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Original Article

Biochemical Characterisation and Sensory Evaluation of Differently Coloured and Shaped Tomato Cultivars

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Abstract

Antioxidant capacity, total phenolic content, colour, sugar, volatiles, ascorbic acid and carotenoid (β-carotene and lycopene) contents of differently coloured and shaped tomato cultivars (cvs) grown in the Eastern Mediterranean region, Turkey were determined, along with a sensory evaluation. Tomato cultivars of two different types (cherry and beefsteak) and four different colours (red, yellow, orange and brown) were analysed. All plants were simultaneously grown in the same field and subjected to identical horticultural practices to minimise the effects of environmental conditions and to maximise those related to genotype. The red cherry cultivar had the highest lycopene content, while the orange beefsteak cultivar had the highest β-carotene content. The highest antioxidant capacity, total phenolic content and hardness scores were found in cherry-type tomatoes, except the yellow one. The red cherry cultivar had the highest sugar content. Red and brown cherry cultivars were also significant in terms of their high carotenoid and sugar contents, along with a high antioxidant activity. The brown cherry cultivar had the highest total phenol content. The highest quantities of 2-hexenal, 3-hexen-1-ol, and 6-methyl-5-hepten-2-one were detected in red cultivars. The brown cherry cultivar had the highest sweetness, typical aroma and hardness scores, while the yellow beefsteak cultivars the lowest sweetness typical aroma scores. In terms of sensory parameters, red and brown cultivars scored higher than yellow and orange ones.

Keywords: ascorbic acid; antioxidant activity; carotenoids; phenols; sensory panel; sugars; volatiles

Abbreviations: AsA - ascorbic acid; BB - brown beefsteak; BC - brown cherry; BHT- butylated hydroxytoluene; cv - cultivar; OB - orange beefsteak; OC - orange cherry; RB - red beefsteak; RC - red cherry; YB - yellow beefsteak; YC - yellow cherry.

Introduction

Tomato is an important annual plant with a worldwide distribution. It has a high economic value, with fruits being high in natural antioxidants including phenolic and carotenoid compounds as well as vitamins (Gómez-Romero *et al*., 2010). In Turkey, tomato production increased from 3.96 to 12.60 million tons between 1994 and 2016 (FAOSTAT, 2018). Freshness, size, firmness, flavour and nutritional properties of tomato fruits are important, while sugars (glucose and fructose) and organic acids (citric and malic acids) are responsible for the sweet-sour taste and flavour (Kapoulas *et al*., 2011). Firmer, and therefore more easily harvestable, tomatoes are desired by modern agriculture. Small fruits can be advantageous as they are more easily removable, while the tomato market prefers larger and more portable varieties (Tanksley, 2004). Generally, cherry tomato varieties have higher contents of sugars (fructose and glucose) and organic acids (citric and malic) and are characterised by a higher dry matter and higher soluble solid levels compared to normal-sized cultivars (cvs) (Raffo *et al*., 2002). Some studies have shown that cherry tomatoes have relatively high levels of carotenoids and higher lipophilic and hydrophilic antioxidative abilities than cluster, elongate and salad tomatoes (Leonardi *et al*., 2000).

Beefsteak tomatoes contain lower amounts of pulp and are therefore more suitable for sandwiches and sauces (Kacjan Maršić *et al*., 2005). They also have higher yields than cluster and cherry tomatoes, but calyx and stem are more sensitive to puncture wounds (Frias-Moreno *et al*., 2014).

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Generally, an increase in fruit size results in higher yields, but there is no empirical relationship between large fruits and high yields. In modern breeding experiments, yield is an important parameter, but the natural selection of large fruits may be related to phenotypic variation, which increases with the pleiotropic effects on fruit shape (Tanksley, 2004). Carotenoids, which are considered as semi-chemicals due to their visual effects, play important roles as precursors of smell in the communication of plants with other organisms (Lewinsohn *et al*., 2005).

The major antioxidant contained in the tomato hydrophilic fraction is vitamin C (ascorbic acid-AsA). It neutralises the effects of free radicals and prevents oxidative damage (Pinela *et al*., 2012). Tomato volatiles are classified into six groups: lipid-derived, carotenoid-related, amino-acid-derived, carbohydrate-derived and related to terpenoids and lignins (Klee, 2010). More than 400 volatile compounds have been identified in tomato fruits, but only few of them contribute to flavour. The most common tomato volatiles are acetaldehyde, acetone, methanol, ethanol, l-penten-3-one, hexanal, cis-3-hexenal, 2-methylbutanol, 3-methylbutanol, trans-2-hexenal, trans-2-heptenal, 6-methyl-5-hepten-2-one, cis-3-hexenol, geranylacetone, 2-isobutylthiazole and β-ionone (Krumbein *et al*., 2004).

Resistance to biotic and abiotic stresses, uniformity, appearance, firmness and extended shelf-life are important factors in tomato breeding. These breeding strategies conflicted consumer desires. In recent years, the importance of a well-balanced diet has changed nutritional habits. In this context, the aim of this research was to demonstrate the characteristics of different types and colours of tomatoes grown under the same conditions. We investigated various quality parameters such as carotenoids, sugars (glucose, fructose), antioxidant capacity, total phenolic content, ascorbic acid, colour, volatiles and sensory characteristics.

Materials and Methods

Tomato cultivation

In March, tomato seeds were sown in greenhouses under hygienic conditions in the Alata Horticultural Research Institute. The seedlings were transplanted in April into a sandy soil, with a spacing of 150 cm within rows and 50 cm between rows, in an open-field in Mersin Province, on the Mediterranean coast of Turkey (latitude 36°37'59"N, longitude 34°20'51"E; decimal degrees 36.633094; 34.347624). After transplanting, drip irrigation was applied with 4 L h^{-1}; drippers were placed at 0.2-m intervals along the irrigation line. Drip irrigation was carried out for 1-2 h every 2 to 3 days, depending on potential, climate data and crop coefficient. A chemical fertiliser solution was added to the irrigation water by pump injection twice a week. The production methods also included hand-weeding and plant-pathogen control with synthetic chemical pesticides. Bacteria and fungal pathogens were managed with chemical substances. Pesticides, bactericides and fungicides were applied once.

Tomatoes were cultivated during two successive years in the growing seasons (April-August). Two different types (cherry and beefsteak) and four different colours (red, yellow, orange and brown) of tomatoes were used in this study (red cherry (RC), yellow cherry (YC), orange cherry (OC), brown cherry (BC), red beefsteak (RB), yellow beefsteak (YB), orange beefsteak (OB), brown beefsteak (BB)).

Preparation

Tomato fruits were harvested by hand randomly from the rows and from the middle part of each plant at the colour-ripening stage. At least 2 kg of visually selected injury-free tomato fruits was harvested from each cultivar, transported to the laboratory and immediately frozen at -80 °C. Sampling was repeated three times during the growing season. Tomato fruits were then washed, cut into small pieces, homogenised in a mixer (IKA Ultratrax, US) and used to determine carotenoids, ascorbic acid and antioxidant activity (Phillips *et al*., 2010). Soluble solid contents were measured by using a digital refractometer (Model PAL-01, Atago Co., Tokyo). Titratable acidity, expressed as citric acid, was determined by titrating 10-mL aliquots of tomato extracts with 0.1 N NaOH to pH 8.2. Tomato firmness was determined by using a hand-type penetrometer (mod, FT011, EFFGI, Italy). Measurements were made using the middle section of the fruit, at the position of opposing underlying locules, and the 1/2"-3/4" diameter disc of the peel was measured.

Colour

Fruit colour was objectively measured with a Minolta CR-400 chromameter (Minolta, Osaka, Japan) at four equatorial points on the fruit surface. The chromameter was calibrated with a standard white tile. In the CIE colour system, positive a* values describe the intensity of red colour, positive b* values describe the intensity of yellow colour, and the L* value describes lightness (black = 0, white = 100). The values a* and b* were used to calculate the hue angle ($H = \arctan(b^* / a^*)$) and the metric chroma value ($C = (a^{*2} + b^{*2})^{1/2}$).

Determination of antioxidant capacity and total phenolic content

The antioxidant capacity was determined following the technique described by (Klimczak *et al*., 2007), with minor modifications. Briefly, 5 g of tomato juice were mixed with 5 mL of 80% methanol solution; the mixture was stirred and subsequently vortexed at 4 °C and 4,000 rpm for 15 minutes in a Hettich Micro 220R (Germany) centrifuge. The resultant extracts were used to determine antioxidant activities and total phenolic contents. For this, 100 µL of the samples were centrifuged at 2,460 µL of juice and 1.1-diphenyl-2-pikrilhidrazil (DPPH*, 80% methanol 0.025 g L^{-1}) was added. As control, 100 µL of distilled water were used. Absorbance was measured as the time to loss of 80% methanol for 0, 20, 30, 45, 60 minutes. A Biotek PowerwaveHT (USA) UV-Vis plate reader, set at 515 nm, was used, and the measurement set at 5-minute data was used.

Total phenolic content was determined by using the modified Folin-Ciocalteau method (Singleton *et al*., 1999). For this, a 0.1-mL aliquot of tomato extract was mixed with 0.5 mL of Folin-Ciocalteau reagent. After 1 min of

equilibrium time at 25°C, 1.5 mL of (20%, w/v) Na_2CO_3 solution were added to the extract. The solutions were mixed and kept for 2 h at 20°C; absorbance was measured at 760 nm (Biotek PowerWave HT, USA). Total phenolic compounds were calculated by using a standard curve of gallic acid and expressed as mg of gallic acid equivalents (GAE) 100 g^{-1} FW.

Determination of carotenoid components and total carotenoids

Carotenoid components (β-carotene and lycopene) were extracted by following a modified version of the method described by Meléndez-Martínez *et al*. (2007). Tomato samples were homogenised in a mixer, and 1 g of puree was transferred into a centrifuge tube and extracted with 10 mL of HPLC-grade solvents (hexan: aceton: methanol, 50: 25: 25, containing 0.1% of BHT). Lycopene and β-carotene were separated by using an InertSIL ODS2 column (4.6 × 250 mm). A gradient method was used with three solvents: (A) methanol (% 0.1 BHT and 0.02%. ammonium acetate), (B) tert butyl methyl ether (C) water. Gradient conditions were as follows: Initial conditions, 65% solvent A plus 30% solvent B and 5% solvent C plus 30 min, gradient switched to 25% solvent A, 75% solvent B; final gradient conditions were 20 min gradient of 10% solvent A, 35% solvent B, 55% solvent C, maintained for 10 min. Mobile phases were returned to initial conditions over 5 min. We used 10-µL injection volumes for each sample and standard. External standards (β-carotene, lycopene) were obtained from Sigma (St. Louis, MO).

Total carotenoids were extracted following the modified version of the method described by Lee *et al*. (2001). Firstly, watermelon flesh samples were homogenised in a laboratory blender to obtain puree; 5 g of the puree were transferred into a centrifuge tube and extracted with 25 mL of HPLC-grade solvents (hexane/acetone/methanol, 50/25/25, with 0.1% BHT). The aliquot was thoroughly mixed and then centrifuged at 4,000 rpm and 4 °C for 10 min. The supernatant was used for absorbance measuring (450 nm) in a spectrophotometer (Perkin Elmer Lambda 25-UV/VIS, USA).

Determination of AsA and sugar contents

The levels of AsA were determined via HPLC-UV-Vis (Shimadzu, LC-20AD, Kyoto, Japan, 2010). A similar procedure is described in Téllez-Pérez *et al*. (2013) with some modifications. A reverse-phase ODS3 (GL Sciences, 5 µM, 4.6 × 250) column was used, with an isocratic mobile phase of 2% KH_2PO_4 (pH 2.4). Total run time was 15 min. At 0.6 mL min^{-1}, injection volume was 10 µL. Quantification of AsA was performed at 244 nm by external standard calibration. The L-ascorbic acid was obtained from Merck (Merck, Darmstad, Germany), and HPLC-grade solvents and ultrapure water (Milli-Q) were used.

Sugar separation was performed with an NH_2-bound silica column (GL Sciences, 5 µM, 4.6 × 250) at 30 °C. Elution was carried out isocratically with a mobile phase of acetonitrile/water (80:20, v/v), at a flow rate of 1.3 mL min^{-1}. Detection and sugar quantification were performed with a refractometer index detector (Shimadzu LC-20AD-RID) (Melgarejo *et al*., 2000). Sugars and AsA were determined after three complete repetitions were completed.

Determination of volatile contents

Frozen tomato samples were sliced and immediately placed in glass bottles at -80 °C. Volatiles were extracted by using a solventless extraction technique (Pawliszyn, 1997). For SPME–GC/MS analysis, 3 g of tomato puree were weighted into 20-mL headspace vials and pre-incubated at +35 °C for 30 min in closed headspace vials. Extraction of volatile compounds was performed at 35 °C for 60 min, using a preconditioned (300 °C, 1 h) 75-µm Carboxen/PDMS SPME-fibre (Sulpelco, USA). After extraction, the analytics were desorbed for 5 min at 260 °C in a splitless injector (flow 19.4 mL min^{-1}) of the gas chromatograph (Shimadzu GC-2010 Plus, Kyoto Japan), combined with a MS detector (Shimadzu, QP-2010, Kyoto Japan) and an SPME autosampler (Combipal, AOC-5000 Plus., USA). Analytics were separated in an Ultra-2 capillary column (60 m × 0.25 mm × 1 l m) (Restek, USA), with a constant flow of 1.5 mL min^{-1} by using helium as carrier gas. The temperature program started at 45 °C for 3 min, followed by an increase of 10 °C min^{-1} to up to 100 °C, which were increased at 5 °C min^{-1} to reach 150 °C. Finally, with an increase of 10 °C min^{-1}, 300 °C were reached and maintained for 9 min. The mass spectrometer was set to record at 33 to 450 amu (threshold 1.000) at a sampling rate of 1.11 scans s^{-1}. The peak identifications were based on the comparison of mass spectra of unknown compounds with those in the Wiley 7 (7th edition) and the NIST/EPA/NIH 02 mass spectral libraries. Ion source temperature was 230 °C, and the interface was 280 °C. Each sample was analysed three times, and the mean of these values was used in further calculations.

Sensory analysis

Sensory evaluation was performed in a specially designed room which provided space for 12 panellists in 12 separate booths divided by vertical walls. Red light was used to minimise the influence of colour on the panellists' perceptions. Samples were presented to the panellists through sliding doors in each booth. Three-digit coded samples were presented monadically, and the presentation was made randomly. The sensory panel consisted of 12 panellists (women and men between the ages of 25 and 55) recruited via the Alata Horticultural Directorate in Mersin, Turkey. The panellists were able to define the reference materials (citric acid 0.43 g L^{-1}; caffeine 0.195 g L^{-1}; sodium-chloride 1.19 g L^{-1}; sucrose 5.76 g L^{-1}; monosodium glutamate 0.595 g L^{-1}; ferrous sulphate heptahydrate 0.00475 g L^{-1}) (TS 3904 ISO 3972). The panellists analysed the taste properties (sweetness, sourness, saltiness, metallic taste), the flavour properties (typical tomato aroma, candy aroma, lemon aroma) and the textural properties (hardness, mealiness, skin thickness) of tomatoes. Water and unsalted crackers were given to neutralise the taste. Tomatoes were pureed 20 minutes before analysis, and one undamaged tomato was presented to the panellists. One whole tomato and 40-50 g of tomato puree were kept at room temperature in capped glass containers. First, the aroma emitted from the sample was evaluated by removing the lid of the glass

container, and subsequently, tasting was performed. The panellists tasted the samples by keeping them in the mouth without swallowing. Finally, the panellists evaluated the textural properties by breaking the tomato peel and flesh with the help of a knife. They determined all properties at the same time in four sessions on four consecutive days. Each attribute was rated on a 15-cm unstructured scale with anchor points at the end of each scale (TSE 3904 ISO 3972). After completing the training, the panellists had to evaluate the flavour profiles of the fruits of 12 different freshly picked field tomato cultivars, about four times per season. They were asked to rate the intensities of the taste and flavour qualities they had previously chosen on a 15-cm unstructured line scale from 0 (not perceptible) to 15 (strongly perceptible) in increments of 1. Texture features were labelled from 0 (too low) to 15 (too high). They also had to rank the tomatoes in terms of preference from 1 (the most preferred) to 10 (the least preferred). The sensory profiles of eight cultivars were compared in terms of significant differences for each of the 10 sensory qualities by statistical analysis, using the JUMP procedure.

Statistical analysis

Analysis of variance (ANOVA) was carried out by using the software package SPSS 16.0 (SPSS Inc., USA). Duncan's multiple-comparison test was used as a guide for dual comparisons of treatment means; the level of significance was $p < 0.05$. Multi-variable statistical analysis of sensory analysis was implemented by using the Numerical Taxonomy and Multivariate Analysis System (NTSYS), version 2.1, developed by Rolf (1993).

Results and Discussion

Antioxidant capacity and total phenolic content

Among the different cultivars, significant differences ($p < 0.05$) in terms of antioxidant capacity were observed. Average values ranged from 12.16 g 100 g^{-1}fw in YC to 27.66 g 100 g^{-1} fw in BC (Table 1). The highest antioxidant capacities were detected in RC and BC. Cherry cultivars had a higher antioxidant capacity than the beefsteak cv, except for the cherry yellow cv. However, Pinela *et al.* (2012) detected the highest antioxidant capacity in yellow tomato ('Amarelo').

The amounts of phenolic compounds were affected by the degree of ripeness, variety, climate, soil composition, geographic location and storage conditions (Haminiuk *et al.*, 2012). The concentrations of total phenolics in tomato cultivars varied between 308.56 (OB) and 468.66 mg kg^{-1} (BC). The highest total phenolics were detected in BC, while OB had the lowest phenolic content. Our values are in line with the findings of previous studies (115-560 mg GAE kg^{-1} fw) (Socaci *et al.*, 2014).

Carotenoid contents and total carotenoids

The lycopene, β-carotene and total carotenoid contents differed significantly among the different cultivars ($p < 0.05$). The differences in lycopene are mainly due to genotypic factors and, most likely, to an increased lycopene metabolism to synthesise carotenes, to lycopene accumulation or to an increased enzymatic activity of phytoene synthase (Fraser *et al.*, 2009). Lycopene ranged from 0.01 mg kg^{-1} fw in YB to 43.08 mg kg^{-1} fw in RC, while β-carotene ranged from 1.29 mg kg^{-1} fw in YB to 10.09 mg kg^{-1} fw RC. Yellow cultivars had lower lycopene and β-carotene contents when compared to the other cultivars. The reason of the accumulation of extremely low levels of carotenoids in yellow-fleshed tomatoes may be a non-functional phytoene synthase (psy1) gene (Lewinsohn *et al.*, 2005). The pro-vitamin A activity of tomato fruit is essentially derived from β-carotene, and the biosynthesis pathway of β-carotene in tomato is as follows: phytoene → phytofluene → ζ-carotene → neurosporene → lycopene → γ-carotene → β-carotene (Selahle *et al.*, 2014). There was a variation in β-carotene content, similar to that observed for lycopene. The cultivar OB had the highest average β-carotene value, but a low amount of lycopene. These results are in line with the argument that high-lycopene tomato cultivars compensate the increase in lycopene by reducing other antioxidants such as β-carotene (Sacks and Francis, 2001; Ilahy *et al.,* 2018). The values of total carotenoids in the tomato fruits were in the range of 1.66-48.20 mg kg^{-1} fw. The cultivars YB and YC had the lowest total carotenoid contents (1.66-3.44 mg kg^{-1} fw), but may contain the colourless carotenoids phytoene and phytofluene. Generally, carotenoid levels in food sources are relatively low (0-2 mg 100 g^{-1} fw) (Meléndez-Martínez *et al.*, 2015).

AsA and sugar contents

The AsA contents differed significantly among the different cultivars ($p < 0.05$) and ranged from 151.59 mg kg^{-1} fw in RB to 328.84 mg kg^{-1} fw in RC. The AsA contents in all cherry cultivars were significantly higher than those in the beefsteak cultivars, except for BB.

Table 1. Antioxidant capacity, total phenol, β-carotene, lycopene, total carotenoid, ascorbic acid and sugar contents of tomato cultivars (average values ± standard deviation)

Tomato type cv.	β-carotenE (mg kg^{-1}fw)	Lycopene (mg kg^{-1}fw)	Total carotenoid (mg kg^{-1}fw)	Ascorbic acid (mg kg^{-1}fw)	Fructose (g $100g^{-1}$fw)	Glucose (g $100g^{-1}$fw)	Antioxidant capacity g $100g^{-1}$fw	Total phenol (mg kg^{-1}fw)
RC	3.78±0.14cd	43.08±0.35a	47.8±0.09a	328.84±0.81a	2.76±0.04a	2.93±0.03a	26.06±0.55a	440.11±1.03ab
YC	3.04±0.05d	0.02±0.01g	3.44±0.04f	199.10±0.95c	1.39±0.02g	1.38±0.02f	12.16±0.34e	354.45±1.05d
OC	4.22±0.22c	2.01±0.01e	7.40±0.5e	228.34±0.42b	1.53±0.03f	1.49±0.01e	16.49±0.39c	423.79±2.25b
BC	5.40±0.01b	8.45±0.13d	15.46±0.05b	156.76±0.76e	1.85±0.03d	2.17±0.01b	27.66±0.46a	468.66±1.19a
RB	5.92±0.56b	35.31±0.30b	48.20±0.37a	151.59±0.45f	1.98±0.01c	1.94±0.01c	18.45±0.31b	397.28±0.33c
YB	1.29±0.02e	0.01±0.00g	1.66±0.3g	157.42±0.31e	1.62±0.02e	1.71±0.01d	16.53±0.91c	421.75±2.23b
OB	10.09±0.31a	0.99±0.01f	11.37±0.4d	171.65±0.96d	1.52±0.02f	1.33±0.02g	14.27±0.44d	308.56±1.05ef
BB	1.66±0.11e	10.45±0.41c	12.87±1.27c	222.01±0.40b	2.13±0.04b	2.21±0.01b	16.61±0.62c	323.85±1.05e

[a–g]Means in a column followed by the same letter are not significantly different at the 5% level of probability ($p < 0.05$); red cherry (RC), yellow cherry (YC), orange cherry (OC), brown cherry (BC), red beefsteak (RB), yellow beefsteak (YB), orange beefsteak (OB), brown beefsteak (BB)

In the cherry cultivars, AsA ranged from 156.76 mg to 328.84 mg kg^{-1} fw, while in the beefsteak cultivars, the values were between 151.59 and 222.01 mg kg^{-1} fw. These results are similar to those found by Lenucci *et al.* (2006). An increase in the production of various antioxidants such as vitamin C has been observed in tomatoes with high lycopene contents (Mustilli *et al.*, 1999). Sugars account for 60% of the dry matter and not only contribute to soluble solids (°Brix), but are also essential molecules in the determination of overall flavour intensity (Beckles, 2012). We found significant differences among the analysed tomato cultivars in terms of fructose contents ($p < 0.05$). Fructose content ranged from 1.52 g 100 g^{-1} fw in OB to 2.76 g 100 g^{-1} fw in RC, while the cultivar BB had a fructose level of 2.13 g 100 g^{-1} fw). The cultivar RB showed levels of 1.98 g 100 g^{-1} fw. In YB and BB, fructose levels were higher than in the respective cherry cultivars YC and BC. Glucose contents ranged from 2.93 g 100 g^{-1} fw (RC) to 1.33 g 100 g^{-1} fw (OB). Among the cherry cultivars, the lowest glucose content (1.38 g 100 g^{-1} fw) was recorded in YC, while the maximum glucose content was detected in BB (2.21 g 100 g^{-1} fw). Significantly lower fructose contents (0.04-0.13 g 100 g^{-1} fw) have been reported by Lenucci *et al.* (2008) in a cherry tomato cultivar grown in Italy, while the glucose values were similar to those found in our study (2.3-5.3 g 100 g^{-1} fw).

Colour

Fruit colour and aroma are important parameters determining the quality and market rates of tomatoes. The L*(lightness), a* (red-green) and b* (yellow-blue) values ranged from 35.03 to 64.96, 0.86 to 41.03 and 20.15 to 59.46, respectively (Table 2).

Chroma (C*) and colour component a*, respectively, express the overall colour intensity and the specific intensity of the red hue. The cherry yellow cultivar had the highest mesocarpic tissue lightness value (64.96). In BC, the values of C* = 22.06 and Hue* = 67.47 resulted in a brown colour, while in the cherry red cultivar, the values of C*= 45.72 and Hue* = 27.34 resulted in a reddish colour. The cultivar YB showed value of C*= 56.26 and Hue* = 87.31. According to Selahle *et al.* (2014), the intensity of the red colour pigment in tomatoes is determined by the relative compositions of lycopene and chlorophyll, while yellowness depends on the β-carotene content. The orange cultivars had values of C* and Hue* in the range of 55.07 to 59.07 and 80.11 to 90.64, respectively. In addition, these cultivars had the highest and lowest values of the Hue angle and the colour parameter, respectively. It is important to mention that Hue* values close to 90° indicate that the cultivar has a greater tendency to be yellow. The Hue angle is visually correlated with colour, and C* values describe the saturation or colour intensity of the samples. In this context, lowest the Hue angle values in the cultivars RS and BC indicate high lycopene contents, responsible for red pigmentation. According to Arias *et al.* (2000), there is a good correlation between colour measured with a chromameter and lycopene content.

Volatiles

Recent global studies on consumer habits have shown that consumers would accept an increase in price for better flavour and for higher nutritional value in fresh vegetables and fruits (Causse *et al.*, 2003). In this study, approximately 80 volatile compounds were detected, including different aldehydes, ketones, alcohols, furans and terpenes, but only the dominant 21 volatiles were discussed. The main volatile compounds identified in all tomato cultivars investigated in this study were hexanal, 2-hexenal, 3-hexanol, 1- hexanol, 6-methyl-5-hepten- 2-one, 2- pentenol, 2 octenal and 2 pentyl furane. The concentrations of hexanal varied between 1.51 and 76.38 μg kg^{-1} (Table 3); the cultivar RB had the highest levels of hexanal. The C6 aldehydes (hexanal, cis-3-hexenal, trans-2-hexenal) are released from vegetative tissues when disrupted and are known as 'green' compounds, as they provide a fresh, green character to the tomato aroma; ketones (acetone, geranylacetone and ß-ionone), on the other hand, contribute to the fruity aroma (Rambla *et al.*, 2014). The compounds 6-methyl-5-hepten-2-one, geranylacetone, β-ionone, pseudoionone and citral are derived from carotenoids by enzymatic cleavage (Tieman *et al.*, 2006); 6-methyl-5-hepten-2-one was found in all tomato samples except the yellow cultivars, which is consistent with the fact that it is a lycopene-derived flavour. Iijima *et al.* (2016) have found that the effects of aldehydes were positive, while cis-3-hexenol, hexanal and apocarotenoids had a negative effect on fresh tomatoes. The formation of carotenoid-related 6-methyl-5-hepten-2-one and geranylacetone was detected in the cultivar RB, which had higher lycopene content. The compound 6-methy1-5-hepten-(*Z*)-one is responsible for the sweet or floral note in the tomato aroma, while geranylacetone is related with the sweet, citrus or ester aroma in tomatoes; both compounds are known as lycopene degradation products (Selahle *et al.*, 2014). We only found D-limonene in the cultivar YB. Extensive breeding programmes primarily focus on larger fruit yields and may have decreased the amount of defensive

Table 2. Color coordinates and contents of tomato cultivars (average values ±standard deviation)

Tomato type cv	L*	a*	b*	Hue*	Chroma*
RC	35.95±1.39e	41.03±1.47a	20.15±1.80f	27.34±1.04g	45.72±2.94d
YC	64.96±1.24a	1.57±0.20 g	59.05±1.76 ab	90.64±1.71 a	59.07±1.77 a
OC	58.33±1.72c	7.60±0.42e	54.13±1.61d	81.98±4.91c	54.78±6.53c
BC	35.25±1.93e	9.04±0.85d	59.46±1.47a	67.47±12.21d	22.06±5.31d
RB	41.45±0.21d	29.25±1.20b	29.04±1.48e	44.79±1.93f	41.24±1.31e
YB	60.82±1.54b	0.86±0.54f	56.19±1.83c	87.31±1.79b	56.26±1.76b
OB	57.91±1.64c	9.45±0.64d	54.18±1.06d	80.11±3.59c	55.07±1.11bc
BB	35.03±1.39e	10.81±0.33c	58.40±1.47b	66.10±3.75de	21.50±2.23g

[a–g]Means in a column followed by the same letter are not significantly different at the 5% level of probability ($p<0.05$); red cherry (RC), yellow cherry (YC), orange cherry (OC), brown cherry (BC), red beefsteak (RB), yellow beefsteak (YB), orange beefsteak (OB), brown beefsteak (BB)

terpenoids produced in the vegetative part of the plant; therefore, terpene levels are relatively low in tomatoes (Falara *et al*., 2011), which was also found in our study. The compound 2-isobutylthiazole creates a spoiled wine-like, slightly horseradish-type flavour in tomatoes (Yilmaz, 2001) and was most abundant in the cultivar YC, which also had a salty and metallic taste (Table 4).

The consumer preference for fresh tomatoes was correlated with C5 volatiles such as 1-penten-3-one, pentanal and 1-pentanol (Shen *et al*., 2014). The cultivars RC, BC and BB had the highest levels of C5 volatile compounds and the highest typical tomato aroma scores. Mayer *et al*. (2008) have reported that 1-penten-3-one, 2,4-decadiene and furanol compounds were more abundant volatiles in tasty tomato cultivars. In tomatoes, colour and aroma compounds are frequently associated, and this relationship is probably a result of the degradation of carotenoids into aroma volatiles.

Sensory evaluation

The cultivar BC had more sweetness, less sourness and a greater ratio of glucose/fructose than the other cultivars (Table 4). The perception of taste descriptors such as overall taste, sourness or sweetness can be modified by the naturally occurring levels of some volatiles (Tieman *et al*., 2012). The sweetness scores of cherry cultivars were higher than those of beefsteak cultivars. The cultivar RC had a high sourness score and titratable acidity, while YC had a high saltiness score and a metallic taste. The cultivar YC had the highest amount of 2-isobutylthiazole. The less preferred cultivars had higher odour units such as methional, phenylacetaldehyde, 2-phenylethanol or 2-isobutylthiazole (Mayer *et al*., 2008). At lower levels, 2-isobutylthiazole increased fresh tomato aroma, but at higher levels, the aroma became objectionable, rancid and medicinal, and metallic off-odours were more dominant (Yilmaz, 2001). In accordance with these findings, that the highest hexanal amount was found for the cultivar RB; this compound provides a fresh, grassy, green or floral note to the tomato aroma and mainly contributes to the tomato odour (Socaci *et al*., 2014). The cultivar BC had the highest typical tomato and candy aroma (Table 5); it also had the highest amounts of 1-hexanol and 1-pentanol and the highest score in terms of sweetness. Some alcohol compounds may be responsible for the sweetness of tomato fruits (Beckles, 2012). The cultivars RC and BB had the highest and the lowest lemon aroma scores, respectively. The cultivar BC had consistent hardness and thickness values, followed by YC (Table 6). The cultivar BB, which had the lowest hardness and skin thickness scores, had the highest mealiness score.

Computer-assisted multivariate analysis of the sensory score was carried out, and the distance obtained in the graphic was used to analyse the sensory panel results in terms of different shapes and colours (Fig. 1). According to the dendogram, cherry and beefsteak tomato cultivars were in different groups. The cultivar CR had the highest sensory analysis score, and the cherry cultivars were in the same cluster.

Table 3. Volatiles (µg kg^{-1}) of tomato cultivars (average values ±standard deviation)

Volatiles	RI	RC	YC	OC	BC	RB	YB	OB	BB
Hexanal	777	32.21±0.78e	0.96±0.05h	32.21±6.30d	1.51±0.28g	76.38±4.53a	34.05±0.01d	37.36±2.31b	30.73±0.60f
2-Hexenal	827	7.42±0.35a	nd	2.93±0.73c	nd	3.23±0.04fb	2.62±0.01d	2.25±0.44e	2.01±0.11f
3-Hexen-1-ol	836	13.46±0.25a	11.80±0.79b	11.24±1.72c	8.49±0.82d	2.56±0.19g	8.38±0.01d	4.65±0.15f	6.96±0.59e
1-Hexanol	855	11.54±0.83c	5.36±0.13f	7.63±0.72d	nd	17.68±0.62a	3.39±0.01g	5.99±0.42e	14.10±0.57b
Pentanal	675	1.96±0.92e	nd	3.46±0.21b	nd	2.24±0.06d	nd	2.90±0.01c	7.80±0.01a
2-Pentenol	746	3.51±0.59d	4.40±0.47c	3.58±0.73cd	5.23±0.13a	0.72±0.05f	nd	3.31±0.01e	4.58±0.72b
6-Methyl-5-hepten-2-one	964	3.40±0.24b	nd	2.89±0.02c	1.29±0.04e	4.40±0.01a	nd	1.71±0.11d	1.77±0.16d
Valeraldehyde	753	nd	4.22±0.97b	1.30±0.01e	5.42±0.41a	1.12±0.02e	nd	3.69±0.13c	2.66±0.17d
1-Penten-3-on	666	3.25±0.20a	1.68±0.27f	1.84±0.01d	2.71±0.96b	0.94±0.07h	1.56±0.01g	1.75±0.05e	2.16±0.21c
2-Butanone	684	nd	nd	nd	nd	nd	nd	0.89±0.01	nd
3-Pentanone	883	nd	6.73±3.24a	5.47±0.08b	nd	nd	nd	nd	nd
3-Hexenal	770	nd	nd	1.47±0.20b	nd	nd	5.73±0.01a	1.13±0.01c	nd
Acetic acid, methyl ester	996	nd	11.94±2.8a	2.35±0.01c	nd	nd	nd	1.11±0.01d	3.60±0.02b
2-Isobutylthiazole	989	nd	1.31±0.01a	nd	nd	nd	nd	nd	nd
p-Mentha-1,5-dien-8-ol	1145	nd	nd	1.61±0.11a	nd	0.47±0.06c	nd	1.33±0.13b	nd
2-Octenal	1035	0.74±0.06d	nd	1.19±0.14a	nd	0.85±0.01c	nd	1.01±0.20b	1.16±0.19ab
Furan, 2-pentyl-	979	0.71±0.09d	0.71±0.09d	1.46±0.06b	1.75±0.2a	0.52±0.01e	nd	1.07±0.13c	1.45±0.32b
D-Limonene	1024	nd	nd	nd	nd	nd	9.68±0.01	nd	nd
2-Hexen-1-ol	849	nd	nd	nd	2.36±0.07	nd	nd	nd	nd
Propane, 2-methoxy-2-methyl-	1221	nd	nd	nd	nd	nd	2.26±0.01a	0.84±0.01b	nd
5,9-Undecadien-2-one, 6,10-dimethyl (geranyl acetone)	1431	4.31±0.01b	nd	nd	nd	5.06±1.55a	nd	nd	nd

RI, retention index; a–fMeans in a row followed by the same letter are not significantly different at the 5% level of probability ($p<0.05$); nd, not detected; red cherry (RC), yellow cherry (YC), orange cherry (OC), brown cherry (BC), red beefsteak (RB), yellow beefsteak (YB), orange beefsteak (OB), brown beefsteak (BB)

Table 4. Glucose/fructose ratios, titratable acidity (%) and sensory panel scores of sweetness, sourness, saltiness and metalic taste for tomato cultivars

Tomato type cv	Sweetness score	Glucose/Fructose ratio	Sourness score	Titratable acidity (%)	Saltiness Score	Metallic Taste
RC	6.31±0.01c	1.06±0.02b	6.62±0.02a	0.50±0.02a	1.57d	1.33±0.01g
YC	2.50±0.02g	0.99±0.01d	4.47±0.01c	0.23±0.02d	2.48a	3.4±0.018a
OC	3.31±0.01e	0.97±0.01d	3.06±0.01f	0.16±0.01e	2.38b	1.57±0.02e
BC	6.99±0.02a	1.18±0.03a	2.96±0.01g	0.29±0.01c	1.46f	2.75±0.01c
RB	6.00±0.01d	0.98±0.01d	6.39±0.03b	0.36±0.03b	1.96c	2.98±0.01b
YB	2.10±0.01h	1.06±0.02b	3.90±0.02d	0.24±0.01d	0.17h	0.51±0.01h
OB	3.02±0.02f	0.88±0.01e	3.38±0.02e	0.11±0.01f	1.16g	1.45±0.01f
BB	6.94±0.01b	1.04±0.01bc	4.00±0.01d	0.03±0.01g	1.50e	1.61±0.02d

[a–h]Means in a column followed by the same letter are not significantly different at the 5% level of probability ($p<0.05$); red cherry (RC), yellow cherry (YC), orange cherry (OC), brown cherry (BC), red beefsteak (RB), yellow beefsteak (YB), orange beefsteak (OB), brown beefsteak (BB)

Table 5. Sensory panel scores of typical tomato, candy and lemon aroma for tomato cultivars

Tomatos	Typical tomato aroma scores	Candy Aroma Scores	Lemon Aroma scores
RC	7.57±0.03c	3.95±0.04a	5.29±0.04a
YC	6.50±0.04e	1.13±0.01f	4.40±0.06b
OC	4.81±0.05g	2.31±0.04d	3.43±0.06c
BC	9.13±0.06a	1.49±0.02g	1.04±0.05f
RB	6.02±0.03f	2.51±0.06c	1.28±0.04e
YB	2.81±0.02h	0.93±0.03h	1.69±0.02d
OB	7.09±0.04d	1.85±0.02e	1.07±0.05f
BB	9.05±0.05b	2.91±0.04b	0.86±0.02g

[a–h]Means in a column followed by the same letter are not significantly different at the 5% level of probability (p<0.05); red cherry (RC), yellow cherry (YC), orange cherry (OC), brown cherry (BC), red beefsteak (RB), yellow beefsteak (YB), orange beefsteak (OB), brown beefsteak (BB)

Table 6. Firmness (kg cm^{-2}) and sensory panel scores of hardness, mealiness and skin thickness for tomato cultivars

Tomato	Hardness scores	Mealiness Scores	Skin thickness	Firmness(kg cm^{-2})
RC	7.20±0.05c	3.69±0.04e	7.03±0.03c	0.10±0.01g
YC	9.37±0.04b	3.09±0.03g	7.16±0.06b	2.10±0.01a
OC	5.21±0.01e	3.15±0.04f	4.27±0.04g	1.20±0.02d
BC	10.83±0.05a	1.99±0.03h	8.63±0.06a	2.20±0.01a
RB	6.77±0.02d	4.88±0.03c	6.34±0.05d	1.47±0.01c
YB	6.87±0.06d	4.42±0.04d	4.82±0.03e	1.80±0.02b
OB	4.92±0.04f	6.04±0.05b	4.58±0.05f	0.80±0.01e
BB	3.31±0.04g	9.11±0.04a	3.71±0.04h	0.20±0.01f

[a–h]Means in a column followed by the same letter are not significantly different at the 5% level of probability (p<0.05); red cherry (RC), yellow cherry (YC), orange cherry (OC), brown cherry (BC), red beefsteak (RB), yellow beefsteak (YB), orange beefsteak (OB), brown beefsteak (BB)

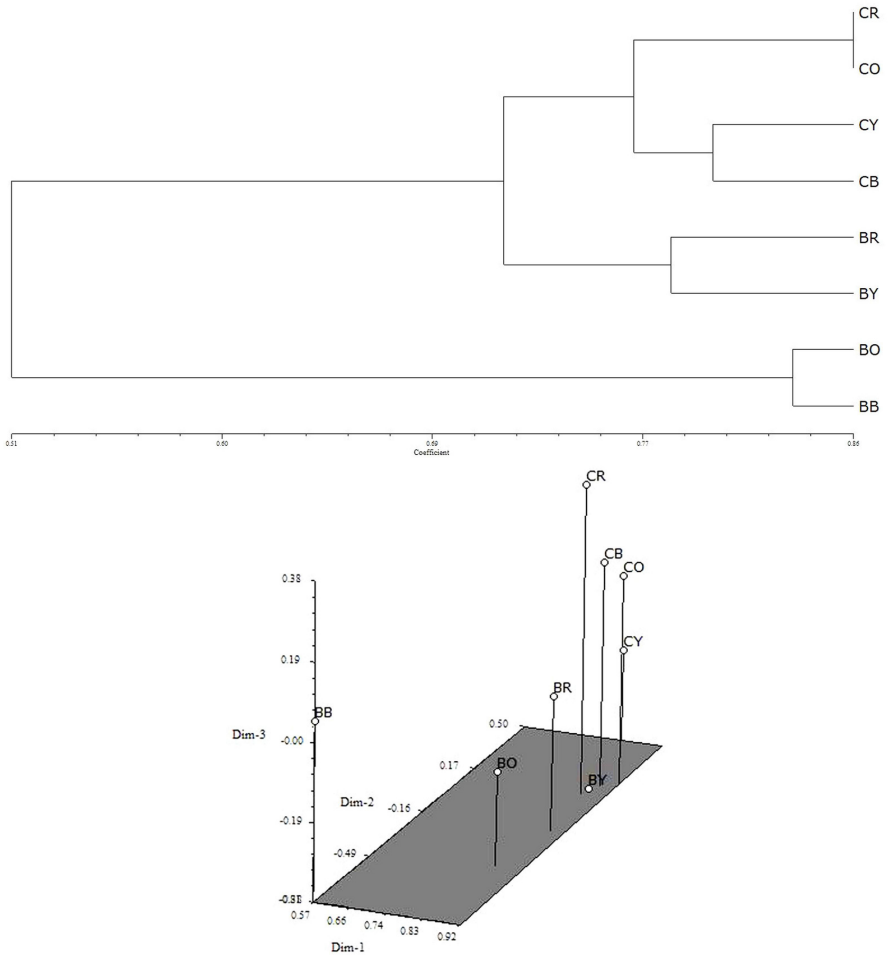

Fig. 1. Sensory analysis scores dendograms and PCA graphs of differently colored and shaped tomato cvs

Conclusions

We observed significant differences in carotenoids and ascorbic acid contents, antioxidant activity, glucose and fructose values, volatile compounds and sensory scores among the evaluated tomato cultivars. Although a significant correlation between lycopene content and antioxidant capacity has been reported previously, in this study, there was no such correlation. Apart from the cultivar YC, all cherry-type tomatoes had a higher antioxidant capacity, higher total phenol contents and higher hardness scores than the beefsteak cultivars. Among the beefsteak tomatoes, the brown cultivar had the highest fructose, glucose and sweetness levels and the highest typical tomato aroma scores, while yellow and orange cultivars had the lowest sugar contents and sweetness scores. There is a consistent relationship between colour and taste, especially in red cultivars, but according to the results of the sensory analysis, brown cultivars were appreciated as much as their red counterparts.

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