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Antioxidant Compounds, Mineral Content and Antioxidant Activity of Several Tomato Cultivars Grown in Southwestern Romania

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Abstract

Ten indeterminate tomato cultivars differing in fruit shape and typology, grown simultaneously in a greenhouse from Oltenia (Southwestern Romania) and harvested at red ripe stage, were investigated for the contents in ascorbic acid, lycopene, β-carotene, total phenolics, minerals (K, Na, Ca and Mg) and trace elements (Fe, Cu, Mn, Cr, Zn and B). In addition, their antioxidant activities were determined. Significant differences were found among tomato cultivars in all studied antioxidant compounds, as well as in the antioxidant activity. Ascorbic acid ranged from 91.9 to 329.7 mg kg^{-1} fw, lycopene ranged from 19.7 to 49.0 mg kg^{-1} fw, while total phenolic compounds varied between 300.2 and 557.8 mg kg^{-1} fw. Antioxidant activity ranged from 0.81 mmol Trolox kg^{-1} fw to 1.74 mmol Trolox kg^{-1} fw and it was significantly correlated to total phenolics content ($r = 0.91$; $p < 0.05$). The cocktail type cultivar 'Tiger' and the cherry type cultivar 'Belle' proved to be the most powerful in antioxidant activity and phenolic compounds while the rectangular plum shaped cultivar 'Porto' recorded the highest average lycopene content. A valuable cultivar proved to be the brownish red 'Sacher' which registered among the highest contents of phenolics, lycopene and ascorbic acid. Mineral and trace elements contents were also significantly affected by cultivars. Values recorded for K, Ca and Mg ranged from 2139.6 to 3056.9 mg kg^{-1}, 137.7 to 325.8 mg kg^{-1} and 27.3 to 168.7 mg kg^{-1} respectively.

Keywords: antioxidant activity, ascorbic acid, carotenoids, minerals, phenolics, tomatoes

Introduction

Tomato (*Solanum lycopersicum* L.) is a horticultural crop of great interest, being widely consumed either fresh or processed in products such as tomato juice, soup, paste, puree, ketchup, sauce and salsa (Helyes *et al*., 2009; Ray *et al*., 2011).

Among the most prominent phytochemicals in tomatoes are the carotenoids, of which lycopene is the most abundant in the ripened fruit, accounting for approximately 80-90% of the total pigments (Hernández *et al*., 2007; Helyes *et al*., 2009). Besides lycopene, tomatoes also contain α-, β-, γ-, δ-carotene, zeaxanthin and lutein and also neurosporene, phytoene, and phytofluene (Capanoglu *et al*., 2010; Ray *et al*., 2011).

Lycopene mainly accumulates in the final period of ripening, giving the fruit its attractive red color although its content is not linearly related to color changes. The lycopene pigment has attracted much interest among researchers because of its biological and physicochemical properties, especially related to its effect as a natural antioxidant and its various benefits for human health (Hernández *et al*., 2007). Lycopene as well as β-carotene are apparently the main tomato microconstituents responsible for the effect of tomato products on antioxidant status (Ray *et al*., 2011).

Tomatoes and tomato products are the primary suppliers of lycopene to the human diet, at least 85% of our dietary lycopene coming from these foods, the remainder being obtained from other dietary sources such as apricots, pink grapefruit, watermelon, guava, and papaya (Capanoglu *et al*., 2010; Radzevičius *et al*., 2009). Of all the carotenoid pigments, lycopene is not only the most abundant but also is the most efficient free radical scavenger with a capacity found to be more than twice that of β-carotene. Lycopene in tomato seems also to be more stable to changes occurring during peeling and juicing than the other carotenoids (Capanoglu *et al*., 2010).

Tomatoes are also a concentrated source of phenolic compounds, such as flavonoids and hydroxycinnamic acid derivatives, containing 98% of the total flavonols in tomato skin as conjugated forms of quercetin and kaempferol (Hernández *et al*., 2007; Ray *et al*. 2011). The flavanone naringenin is present in small quantities in tomatoes in its conjugated form. Many of these phytochemicals present in tomatoes have antioxidant properties and in combination with lycopene may contribute to the numerous health benefits (Ray *et al*., 2011).

Tomatoes contain a multitude of vitamins and minerals that act to support human health. They are an excellent source of vitamins C, E, B6, folic acid, niacin, potassium, and trace elements, i.e. selenium, copper, manganese and zinc, which are cofactors of antioxidant enzymes (Borguini and Da Silva Torres, 2009; Luthria *et al*., 2006). It is assumed that these trace elements play a key role in the protection mechanisms by scavenging free radicals (Fernández-Ruiz *et al*., 2011).

The vitamin C content of fresh tomatoes depends on the variety and the cultivation conditions (Adalid *et al*., 2010). Vitamin E in tomatoes is predominantly represented by α-tocopherol. Like lycopene, vitamin E belongs to the lipophilic antioxidant fraction of the tomato fruit and has been linked to positive effects on human health (Capanoglu *et al*., 2010). These tomato antioxidants have an important role in chronic disease prevention, including cancer, neurodegenerative diseases, cardiovascular disease, asthma, and cataract and also in improving the immune function (Fernández-Ruiz *et al*., 2011). All these have led tomatoes and processed tomato products to be a key component of the Mediterranean diet, which is recognized as being particularly healthy and strongly associated with a reduced risk of chronic degenerative diseases (Fernández-Ruiz *et al*., 2011; Pinela *et al*., 2012; Ray *et al*., 2011).

The chemical composition of the fruit depends on genetics, environmental factors (temperature, light, water and nutrient availability, air composition), agricultural techniques (varieties, plant growth regulators, ripening stage at harvest, training and irrigation system), and on post-harvest storage conditions (Borguini and Da Silva Torres, 2009; Maršić *et al*., 2011; Vinkovic Vrcek *et al*., 2011). Nevertheless lycopene content is mainly determined by the genetics of the variety being grown. According to Kuti and Konuru (2005) lycopene content varied significantly among the tomato varieties, with cherry tomato types having the highest lycopene content.

The nutritional importance of tomato indicates that it is necessary to formulate breeding programme and to develop cultivars rich in antioxidant compounds, processing traits with high quality of fruit as well as yield (Dar and Sharma, 2011). New tomato varieties with improved nutritional content and potential health benefits are being developed. As a result, at present, there is a large number of tomato cultivars with a wide range of morphological and sensorial characteristics which determine their use (Fernández-Ruiz *et al*., 2011; Pinela *et al*., 2012). Therefore it is becoming increasingly important to assess their nutritional value in terms of content.

The present investigation was carried out to evaluate ten newly evolved tomato hybrids grown simultaneously in the same greenhouse from Oltenia region (Southwestern Romania), for the content of total dry matter, soluble solids, titratable acidity, total phenolics, lycopene, β-carotene, ascorbic acid, mineral (Na, K, Ca, Mg) and trace elements (Fe, Mn, Cu, Cr, Zn, B) as well for the antioxidant properties.

Materials and methods

Plant material

Ten indeterminate tomato F1 hybrids ('Antalya', 'Belle', 'Cemile', 'Izmir', 'Lorely', 'Plumty', 'Porto', 'Sacher', 'Tiger', 'Vanessa') differing in fruit typology (round, elongated, cherry, cocktail) were considered for analysis (Tab. 1). All plants from each tomato cultivar were grown in cambic chernozem at Rusanesti, Olt district (43°56′N, 24°36′E), in an unheated greenhouse covered with polymeric film. Date of planting to the greenhouse was April 10 th while plant density was 4.7 plants m^{-2}. During the growing season all cultivation procedures (nutrition supply, irrigation and plant protection) were conducted according to technological expectations. The plants were fertilized with nutrient solution of MAP (12-61-0) through irrigation water until blossom, Polyfeed 19-19-19 (0.5%), three applications up to fruit formation and Multi-K (potassium nitrate) from first ripening until end of the crop cycle. Plant protection included treatments with insecticides such as Mospilan, and fungicides such as Sumilex and Dithane.

Tab. 1. Main characteristics of the *Solanum lycopersicum* cultivars evaluated

Cultivar	Color mature	Shape	Fruit height (mm)	Fruit diameter (mm)	Index of fruit shape	Average weight (g)
'Antalya'	red	round	51.48^{bcd}	61.32^{c}	0.84^{abc}	111.16^{cd}
'Belle'	red	cherry	26.54^{a}	28.52^{a}	0.91^{bc}	12.12^{a}
'Cemile'	red	round	50.04^{b}	62.49^{c}	0.79^{a}	105.72^{cd}
'Izmir'	red	round	56.86^{bcd}	69.36^{d}	0.80^{ab}	141.88^{d}
'Lorely'	red	round	53.74^{bc}	59.13^{c}	0.90^{bc}	100.87^{bc}
'Plumty'	red	ellipsoid	72.54^{e}	47.96^{b}	1.50^{e}	82.3^{bc}
'Porto'	red	plum, rectangular	56.18^{cd}	49.86^{b}	1.07^{d}	74.16^{bc}
'Sacher'	brownish red	round	48.46^{b}	52.03^{b}	0.92^{c}	67.90^{b}
'Tiger'	bi-colored, dark red and green	cocktail	31.14^{a}	32.61^{a}	0.95^{c}	17.96^{a}
'Vanessa'	red	round	62.06^{d}	68.62^{d}	0.89^{abc}	151.34^{d}

*Values in the same column followed by different superscript letters are significantly different at $p < 0.05$

Sampling

Three tomatoes selected from each sample were washed, blotted with a paper towel and cut into halves, the seeds were removed and the pericarp and mesocarp were ground to a homogeneous puree in a blender for 1 min. The samples were stored at -18°C until analysis. Experiments were executed in four repetitions, and the results were expressed as average ± standard error of average of repetitions.

Analytical methods

Dry matter content (%) was determined gravimetrically by drying 5 g tomato homogenate to a constant weight at 105°C. Soluble solids content (%) was determined with a digital refractometer after tomato homogenate clarification by centrifugation (4000 rpm, 10 min) and expressed as a percentage. Titratable acidity (% as citric acid) was determined by titrating the water extract of tomato homogenate with 0.1 N sodium hydroxide (NaOH) to an end point of neutral pH (8.1) with phenolphthalein as colorimetric indicator.

Determination of antioxidant compounds

Carotenoids

Determination was based on a spectrophotometric analysis following the method developed by Nagata and Yamashita (1992) for the simultaneous determination of chlorophyll and carotenoids in tomato fruit. The samples were thawed in the dark in a refrigerator at 4°C to avoid carotenoid oxidation. Sixteen mililiters of acetone-hexane (4:6) solvent were added to 1.0 g of tomato homogenate and mixed in a test-tube. Automatically, two phases separated, and an aliquot was taken from the upper solution for measurement of optical density at 663, 645, 505, and 453 nm in a spectrophotometer (Varian Cary 50 UV-Vis, Varian Co., USA). Lycopene and β-carotene contents were calculated according to the equations: Lycopene (mg 100 mL^{-1} of extract) = - 0.0458 × A_{663} + 0.204 × A_{645} + 0.372 × A_{505} - 0.0806 × A_{453}; β-Carotene (mg 100 mL^{-1} of extract) = 0.216 × A_{663} - 1.22 × A_{645} - 0.304 × A_{505} + 0.452 × A_{453}. Lycopene and β-carotene were finally expressed as mg kg^{-1} fw.

Ascorbic acid

Ascorbic acid was extracted and analyzed by reversed-phase HPLC. Frozen tomato homogenate (5 g) was mixed and diluted to 100 mL with 0.1 N HCl. After 30 minutes the extraction solution was centrifuged at 4200 rpm for 10 minutes. The supernatant was filtered through 0.2 μm pore size filter.

HPLC-DAD analysis was performed on a Finningan Surveyor Plus system (Thermo Electron Corporation, San Jose, CA, USA) coupled with a photodiode array detector (DAD) set at 245 nm. The separation was performed using a Hypersil Gold aQ column (25 cm x 4.6 mm) with a particle size of 5 μm while a 50 mM water solution of KH_2PO_4 buffer adjusted to pH 2.8 with ortho-phosphoric acid was used as the mobile phase. The column temperature was kept at 10°C and the flow rate at 0.7 mL min^{-1}. All the results were expressed in mg kg^{-1} fw. Acetonitrile was HPLC grade (Merck, Germany) while potassium dihydrogen orthophosphate and phosphoric acid were of analytical purity (Sigma-Aldrich, Germany). Ultrapure water was obtained from a Milli-Q water purification system (TGI Pure Water Systems, USA).

Total phenolic content

Total phenolic content was assessed by using the Folin-Ciocalteau phenol reagent method (Singleton and Rossi, 1965). Folin Ciocalteu reagent (2N, Merk), gallic acid (99% purity, Sigma), anhydrous sodium carbonate (99% purity, Sigma) were used.

Samples (3 g of tomato homogenate) were extracted with 5 mL methanol in an ultrasonic bath for 45 min at ambient temperature. After extraction, the samples were centrifuged for 5 min at 4200 rpm. Supernatants were filtered through polyamide membranes with pore diameter of 0.45 μm and stored at a temperature of -20°C. 100 μL of each tomato methanolic extract were mixed with 5 mL of distilled water and 500 μL of Folin-Ciocalteau reagent. After 30 sec to 8 min, 1.5 mL of sodium carbonate (20% w/v) was added. The reaction mixture was diluted with distilled water to a final volume of 10 mL. The same procedure was also applied to the standard solutions of gallic acid. The absorbance at 765 nm of each mixture was measured on a Varian Cary 50 UV spectrophotometer (Varian Co., USA) after incubation for 30 min at 40°C. Results were expressed as mg of gallic acid equivalents (GAE) kg^{-1} fw.

Determination of antioxidant activity

Relative antioxidant activity was measured in methanol tomato extracts using the DPPH (2,2-diphenyl-1-picrylhydrazyl) assay. Methanol (Merck, Germany), 2,2-diphenyl-1-picrylhydrazyl (DPPH) (Sigma-Aldrich, Germany), and 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) (Merck, Germany) were employed. The extraction of samples was made according to the same protocol as described for total phenolic content. The free radical scavenging ability of the extracts against DPPH free radical was evaluated as described by Oliveira *et al.* (2008), with some modifications. Briefly, each methanol tomato extract (50 μL) was mixed with 3 mL of a 0.004% (v/v) DPPH methanolic solution. The mixture was incubated for 30 min at room temperature in the dark and the absorbance was measured at 517 nm on Varian Cary 50 UV-Vis spectrophotometer. The DPPH free radical scavenging ability was subsequently calculated with respect to the Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid), which was used as a standard reference to convert the inhibition capability of each extract solution to the mmol Trolox equivalent antioxidant activity

L^{-1}. The radical was freshly prepared and protected from the light. A blank control of methanol/water mixture was run in each assay. All assays were conducted in triplicate. Results were expressed in mmol Trolox kg^{-1} fw.

Determination of mineral and trace elements content

Sodium (Na), calcium (Ca), magnesium (Mg), potassium (K), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), chromium (Cr), and boron (B) were determined by microwave digestion followed by inductively coupled plasma mass spectrometry (ICP-MS). Samples of approximately 2.0 g tomato homogenate were weighed in TFM vessels, over that 5 mL nitric acid 65% and 2 mL hydrogen peroxide 30% were added. The vessels were then closed and mounted in special outer vessels and heated at 180°C for 20 min in the Milestone digestion microwave system. Reagent blanks were included in each series of digestions. After digestion was completed, the clear, colourless solution was transferred into a 50 mL volumetric flask and make up to the mark with ultrapure water. The sample solutions were stored in polyethylene vials at 6°C until analysis. An Elan 9000 inductively coupled plasma mass spectrometer (Perkin Elmer Sciex, Canada) equipped with Meinhard nebulizer and Scott-type double-pass spray chamber was used throughout. The results were expressed in mg kg^{-1} fw.

Statistical analyses

Data were evaluated by one-way analysis of variance (ANOVA) using Statgraphics Centurion XVI software (StatPoint Technologies, Warrenton, VA, USA). Differences in content levels among the cultivars were estimated with a multiple range test using the least significant difference (LSD) at $p < 0.05$.

Results and discussion

Data on dry matter content, soluble solids content and titratable acidity are shown in Tab. 2. Dry matter content ranged between 5.88% in the ellongated tomato cultivar ('Porto') and 10.04% in the cherry-type tomato cultivar ('Belle'). These results were close to the values presented by Gupta *et al*. (2011) who reported 5.55% and 7.73% for two newly developed tomato genotypes, or by Pinela *et al*. (2012) who reported 6.3% to 9.37% dry matter content in four tomato varieties grown in Northeastern Portugal.

The total soluble solids were determined between 4.98% and 8.38% in the analysed tomato cultivars. Significantly ($p < 0.05$) higher amounts of total soluble solids were found in the fruits of 'Tiger' (8.38%) and 'Belle' (8.15%) cherry type cultivars, followed by 'Cemile' (7.98%) while the lowest levels were found in 'Vanessa' (4.98%) and 'Porto' (5.35%) tomatoes. Gupta *et al*. (2011) reported 5.1% and 5.5% total soluble solids in the fruits of two tomato genotypes.

The level of acidity in tomato fruits is an important parameter associated with sensory attributes like flavor and astringency. Titratable acidity varied significantly between 0.10% ('Vanessa') and 0.41% ('Plumty'). Similar results were reported by other authors in studies of different tomatoes genotypes (Olaiya *et al*., 2010; Owusu *et al*., 2012). However, some of the data reported in the literature for ripened tomatoes were slightly higher than our data (Geboloğlu *et al*., 2011; Gupta *et al*., 2011). The cherry type cultivar 'Belle' registered a titratable acidity of 0.32%, result in good agreement with 0.35% titratable acidity reported by Žnidarčič *et al*. (2010) for the fruits of the same cultivar.

Antioxidants such as ascorbic acid, carotenoids and phenolics were determined and the results are provided in Tab. 2. There were significant differences in the amount of ascorbic acid in the different cultivars of tomatoes studied, and the highest concentration was found in the samples of the so-called cocktail tomato cultivar 'Tiger' (329.7 mg kg^{-1}) followed by the cultivar of cherry type tomato 'Belle' (227.5 mg kg^{-1}). Other two cultivars, 'Sacher' and 'Lorely' have shown contents slightly above the commonly accepted average level in the commercial tomato (200 mg kg^{-1}) while 'Vanessa' and 'Plumty' presented nearly half of this content (91.9 and 95.8 mg kg^{-1} fw respectively). Pinela *et al*. (2012) found contents of ascorbic acid between 108.6 and 185.6 mg kg^{-1} fw, Dar and Sharma (2011) found ascorbic acid content in the range 197.7-378 mg kg^{-1} fw while Frenich *et al*. (2005), using liquid chromatography with mass spectrometry detection, determined 97 to 180 mg kg^{-1} ascorbic acid in different tomato cultivars. Likewise, our results are in agreement with those of Adalid *et al*. (2010) and Vinkovic Vrcek *et al*. (2011) who concluded that smaller fruits (cherry type tomatoes) have generally higher vitamin C content.

The results on lycopene content show a significant variation among the different cultivars of tomato (Tab. 2), ranging from 19.7 mg kg^{-1} fw to 49.0 mg kg^{-1} fw. Data corresponds to earlier study made by Dar and Sharma (2011) on 60 diverse genotypes of tomato, who reported lycopene content between 19.5 and 46.2 mg kg^{-1} fw. Kuti and Konoru (2005) also found the total lycopene content in fresh market tomato varieties grown in the greenhouse ranging from 5.7 mg kg^{-1} to 47.8 mg kg^{-1} fw while Frenich *et al*. (2005) determined 8 to 37 mg kg^{-1} lycopene using liquid chromaography with mass spectrometry detection. Besides, the average lycopene content of raw tomatoes has been reported at 30 mg kg^{-1} (Adalid *et al*., 2010; Kuti and Konuru, 2005). Significant differences ($p < 0.05$) were found among the average lycopene content of examined cultivars. The plum shaped cultivar 'Porto' recorded the highest average lycopene content of all (49 mg kg^{-1} fw). Aherne *et al*. (2009) reported also that Spanish plum tomatoes had the highest ($p < 0.05$) lycopene content when compared to cherry, cherry-on-the-vine, and round tomatoes while Muratore *et al*. (2005) reported that five out of

Tab. 2. Chemical characteristics, contents of antioxidant compounds and antioxidant activity of the *Solanum lycopersicum* cultivars evaluated

Cultivar	Dry matter (%)	Soluble solids (%)	Titratable acidity (% as citric acid)	Ascorbic acid (mg kg^{-1})	β-carotene (mg kg^{-1})	Lycopene (mg kg^{-1})	Total phenolics (mg GAE kg^{-1})	Antioxidant activity (mmol Trolox kg^{-1})
'Antalya'	7.96 ± 0.38^{d}	6.98 ± 0.46^{cd}	0.19 ± 0.02^{cd}	146.0±2.8^{cd}	8.2 ± 0.8^{abc}	31.8 ± 2.4^{b}	300.2 ± 4.1^{a}	0.87 ± 0.2^{a}
'Belle'	10.04 ± 0.25^{a}	8.15 ± 0.58^{e}	0.32 ± 0.03^{e}	227.5 ± 6.9^{e}	12.8 ± 1.4^{d}	20.2 ± 1.8^{a}	557.8 ± 10.2^{e}	1.62 ± 0.2^{c}
'Cemile'	8.63 ± 0.18^{c}	7.98 ± 0.74^{de}	0.16 ± 0.02^{bc}	153.2 ± 5.6^{d}	7.9 ± 0.6^{abc}	23.5 ± 3.0^{a}	329.6 ± 11.3^{b}	0.99 ± 0.1^{ab}
'Izmir'	6.08 ± 0.22^{f}	5.68 ± 0.31^{ab}	0.13 ± 0.01^{ab}	114.8 ± 4.4^{b}	7.2 ± 0.9^{ab}	21.0 ± 2.8^{a}	312.2 ± 9.8^{a}	1.05 ± 0.1^{ab}
'Lorely'	7.78 ± 0.21^{d}	7.00 ± 0.75^{cd}	0.22 ± 0.01^{d}	218.9 ± 7.1^{e}	6.4 ± 1.0^{a}	31.2 ± 2.6^{b}	337.3 ± 6.6^{bc}	0.81 ± 0.1^{a}
'Plumty'	6.70 ± 0.33^{e}	6.20 ± 0.78^{bc}	0.41 ± 0.02^{f}	91.9 ± 3.3^{a}	8.5 ± 0.8^{bc}	32.4 ± 2.8^{b}	351.4 ± 8.9^{c}	0.87 ± 0.1^{a}
'Porto'	5.88 ± 0.11^{f}	5.35 ± 0.62^{ab}	0.29 ± 0.02^{e}	137.6 ± 6.6^{c}	9.3 ± 1.1^{c}	49.0 ± 4.1^{c}	408.8 ± 12.0^{d}	1.23 ± 0.3^{b}
'Sacher'	6.98 ± 0.21^{e}	6.23 ± 0.48^{bc}	0.19 ± 0.01^{cd}	225.4 ± 8.8^{e}	16.2 ± 1.0^{e}	35.8 ± 3.3^{b}	35.05 ± 0.44^{c}	1.08 ± 0.1^{ab}
'Tiger'	9.19 ± 0.26^{b}	8.38 ± 0.46^{e}	0.13 ± 0.01^{ab}	329.7 ± 11.2^{f}	20.6 ± 1.8^{f}	44.6 ± 2.8^{c}	557.2 ± 11.0^{e}	1.74 ± 0.2^{c}
'Vanessa'	5.92 ± 0.15^{f}	4.98 ± 0.68^{a}	0.10 ± 0.02^{a}	95.8 ± 3.0^{a}	6.5 ± 0.6^{a}	19.7 ± 2.2^{a}	337.9 ± 7.8^{bc}	0.96 ± 0.2^{ab}

* Values in the same column followed by different superscript letters are significantly different at $p < 0.05$

six Italian grown plum tomato cultivars contained greater amounts of lycopene than cherry tomatoes. These nutritional characteristics explain why in recent years there has been an increased demand for this tomato variety. Fruits of the cocktail type cultivar 'Tiger' presented the second average lycopene content (44.6 mg kg^{-1}) followed by the brownish red cultivar 'Sacher' (35.8 mg kg^{-1} fw). The high contents of lycopene of these remarkable cultivars contribute to the attractive appearance of the fruits, knowing that lycopene is the predominant carotenoid in red ripe tomatoes and the main responsible for their red colour. The cherry type cultivar 'Belle' presented lower lycopene content although cherry tomato types usually showed a higher lycopene content than common tomatoes (Adalid *et al*., 2010; Kuti and Konoru, 2005).

The 'Tiger' tomatoes presented also the highest content of β-carotene (20.6 mg kg^{-1} fw) followed by the 'Sacher' tomatoes (16.2 mg kg^{-1} fw) while the fruits of cherry type cultivar 'Belle' presented a β-carotene content of 12.8 mg kg^{-1} fw. Like Adalid *et al*. (2010) who found the highest content of β-carotene (13 mg kg^{-1}) in the fruits of a cherry type cultivar, other workers also reported that cherry tomatoes are richest in β-carotene. The rest of the cultivars evaluated in the present work had β-carotene contents between 6.4 and 9.3 mg kg^{-1} fw, values in good agreement with previous studies (Adalid *et al*., 2010; Gupta *et al*., 2011).

Besides antioxidants lycopene, β-carotene and ascorbic acid, tomatoes also contain flavonoids and related phenolics. The main phenolic compounds found in tomato are the flavonols quercetin and kaempferol and the hydroxycinnamic acids, particularly the caffeic and chlorogenic acids (Vallverdú-Queralt *et al*., 2011). Total phenolic content ranged from 312.2 mg GAE kg^{-1} to 557.8 mg kg^{-1}. Significant differences in the mean values of total phenolic compounds were found between the cultivars of tomatoes considered, the cherry tomatoes 'Belle' and the cocktail tomatoes 'Tiger' showing the greatest contents (557.8 mg GAE kg^{-1} and 557.2 mg GAE kg^{-1} respectively). Higher levels of total phenolic content in smaller tomatoes, compared to cultivars with larger fruits, are due to the higher skin to volume ratio of these varieties, which could enhance their phenolic content, particularly flavonols, since these compounds are mainly found in the skin (Maršić *et al*., 2011). The total phenolic concentrations found in this study were similar to those reported by other studies (Luthria *et al*., 2006; Hernández *et al*., 2007; Helyes *et al*., 2012; Martínez-Valverde *et al*., 2002).

Considering the content of antioxidant compounds, it is of great interest to determine the total antioxidant activity of the cultivars evaluated expressed by the capacity to scavenge the stable free radical DPPH. Antioxidant activities of tomatoes were found between 0.81 and 1.74 mmol Trolox kg^{-1} fw (Tab. 2), in agreement with the results found by other authors (Erge and Karadeniz, 2011). The data show that the antioxidant activities of two cultivars ('Tiger' and 'Belle') are significantly higher compared to the rest of cultivars.

Tomatoes can be considered as good sources of some mineral elements, some of them with antioxidant properties. Mineral content was significantly affected by cultivars (Tab. 3). Among macroelements, K (potassium) presented the highest concentration, ranging from 2139.6 mg kg^{-1} to 3056.9 mg kg^{-1}, values similar with those reported by most authors (Costa *et al*., 2011; Fernández-Ruiz *et al*., 2011; Guil-Guerrero and Rebolloso-Fuentes, 2009). The 'Tiger' tomatoes showed the highest mean K content followed by 'Lorely' (3018.4 mg kg^{-1}) and 'Cemile' (3014.2 mg kg^{-1}), with significant differences in relation to the rest of the cultivars. Mg (magnesium) contents ranged between 137.7 mg kg^{-1} and 325.8 mg kg^{-1}, results higher than some previous reported data which do not exceed 220 mg kg^{-1} fw (Guil-Guerrero and Rebolloso-Fuentes, 2009; Costa *et al*., 2011; Hernández Suárez *et al*., 2007). Ca (calcium) content ranged between 27.3 mg kg^{-1} and 168.7 mg kg^{-1}, results in good agreement with those reported by Guil-Guerrero and Rebolloso-Fuentes (2009) and Geboloğlu *et al*. (2011) but lower than those reported by Costa *et al*.

Tab. 3. Mineral and trace elements content of the *Solanum lycopersicum* cultivars evaluated (mg kg^{-1} fw)

Cultivar	Ca	Mg	K	Na	Fe	Mn	Cu	Cr	Zn	B
'Antalya'	168.7 ± 11.2f	241.8 ± 13.3^{c}	2139.6 ± 83.3^{a}	166.1 ± 5.6^{f}	5.8 ± 0.7^{b}	1.3 ± 0.2^{bc}	2.0 ± 0.4^{c}	0.6 ± 0.1^{b}	6.8 ± 0.1^{b}	2.7 ± 0.3^{cd}
'Belle'	156.5 ± 11.2^{f}	218.3 ± 9.4^{b}	2817.8 ± 69.8^{d}	103.6 ± 6.7^{e}	9.7 ± 1.0^{f}	1.8 ± 0.3^{d}	1.9 ± 0.4^{c}	0.6 ± 0.1^{b}	8.0 ± 0.3^{d}	2.3 ± 0.3^{bc}
'Cemile'	67.7 ± 5.6^{bc}	325.8 ± 15.5^{f}	3014.2 ± 114.5^{ef}	68.1 ± 4.5^{b}	5.5 ± 0.5^{ab}	1.7 ± 0.3^{d}	2.0 ± 0.3^{c}	0.6 ± 0.2^{b}	6.2 ± 0.1^{a}	2.1 ± 0.2^{b}
'Izmir'	129.8 ± 8.1^{e}	209.4 ± 8.4^{b}	2826.5 ± 96.6^{d}	42.5 ± 3.4^{a}	7.1 ± 0.8^{c}	1.0 ± 0.1^{ab}	1.3 ± 0.2^{ab}	0.4 ± 0.1^{ab}	8.0 ± 0.2^{d}	3.1 ± 0.3^{de}
'Lorely'	137.8 ± 7.8^{e}	285.1 ± 12.3^{de}	3018.4 ± 57.8^{ef}	69.2 ± 5.9^{b}	6.3 ± 0.8^{bc}	1.3 ± 0.1^{bc}	1.6 ± 0.2^{bc}	0.4 ± 0.1^{ab}	6.2 ± 0.1^{a}	2.1 ± 0.2^{b}
'Plumty'	60.5 ± 5.3^{b}	253.8 ± 11.1^{c}	2898.5 ± 101.2^{de}	42.5 ± 3.3^{a}	5.9 ± 0.5^{b}	1.8 ± 0.2^{d}	1.0 ± 0.1^{a}	0.4 ± 0.1^{ab}	6.8 ± 0.2^{b}	3.2 ± 0.3^{de}
'Porto'	27.3 ± 2.8^{a}	305.1 ± 13.8^{ef}	2827.9 ± 68.8^{d}	39.5 ± 2.2^{a}	8.7 ± 0.8^{ef}	2.5 ± 0.3^{e}	1.9 ± 0.2^{c}	0.3 ± 0.1^{a}	6.5 ± 0.1^{ab}	3.0 ± 0.3^{de}
'Sacher'	80.1 ± 8.9^{c}	137.7 ± 7.7^{a}	2481.0 ± 44.4^{c}	88.4 ± 4.1^{d}	4.6 ± 0.5^{a}	0.7 ± 0.1^{a}	0.9 ± 0.1^{a}	0.3 ± 0.1^{a}	7.7 ± 0.3^{d}	1.3 ± 0.2^{a}
'Tiger'	107.4 ± 7.8^{d}	277.5 ± 13.1^{d}	3056.9 ± 99.8^{f}	78.9 ± 3.8^{c}	8.4 ± 0.6^{de}	1.5 ± 0.2^{cd}	1.7 ± 0.3^{bc}	0.4 ± 0.1^{ab}	7.3 ± 0.2^{c}	3.3 ± 0.4^{e}
'Vanessa'	131.6 ± 6.6^{e}	281.3 ± 14.4^{d}	2301.3 ± 63.4^{b}	41.1 ± 2.8^{a}	7.4 ± 0.5^{cd}	1.6 ± 0.2^{cd}	1.1 ± 0.2^{a}	0.6 ± 0.2^{b}	6.8 ± 0.1^{b}	3.9 ± 0.4^{f}

* Values in the same column followed by different superscript letters are significantly different at $p < 0.05$

(2011). 'Antalya' cultivar showed the highest mean of Na and Ca content and the lowest K content, with signifficant differences in relation to the rest of cultivars.

Fe (iron), Mn (manganese), Cu (copper), Cr (chromium), Zn (zinc) and B (boron) were the trace elements determined in our study (Tab. 3). Fe contents (5.5 mg kg^{-1} to 9.7 mg kg^{-1}) were higher than those reported by Geboloğlu *et al*. (2011), but similar with those reported by Fernández-Ruiz *et al*. (2011). Also, values determined for Mn and Zn in our work are in agreement with those reported by other authors (Fernández-Ruiz *et al*., 2011; Geboloğlu *et al*., 2011; Hernández Suárez *et al*., 2007). With respect to copper, we found between 0.9 mg kg^{-1} and 2.0 mg kg^{-1} in the samples analysed, Hernández Suárez *et al*. (2007) reported 1.8 to 3.0 mg kg^{-1} while Fernández-Ruiz *et al*. (2011) found 4.3 to 7.4 mg kg^{-1}. Note that tomatoes of the cherry type cultivar 'Belle' registered the highest contents of Fe (9.7 mg kg^{-1}), Mn (1.7 mg kg^{-1}) and Zn (8.0 mg kg^{-1}), presenting also among the highest concentrations of Ca, Mg and Cu. On the other hand, tomatoes of 'Tiger' cultivar registered the highest content of K and significantly higher contents of Mg, Fe, Cu, Zn and B as compared with the other cultivars. These results are in agreement with those of Costa *et al*. (2011) who found that cherry tomatoes presented the highest content of minerals amongst the studied tomato types.

Conclusions

Significant differences were detected among tomato cultivars in all studied antioxidant compounds, as well as in their antioxidant activity and mineral content. Since tomato cultivars were grown under the same agricultural, geographical and climatic conditions, the results showed the great variability in the bioactive component contents of tomato fruits and the significant influence of the cultivar on them. Lycopene and ascorbic acid content showed 1-2.5 fold and 1-3 fold variation on fresh weight basis, respectively.

Some of the evaluated cultivars are of great interest given their high content of bioactive compounds and antioxidant activity. Thus, the so-called cocktail tomato cultivar 'Tiger' and the cherry type cultivar 'Belle' proved to be the most powerful in antioxidant activity. The high antioxidant status of these two genotypes can be explained on the basis of their high phenolic, ascorbic acid and lycopene contents. A remarkable cultivar is 'Sacher', which, besides an interesting appearance given by its brownish red color resembling chocolate, revealed valuable nutritional composition, including among the highest contents of phenolics, carotenoids and ascorbic acid.

Mineral content was also significantly affected by cultivars. In this respect, the best-graded cultivars were 'Belle', with the highest contents of Fe, Mn and Zn, and among the highest concentrations of Ca, Mg and Cu, and 'Tiger' with the highest content of K and significantly higher contents of Mg, Fe, Cu, Zn and B as compared with the rest of cultivars.

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