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RESEARCH ARTICLE

Effects of organic farming system on some nutritional parameters of tomatoes fruits at different ripening stages

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ABSTRACT

Tomatoes (*Solanum lycopersicum* L.) are the most cultivated and consumed vegetable species in the world and deserve special attention due to their nutritional and functional value. The aim of this study was to assess the nutritional value of organically grown tomatoes in greenhouses, at different maturity phases. Five hybrids were studied: Antalya F_1, Cemile F_1, Lorely F_1, Tiger F_1 and Sacher F_1. The observed parameters in each harvest phase were: Content of chlorophyll *a* and *b*, total carotenoids, total soluble solids (TSS), ascorbic acid (vitamin C) and titratable acidity (TA). Taking into account the content of TSS and TA, taste and maturity index was established. Tiger F_1, Sacher F_1 and Cemile F_1 hybrids were significantly standing out for all analysed parameters. Sacher F_1 had a carotene content of 10.3 mg 100 g^{-1} FW in green fruit and 17.0 mg 100 g^{-1} FW in red fruit. Vitamin C was 6.2 mg 100 g^{-1} FW in green fruits, increasing to 16.0 mg 100 g^{-1} FW in red fruits. The mineral content depended on the hybrid and harvest stage. In the rose phase the highest K content was in Cemile F_1 (151.53 mg 100^{-1} g), Ca in Lorely F_1 (8.16 mg 100 g^{-1}), Mg in Sacher F_1 and Tiger F_1 with values over 22.0 mg 100 g^{-1}, and Tiger F_1 and Sacher F_1 distinguish in Zn, Cu and Fe content. In the red fruit phase, Tiger F_1 and Sacher F_1 hybrids are representative for almost all minerals excepting Lorely F_1 and Cemile F_1.

Key words: Crop, hybrids, nutraceutical, organic, *Solanum lycopersicum*.

INTRODUCTION

Tomatoes (*Solanum lycopersicum* L.) are currently grown and distributed on all continents, which is why this species is considered one of the crops with the greatest economic impact in the world. They have considerable nutritional benefits due to the high content of trace elements such as lycopene, β-carotene, ascorbic acid (vitamin C) and polyphenols. Moreover, the consumption and marketing of this species were not limited only to the fresh product. The processing and industrialization of fruit is commercialized as tomato paste, juices, sauces, concentrates and other products derived from it.

Organic farming is growing very rapidly worldwide. According to the Food and Agriculture Organization of the United Nations (FAO), in 2019, the global tomato production was about 1808 million tons. The countries with the highest production in the same year were China (628 million tonnes), India (190 million tonnes) and Turkey (128 million tonnes) (FAO, 2020). In addition, in 2019, the organic farming in general increased by 2.9% compared to the previous year, and for the following years a considerable increase in trade with organic products is expected (IFOAM-Organics International, 2020), tomatoes being the most relevant species of this type of unconventional agriculture.

The performance of tomato crops is influenced by the management of the plantation, which should promote the efficient development of the plants, as well as both the quantitative and qualitative production of fruit. Issues related to production quality are the key objectives of low environmental impact strategies, in which the use of organic fertilizers is a useful tool for preventing or reducing abiotic and biotic stress.

Due to the multiple healing properties of the tomatoes used in human food, the use of ecological technologies is being pursued to the detriment of conventional technologies. Numerous studies have been conducted worldwide demonstrating that the growing system and fertilization level influences the antioxidant activity of harvested crops. Fertilization with humic acid influences the total carbohydrate content and increases the production of *Solanaceae*.

Worldwide, there is an increased interest in the consumption of tomatoes obtained in an ecological system. For this reason, a more detailed evaluation is required regarding the quality and nutritional composition of the obtained production. Kapoulas et al. (2011), in a study conducted in Greece on a conventional and an organic tomato crop, reported a significantly higher content of carotene and lycopene in organic tomatoes. However, there are studies that state the opposite about tomatoes grown in organic system. Tomatoes are well known to be consumed fresh, dried or processed in different forms: Juice, paste, sauce or ketchup, being excellent sources of vitamins, mineral salts, trace elements, etc. (Ray et al., 2011). Tomato fruits and products made from them are rich in antioxidant compounds such as carotenoids, β-carotene and especially lycopene that are largely responsible for fruit redness, ascorbic acid and phenolic compounds (Dinu et al., 2016). The positive effect of this species consumption is currently attributed to the existing antioxidants in fruits (Kotkov et al., 2011; Carocho and Ferreira, 2013). Variation in bioantioxidant content of carotenoids and ascorbic acid in tomato differs according to genetic factors, varieties, technology, destination of production, resulting in large differences between fresh consumption varieties and those for industrialization (Dinu et al., 2015; Sellitto et al., 2019).

Several studies have shown that tomatoes in organic farming have a higher amount of nutrients than those in conventional agriculture (Borguini et al., 2013; Oliveira et al., 2013; Vinha et al., 2014). The impact of organic and conventional production systems on the quality and nutritional parameters of vegetable fruit is still under discussion. An increased interest in the production of organic tomatoes is the assessment of the nutritional quality of organic fruits (Kapoulas et al., 2013; Zoran et al., 2014).

The results of research on the effects of the application of organic or conventional technology on fruit quality are sometimes contradictory. In terms of quality, some studies report better taste, higher levels of vitamin C and other quality compounds for organic vegetables, while other studies found opposite or lacking quality differences between organically and conventional grown species (Vélez-Terreros et al., 2021). Identifying tomato cultivars with high nutritional value is a useful approach that is taken into account when selecting those that have beneficial properties for better health. During the ripening process of tomato fruits, a series of quantitative and qualitative changes take place, which influence the aroma and volatile profiles of tomato taste (Soare et al., 2019). However, the increase or decrease in nutrients in tomatoes can be influenced by genotype, climate and soil conditions and the farming system.

Therefore, as highlighted above, the purpose of this paper was to determine the major content of minerals and nutrients present in five hybrids of organically grown tomatoes, in different ripening phases, to highlight the quality and benefits of this type of food.

MATERIALS AND METHODS

Experimental protocol and culture conditions

The research was conducted in 2017-2019 on five tomato (*Solanum lycopersicum* L.) hybrids with fruits of different sizes, shapes and colours (Table 1). The studied biological material was represented by: Antalya F_1, Cemil F_1, Lorely F_1, Tiger F_1 and Sacher F_1. The experiment was set up in a cold greenhouse, in the Didactic Field of the Faculties of Horticulture and Agronomy, University of Craiova (40°49′ N, 14°20′ E, 63 m a.s.l.), Romania. The planting took place on 19 April 2017, 16 April 2018 and 21 April 2019, in a greenhouse with a width of 10 m and a length of 40 m. A seedling produced in a warm greenhouse was used. The technological scheme of planting was: 50 + 100 (9) + 50 × 35 cm (in a 10-m-wide solar plant, 10 rows of tomatoes were planted at 100 cm distance and 35 cm distance between the plants per row, leaving a 50 cm side distance, resulting in nine intervals), resulting in 2.63 plants m^{-2}. The experiment was configured in randomized blocks, with three replicates, with 30 plants per replicate. The trial was established on a reddish brown Preluvosol with the following chemical properties: 26.6 mg kg^{-1} total N, 789 mg kg^{-1} total P, 331 mg kg^{-1} total K, 2.67% humus, and pH 7.06.

The technology recommended by the literature for the organic cultivation of tomatoes in the greenhouse was applied, namely: Control of nematodes with an organic nematicide based on *Tagetes erecta* 80% extract, 10% seaweed extract and organic matter (applied by three at a dose of 15 L ha^{-1} (Nemagold, Atlantica Agricola, Alicante, Spain), control of diseases and pests through specific preventive treatments with certified products for organic agriculture.

Table 1. Morphological characters of studied tomato hybrids.

Hybrids	Fruit colour at physiological maturity	Fruit shape	Fruit dimensions		Form index	Average fruit weight
			Fruit height	Fruit diameter		
			mm	mm		g
Antalya F1	Red	Round	51.38	60.97	0.84	190.00
Cemil F1	Bright red	Round	59.04	62.40	0.94	300.00
Lorely F1	Red	Round	54.10	59.00	0.91	220.00
Tiger F1	Bicolour brick-red with dark green	Round (cherry type)	31.24	32.74	0.98	45.00
Sacher F1	Red brown	Round	48.50	52.00	0.93	150.00

The main fertilization, before crop establishment, was done with well decomposed grape pomace. Grape pomace is a by-product of grape processing, which represents approximately 4.5-9.0 m^3 residual material ha^{-1}, it is mineralized through composting and becomes organic fertilizer. The use of this product ensures the recycling of winery by-products. In order to highlight the agrochemical properties of grape pomace used in the experiment, the content of the main chemical elements was determined: 1.90% total N, 0.83% total P, 0.363% mobile P, 0.93% total K, 0.772% mobile K, 67.75% organic matter, 31.56% humus and pH 7.6. In addition to the high content of nutrients, grape pomace offers the advantage over manure, that it is devoid of weed seeds, pathogens and pests. Grape pomace was applied before planting by incorporating 30 t ha^{-1} into the soil.

Four foliar fertilizations with humic acids 0.5% were applied at the vegetative phase at an interval of 10 d between them. The first treatment was applied 2 wk after planting. All hybrids were grown under identical organic growing practices. In order to achieve the objectives, determinations and analyses were carried out on the tomato fruits in the dynamics depending on the harvesting phase (green, rose and full red). The harvesting stages of the tomato fruits were visually determined, as follows: Green fruit stage when some light colour stripes appear at the top of the fruit, usually star-shaped, indicating the fact that the fruit is in the mature green phase; rose fruit stage when 30%, but not more than 60% of the surface of the fruit is of a red-pink colour; red ripening stage (full red) when more than 90% of the surface of the fruit is red.

Mineral elements, chlorophyll pigments, total carotenoids, ascorbic acid, titratable acidity (TA), total soluble solids (TSS), taste and maturity index were monitored.

Sample preparation

Depending on the maturation, nine fruits (3 fruits replicate^{-1}) were harvested from each hybrid and brought to the laboratory where they were washed and then wiped with paper towels. The pericarp tissue was separated from the placenta and seeds and dried in an oven at 75 °C to a constant weight. The dry pieces of pericarp tissue were then ground well with mortar and pestle (made of glass) to a fine powder. The powder was stored in a Kraft paper bag inside the desiccator for later use. Mineral extraction was performed from this material.

Determination of mineral elements. It was performed according to the method described by Cosmulescu et al. (2010). Determination of total carotenoids and chlorophylls were performed simultaneously by spectrophotometric method. All pigments in the samples were extracted with acetone:hexane (4:6) in a ratio of 1 g:20 mL and the absorbance of the hexane layer was measured at 663, 645, 505, and 453 nm using a

UV-VIS spectrophotometer (Evolution 600 UV-VIS spectrophotometer, Thermo Scientific, Oxford, UK) with VISION PRO software (Cognex Corporation, Natick, Massachusetts, USA).

Carotenoid and chlorophyll contents. They were calculated with the equations proposed by Nagata and Yamashita (1992):

$$\text{Lycopene (mg 100 g}^{-1}\text{ FW)} = -0.0458\,A_{663} + 0.204\,A_{645} + 0.372\,A_{505} - 0.0806\,A_{453}$$

$$\text{Chlorophyll } a\ (\mu\text{g g}^{-1}\text{ FW}) = 0.999\,A_{663} - 0.0989\,A_{645}$$

$$\text{Chlorophyll } b\ (\mu\text{g g}^{-1}\text{ FW}) = -0.328\,A_{663} + 1.77\,A_{645}$$

$$\beta\text{-Carotene (mg 100 g}^{-1}\text{ FW)} = 0.216\,A_{663} - 1.22\,A_{645} - 0.304\,A_{505} + 0.452\,A_{453}$$

Total soluble solids content. It was determined using an optical digital handheld refractometer Dr 301-95 (Hanna Instruments, Woonsocket, Rhode Island, USA) set at 20 °C.

Determination of titratable acidity. From a sample of 5-10 g tomato pulp homogenised with a vertical blender (MR 404 Plus, Braun, Kronberg, Germany) for 1 min, 1-2 mL were taken and diluted in 10 mL distilled water and titrated with 0.1 N sodium hydroxide in the presence of phenolphthalein. Titratable acidity (TA) results are expressed as % citric acid.

Taste and maturity indexes. They were calculated according to the method described by Navez et al. (1999) and Nielsen (2003). The maturity index was calculated as the TSS ratio to TA and the taste index [(TSS/20 × titratable acidity) + titratable acidity].

$$\text{Taste index} = \frac{Brix\ degree}{20\ x\ acidity} + acidity; \qquad \text{Maturity} = \frac{Brix\ degree}{20\ x\ acidity}$$

Ascorbic acid. Was extracted from fresh tomato homogenate with 0.1 N HCl (1:20; w:v). After extraction, the samples were centrifuged for 10 min at 4200 rpm and supernatants were filtered through 0.45 µm pore size filter. Determination of ascorbic acid was performed by reversed phase high performance liquid chromatography using an HPLC system (Finningan Surveyor Plus system, Thermo Electron Corporation, San Jose, California, USA) coupled with a photodiode array detector (DAD) set at 245 nm. The chromatographic separations were performed using a Hypersil Gold aQ column (25 cm × 4.6 mm, 5 µm particle size); the mobile phase consisted of 50 mM KH_2PO_4 buffer (pH = 2.8 with orthophosphoric acid). The column temperature was kept at 10 °C and the flow rate at 0.7 mL min^{-1}.

The results were expressed in mg 100 g^{-1} FW. Acetonitrile was HPLC grade (Sigma-Aldrich, Munich, Germany) potassium dihydrogen orthophosphate and orthophosphoric acid were of analytical purity (Sigma-Aldrich).

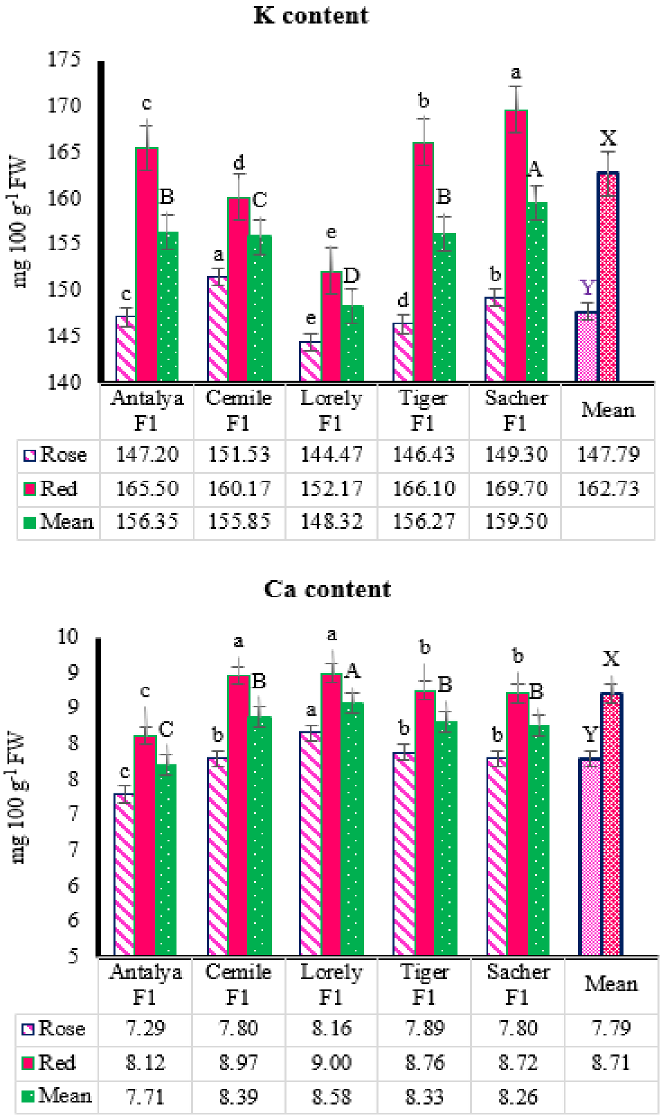
Statistical analysis

The data recorded were statistically processed by ANOVA. The means were compared using Duncan's multiple range test ($P \leq 0.05$).

RESULTS AND DISCUSSION

Greenhouse-grown vegetables offer advantages compared to those cultivated in open field in terms of quality assurance mainly because the plants are not exposed directly to rapid climate change. An important role in this respect is the selection of cultivars by using tomato hybrids with a productive and high-quality yield.

Mineral content. Tomatoes can be considered important sources of certain minerals, some of them with antioxidant properties. The mineral content of organically obtained tomatoes was obviously influenced by the genotype and sometimes by the ripening phase. During fruit harvest, K content in the pink fruit stage ranged from 144.47 (Lorely F_1) to 151.53 mg 100 g^{-1} (Cemile F_1). In the red fruit phase, the content of this mineral varied from 160.17 mg 100 g^{-1} in Cemile F_1 to 169.70 mg 100 g^{-1} in Sacher F_1 (Figure 1). A variation of this mineral was observed depending on the hybrid where a growth trend was found from the pink fruit stage to the red fruit stage. Standard deviation showed a significantly higher K content in the red fruit stage than in the pink fruit stage (Figure 1).



	Antalya F1	Cemile F1	Lorely F1	Tiger F1	Sacher F1	Mean
◻ Rose	147.20	151.53	144.47	146.43	149.30	147.79
■ Red	165.50	160.17	152.17	166.10	169.70	162.73
🟩 Mean	156.35	155.85	148.32	156.27	159.50	

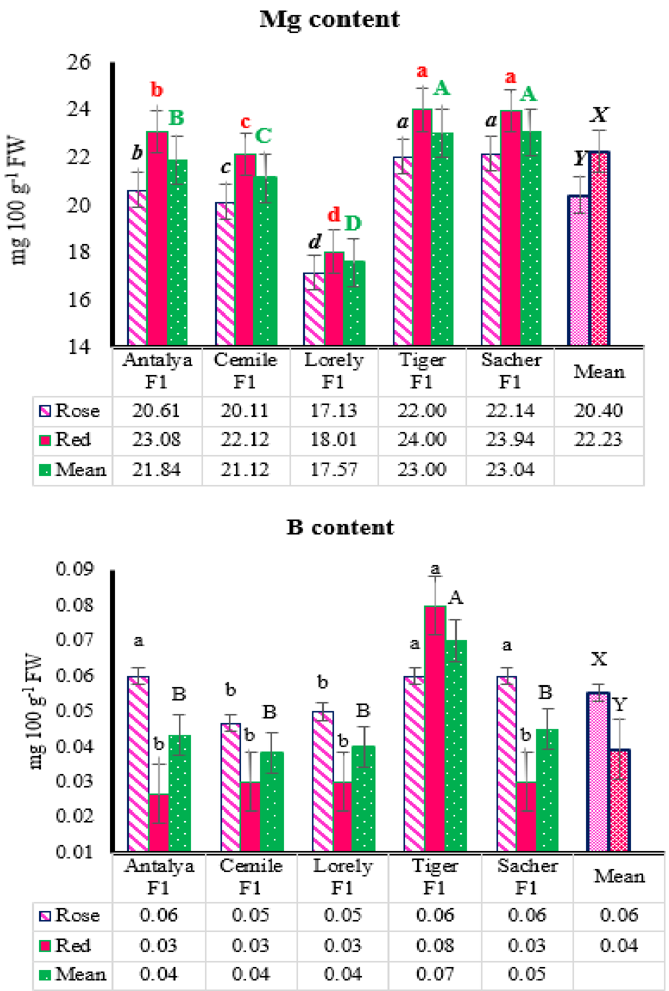
	Antalya F1	Cemile F1	Lorely F1	Tiger F1	Sacher F1	Mean
◻ Rose	7.29	7.80	8.16	7.89	7.80	7.79
■ Red	8.12	8.97	9.00	8.76	8.72	8.71
🟩 Mean	7.71	8.39	8.58	8.33	8.26	

Figure 1. Potassium and calcium content at tomato fruit harvesting stages. Bars represent standard error (SE).

The values obtained in this study are lower than those reported by Hadayat et al. (2018) in an organic tomato crop or by Araújo et al. (2014). Also, our results showed that K from cultivated tomatoes in the ecological system, recorded higher values for hybrids with fruits of smaller sizes and different colours (Tiger F_1 and Sacher F_1). This finding is also supported by Ordóñez-Santos et al. (2011), who states that the main factor influencing the micronutrient content in tomatoes is the hybrid, but also the farming system (Araújo et al., 2014).

The content of Ca varied from 7.29 mg 100 g^{-1} in Antalya F_1 (in the pink stage) to 9.00 mg 100 g^{-1} in Lorely F_1 (in the red fruit stage) (Figure 1). The Ca content in red fruits had values between 8.12 and 9.00 mg 100 g^{-1}, values that are consistent with that reported by Kapoulas et al. (2013), but lower than that reported by Ordóñez-Santos et al. (2011). This mineral from tomatoes is important because 99% of Ca deposits in the human body are found in the bones. It is the most important mineral in the human body (Shariff et al., 2021).

The Mg content varied significantly from 17.13 mg 100 g^{-1} in the Lorely hybrid to 22.14 mg 100 g^{-1} in Sacher F_1 in the pink fruit stage. This variation is kept in the red fruit stage, in all studied hybrids (Figure 2). At the hybrid level, comparing the two harvesting stages, there is a significant increase in the Sacher F_1 and Tiger F_1 hybrids. The high Mg content was correlated with the structure of the fruit, which is very strong, very obvious in these hybrids, which confirms that the deposition of this element is done in the cell walls, during the ripening of the fruit. The average values recorded in the red fruit stage are higher than those reported by Kapoulas et al. (2013) in an organic tomato crop (17.36-22.22 mg 100 g^{-1}).



	Antalya F1	Cemile F1	Lorely F1	Tiger F1	Sacher F1	Mean
▨ Rose	20.61	20.11	17.13	22.00	22.14	20.40
🟥 Red	23.08	22.12	18.01	24.00	23.94	22.23
🟩 Mean	21.84	21.12	17.57	23.00	23.04	

	Antalya F1	Cemile F1	Lorely F1	Tiger F1	Sacher F1	Mean
▨ Rose	0.06	0.05	0.05	0.06	0.06	0.06
🟥 Red	0.03	0.03	0.03	0.08	0.03	0.04
🟩 Mean	0.04	0.04	0.04	0.07	0.05	

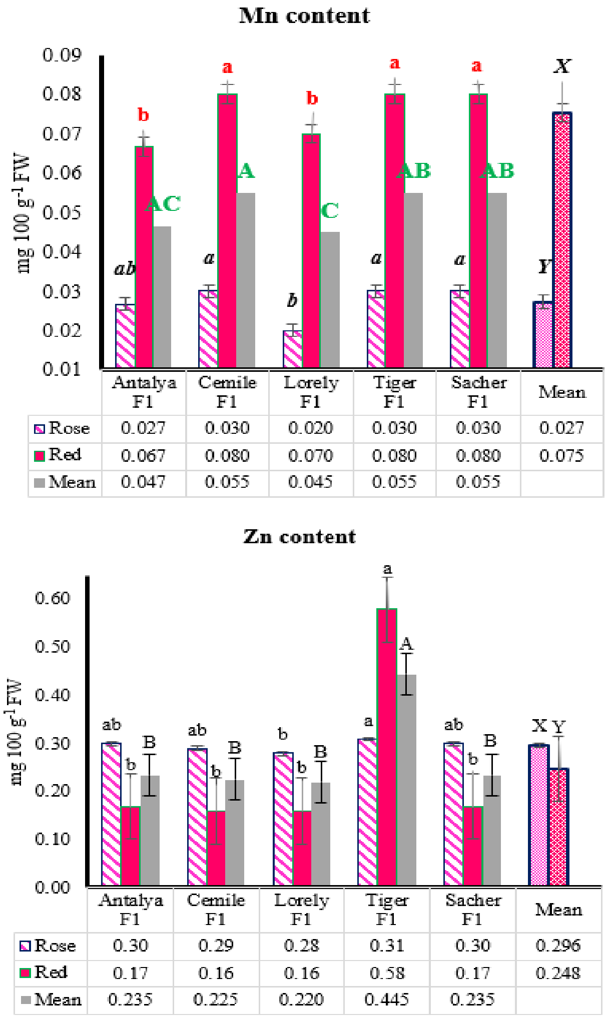
Figure 2. Magnesium and boron content at tomato fruit harvesting stages. Bars represent standard error (SE).

Hadayat et al. (2018) also report higher Mg concentrations in organic tomato crops. This mineral plays a vital role in over 300 enzyme systems in the human body. Its functions include nerve function, protein synthesis, cardiac excitability, attenuation of migraine, Alzheimer’s disease and stroke (Volpe, 2013). A low dietary intake of Mg has been associated with insulin resistance in seemingly healthy adults, as well as worsening cataract problems (Agarwal et al., 2012).

The B, in general, recorded insignificant differences between hybrids both in the pink fruit stage and in the red fruit stage (Figure 2). It should be noted that this mineral recorded higher values in the pink fruit stage than in the red fruit stage when the values decreased in all hybrids. There is only one exception to Tiger F_1, which in the pink fruit stage had 0.06 mg 100 g^{-1} and in the red fruit stage it accumulated 0.08 mg 100 g^{-1}. Our results are consistent with those reported by Ramesh et al. (2020) for tomato varieties in India.

The Mn level ranged from a minimum of 0.02 mg 100 g^{-1} (Lorely F$_1$ in the pink fruit stage) to a maximum of 0.08 mg 100 g^{-1} (Tiger F$_1$, Sacher F$_1$ and Cemil F$_1$ at the red fruit stage) (Figure 3). Comparing the hybrids in the pink fruit stage, nonsignificant differences were observed between them in terms of this microelement. There was a significant increase in this microelement compared to the previous harvest stage. A substantial accumulation in Mn was noted in the fruits of the five tomato hybrids at the red fruit stage as they passed from the pink fruit stage to the red fruit stage.

Nonsignificant differences in Zn concentrations were observed in the present study in four of the five red-fruit tomato hybrids. It ranged from 0.16-0.17 mg 100 g^{-1} in Antalya, Cemile, and Lorely hybrids and increased to 0.58 mg 100 g^{-1} in Tiger F$_1$. In the pink fruit phase, this microelement ranged 0.28-0.31 mg 100 g^{-1} in the five hybrids. We can state that the accumulation of Zn in organic tomato fruits is influenced by the harvesting phase because in the pink fruit stage the content in this microelement was significantly higher than in the red fruit stage (Figure 3). Khan et al. (2017) observed that tomatoes fertilized with organic fertilizers accumulated higher amounts of Zn in fruits but also in roots and shoots. This mineral is seen as a potential antitumor agent in the treatment of cancer (Wiesmann et al., 2018).

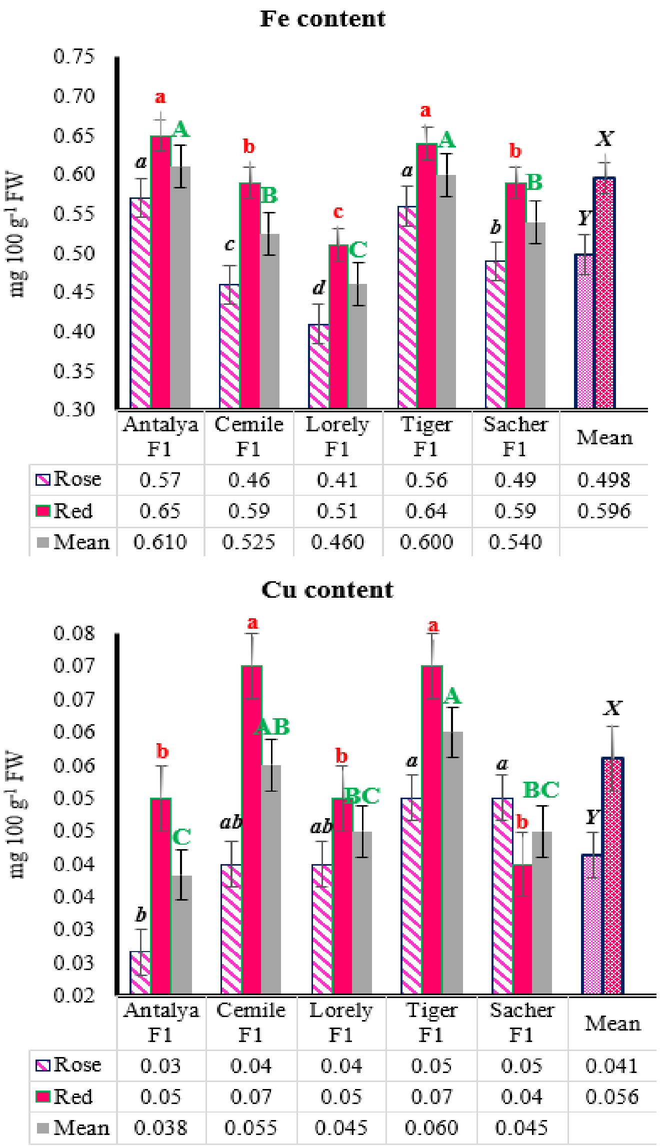


	Antalya F1	Cemile F1	Lorely F1	Tiger F1	Sacher F1	Mean
▨ Rose	0.027	0.030	0.020	0.030	0.030	0.027
■ Red	0.067	0.080	0.070	0.080	0.080	0.075
■ Mean	0.047	0.055	0.045	0.055	0.055	

	Antalya F1	Cemile F1	Lorely F1	Tiger F1	Sacher F1	Mean
▨ Rose	0.30	0.29	0.28	0.31	0.30	0.296
■ Red	0.17	0.16	0.16	0.58	0.17	0.248
■ Mean	0.235	0.225	0.220	0.445	0.235	

Figure 3. Manganese and zinc content at tomato fruit harvesting stages. Bars represent standard error (SE).

The accumulation of Fe in organically grown tomato fruits had average values between 0.41 mg 100 g^{-1} in Lorely F$_1$ in the pink fruit stage and 0.65 mg 100 g^{-1} in Antalya F$_1$ in the red fruit stage (Figure 4). Significant differences were observed between hybrids during the same harvesting stage, but also from one stage to another. The growth of the content in this constituent, from the green fruit stage to the ripe fruit stage is also supported by Shariff et al. (2021) in cucumber. Khan et al. (2017) and Hadayat et al. (2018) reported higher concentrations of Fe in organic or organically fertilized crops of tomatoes.



Fe content

	Antalya F1	Cemile F1	Lorely F1	Tiger F1	Sacher F1	Mean
▨ Rose	0.57	0.46	0.41	0.56	0.49	0.498
■ Red	0.65	0.59	0.51	0.64	0.59	0.596
■ Mean	0.610	0.525	0.460	0.600	0.540	

Cu content

	Antalya F1	Cemile F1	Lorely F1	Tiger F1	Sacher F1	Mean
▨ Rose	0.03	0.04	0.04	0.05	0.05	0.041
■ Red	0.05	0.07	0.05	0.07	0.04	0.056
■ Mean	0.038	0.055	0.045	0.060	0.045	

Figure 4. Iron and copper content at tomato fruit harvesting stages. Bars represent standard error (SE).

The Cu content ranged from the lowest level of 0.03 mg 100 g^{-1} in Antalya F$_1$ in the pink fruit stage to the highest of 0.07 mg 100 g^{-1} in Cemile F$_1$ hybrids and Tiger F$_1$ in the red fruit stage (Figure 4). Comparing the values of Cu in the pink fruit stage with those in the red fruit stage in the five hybrids of organic tomatoes, significant increases are observed.

The accumulation of microelements in organically grown tomato fruits has a special significance: it is known that Mg is involved in antioxidant and nutritional activity, Ca influences the storage period after harvest helping the fruit to not soften and Mn in antioxidant activity.

The tomatoes colour is the most important maturity and quality index. The green colour of uncooked tomatoes is due to the presence of chlorophyll, but during maturation degradation of this pigment occurs, and the synthesis of yellow pigments such as β-carotene and xanthophylls, and red colour is due to lycopene presence (Duma et al., 2015). The carotenoids indirectly affect flavour as precursors of aromatic compounds, while chlorophylls contribute to sugar production through the process of photosynthesis (Aono et al., 2021).

In this study, chlorophyll *a* had the highest values at Cemile F_1, Tiger F_1 and Sacher F_1 hybrids, hybrids with large and medium-sized fruits. This content ranged from 47.0 µg g^{-1} FW in Antalya F_1 to 79.4 µg g^{-1} FW in Sacher F_1, in the green fruit stage. There is a decrease in this constituent in the pink fruit stage, Antalya F_1 having 25.5 µg g^{-1} FW, and Sacher F_1 having 63.0 µg g^{-1} FW. This decrease was very obvious in large fruit hybrids (Antalya F_1, Cemile F_1 and Lorely F_1).

This content is also observed in the rose fruit stage where Sacher F_1 hybrid stands out. Chlorophyll *b* had high values at Sacher F_1 hybrid, in the green fruit phase, and at Tiger F_1 and Sacher F_1 hybrids in the rose fruit phase (Table 2). Similar results were reported by Soare et al. (2019) in a conventional tomato crop. Consequently, it can be stated that the organic culture system has directly influenced the accumulation of chlorophyll *a* and *b* in tomato fruits, a statement also supported by Khan et al. (2017), who observed that chlorophyll *a* and *b* in tomato fruits can be significantly larger in organically fertilized plants. Reduction of chlorophyll during ripening is replaced by carotenoids, mainly lycopene. Starting with the white-yellow phase, the antioxidant activity of tomato fruits begins to increase as the lycopene content of the fruit begins to increase. Our results suggest the importance of these pigments not only as components of fruit colour, but also as constituents that influence flavour traits, such as sugars and flavour composition.

Table 2. Variation of content in chlorophylls by harvesting stages of tomato fruits taken into study. Means followed by the same letter are not significantly different according to Duncan's multiple range test (P = 0.05).

	Green harvesting phase		Beginning of ripening (rose stage)	
Hybrids	Chlorophyll *a*	Chlorophyll *b*	Chlorophyll *a*	Chlorophyll *b*
	µg g^{-1} FW			
Antalya F_1	47.0^b	24.2^c	25.5^e	13.4^b
Cemil F_1	70.4^a	32.8^b	32.5^c	14.8^b
Lorely F_1	48.7^b	26.0^c	27.4^d	13.3^b
Tiger F_1	70.4^a	32.8^b	55.7^b	28.7^a
Sacher F_1	79.4^a	41.8^a	63.0^a	27.2^a

Content in total soluble solids (TSS). It is one of the most important quality factors for the vast majority of fruits intended for fresh consumption. It is also a taste indicator because reducing sugars (glucose and fructose) are soluble in the main components of tomatoes. Fruits with a high concentration of dry substances have a better taste, a higher processing yield and have a better transportability and storage quality during storage.

In this study, dry soluble substances experienced a continuous increase during harvesting steps, the highest content being at physiological maturity (Table 3). It recorded variations from 2.3-4.9 °Brix in the green fruit phase, then to 3.3-5.9 °Brix before ripening (rose) stage and to increase to 4.2-7.9 °Brix in the red fruit stage. There were differences between hybrids on all three harvesting phases, Sacher F_1 and Tiger F_1 standing out.

The average values of this constituent highlight the hybrids with red-brick and red-brown fruits (dark fruits). This observation is also supported by Kurina et al. (2021) on a batch of 70 organically fertilized tomato genotypes, which found that hybrids with dark red or reddish-brown fruits accumulated more DM (6.46%) than other hybrids.

The recorded values are comparable to those obtained by Duma et al. (2015) and Tudor-Radu et al. (2016) according to the harvesting phase. Oliveira et al. (2013) report 57% higher soluble solids content at full maturity in organically obtained tomato fruits.

Table 3. Content variation in total soluble solids (TSS) and titratable acidity (TA) in tomato fruit on harvesting phases. Means followed by the same letter are not significantly different according to Duncan's multiple range test (P = 0.05).

Hybrids	Green harvesting phase		Beginning of ripening (rose stage)		Red harvesting phase	
	TSS	TA	TSS	TA	TSS	TA
	°Brix	% citric acid	°Brix	% citric acid	°Brix	% citric acid
Antalya F_1	3.2^b	0.68^a	4.3^c	0.68^a	5.3^c	0.69^a
Cemil F_1	3.6^{ab}	0.64^a	4.5^{bc}	0.63^a	5.8^{bc}	0.50^{ab}
Lorely F_1	2.3^b	0.47^b	3.3^d	0.45^b	4.2^d	0.48^b
Tiger F_1	4.8^a	0.69^a	5.6^a	0.70^a	7.9^a	0.65^a
Sacher F_1	4.9^a	0.74^a	5.9^a	0.73^a	7.8^a	0.68^a

Titratable acidity (TA). It was variable in the three harvesting phases and different by hybrid (Table 3). Highest values were recorded at Tiger F_1 and Sacher F_1 hybrids in the first two harvesting phases with the maximum value at the beginning of ripening (Sacher F_1 0.73% citric acid and Tiger F_1 0.70% citric acid) and then decreasing in the red fruit stage. The results at Antalya F_1, Cemile F_1 and Lorely F_1 hybrids of this study are similar to those of Oliveira et al. (2013) in that TA was greater or equal in green and red harvesting stages and lower at the beginning of ripening. Oliveira et al. (2013) state that TA of organically obtained tomato fruits was + 29% higher than that of fruits obtained in conventional culture.

The effect of culture system on TA may actually be an important factor in the physiological maturity of the fruit. This can be influenced by the vegetative growth of plants which in conventional culture is higher than in the organic one. Vegetative growths can shade the fruit and can therefore reduce the content of TSS and TA. Also, the tomato culture being set up in a polyethylene tunnel, thanks to the covering polyethylene film, a UV selectivity is achieved which influences the acidity of fruits. This affirmation is supported by Pop (2014), who found that mulched strawberry culture film, compared to agrotextil foil or straw mulched culture, had the lowest TA.

Taste and maturity indexes. They are calculated using °Brix and TA to characterize tomato quality and taste. Using these data, average values of the taste index for all the analysed tomato hybrids on the three ripening stages had maximum values of 0.39 for the Tiger F_1 (rose stage and red phase) and Sacher F_1 hybrids (in red phase) (Table 4). At full maturity, the taste index is a better predictor of flavour impact than acidity (°Brix). The TSS content increases during fruit maturation and reaches the highest value in the red stage (Table 3). It has been noticed that tomato hybrid and maturing stage have a significant influence on the maturity value. Tiger F_1 hybrid had an average maturity of 6.9 in the green phase, increased to 8.0 before ripening phase and at physiological maturity reached 12.1. These rising values are also observed in Sacher F_1, Cemile F_1 and Lorely F_1 hybrids. Comparing maturity increases on maturation stages, the recorded values are similar to those documented by Duma et al. (2015). The taste of the fruit is an indicator that changes depending on cultivation technology, varietal characteristics of genotypes, as well as the degree of ripeness of the fruit. Sugar index and TA are indicators of fruit quality: The higher they are, the tastier is the product.

Table 4. Variation of the taste and maturity index of tomato fruit on harvesting phases.

Hybrids	Green harvesting phase		Beginning of ripening (rose stage)		Red harvesting phase	
	Taste index	Maturity	Taste index	Maturity	Taste index	Maturity
Antalya F_1	0.16	4.7	0.21	6.3	0.26	7.6
Cemil F_1	0.18	5.6	0.22	7.1	0.29	11.6
Lorely F_1	0.11	4.8	0.16	7.3	0.21	8.7
Tiger F_1	0.24	6.9	0.39	8.0	0.39	12.1
Sacher F_1	0.24	6.6	0.29	8.0	0.39	11.4

Carotenoid content. Results of this study revealed an increase in carotenoid content in all studied hybrids that are significantly higher during ripening. Comparing the five tomato hybrids, it can be observed that carotenoid content did not show very large variations between green phase (average 6.44 mg 100 g^{-1} FW), but there were significant differences in red phase (Table 5). The highest content was recorded in small (Tiger F_1) and medium (Sacher F_1) fruit tomatoes compared to large fruit tomatoes (Cemile F_1), which shows that this content can also be influenced by fruit size. Thus, this content was influenced by the hybrid, the size or the characteristics of the fruits and the organic culture system. This statement is in consensus with the results obtained by Hallmann (2012), which in a study on cherry tomatoes and standard tomatoes found that cherry fruit in the 2 yr experiment had a higher content of β-carotenes than the standard ones. Similar results were obtained by Duma et al. (2015). Accumulation of carotene may be influenced by the fruit maturity phase, genotype, and culture system (Soare et al., 2019). Zoran et al. (2014) found that 'Robin' hybrid cultivated in organic system had the highest content in fruit carotenoids (4.03 mg 100 g^{-1}) compared to the other two studied varieties. Organic grown tomatoes have a higher content of carotenoids compared to conventional crops, as found by Kapoulas et al. (2011), in a comparative study between the organic and conventional systems, with higher carotenoid content in organic system.

Table 5. Variation in ascorbic acid (vitamin C) and total carotene content in tomato fruit on harvesting phases. Means followed by the same letter are not significantly different according to Duncan's multiple range test (P = 0.05).

	Green harvesting phase		Beginning of ripening (rose stage)		Red harvesting phase	
Hybrids	Total carotene	Ascorbic acid	Total carotene	Ascorbic acid	Total carotene	Ascorbic acid
	mg 100 g^{-1} FW					
Antalya F_1	6.1^b	6.7^a	8.3^c	17.2^a	10.6^{bcd}	21.3^a
Cemil F_1	5.0^b	4.8^b	8.2^c	16.9^a	10.3^{cd}	19.9^{ab}
Lorely F_1	5.8^b	5.7^{ab}	8.5^c	15.2^b	9.5^d	16.7^{bc}
Tiger F_1	5.0^b	5.9^a	11.8^b	15.0^b	18.0^a	15.8^{bc}
Sacher F_1	10.3^a	6.2^a	14.5^a	15.3^b	17.0^a	16.0^{bc}

Quality of tomato fruit is defined as the sum of all the characteristics that satisfy the consumer. In addition to nutritional and functional characteristics, also culture system (organic or conventional) can be included, culture place (in open field or protected culture), cultivar, colour fruits, consistency and many other features. Our study highlights high carotenoid content in dark fruits (Tiger F_1 and Sacher F_1) just like the study of Kurina et al. (2021) but with superior results than those.

The nutritional value of tomato fruits is determined, first of all, by the high content of vitamins, among which ascorbic acid (vitamin C) occupies one of the first places. Vitamin C is one of the most important natural antioxidants, its biological significance is based on the ability to participate in various enzymatic processes, hydroxylation, and oxidation-reduction. Vegetable vitamin C content may vary depending on environmental and stress factors, such as light intensity, temperature, humidity, air pollution, etc. (Singh et al., 2012).

Average values that refer to vitamin C content of this study showed that physiological maturity stage had a significant influence (Table 5). Antalya F_1 hybrid in the green phase had the highest vitamin C content of 6.7 mg 100 g^{-1} FW with significant differences between hybrids. Results show that this hybrid has maintained these high values also in the ripening stage (17.2 mg 100 g^{-1} FW) and at full maturity (21.3 mg 100 g^{-1} FW). Values obtained in this study were similar or slightly different from those reported by other researchers (Harish et al., 2012; Oliveira et al., 2013; Duma et al., 2015). In organically grown tomatoes, it was observed that tomato fruits from plants that have undergone stressful conditions of culture, conditions that have led to oxidative stress and accumulation of higher TSS like sugars and other compounds contribute to the nutritional quality of fruits such as vitamin C and phenolic compounds.

Kapoulas et al. (2011) conducted a study on three tomato hybrids cultivated in greenhouses in north-east Greece in organic and conventional system and found that ascorbic acid content of all organically grown varieties was lower while the content in carotene was higher in organic than conventional farming. Results on ascorbic acid content in this study showed that was higher in the fruit harvested at the full physiological maturity stage than that obtained by Kapoulas et al. (2011).

Results of this study show significant differences between ascorbic acid content of organically produced tomatoes, depending on the hybrid. Martí et al. (2018) found that the ascorbic acid content may increase depending on the hybrid in some organically grown tomato cultivars. The effect of organic culture on ascorbic acid was dependent on the cultivar and the environment and only led to a 58% increase over conventional culture.

After a general analysis of the nutritional parameters of tomato fruits grown in organic culture, our observations suggest that they experienced stressful conditions that led to oxidative stress and accumulation of higher TSS, TA, ascorbic acid and other compounds that contribute to the nutritional quality of fruits.

CONCLUSIONS

The present study clearly shows that organic tomatoes are of better quality with regard to ascorbic acid content and carotenes. The quality elements (chlorophyll *a* and *b*, titratable acidity, total soluble solids and maturity index) changed during the maturity stages for all the five organically grown tomato cultivars. The content of minerals (K, Ca, Mg, Cu, Fe and Mn) in tomato fruits in the red fruit stage have increased significantly in this organic crop. This can reduce the application of chemical fertilizers and can therefore be considered a noble practice in sustainable agriculture.

Until recently, the emphasis in vegetable growing was mainly on the obtained production and less on the taste and nutritional qualities of fruit. Our observations suggest that at least for vegetables and fruits there should be insisted more on the nutritional quality and less on yield, this being done successfully in an ecological culture system. Future research is required to better understand the physiological mechanisms that are at the base of organic system and which positively influence the quality of vegetables. The crop system, the hybrid and the size of the fruit had a significant influence on the K content. Finally, environmental issues help organic products to gain a better position on the market.

Author contribution

Conceptualization: M.D., R.S., G.H. Methodology: M.D., C.B. Software: M.B. Validation: M.B. Formal analysis: M.B. Investigation: C.B., M.D., R.S., G.H. Resources: M.D., S.R. Data curation: M.D., C.B. Writing-original draft: M.D. Writing-review & editing: M.D., R.S., M.B. Visualization: M.D., R.S. Supervision: M.B. All co-authors reviewed the final version and approved the manuscript before submission.

References

Agarwal, R., Iezhitsa, I., Agarwal, P., and Spasov, A. 2012. Magnesium deficiency: Does it have a role to play in cataractogenesis? Experimental Eye Research 101:82-89.

Aono, Y., Asikin, Y., Wang, N., Tieman, D., Klee, H., Kusano, M. 2021. High-throughput chlorophyll and carotenoid profiling reveals positive associations with sugar and apocarotenoid volatile content in fruits of tomato varieties in modern and wild accessions. Metabolites 11(6):398. doi:10.3390/metabo11060398.

Araújo, D.F.S., da Silva, A.M.R.B., Lima, L.L.A., Vasconcelos, M.A.S., Andrade, S.A.C., Sarubbo, L.A. 2014. The concentration of minerals and physicochemical contaminants in conventional and organic vegetables. Food Control 44:242-248. doi:10.1016/j.foodcont 2014.04.005.

Borguini, R.G., Bastos, D.H.M., Moita-Neto, J.M., Capasso, F.S., Silva-Torres, E.A.F. 2013. Antioxidant potential of tomatoes cultivated in organic and conventional systems. Brazilian Archives of Biology and Technology 56:521-529. doi:10.1590/S1516-89132013000400001.

Carocho, M., Ferreira, I.F. 2013. Role of phenolic compounds in the fight against cancer- A review. Anticancer Agents in Medicinal Chemistry 13(8):1236-1258.

Cosmulescu, S., Botu, M., Trandafir, I. 2010. Mineral composition and physical characteristics of walnut (*Juglans regia* L.) cultivars originating in Romani. Selcuk Journal of Agriculture and Food Sciences 24(4):33-37.

Dinu, M., Dumitru, M.G., Soare, R. 2015.The effect of some biofertilizers on the biochemical components of the tomato plants and fruits. Bulgarian Journal of Agricultural Science 21(5):998-1004.

Dinu, M., Soare, R., Gruia, M. 2016. Bioactive compounds and antioxidant activity in commercial cultivars of tomato (*Lycopersicum esculentum* L.) 16th International Multidisciplinary Scientific GeoConference (SGEM 2016), Albena, Bulgaria. 20 June-6 July. Book 5(2):149-156.

Duma, M., Alsina, I., Dubova, L., Erdberga, I. 2015. Chemical composition of tomatoes depending on the stage of ripening. Chemine Technologija 1(66):24-28.

FAO. 2020. FAOSTAT. Base de datos cultivos. Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO), Roma, Italia. http://www.fao.org/faostat/es/#data/QC/visualize (accessed 3 June 2022).

Hadayat, N., de Oliveira, L.M., da Silva, E., Han, L., Hussain, M., Liu, X., et al. 2018. Assessment of trace metals in five most-consumed vegetables in the US: Conventional vs. organic. Environmental Pollution 243:292-300. doi:10.1016/j.envpol.2018.08.065.

Hallmann, E. 2012. The influence of organic and conventional cultivation system on the nutritional value and content of bioactive compounds in selected tomato types. Science Food and Agriculture 92(14):2840-2848.

Harish, M.CH., Shanmugaraj, B.M., Balamurugan, S., Sathishkumar, R. 2012. Influence of genotypic variations on antioxidant properties in different fractions of tomato. Journal of Food Science 77(11):1174-1178. doi:10.1111/j.1750-3841.2012.02962.x.

IFOAM-Organics International. 2020. Global organic area continues to grow! IFOAM-Organics International, Bonn, Germany. Available at https://ifoam.bio/global-organic-area-continues-grow (accessed 6 March 2021).

Kapoulas, N., Ilic, Z., Durovka, M., Trajkovic, R., Milenkovic, L. 2011. Effect of organic and conventional production practices on nutritional value and antioxidant activity of tomatoes. African Journal of Biotechnology 10(71):15938-15945.

Kapoulas, N., Ilić, Z.S., Milenković, L., Mirecki, N. 2013. Effects of organic and conventional cultivation methods on mineral content and taste parameters in tomato fruit. Agriculture & Forestry 59(3):23-34.

Khan, M.Y., Haque, M., Molla, A.H., Rahman, M., Alam, M.Z. 2017. Antioxidant compounds and minerals in tomatoes by *Trichoderma*-enriched biofertilizer and their relationship with the soil environments. Journal of Integrative Agriculture 16(3):691-703.

Kotkov, Z., Lachman, J., Hejtmnkov, A., Hejtmnkov, K. 2011. Determination of antioxidant activity and antioxidant content in tomato varieties and evaluation of mutual interactions between antioxidants. LWT-Journal of Food Science and Technology 44(8):1703-1710.

Kurina, A.B., Solovieva, A.E., Khrapalova, I.A., Artemyeva, A.M. 2021. Biochemical composition of tomato fruits of various colors. Vavilovskii Zhurnal Genet Selektsii 25(5):514-527. doi:10.18699/VJ21.058.

Martí, R., Leiva-Brondo, M., Lahoz, I., Campillo, C., Cebolla-Cornejo, J., Roselló, S. 2018. Polyphenol and L-ascorbic acid content in tomato as influenced by high lycopene genotypes and organic farming at different environments. Food Chemistry 239:148-156. doi:10.1016/j.foodchem.2017.06.102.

Nagata, M., Yamashita, I. 1992. Simple method for simultaneous determination of chlorophyll and carotenoids in tomato fruit. Nippon Shokuhin Kogyo Gakkaish 39(10):925-928. doi:10.3136/nskkk1962.39.925.

Navez, B., Letard, M., Graselly, D., Jost, J. 1999. Les critéres de qualité de la tomate. Infos CTIFL 155:41-47.

Nielsen, S. 2003. Food analysis. 3rd ed. Kluwer Academic, New York, USA.

Oliveira, A.B., Moura, C.F.H., Romero, D.C. 2013. The impact of organic farming on quality of tomatoes is associated to increased oxidative stress during fruit development. PLOS ONE 8(2):e56354. doi:10.1371/journal.pone.0056354.

Ordóñez-Santos, L.E., Vázquez-Odériz, M.L., Romero-Rodríguez M.A. 2011. Micronutrient contents in organic and conventional tomatoes (*Solanum lycopersicum* L.) International Journal of Food Science and Technology 46:1561-1568.

Pop, D.F. 2014. Cercetări privind comportarea unor soiuri de căpşun în sistem clasic şi ecologic în condițiile pedoclimatice din Depresiunea Transilvaniei. Teză de doctorat. Universitatea de Ştiinţe Agricole şi Medicină Veterinară (USAMV), Facultatea de Horticultură, Cluj-Napoca, Romania.

Ramesh, K.V., Paul, V., Pandey, R. 2020. Dynamics of mineral nutrients in tomato (*Solanum lycopersicum* L.) fruits during ripening: part I - on the plant. Plant Physiology Reports 26(1):23-37. doi:10.1007/s40502-020-00546-0.

Ray, R.C., El Sheikha, A.F., Panda, S.H., Montet, D. 2011. Anti-oxidant properties and other functional attributes of tomato: An overview. International Journal of Food Farmacy and Technology 1(2):139-148.

Sellitto, V.M., Golubkina, N.A, Pietrantonio, L., Cozzolino, E., Cuciniello, A., Cenvinzo,V., et al. 2019. Tomato yield, quality, mineral composition and antioxidants as affected by beneficial microorganisms under soil salinity induced by balanced nutrient solutions. Agriculture 9(5):110. doi:10.3390/agriculture9050110.

Shariff, A.H.M., Zulaikha, P.N., Wahab, M.M.A., Jahurul, A.H., Huda, N., Romes, N.B., et al. 2021. Nutrient composition, total phenolic content, and antioxidant activity of tropical Kundasang-grown cucumber at two growth stages. Chilean Journal of Agricultural Research 81:220-227.

Singh, D.P., Beloy, J., McInerney, J.K., Day, L. 2012. Impact of boron, calcium and genetic factors on vitamin C, carotenoids, phenolic acids, anthocyanins and antioxidant capacity of carrots (*Daucus carota*). Food Chemistry 132(3):1161-1170.

Soare, R., Dinu, M., Apahidean, A.I., Soare, M. 2019. The evolution of some nutritional parameters of the tomato fruit during the harvesting stages. Horticultural Science (Prague) 46(3):132-137. doi:10.17221/222/2017-HORTSCI.

Tudor-Radu, M., Vijan, L.E., Tudor-Radu, C.M., Tita, I., Sima, R., Mitrea, R. 2016. Assessment of ascorbic acid, polyphenols, flavonoids, anthocyanins and carotenoids content in tomato fruits. Notule Botanicae Horti Agrobo 44(2):477-483.

Vélez-Terreros, P., Romero-Estévez, D., Yánez-Jacomeá, Simbãna-Farinango, K., Navarrete, H. 2021. Comparison of major nutrients and minerals between organic and conventional tomatoes. A review. Journal of Food Composition and Analysis 100:103922. doi:10.1016/j.jfca.2021.103922.

Vinha, A.F., Barreira, S.V.P., Costa, A.S.G., Alves, R.C., Oliveira, M.B.P.P. 2014. Organic *versus* conventional tomatoes: Influence on physicochemical parameters, bioactive compounds and sensorial attributes. Food and Chemical Toxicology 67:139-144. doi:10.1016/j.fct.2014.02.018.

Volpe, S.L. 2013. Magnesium in disease prevention and overall health. Advances in Nutrition 4(3):378S-383S. doi:10.3945/an.112.003483.

Wiesmann, N., Kluenker, M., Demuth, P., Brenner, W., Tremel, W., Brieger, J. 2018. Zinc overload mediated by zinc oxide nanoparticles as innovative anti-tumor agent. Journal of Trace Elements in Medicine and Biology 51:226-234.

Zoran, I.S., Kapoulas, N., Sunić, L. 2014. Tomato fruit quality from organic and conventional production. p.147-169. In Pilipavicius, V. (ed.) Organic agriculture towards sustainability. IntechOpen, London, UK.