https://doi.org/10.17221/222/2017-HORTSCI

The evolution of some nutritional parameters of the tomato fruit during the harvesting stages

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Citation: Soare R., Dinu M., Apahidean A.I., Soare M. (2019): The evolution of some nutritional parameters of the tomato fruit during the harvesting stages. Hort. Sci. (Prague), 46: 132–137.

Abstract: The main purpose of this study was to highlight the nutraceutical value of the tomato fruit for five hybrids recently introduced in culture, during the harvesting phases: mature green, half ripen and full ripen: 'Antalya', 'Cemil', 'Lorely', 'Tiger' and 'Sacher'. They differentiate because of their size and fruit colour. The parameters to be followed for each harvest phase were: the chlorophyll a and b content, the total carotenes, the soluble substance, vitamin C, the titratable acidity, and also a maturity index was established. The results obtained showed significant differences between the hybrids, but also during the maturation phases. It singularised Tiger F_1 with a total carotene content of 7.1 (green) to 12.5 (half ripen) and 18.6 mg/100g f.w. (in full ripen) and Sacher F_1 with vitamin C from 6.2 (green) to 17.2 (half ripen) and 20.7 mg/100g f.w. (in full ripen). This variability can be attributed to these harvesting phases, but also to the genetic factors, such as cultivar type, fruit size and colour.

Keywords: mature green; half ripen; full ripen; vitamin C; carotene

Tomatoes (*Lycopersicon esculentum* L.) are among the most famous vegetables in the world and they are highly used in Mediterranean food consumption as an important antioxidant source with a beneficial effect on man's health, especially as the prevention of different cancer types and heart diseases are concerned (Pinela et al. 2012; Dinu et al. 2017). The tomato species (*Lycopersicon esculentum* Mill.) is one of the most important species in economic and nutritional terms because of its high content in carotenoids, phenols, vitamins and minerals (Ray et al. 2011). The fruit of this species have a rich content of bioactive compounds, which explains the consumer's high interest in the relationship between food and health (Dinu et al. 2016).

Tomato fruits can be harvested according to market and consumer requirements during the different ripening stages, according to the consumer and market requirements: green, green-orange, orange-red and red-ripe (Leonardi et al. 2000; Ilahy et al. 2011). Usually, tomatoes are consumed when they reach physiological maturity, the moment of their highest quality value. Taking the growing conditions, the cultivar and other factors into consideration, tomato fruits are often harvested during their mature green stage to minimise post-harvest damage (Duma et al. 2015; Moneruzzaman et al. 2008). Many vegetables, in particular leafy vegetables and immature fruit-vegetables reach their optimum eating-quality prior to reaching full maturity. This often results in a delayed harvest, and, consequently, in low quality production (Kader, Rolle 2004). The producer must know the optimum harvesting time because the quality can be affected either by early harvesting or by

https://doi.org/10.17221/222/2017-HORTSCI

yield overtaking and the storage conditions. In terms of the nutritional value, tomatoes are perfect for picking if they are over-matured on the plants rather than being stored (Weingerl, Unuk 2015). Tomato hybrids which have been recently introduced on the market require thorough studies for their ecological stability and plasticity as well as the nutritional qualities. The purpose of this study was the evolution of some nutritional parameters of the tomato fruits collected from a plastic greenhouse, during their different stages of harvesting.

MATERIAL AND METHODS

Plant material. The biological material was represented by 5 tomato hybrids: 'Antalya', 'Cemil', 'Lorely', 'Tiger' and 'Sacher'. The hybrids were cultivated in an unheated greenhouse (plastic) of the Faculty of Agriculture and Horticulture, Craiova, Romania. The planting was undertaken in the first of May 2014, according to the following technological scheme: 50 + 100 (9) + 50 × 35 cm, (in a 10-meter-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 9 intervals). All hybrids were grown under identical conventional growing practices. In order to achieve the objectives set, determinations and analyses were carried out on the tomato fruits, in the dynamics depending on the harvesting phase (green, half ripen and full ripen).

The harvesting stages of the tomato fruits were visually determined, as follows: the green fruit stage (green) – when some light colour stripes appeared at the top of the fruit, usually star-shaped, indicating the fact that the fruit is in the mature green phase, i.e., it is ready to be harvested; the pink fruit stage – when 30%, but not more than 60%, of the surface of the fruit is of a red-pink colour; the red ripening stage (full ripen) – when more than 90% of the surface of the fruit is red.

These are differentiated by the fruit size and colour and fruit weight (Table 1).

For each harvesting stage, the chlorophyll pigments (chlorophyll *a* and *b*), the total carotene, vitamin C, the titratable acidity (TA), the total soluble substance and the taste and maturity index were monitored.

Samples preparation. Depending on the maturation, from each hybrid, 10 fruits were harvested and brought to the laboratory where they were washed and then they were wiped with paper towels. The pericarp and mesocarp were placed in a blender for 1 min, resulting in a homogeneous purée. The experiments were performed three times in order to measure the parameters analysed in the study and the results were expressed as a means of the repetitions. All the reagents used for the analysis were from Sigma Aldrich, Germany.

The determination of the total carotenoids and chlorophylls. The weighed samples, having been put separately in 95% acetone (50 ml for each gram), were homogenised with a Braun MR 404 Plus for one minute. The homogenate was filtered and was centrifuged using a Hettich Universal 320/320R centrifuge at 2,500 rpm for ten minutes. The supernatant was separated and the absorbances were read at 400–700 nm on a Cary 50 spectrophotometer. It was recorded that chlorophyll *a* showed the maximum absorbance at 662 nm, chlorophyll *b* at 646 nm and the total carotene at 470 nm. The value of these pigments was calculated according to the formulas (Dere et al. 1998). The results were expressed as mg/100 g f.w.

The determination of the titratable acidity. From a sample of 5–10 g of tomato homogenate with a vertical Braun MR 404 Plus blender for 1 min, 1–2 ml were taken and were diluted in 10 ml of distilled water and titrated with 0.1 N sodium

Table 1. The morphological characteristics of the tomato cultivars taken into the study

Hybrid	Colour at maturation	Fruit shape	Fruit dimension		Shape index (SI = H/D)	Average fruit weight (g)
			height (mm)	diameter (mm)		
Antalya F_1	red	round	54.11	61.83	0.87	180
Cemil F_1	red	round	56.2	62.1	0.90	250
Lorely F_1	red	round	54.10	61.0	0.88	220
Tiger F_1	bi-colored dark red and green	round (cherry)	32.24	32.14	1.00	35
Sacher F_1	brownish red	round	49.50	52.5	0.94	105

for each harvesting stage, chlorophyll pigments (chlorophyll *a* and *b*), total carotene, vitamin C, titratable acidity (TA), total soluble substance and taste and maturity index were monitored; SI – shape index; H – height; D – diameter

https://doi.org/10.17221/222/2017-HORTSCI

hydroxide in the presence of phenolphthalein and expressed as a (%).

The acidity (*TA*) is calculated by using the formula:

$$TA,(\%) = \frac{V \times N}{m} \times 100$$

where: V – the volume of the NaOH solution used for titration (ml); m – the sample weight (g);
N – the normality of the NaOH solution

The ascorbic acid was determined by titration using a 2,6-dichlorophenolindophenol sodium salt solution (AOAC 1990). 2 g of tomato purée was used and a 50 ml of a 1% HCl and 5% HPO_3 mixture was added (1 : 1 v/v). The obtained solution was filtered after 30 minutes. Then, 10 ml of the filtered solution was taken and the titration was performed with the 2,6- dichlorophenolindophenol. The concentration of the ascorbic acid was calculated according to the equation by Moneruzzaman et al. 2008.

The total soluble substance (TSS) content was determined using a Portable Refractometer from Optech Optimal Technology, Germany.

The maturity index was calculated as the ratio of TSS to the titratable acidity and the flavour index [(TSS/20 × titratable acidity) + titratable acidity] (Navez et al. 1999; Nielsen 2003).

The statistical analysis. The data recorded were statistically processed by using the analysis of variance (ANOVA). The means were compared by using Duncan's multiple range test and the Least Significant Difference (LSD) at the level of probability $P \leq 0.05\%$.

RESULTS AND DISCUSSION

Tomato fruits contain high levels of antioxidants, such as vitamin C, polyphenols (including flavonoids), carotenoids (lycopene and beta-carotene) and minerals. These concentrations depend on the genetic factors, the crop system and the environmental factors, on the cultivar, but also on the harvest stage.

The colour of the tomatoes is an important index for the maturity and quality. The green colour of an unripe tomato fruit is due to the presence of chlorophyll, but the degradation of this pigment takes place during maturation and the synthesis of the yellow pigments such as β-carotene and xanthophylls or the redness due to the presence of lycopene starts to occur (Ilahy et al. 2011; Duma et al. 2015). In the present study, in the green fruit phase, there is a high chlorophyll content, so the Sacher F_1 had the highest values in chlorophyll *a* in both the green and half ripen phases, followed by the Cemil F_1 and Tiger F_1 hybrids. As chlorophyll *b* is concerned, high values were recorded by the Sacher F1, in the green fruit phase and in the half ripen fruit stage by the Tiger F_1 and Sacher F_1. The reduction of chlorophylls during the ripening phase was replaced by the carotenoid growth (Table 2).

Harvest maturation is very important in terms of the tomatoes' contents and quality. Numerous studies have shown that the crop system and the harvesting time influence the nutritional value of the obtained yield. High levels of sugars and organic acids are essential components of a fruit's quality. Patanè and Cosentino (2010) claim that during maturation, the concentrations of sugars, carotenoids and organic acids tend to increase. These ingredients are responsible for the sweet and sour taste of the tomato fruits. The increase in the carbohydrate level has led to a higher ratio of sugar and organic acids that makes the fruits sweet and pleasantly flavoured. Moneruzzaman et al. (2008) reported an increase in the total soluble substance content in tomatoes that reached physiological maturity because of the synthetic polysaccharide degradation. The total soluble solids are one of the most important quality factors for most fruits,

Table 2. The variation in the tomatoes' chlorophyll content during the harvesting phases

Hybrid	Green harvesting phase		Half ripen harvesting phase	
	chlorophyll *a*	chlorophyll *b*	chlorophyll *a*	chlorophyll *b*
Antalya F_1	51.0^{b}	24.7^{bc}	26.2^{c}	11.3^{c}
Cemil F_1	47.0^{b}	26.3^{ab}	27.0^{c}	14.7^{bc}
Lorely F_1	34.2^{c}	16.0^{c}	22.2^{c}	16.3^{b}
Tiger F_1	47.0^{b}	26.3^{ab}	44.6^{b}	23.1^{a}
Sacher F_1	63.0^{a}	35.9^{a}	54.0^{a}	21.9^{a}
LSD ≤ 0.05	10.21	10.11	4.41	3.67

values represent the mean in the same column followed by different superscript letters are significantly different at $P < 0.05$

https://doi.org/10.17221/222/2017-HORTSCI

Table 3. The content variation in the TSS and titratable acidity in the tomato fruit during the harvesting phases

Hybrid	Stage of ripening					
	green		half ripen		full ripen	
	TSS (°Brix)	titratable acidity (%)	TSS (°Brix)	titratable acidity (%)	TSS (°Brix)	titratable acidity (%)
Antalya F_1	3.8^b	0.68^b	4.0^b	0.55^b	5.5^b	0.42^a
Cemil F_1	3.5^b	0.64^c	4.3^b	0.53^b	5.1^b	0.41^b
Lorely F_1	3.1^c	0.50^c	4.5^b	0.48^b	5.8^b	0.41^b
Tiger F_1	4.3^a	0.69^b	6.2^a	0.68^a	7.5^a	0.39^c
Sacher F_1	4.5^a	0.72^a	6.5^a	0.71^a	7.2^a	0.33^d
LSD ≤ 0.05	0.32	0.15	1.22	0.12	1.11	0.11

values represent the mean in the same column followed by the different superscript letters are significantly different at $P < 0.05$

and being within the range of 4.8–8.8°Brix indicates the highest tomato quality (Duma et al. 2015). In the present study, the total soluble substance recorded a continuous increase during the harvesting stages, the highest content being reached when at the physiological maturity (Table 3). Thus, the values were 2.3 to 4.9°Brix in the green fruit phase, then the values of 3.3–5.9°Brix were reached in the half ripen fruit phase and increased to 4.2–7.9°Brix in the full ripen phase. The difference in the values is due to both the harvesting phase and to the hybrids studied, singularising the Sacher F_1, Tiger F_1 and Cemil F_1 with higher values. The recorded values are comparable to those obtained by Duma et al. (2015); Luna-GuevarA et al. (2014) and Oliveira et al. (2013).

The results of the analyses which refer to the tomato fruit acidity are presented in Table 3. Our results indicate a decrease in the acidity along with the fruit maturation, recording significant differences for the Tiger and Sacher hybrids. The results are, in general, similar to those reported by other researchers who showed a decrease in acidity during the full maturity phase (Duma et al. 2015; Weingerl, Unuk 2015). The quantity of the nutrients depends on the cultivar's yield potential, ripening, maturity, variety and environmental conditions (Sima et al. 2009).

In the present study, a significant variation was recorded in the vitamin C content during all the harvesting stages. Thus, during the green phase, the minimum value of 4.8 mg/100 g f.w. was recorded by the Cemil F_1 and the highest of 6.7 mg/100 g f.w. by the Antalya F_1. During fruit growth in the half ripen phase, the vitamin C content was also 19.2 mg/100 g f.w. by the Antalya F_1. During the full ripen phase, the maximum content of vitamin C was 20.7 mg/100 g f.w. by the Sacher F_1. These values are in agreement with the concentration of the ascorbic acid reported by Tigist et al. (2013), between 14.6 and 21.7 mg/100 g f.w. for a ripe tomato fruit, while Sima et al. (2009) reported values between 20.42–24.28 mg/100 g f.w. The values of the vitamin C content during the maturation phases have also been reported by Oliveira et al. (2013), showing the maximum accumulations during full ripen phase and Radzevičius et al. (2012) reported values of 20.4 mg/100 g for the fully ripen fruits. It can be said that there is a large variation in the vitamin C content between the tomato cultivars.

The dynamics of the variations in the carotene total content in the tomato fruit during the different maturity stages and hybrids is clearly illustrated in Table 4. During the green harvesting phase, the highest total carotene value was recorded in the Sacher F_1, at 9.4 mg/100 g f.w. followed by the Tiger F_1 with 7.1 mg/100 g f.w. These hybrids recorded increases in the total carotene content during the subsequent phases and also reaching 20.7 mg/100 g f.w. (the Sacher F_1) and 19.2 mg/100 g f.w. (the Tiger F_1, a hybrid with a cherry fruit) during their full ripening stage. Ilahy et al. (2011) said that, during the green stage, the general low levels of the total carotenoids and lycopene are due to the numerous genes involved in the carotenogenesis which are activated during the early stages of ripening and continue to be active up to the full ripen stage. Numerous studies have also illustrated the increased carotene content during the fully ripened fruit phase (Radzevičius et al. 2012; Ilahy et al. 2011). In other studies, researchers indicated a high content of carotenoids in cocktail fruit tomatoes compared to hybrids with large fruits (Kotíková et al. 2011; Bhandari et al. 2016).

https://doi.org/10.17221/222/2017-HORTSCI

Table 4. The variation in the vitamin C content and the total carotene in the tomato fruits during the harvesting phases

Hybrid	Stage of harvesting					
	green		half ripen		full ripen	
	total carotenes (mg/100 g f.w.)	vitamin C (mg/100 g f.w.)	total carotenes (mg/100 g f.w.)	vitamin C (mg/100 g f.w.)	total carotenes (mg/100 g f.w.)	vitamin C (mg/100 g f.w.)
Antalya F_1	6.8^{b}	6.7^{a}	8.7^{c}	19.2^{a}	10.3^{b}	19.0^{ab}
Cemil F_1	5.2^{c}	4.8^{b}	8.8^{c}	17.9^{ab}	9.6^{b}	17.2^{bc}
Lorely F_1	6.5^{b}	5.7^{ab}	8.2^{c}	15.3^{b}	8.8^{b}	15.5^{c}
Tiger F_1	7.1^{b}	5.9^{ab}	12.5^{b}	18.6^{a}	18.6^{a}	19.2^{ab}
Sacher F_1	9.4^{a}	6.2^{ab}	15.1^{a}	17.2^{ab}	17.4^{a}	20.7^{a}
LSD ≤ 0.05	2.25	1.67	1.90	2.69	4.17	2.99

values represent the mean in the same column followed by the different superscript letters are significantly different at $P < 0.05$

Maturity indices are important in determining a tomato's consumption time and are a combination between the fruits' development stage, their diameter and colour, significantly correlated with the nutritional characteristics, including the total soluble solids (TSS), the titratable acidity (TA) and the protein content (Okiror et al. 2017).

When reaching full maturity, the taste index is a good indicator of the flavour impact compared to the °Brix or acidity index. The total soluble substance content increases during the fruit maturation and reaches the highest value during the full ripen stage. The results of the analysis which refer to the tomato fruit taste and maturity index are presented in Table 5.

Thus, the taste index registered values ranging from 0.57 to 0.88 during the green phase, from 0.58 to 0.94 during the half ripen phase and 0.34 to 0.53 during the full ripen phase. The maturity index recorded values of 6.25 during the green phase, 9.37 during the half ripen phase and 21.81 during the full ripen phase (Table 5). These variations can be attributed to the influence of the cultivar. Comparing the maturity increases during the harvesting stages, the values recorded are similar to those obtained by Duma et al. (2015).

CONCLUSION

The tomato fruits showed great differences in terms of the nutritional value. It has been observed that the harvest time and the tomato hybrids significantly influence the levels of the biochemical compound accumulation. Thus, during the harvesting stages, the values of the chlorophyll pigments *a* and *b* decreased from the green stage to the half ripen stage and in the full ripen stage they could not be identified because of the increase in the carotenoids. As the total soluble substance content is concerned, it increased from the green stage to full ripen stage and the acidity value had an opposite evolution, being higher during the green phase and it significantly decreased during the full ripen stage. The highest vitamin C content and total carotene was found during the full ripen stage for all the hybrids; The Sacher and Tiger hybrids singularised due to their valuable nutritional composition and

Table 5. The variation in the taste and maturity index of the tomato fruit on the harvesting phases

Hybrid	Stage of ripening					
	green		half ripen		full ripen	
	taste index	maturity	taste index	maturity	taste index	maturity
AntalyaF_1	0.80	5.58	0.66	7.27	0.53	13.09
Cemil F_1	0.75	4.68	0.64	8.11	0.51	12.40
Lorely F_1	0.57	6.20	0.58	9.37	0.52	14.14
Tiger F_1	0.83	6.23	0.89	9.11	0.52	19.23
Sacher F_1	0.88	6.25	0.94	9.15	0.34	21.81

https://doi.org/10.17221/222/2017-HORTSCI

also due to their fruit colour (chocolate and marble like), flavour and good taste.

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Received for publication November 26, 2017
Accepted after corrections January 22, 2019