soluble solids (SS) values for cherry varieties ranged from 3.3 (ʽCherry pera clásico’, ʽCherry pera naranja’ and ʽMinichocmato’) to 3.7 ºBrix (ʽCherry cereja’). These were lower than those reported in other studies for tomatoes of this class. Thus, values between 5.2 and 8.8 ºBrix for round varieties (Figàs et al., 2015; Flores et al., 2017)and between 5.5 and 7.4 ºBrix for pear varieties (Flores, Sáncez, Fenoll, & Hellín, 2016) have been described elsewhere. It was not possible to gather more information that helped understand the low values of SS of the cherry varieties, since these were obtained from a local market and the agronomic and environmental factors were unknown. However, due to the low weight of the cherry varieties reported previously and in relation to studies of red cherry varieties carried out by our research group (Coyago-Cruz et al., 2018; Coyago-Cruz, Corell, Moriana, et al., 2017; Coyago-Cruz, Corell, Stinco, et al., 2017), we believe that these varieties were harvested without reaching physiological maturity, which contributed to the observed low SS values. On the other hand, the storage conditions that the cherry varieties could have been subjected to, may not have favoured the increase of SS (Beckles, 2012), as suggested in other investigations, which indicate that neither the degree of maturity nor the storage caused change in the SS in the Tayfun variety they studied (Kasim & Kasim, 2015). Contrastingly, the SS values found in the present study for common varieties, which ranged from 4.6 (ʽTigerella’ and ʽPalamós’) to 6.2 (ʽGreen Zebra’), were similar to those reported by other authors for pear common varieties (ranges from 4.8 to 5.9 ºBrix) (Flores et al., 2017) and for round common varieties (ranges from 3.2 to 6.2 °Brix) (Flores et al., 2017; Gómez et al., 2001). No significant differences in the SS values were found among the pear samples and among the common tomato samples. Overall, direct correlation between SS and size and weight were observed with coefficients of variation between 0.5 and 0.6. Other authors have also found direct correlation between SS and fruit size (Beckles, 2012; Coyago-Cruz, Corell, Moriana, et al., 2017).

3.1.4 Colour

Taking into account both the cherry and the common tomato varieties the values of the different colour parameters ranged as follows: for yellow and orange varieties, L* from 44.6 ('Cherry amarillo') to 50.7 ('Orange'), C^*_{ab} from 40.9 ('Cherry amarillo') to 62.3 ('Orange') and h_{ab} from 62.7 ('Orange') to 81.2 ('Cherry amarillo'); for red varieties, L* from 34.0 ('Cherry pera clásico') to 43.3 ('Palamós'), C^*_{ab} from 35.4 ('Tigerella') to 44.8 ('Byelsa') and h_{ab} from 40.9 ('Cherry pera clásico') to 52.6 ('Palamós'); and for green varieties L* from 31.5 ('Minichocmato') to 44.4 ('Green Zebra'), C^*_{ab} from 17.0 ('Sunchocola') to 41.9 ('Green Zebra') and h_{ab} from 58.7 ('Sunchocola') to 96.0 ('Green Zebra') (Table 1 and 2). Thus, the different tomatoes studied clustered into four clear groups by considering their colour in terms of a* and b* values, as it can be readily observed in Figure 1. The varieties were grouped by specific colorimetric terms such as orange, red, yellow and dark, without noticing odd cases of isolation of samples as it could be the case of cherry varieties. This could be largely due to the fact that tomato is a climacteric fruit and can continue to ripen outside the plant, achieving the commercially required colour (Lopéz Camelo, 2003).

The h_{ab} parameter values were similar in the cases of 'Cherry pera clásico' and 'Cherry cereja' among cherry varieties and 'Tigerella' and 'Palamós' among common varieties, with no statistically significant differences between these varieties.

3.2 Sugars, phenolic compounds and carotenoids

3.2.1 Sugars

Individual sugar contents and TSC are shown in Table 1 and 2. TSC in cherry varieties, ranged between 308.4 (ʻMinichocmato pera’) and 524.1 mg/g DW (ʻCherry cereja’) (ca. 2-fold difference), respectively. In common tomatoes, the values oscillated between 410.2 (ʻSunchocola’) and 523.9 mg/g DW (ʻGreen Zebra’), respectively. These values were not comparable to those found by other authors, who reported values between 1000 and 1200 mg/g DW in red cherry varieties(Coyago-Cruz, Corell, Moriana, et al., 2017). However, the TSC found in common varieties were contrastingly higher compared with those reported recently in another study, which ranged from 9.7 to 34.0 g/Kg FW (Figàs et al., 2015). The increase of the TSC is expected to influence positively the flavour of the tomato and therefore the consumer`s preference, as suggested by other authors (Kasim & Kasim, 2015) . In this regard, ʻCherry cereja’ (524.1 mg/g DW), ʻGreen Zebra’ (523.9 mg/g DW), ʻTigerella’ (522.7 mg/g DW) and ʻPalamós’ (511.2 mg/g DW), which were the varieties with high TSC, would present the best flavour characteristics.

In general, high values of sugars were found in different tomato varieties as well. Thus, in ʻOrange’ (156.6 mg/g DW) and ʻCherry amarillo’ (114.1 mg/g DW) high values of fructose were detected; in ʻTigerella’ (416.0 mg/g DW), ʻPalamós’ (406.8 mg/g DW) and ʻCherry cereja’ (426.0 mg/g DW) high glucose values; in ʻByelsa’ (30.0 mg/g DW) and ʻCherry amarillo’ (55.1 mg/g DW) high values of sucrose. Sucrose concentrations were lower than those of fructose (between ca. 3 to 6 times) and glucose (between ca. 6 to 18 times), whereas glucose showed the highest values in both cherries and common tomatoes as observed by other authors, who indicated that fructose and glucose are major sugars and sucrose is present in smaller amounts (Beckles, 2012; Gómez et al., 2001;

Kasim & Kasim, 2015). In spite of its small size, ʽCherry cereja' showed a similar TSC and glucose content than the ʽTigerella', besides, ʽCherry amarillo' and ʽCherry pera clásico' has a similar glucose content than the ʽByelsa' This suggests that these cherry varieties can become strong competitors for traditional varieties in terms of flavour. In addition, an inverse correlation (with a value of -0.46 between TSC and weight) was observed. These data keep relationship with other studies showing inverse correlations of growth fruit rate and size with sugars (Coyago-Cruz, Corell, Moriana, et al., 2017).

3.2.2 Phenolics compounds

Data about total phenolic contents (TPC) and levels of individual compounds are summarized in Table 1 and 2. TPC in cherry tomatoes ranged from 150.2 (ʽCherry cereja') to 307.7 mg/100 g DW (ʽCherry pera naranja') (ca. 2-fold difference), while in common tomatoes they ranged from 286.3 (ʽSunchocola') to 503.1 mg/100 g DW (ʽGreen Zebra') (ca. 1.8-fold difference). ʽCherry pera naranja' and ʽGreen Zebra' were the varieties with the highest TPC among cherry and tomato varieties, whilst 'Cherry cereja' and ʽSunchocola', were those with the lowest levels, respectively.

TPC observed in red and yellow-orange cherry tomatoes ranged from 150.2 (ʽCherry cereja') to 239.8 (ʽCherry pera clásico') (ca. 1.6-fold difference) and from 263.5 (ʽCherry amarillo') to 307.7 mg/100 g DW (ʽCherry pera naranja'), respectively. These values were similar or lower than those reported elsewhere (Cortés-Olmos, Leiva-Brondo, Roselló, Raigónc, & Cebolla-Cornejo, 2014; Figàs et al., 2015). On the other hand, TPC in dark tomatoes, i.e. ʽMinichocmato pera' (D) and ʽSunchocola' (G), fluctuated between 220.9 and 286.3 mg/100 g DW. These values were similar or higher than those reported by other authors (Choi et al., 2014; Cortés-Olmos et al., 2014) .

The values of TPC in red common tomatoes ranged from 292.6 (‘Palamós’) to 344.9 mg/ 100 g DW (‘Tigerella’) and they were in general similar or higher than those detected in other similar tomato varieties (Cortés-Olmos et al., 2014; Periago, Martínez-Valverde, Chesson, & Provan, 2002). On the other hand, ‘Green Zebra’ presented the highest value of TPC within all the varieties under study and likewise greater values of *p*-hydroxybenzoic, *p*-coumaric and chlorogenic acid. Finally, the common variety with yellow colour showed markedly higher values of TPC (345.9 mg/100 g DW for ‘Orange’), relative to those found by other authors, who reported concentrations ranging from 57.2 to 251.2 mg of gallic acid equivalents/100 g DW in yellow and orange common tomatoes (Cortés-Olmos et al., 2014) and lower than ranges reported by Raiola *et al.*, i.e. 50.9 to 53.5 mg/100 g FW in yellow tomatoes.

Overall, there were not statistically significant differences in the values of TPC between ‘Tigerella’ and ‘Orange’ or between ‘Palamós’ and ‘Sunchocola’ in common varieties. This fact indicates that common varieties other than red also provide significant amounts of phenolic compounds, in addition these varieties showed higher contents than the traditional varieties (‘Palamós’) of between 1.2 and 1.7 times; this agreed with other authors (Cortés-Olmos et al., 2014). Interestingly, an inverse correlation with a value of -0.66 between size and TPC was observed. These data agree well with those reported in other studies, who suggest that the size is inversely proportional with total flavonols (Coyago-Cruz, Corell, Moriana, et al., 2017; Slimestada & Verheulb, 2009). On the other hand, the TPC of ‘Cherry pera naranja’ and ‘Palamós’ were comparable, showing that cherry varieties, despite their size, could be an important source of phenolic compounds.

In addition *p*-hydroxybenzoic acid, *p*-coumaric acid, caffeic acid, chlorogenic acid, gallic acid, ferulic acid, naringin, crisin, quercetrin and quercetin were the major phenolic compounds detected in the set of samples studied, which agreed well with the studies of other authors (Periago et al., 2002; Raiola et al., 2015), while ferulic acid, naringin and crisin were not found in cherry tomatoes while quercetrin was detected in traces .

Caffeic acid levels ranged from 3.9 (‘Minichocmato pera’) to 20.7 mg/100 g DW (‘Cherry amarillo’) (ca. 5-fold difference) and from 10.4 (‘Orange’) to 30.1 mg/100 g DW (‘Sunchocola’) (ca. 3-fold difference) in cherry and common varieties respectively. These values were comparable to those found in other studies (Periago et al., 2002; Raiola et al., 2015).‘Cherry amarillo’ and ‘Sunchocola’ were the varieties with the highest contents of this compound in cherry and common tomatoes, respectively.

Chlorogenic acid concentrations in cherries, ranged from 3.8 (‘Cherry cereja’) to 68.5 mg/100 g DW (‘Cherry pera naranja’) (ca. 18-fold difference) and were in general lower than in common tomatoes (the levels in this group ranged from 6.4 (‘Sunchocola’) to 84.9 mg/100 g DW (‘Green Zebra’) (ca. 13-fold difference)). Other authors have reported concentrations of this compound between 1.4 and 236.0 mg/ 100 g FW in different varieties of tomatoes (Periago et al., 2002; Raiola et al., 2015).

The quercetin concentrations fluctuated between 22.4 (‘Cherry cereja’) and 49.6 mg/100 g DW (‘Cherry amarillo’) (ca. 2-fold difference) in cherry varieties, and between 25.8 (‘Orange’) and 62.1 mg/100 g DW (‘Tigerella’) (ca. 2-fold difference) in common tomatoes. Similar values were found by other authors (Choi et al., 2014; Periago et al., 2002; Raiola et al., 2015) .

3.2.3 Carotenoids

Quantitative data on individual and total carotenoids (TCC) are presented in Table 1 and 2. TCC observed in cherry tomatoes varied between 2.2 (‘Cherry amarillo’) and 102.0

mg/100 g DW (‘Minichocmato pera’) (ca. 50-fold difference), while in common tomatoes they ranged from 11.8 (‘Sunchocola’) to 297.9 mg/100 g DW (‘Orange’) (ca. 30-fold difference). Interestingly, the cherry varieties ʽMinichocmato pera’ and ʽCherry cereja’ showed higher TCC values than common varieties like ‘Green zebra’, ‘Sunchocola’ and ‘Palamós’. Considering all the samples studied, the major carotenoids found were phytoene, phytofluene, lutein, lycopene and β-carotene. Lycopene was the main carotenoid in the varieties ʽMinichocmato pera’, ʽCherry cereja’, ‘Tigerella’, ‘Byelsa’ and ‘Palamós’. Phytoene was the predominant carotenoid in ʽCherry pera clásico’, ‘Cherry pera naranja’, ʽGreen Zebra’, ʽSunchocola’ and ʽOrange’, whereas lutein was the most important carotenoid in quantitative terms in ‘Cherry amarillo’.

The clear qualitative and quantitative differences observed not only in tomatoes but also in other dietary fruits and vegetables are not surprising whatsoever as the levels of secondary metabolites in general and carotenoids in particular are dependent on multiple factors (genetic, climatic, agronomic, among others) (Dias et al., 2018).

The levels of the colourless carotenoid phytoene ranged from 0.3 (‘Cherry amarillo’) to 252.6 mg/100 g DW (‘Orange’) (ca. 840-fold difference). These values were comparable with the results presented by other authors, who found that common orange varieties juice had higher phytoene contents than red varieties like TCC (Cooperstone et al., 2015). Those of the colourless carotenoid phytofluene oscillated between non detectable levels and 12.3 mg/100 g DW (‘Orange’). This latter carotenoid was not predominant in any of the varieties surveyed. Tomatoes are indeed one of the best sources of these largely ignored carotenoid rarities, which are attracting increasing interest due to their likely health (protection against light-induced damage, anticarcinogenic activity, protection against oxidation, among other) and cosmetic benefits (A.J. Meléndez-Martínez, Mapelli-Brahm, & Stinco, 2018).

Lycopene was not detected in some of the varieties studied, whereas the highest levels (117.1 mg/100 g DW) were found in the variety ʽTigerella'. Tomatoes are usually the main dietary source of this carotenoid that has been related to diverse health-promoting actions (protection against light-induced damage, anticarcinogenic activity, protection in cardiovascular disease, among others) in the last decades (Böhm, 2012; Giovannucci, 2002). On the other hand, the limitation of sucrose is thought to delay the accumulation of lycopene and phytoene in the tomato pericarp (Li & Yuan, 2013) . The unavailability of sucrose may explain the no detection of lycopene in ʽGreen Zebra'. Sucrose was not detected in ʽSunchocola' and ʽOrange' either, varieties that contain lower lycopene levels as compared to the other varieties of the common tomatoes. In ʽCherry amarillo' and ʽCherry pera naranja', there was availability of sucrose but lycopene was not detected, This might be due to the fact that the biosynthesis of carotenoids was beginning in these varieties, which would suggest low degrees of ripening and would corroborate the initial premise that these varieties were harvested without reaching physiological maturity.

The levels of the provitamin A carotenoid β-carotene ranged from 0.1 ('Cherry amarillo') to 16.1 ('Tigerella') (ca. 160-fold difference). This carotenoid was not predominant in any of the varieties surveyed as the results of other authors show (Cortés-Olmos et al., 2014). The higher content of β-carotene in ʽCherry amarillo' and ʽCherry pera naranja', could be due to the fact that these varieties are thought to have not reached physiological maturity. In this sense, it is to be considered that β-carotene is one of the carotenoids present in photosynthetic tissues and therefore in stay-green tomatoes or those that has not reached a high degree of ripening, which is typically accompanied by the large accumulation of lycopene (Hernández-Gras, De-Pourcq, Angaman, & Boronat, 2017; Antonio J. Meléndez-Martínez et al., 2010), and as also been shown in study in red cherry varieties in different degrees of maturity, years, seasons and clusters (Coyago-Cruz et al., 2018).

3.3 Plastids morphology

The microscopic analysis revealed the existence of different types of plastids among the samples. The most abundant substructures found in the different plastids were plastoglobules and crystals remnants and the relative amount of them among varieties was different. Several authors have suggested that plastoglobules in tomatoes are a source of storage of β-carotene (Cooperstone et al., 2015; R. M. Schweiggert & Carle, 2017). However other authors have suggested that β-carotene could also be present in crystalline form (Harris & Spurr, 1969; Rosso, 1968; Ralf M. Schweiggert, Mezger, Schimpf, Steingass, & Carle, 2012) mainly when there is a hyper-accumulation of this carotenoid in the cells (Li & Yuan, 2013). On the other hand, lycopene is present in a solid crystalline deposition form (Cooperstone et al., 2015; Hernández-Gras et al., 2017; Simkin et al., 2007), . In our study, this crystalline deposition form of lycopene was observed as membranes with undulating shape in empty spaces, which are likely to be due to the leaching out of the lycopene during the dehydration process (R. M. Schweiggert & Carle, 2017). The presence of plastoglobules in the varieties that contained no detectable amounts of lycopene, i.e. 'Cherry amarillo', 'Cherry pera naranja' and 'Green Zebra' could be due to the accumulation of β-carotene. On the other hand, the presence of crystals in 'Cherry pera naranja' could indicate that β-carotene was deposited in this form in this variety.

Chromoplasts in a relative early development stage were found in the greenish common tomatoes, i.e. Green Zebra and Sunchocola varieties, and in the Byelsa variety

(Figures 3 -F, -G and –I), as these still contain chlorophyll pigments and therefore chloroplasts (Hernández-Gras et al., 2017). Among other substructures, they contained plastoglobules and crystal remnants. However, no crystal remnants were found in the Green Zebra variety, which is likely to be due to the lack of lycopene (Table 2); the same was observed in the micrographs corresponding to ʽCherry amarillo' (Figure 2-A and 2-C). In these chromoplasts in a relative early development, starch granules, grana and thylakoids with some degree of breakdown were also found. The presence of starch granules in ʽByelsa' suggests that this variety has not yet reached full maturity, since during tomato fruit ripening it has been demonstrated that there is a decline in starch plastids and a progressive conversion into reducing sugars (Li & Yuan, 2013). On the other hand, the absence of starch plastids in immature cherry varieties suggest that the presence of carbohydrates was due to the degradation of starch and therefore the accumulation of sugars was lower, as suggested by other authors (Beckles, 2012).

On the other hand, chloroplasts were found in the Minichocmato pera variety. In these plastids the plastoglobules can be observed associated to the thylakoid membranes, which has also been reported elsewhere (Li & Yuan, 2013; Shumskaya & Wurtzel, 2013) (Figure 2-D). In the rest of the samples fully developed chromoplasts with different carotenoid-accumulating structures were found. As can be observed in Figure 3-H, there was a great accumulation of plastoglobules and crystal remnants in ʽTigerella', which could be related with the fact that this variety was a richer source of lutein, β-carotene and lycopene compared to the other varieties (Table 1 and 2). Peroxisomes containing crystalline cores were noticed in ʽSunchocola', ʽTigerella' ʽByelsa' and ʽPalamós' (Figures 3 -G, -H and -J). Peroxisomes are known to be multifaceted. Indeed they have been related with processes such as photorespiration, nitrogen metabolism, detoxification, synthesis of some plant hormones (Kaur et al., 2009) and modulation of molecular signals during fruit ripening (Verlag et al., 2003). This might suggest that ‛Tigerella’, ‛Byelsa’ and ‛Palamós’ did not reach their maximum maturity and that the amount of lycopene could increase since these varieties still have sucrose, which would favour biotransformation; however in ‛Sunchocola’ their presence might be related to some extent to detoxification, since this variety was cultivated in autumn and the difficulty in cultivation due to the presence of pests caused the application of chemicals that could cause plant poisoning.. In addition, in the round red cherry several plastoglobules were found distributed along the membranes of the chromoplasts (Figure 2-E). This could be related with the fact that carotenoids are generated in the membrane of the plastids (Li & Yuan, 2013). All of the aforementioned substructures were also found in other studies in different tomato varieties (Cooperstone et al., 2015; Hernández-Gras et al., 2017; Simkin et al., 2007) and the differences found in plastids among the different varieties of the same fruit could be due to some extent to differences in the carotenoid profiles (R. M. Schweiggert & Carle, 2017), as, depending on the carotenoid and its shape, the tendency for aggregation to eventually form crystals can vary drastically. As an example, lycopene is a linear and rigid carotenoid with 11 c.d.b. that is known to crystallize easily when is present in high amounts, even in organic solvents, whereas the linear carotenes phytofluene and phytoene have fewer c.d.b. (5 and 3, respectively) and so they, have a less rigid shape and are not expected to crystallyze as easily. On the other hand, as far as red tomatoes are concerned, lycopene occurs predominantly as the (all-*E*)-isomer, which is more rigid and linear than the corresponding *Z* isomers, whereas phytoene and phytofluene occur largely as *Z* isomers, hence the tendency of the latter two tomato carotenes to aggregate and form crystals within the chromoplast is even lower (Antonio J. Meléndez-Martínez, Paulino, Stinco, Mapelli-Brahm, & Wang, 2014).

In addition, starch granules were clearly observed in ‘Green Zebra’ and ‘Byelsa’ that exhibited a granular structure of the pulp. They were also present in ‘Palamós’, which is a juicier variety. The presence of starch within the structure provides a certain thickening character to the tomato pulp, which can interest for the pulp and sauces industry. In relation to this, the declining of plastid starch content are correlated with fruit ripening such that decreases in plastid starch are usually correlated with increases of carotenoids and reducing sugars, which could explain the limited number of starch granules in the varieties mentioned (Li & Yuan, 2013). In addition, an inverse relationship between the content of lycopene and phytoene with the sucrose content was evidenced in this study (Table 1 and 2), as also noted by other authors (Li & Yuan, 2013).

4. CONCLUSIONS

A comprehensive study of commercial quality parameters, sugars, phenols and carotenoid accumulation in different tomato varieties have been carried out. The study of the cherry and common varieties is particularly interesting due to the scarcity of studies in varieties of tomato with coloration different from red. It has been concluded that, overall, the commercial quality fruit parameter (weight and soluble solid) values in cherry varieties were lower than the common varieties.

On the other hand, within the varieties studied ‘Cherry cereja’ (524.1 mg/g DW), ‘Green Zebra’ (523.9 mg/g DW) and ‘Tigerella’ (522.7 mg/g DW) presented high values of TSC. Besides, ‘Cherry cereja’ showed a similar TSC and glucose content than ‘Tigerella’. In addition, ‘Cherry cereja’ showed high values of TSC associated mainly with the accumulation of glucose, and ‘Cherry amarillo’ high values of fructose and sucrose. The TPC values ranged from 150.2 (‘Cherry cereja’) to 503.1 mg/100 g DW (‘Green Zebra’) (ca. 3.3-fold difference). *p*-Hydroxybenzoic acid, *p*-coumaric acid, caffeic acid, chlorogenic acid, gallic acid, ferulic acid, naringin, crisin, quercetrin and quercetin were the major phenolic compounds detected. The TCC ranged between 2.2 ('Cherry amarillo') and 297.9 ('Orange') mg/100 g DW (ca. 150-fold difference). Lycopene was the major carotenoid in 'Tigerella' (117.1 mg/100 g DW). Phytoene was the predominant carotenoid in 'Cherry pera clásico', 'Cherry pera naranja', 'Green Zebra', 'Sunchocola' and 'Orange'. Plastids observation revealed the existence of different types of carotenoid-accumulating substructures in the plastids among the samples. In general, the most abundant were plastoglobules and crystals remnants, although the relative amount of them varied considerably among varieties as a result of their colour and therefore of their carotenoid profile.

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Notes

The authors declare no competing financial interest

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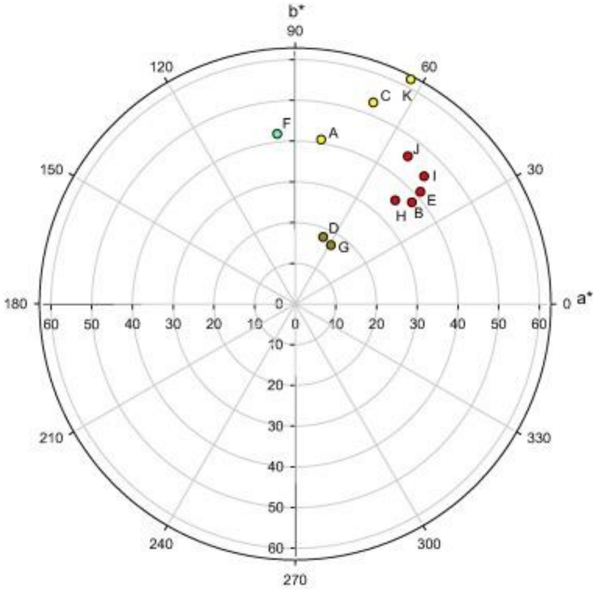

Fig. 1 . Representación de las muestras de tomate en el plano a · b · del espacio de color uniforme de CIELAB. (Para la interpretación de las referencias al color en la leyenda de esta figura, se remite al lector a la versión web de este artículo).

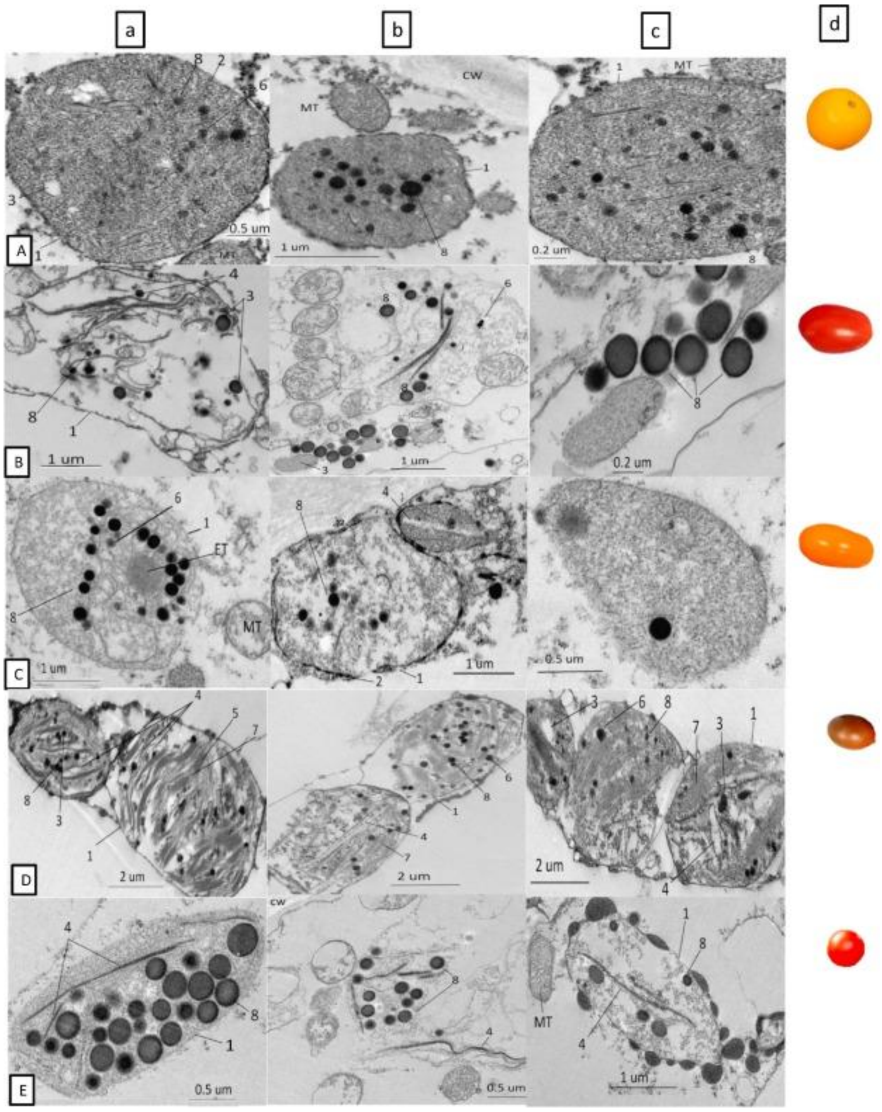

Fig. 2 . Imágenes de microscopía electrónica de plástidos y otras estructuras en tomates cherry de diversos colores. La barra en cada figura representa la escala de tamaño para esa figura. 'Cherry amarillo' (A), 'Cherry pera clásico' (B), 'Cherry pera naranja' (C), 'Minichocmato pera' (D), 'Cherry cereja' (E). 1, membrana externa ; 2, membrana interna ; 3, gránulos de almidón; 4, los restos de cristal; 5, grana; 6, gotas lipídicas; 7, membranas tilacoides ; 8, plastoglobules; MT, mitocondrias ; CW, pared celular. (Para la interpretación de las referencias al color en esta figura, la leyenda hace referencia al lector a la versión web de este artículo).

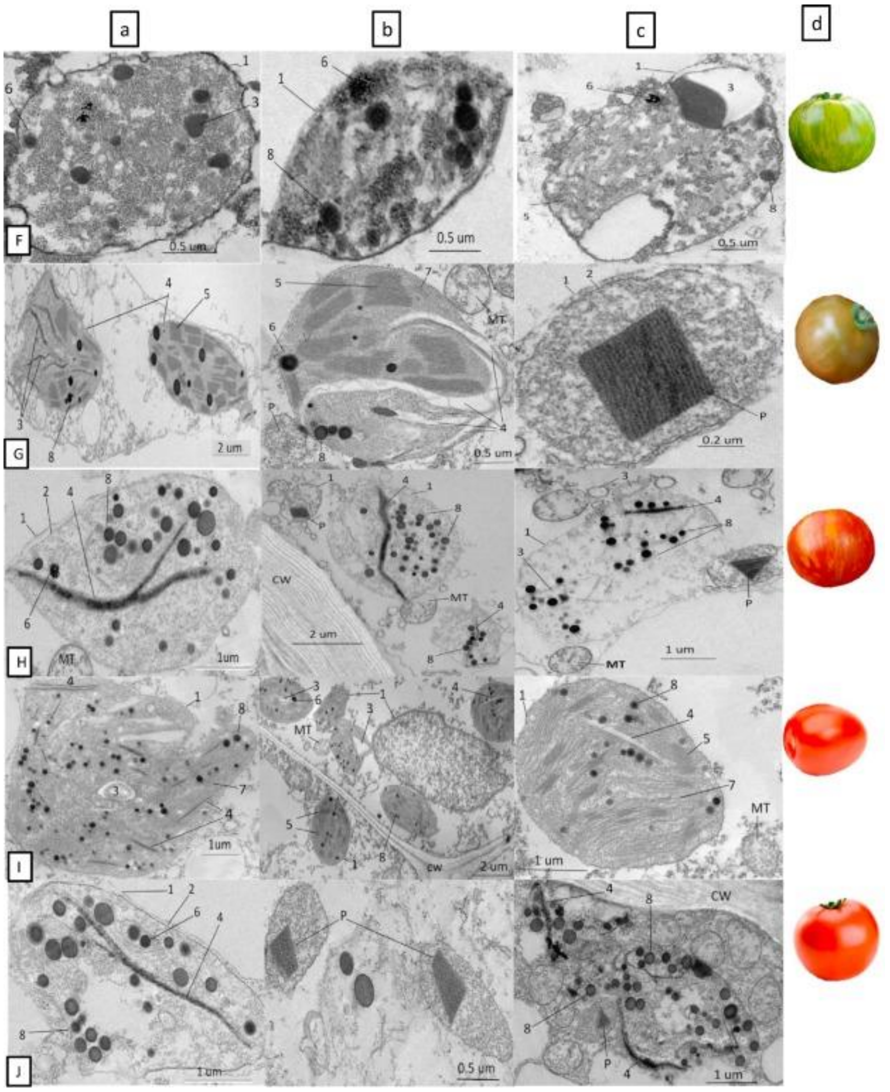

Fig. 3 . Imágenes de microscopía electrónica de plástidos y otras estructuras en tomates comunes con diversos colores. La barra en cada figura representa la escala de tamaño para esa figura. 'Green Zebra' (F), 'Sunchocola' (G), 'Tigerella' (H), 'Byelsa' (I), 'Palamós' (J), 'Orange' (K). 1, membrana externa ; 2, membrana interna ; 3, gránulos de almidón; 4, los restos de cristal; 5, grana; 6, gotas lipídicas; 7, membranas tilacoides ; 8, plastoglobules; MT, mitocondrias ; P, peroxisoma; CW, pared celular. Nota: La variedad naranja (K) no aparece en la figura, ya que no estaba disponible en el momento de los análisis microscópicos. (Para la interpretación de las referencias al color en la leyenda de esta figura, se remite al lector a la versión web de este artículo).

Tabla 1 . Valores promedio de parámetros de calidad comercial, azúcares, fenólicos y carotenoides de tomates cherry .

	'Cherry Amarillo' (A)	**'Cherry pera clásico' (B)**	**'Cereza Pera Naranja' (C)**	**'Minichocmato pera' (D)**	**'Cherry cereja' (E)**	A_c
Color	**Amarillo**	**rojo**	**naranja**	**Verde rojo**	**rojo**	
Parámetros de calidad						
ED (cm)	4.2 ± 0.5 ^{b}	3.6 ± 0.6 ^{d}	3.7 ± 0.8 ^{d}	3.7 ± 0.4 ^{cd}	4.3 ± 0.2 ^{a}	***
LD (cm)	2.6 ± 0.2 ^{d}	3.6 ± 0.3 ^{a}	3.4 ± 0.2 ^{b}	3.0 ± 0.4 ^{c}	2.9 ± 0.2 ^{c}	***
Peso (gramos)	9.6 ± 1.9 ^{b}	9.0 ± 1.9 ^{b}	11.3 ± 3.7 ^{b}	7.9 ± 1.6 ^{c}	11.5 ± 1.0 ^{a}	***
SS (° Brix)	3.5 ± 1.0 ^{ab}	3.3 ± 0.8 ^{ab}	3.3 ± 0.8 ^{ab}	3.3 ± 1.0 ^{ab}	3.7 ± 0.5 ^{a}	*
L^{*}	44.6 ± 0.8 ^{b}	34.0 ± 1.9 ^{d}	49.1 ± 0.9 ^{a}	31.5 ± 1.4 ^{e}	35.6 ± 1.7 ^{c}	***
C^{*}_{ab}	40.9 ± 4.0 ^{b}	38.0 ± 2.6 ^{c}	53.0 ± 2.9 ^{a}	18.3 ± 2.5 ^{d}	41.3 ± 4.0 ^{b}	***
h_{ab}	81.2 ± 3.1 ^{a}	40.9 ± 3.0 ^{d}	68.8 ± 0.8 ^{b}	66.2 ± 10.4 ^{c}	41.7 ± 2.5 ^{d}	***
Carotenoides (mg / 100 g DW) ^{y}						
Fitoeno	0.3 ± 0.1 ^{d}	8.1 ± 0.0 ^{c}	25.4 ± 0.1 ^{a}	11.6 ± 1.2 ^{b}	14.1 ± 0.0 ^{b}	**
Fitoflueno	Dakota del Norte	0.7 ± 0.0 ^{b}	3.2 ± 0.2 ^{a}	Dakota del Norte	3.2 ± 0.0 ^{a}	
Luteína	1.0 ± 0.0 ^{c}	0.5 ± 0.0 ^{d}	0.6 ± 0.0 ^{d}	6.1 ± 0.1 ^{a}	1.6 ± 0.0 ^{b}	***
Licopeno	Dakota del Norte	4.7 ± 0.1 ^{c}	Dakota del Norte	77.5 ± 3.3 ^{a}	69.2 ± 0.9 ^{b}	
β-caroteno	1.2 ± 0.0 ^{c}	0.5 ± 0.0 ^{d}	0.5 ± 0.0 ^{c}	6.9 ± 0.2 ^{a}	2.4 ± 0.0 ^{b}	***
TCC	2.5 ± 0.1 ^{d}	14.4 ± 0.1 ^{c}	29.7 ± 0.2 ^{b}	102.0 ± 3.5 ^{a}	90.7 ± 0.9 ^{a}	***
Compuestos fenólicos (mg / 100 g DW) ^{y}						
p -hidroxi	130.2 ± 1.19 ^{d}	173.5 ± 0.1 ^{a}	165.0 ± 1.8 ^{b}	136.4 ± 0.9 ^{c}	86.2 ± 0.7 ^{e}	***
p -Cumar	30.7 ± 1.1 ^{b}	6.3 ± 0.1 ^{c}	6.4 ± 0.0 ^{c}	33.2 ± 0.2 ^{a}	5,6 ± 0,2 ^{c}	***
Cafeína	20.7 ± 1.5 ^{a}	4.3 ± 0.0 ^{c}	15.3 ± 0.8 ^{b}	3.9 ± 0.1 ^{c}	20.3 ± 0.2 ^{a}	***
Chloroge	23.1 ± 1.7 ^{b}	4.3 ± 0.1 ^{d}	68.5 ± 1.5 ^{a}	13.3 ± 0.1 ^{c}	3.8 ± 0.2 ^{d}	***
gálico	9.3 ± 0.1 ^{c}	12.8 ± 0.4 ^{a}	10.6 ± 0.4 ^{b}	7.8 ± 0.0 ^{d}	12.0 ± 0.1 ^{a}	***
Ferulico	Dakota del Norte	Dakota del Norte	Dakota del Norte	Dakota del Norte	Dakota del Norte	
Naringin	Dakota del Norte	Dakota del Norte	Dakota del Norte	Dakota del Norte	Dakota del Norte	
Crisina	Dakota del Norte	Dakota del Norte	Dakota del Norte	Dakota del Norte	Dakota del Norte	
Quercetrin	tr	tr	tr	tr	tr	
Quercetina	49.6 ± 0.7 ^{a}	38.4 ± 1.2 ^{c}	42.0 ± 0.7 ^{b}	26.4 ± 0.6 ^{d}	22.4 ± 0.7 ^{e}	***
TPC	263.5 ± 0.8 ^{b}	239.8 ± 1.8 ^{c}	307.7 ± 0.1 ^{a}	220.9 ± 0.2 ^{d}	150.2 ± 2.0 ^{e}	***
Azúcares ^{z} *(mg / g DW)* ^{y}						
Fructosa	114.1 ± 1.7 ^{a}	91.2 ± 2.7 ^{b}	95.5 ± 0.4 ^{b}	58.8 ± 0.9 ^{d}	74.1 ± 1.4 ^{c}	***
Glucosa	320.4 ± 8.0 ^{c}	315.9 ± 11.3 ^{c}	359.9 ± 0.1 ^{b}	214.9 ± 1.8 ^{d}	426.0 ± 1.3 ^{a}	***
Sacarosa	55.1 ± 1.3 ^{a}	30.9 ± 0.0 ^{b}	30.5 ± 0.1 ^{b}	34.6 ± 3.3 ^{b}	23.9 ± 0.5 ^{c}	***
TSC	489.6 ± 11.0 ^{b}	438.0 ± 14.0 ^{c}	485.9 ± 0.3 ^{b}	308.4 ± 6.0 ^{d}	524.1 ± 0.4 ^{a}	***

Valores medios ± SD; [^{x} (n = 40); ^{y} (n = 12)]. La importancia de las diferencias entre las variedades de cereza (A_c), se da: ns, no significativo; * , *p* <0.1; **, *p* <0,01; ***, *p* <0,001. Los valores medios seguidos por la misma letra no difieren significativamente en el nivel de confianza del 99% dado. tr, traza; nd, no detectable; DE, diámetro ecuatorial; LD, diámetro longitudinal; SS, sólido soluble; TCC, carotenoides totales; *p*- Hidroxi, ácido *p*-hidroxibenzoico; *p* -Cumar, *p* -ácido cumárico; Cafeico, acido cafeico ; Chloroge, ácido clorogénico; Ácido gálico , gálico ; Ferulic, ácido ferúlico ; TPC,compuestos fenólicostotales; CET, contenido total de azúcares.

Tabla 2 . Valores medios de parámetros de calidad comercial, azúcares, fenólicos y carotenoides de tomates comunes.

	'Cebra Verde' (F)	**'Sunchocola' (G)**	**'Tigerella' (H)**	**'Byelsa' (I)**	**'Palamós' (J)**	**'Naranja' (K)**	**A_H**	**Un_{ch}**
Color	**Verde amarillo**	**Verde rojo**	**Rojo-amarillo**	**rojo**	**rojo**	**naranja**		
Parámetros de calidad								
ED (cm)	9.2 ± 1.7 ^{b}	4.6 ± 0.2 ^{d}	7.2 ± 0.6 ^{c}	6.8 ± 0.7 ^{c}	9.6 ± 0.7 ^{b}	13.7 ± 2.2 ^{a}	***	***
LD (cm)	5.0 ± 0.7 ^{c}	3.9 ± 0.1 ^{d}	4.0 ± 0.4 ^{d}	6.2 ± 1.1 ^{b}	5.1 ± 0.3 ^{c}	7.0 ± 0.6 ^{a}	***	***
Peso (gramos)	94.7 ± 40.3 ^{b}	50.4 ± 6.9 ^{c}	45.6 ± 6.2 ^{c}	56.7 ± 15.7 ^{c}	102.8 ± 19.4 ^{b}	274.9 ± 12.6^{a}	***	***
SS (° Brix)	6.2 ± 0.5 ^{a}	5.6 ± 0.9 ^{a}	4.6 ± 0.9 ^{b}	5.7 ± 1.0 ^{a}	4.6 ± 0.5 ^{b}	6.0 ± 0.5 ^{a}	***	***
L^{*}	44.4 ± 6.1 ^{b}	34.1 ± 0.9 ^{e}	36.7 ± 3.3 ^{d}	39.2 ± 4.2 ^{c}	43.3 ± 3.3 ^{b}	50.7 ± 4.7 ^{a}	***	***
C^{*}_{ab}	41.9 ± 8.5 ^{b}	17.0 ± 1.7 ^{d}	35.4 ± 4.7 ^{c}	44.8 ± 5.0 ^{b}	44.2 ± 8.8 ^{b}	62.3 ± 2.8 ^{a}	***	***
h_{ab}	96.0 ± 3.0 ^{a}	58.7 ± 3.8 ^{c}	46.0 ± 3.0 ^{e}	44.1 ± 6.8 ^{e}	52.6 ± 5.8 ^{d}	62.7 ± 6.2 ^{b}	***	***
Carotenoides (mg / 100 g DW) ^{y}								
Fitoeno	45.9 ± 8.1 ^{b}	12.1 ± 0.4 ^{d}	27.2 ± 4.5 ^{c}	23.5 ± 4.7 ^{c}	21.7 ± 4.0 ^{c}	252.6 ± 21.2^{a}	***	***
Fitoflueno	Dakota del Norte	Dakota del Norte	2.3 ± 0.4 ^{b}	rastro	traza ± 12.3 ± 0.7 ^{a}	**	***	
Luteína	0.8 ± 0.1 ^{d}	3.8 ± 0.8 ^{a}	3.6 ± 0.4 ^{a}	2.8 ± 0.5 ^{b}	1.6 ± 0.2 ^{c}	0.4 ± 0.1 ^{e}	***	***
Licopeno	Dakota del Norte	15.0 ± 0.0 ^{d}	117.1 ± 23.7^{a}	110.4 ± 11.2^{a}	47.4 ± 8.0 ^{b}	30.5 ± 0.6 ^{c}	***	***
β-caroteno	1.1 ± 0.1 ^{e}	4.5 ± 0.1 ^{d}	16.1 ± 1.0 ^{a}	7.0 ± 0.6 ^{c}	10.9 ± 0.3 ^{b}	1.9 ± 0.2 ^{e}	***	***
TCC	50.2 ± 8.4 ^{d}	35.5 ± 0.3 ^{e}	166.4 ± 2.6^{b}	143.7 ± 15.0^{b}	80.9 ± 9.2 ^{c}	297.9 ± 20.7^{a}	***	***
Compuestos fenólicos (mg / 100 g DW) ^{y}								
p -hidroxi	183.9 ± 9.7 ^{a}	102.9 ± 8.4 ^{c}	83.7 ± 1.0 ^{d}	69.7 ± 1.6 ^{e}	68.2 ± 1.1 ^{e}	147.2 ± 9.2 ^{b}	***	***
p -Cumar	104.0 ± 11.3^{a}	31.8 ± 3.7 ^{c}	31.6 ± 0.5 ^{c}	19.7 ± 1.7 ^{d}	24.0 ± 1.1 ^{c}	58.5 ± 2.5 ^{b}	***	***
Cafeína	13.9 ± 0.7 ^{bc}	30.1 ± 2.2 ^{a}	17.0 ± 0.3 ^{b}	11.0 ± 0.3 ^{c}	10.6 ± 0.5 ^{c}	10.4 ± 1.4 ^{c}	***	***
Chloroge	85.0 ± 1.1 ^{a}	6.4 ± 0.1 ^{e}	68.9 ± 5.0 ^{b}	74.5 ± 3.2 ^{ab}	64.8 ± 8.3 ^{c}	40.9 ± 2.2 ^{d}	***	***
gálico	14.8 ± 1.2 ^{b}	21.7 ± 0.5 ^{a}	Dakota del Norte	Dakota del Norte	Dakota del Norte	9.3 ± 0.2 ^{c}	***	***
Ferulico	15.5 ± 2.4 ^{a}	Dakota del Norte	12.8 ± 0.9 ^{b}	11.5 ± 1.8 ^{bc}	10.1 ± 0.5 ^{c}	9.2 ± 0.3 ^{d}	***	***
Naringin	9.5 ± 1.0 ^{b}	2.6 ± 0.0 ^{d}	9.5 ± 0.4 ^{c}	24.7 ± 6.2 ^{a}	13.9 ± 0.7 ^{b}	Dakota del Norte	***	***
Crisina	31.8 ± 0.6 ^{b}	37.5 ± 0.7 ^{a}	31.6 ± 0.3 ^{b}	32.7 ± 0.8 ^{b}	32.6 ± 0.8 ^{b}	32.1 ± 0.3 ^{b}	***	***
Quercetrin	18.1 ± 0.5 ^{c}	15.6 ± 0.3 ^{cd}	27.7 ± 1.1 ^{ab}	29.5 ± 0.7 ^{a}	26.1 ± 1.9 ^{b}	14.9 ± 1.1 ^{d}	***	***
Quercetina	30.4 ± 0.6 ^{c}	37.9 ± 0.4 ^{bc}	62.1 ± 2.6 ^{a}	61.2 ± 8.2 ^{a}	42.2 ± 2.7 ^{b}	25.8 ± 1.8 ^{d}	***	***
TPC	503.1 ± 5.7 ^{a}	286.3 ± 3.5 ^{d}	344.9 ± 7.6^{b}	334.5 ± 12.4^{c}	292.6 ± 12.9 ^{d}	345.9 ± 19.2^{b}	***	***
Azúcares ^{z} *(mg / g DW)* ^{y}								
Fructosa	132.7 ± 2.8 ^{b}	94.5 ± 2.2 ^{c}	83.1 ± 0.3 ^{d}	99.1 ± 3.6 ^{c}	81.3 ± 1.3 ^{d}	156.6 ± 0.7 ^{a}	***	***
Glucosa	391.2 ± 5.0 ^{b}	288.1 ± 8.5 ^{c}	416.0 ± 6.5^{a}	313.2 ± 14.6^{c}	406.8 ± 1.2 ^{a}	307.5 ± 1.7 ^{c}	***	***
Sacarosa	Dakota del Norte	Dakota del Norte	23.6 ± 0.7 ^{b}	30.0 ± 0.5 ^{a}	23.0 ± 0.4 ^{b}	Dakota del Norte	ns	***
TSC	523.9 ± 7.8 ^{a}	410.2 ± 12.6^{d}	522.7 ± 7.0^{ab}	442.4 ± 18.6^{cd}	511.2 ± 0.4 ^{b}	464.1 ± 1.8 ^{c}	***	***

Valores medios ± SD; [^{x} (n = 21); ^{y} (n = 12)]. La importancia de las diferencias entre los tomates comunes (A $_{H}$) y todas las variedades (A $_{CH)}$ se da: ns, no significativo; *, *p* <0.1; **, *p* <0,01; ***, *p* <0,001. Los valores medios seguidos por la misma letra no difieren significativamente en el nivel de confianza del 99% dado. tr, traza; nd, no detectable; DE, diámetro ecuatorial; LD, diámetro longitudinal; SS, sólido soluble; TCC, carotenoides totales; *p*-Hidroxi, ácido *p*-hidroxibenzoico; *p* -Cumar, *p* -ácido cumárico; Cafeico, acido cafeico ; Chlorogeácido clorogénico ; Ácido gálico , gálico ; Ferulic, ácido ferúlico ; TPC,compuestos fenólicostotales; CET, contenido total de azúcares.