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Effect of maturity stage on content, color and quality of tomato (*Lycopersicon lycopersicum* (L.) *Karsten*) fruit

Helyes, L.[1], Dimény, J., Pék, Z., & Lugasi, A.

Szent István University, Department of Horticulture and Technology, Páter K.út 1., H-2103 Gödöllő, Hungary
National Institute for Food Safety and Nutrition, Gyáli út 3/a H-1097 Budapest, Hungary
[1]To whom reprint requests should be addressed. E-mail address: Helyes.Lajos@mkk.szie.hu

Summary: Soluble solids (Brix°), carbohydrate, organic acid, lycopene, polyphenols and HMF content of indeterminate round type tomato Lemance F_1 fruits were measured in six ripeness stages from mature green to deep red stage. Color of fruits was determined by CIELab system. The L*, a*, b* values were received directly and used to calculate from which the a*/b* and the chroma were calculated. The Brix°, carbohydrate, lycopene and HMF content were the highest in the 6^{th} stage (deep red). Carbohydrate contents constitute nearly 50% of the Brix°. The mature green stage had the lowest acid content but in subsequent stages it was fundamentally unchanged. Polyphenol content changed little during fruit ripening. Lycopene content changed significantly during maturation and accumulated mainly in the deep red stage. Analyses showed that a*/b* was closely correlated with lycopene and can be used to characterize stages of maturity in fresh tomatoes.

Key words: Brix° , Lycopene, polyphenols, HMF, color, L*, a*, b*, chroma, maturity stages

Introduction

Tomato is an important horticultural commodity worldwide and plays a key role in the human diet. A total soluble solids range from 4% to 9% (*Atherton & Rudich*, 1986) and inversely related to fruit yield (*Stevens & Rudich*, 1978). Carbohydrates, mainly glucose and fructose, account for about half of the dry matter or 65% of the soluble solids of a ripe tomato fruit and 1.7 to 4.0% of fruit fresh weight. The organic acid in a tomato fruit consist of mainly citric and malic acid with a range of 0.3–0.6% (*Helyes*, 1999). Carbohydrates, acids and their interactions are important components of sweetness, sourness, and flavor intensity in tomatoes. High carbohydrates and relatively high acids are required for best flavor. Helyes et al. (1999) found that the Brix° of tomato fruits is often very high without irrigation, but decreased with irrigation. Carbohydrates and organic acids are major determinants of tomato quality.

In plant cells the lycopene molecule is an intermediate compound in the biosynthesis of beta-carotene. More than 600 carotenoids have been isolated so far. Red color is initiated by lycopene, which is the most abundant carotenoid in ripe tomatoes. The most important isomers of lycopene are cis- and trans-lycopene (*Clinton*, 1998). The trans configuration represents 95.4% of the lycopene in fresh tomatoes. During processing a large part of trans-lycopene transforms into cis-lycopene (*Takeoka* et al., 2001). According to Farkas (1994) lycopene production is inhibited when environmental temperature is above 32°C. During the ripening period, lycopene content of tomatoes increases sharply from the pink stage onwards, but no sufficient attempts have been made so far to assess the changes of the other antioxidants, presented in the fruit (*D'Souza* et al., 1992; *Dumas* et al., 2003; *Lugasi* et al., (2004). According to Helyes *et al.* (2002) the lycopene content of sixteen different tomato varieties in Hungary ranged between 39.3 and 171.0 mg kg^{-1}.

According to *Brandt* et al. (2003) significantly higher lycopene content was observed in tomato harvested in glasshouse-grown (83.0 mg kg^{-1} f.w.) than in field-grown (59.2 mg kg^{-1} f.w.), at different harvesting times. Lycopene content of three different varieties (Daniela F_1, Delfine F_1 and cherry tomato), grown under same conditions, was also investigated. The highest concentration of lycopene was detected in cherry tomato (77.4 mg kg^{-1} f.w.) while Daniela F_1 and Delfine F_1 with 59.2 and 69.6 mg kg^{-1} respectively, were significantly lower. This agrees with *Sass-Kiss* et al. (2005) who found that, fresh market varieties grown in greenhouse contained less lycopene then processing varieties grown in the field.

Tomato fruits are also rich in polyphenols, which amount to the largest part of the antioxidant content of the soluble phase. Thermal stress induces the accumulation of phenolic compounds like flavonoids and phenylpropanoids. At 35°C compared to 25°C the polyphenol level doubled. *George* et al. (2004) measured huge variance among polyphenol

(104–400 mg kg^{-1}) content of different tomato varieties. This phenomenon could be considered as an acclimation mechanism of the plant to heat stress (*Rivero* et al., 2001).

The quality and the chemical composition of a tomato changes during processing. Powerful thermal treatment can evoke a browning reaction, for which enzymatic and non-enzymatic reactions are responsible. The Maillard reaction belongs to the last group. Its intermediate compound is hydroxymethylfurfural (HMF), which is harmful when consumed by humans. The toxicological relevance of this exposure has not yet been clarified (*Janzowski* et al., 2000). HMF at high concentrations is cytotoxic, causing irritation of eyes, upper respiratory tract, skin and mucous membranes; an oral LD_{50} of 3.1 g kg^{-1} body weight has been determined in rats (*Ulbricht* et al., 1984). According to *Cámara* and co-workers (2003) HMF content is in a direct proportion to the lycopene content of processed tomato products.

The aims of the present study were to examine the effect of ripening on tomato components, having regard to HMF content, which was examined little in fresh tomatoes.

Material and method

Plant material

The tomato variety Lemance F_1 (round fruit, average weight 110–130 g) was investigated in the greenhouse in 2004. Fruit samples from six maturity stages (according to *Yamaguchi*, 1983) were gathered randomly by hand in four repetitions.

Stages of maturity were classified as follows:

1. Mature green: fruits are mature and entirely light to dark green,
2. Breaker: yellow or pink color appearance first but not more than 10%,
3. Turning: yellow or pink color is between 10 to 30%,
4. Pink: pink or red color ranges between 30 to 60%,
5. Red: red color is more than 60% but less than 90%,
6. Deep-red: red color exceeds 90% (Yamaguchi, 1983).

Color measurements were performed on the surface of the tomatoes at three points in the equatorial region of fruits. The color of tomato fruits was determined by Color system CIELab with Sheen Micromatch Plus (Sheen Instruments Ltd, Kingston-Upon-Thames, UK). The L*, a*, b* values were received directly, and used to calculate the a*/b* ratio and the chroma ($\sqrt{a^{*2}+b^{*2}}$) values.

Chemical measurements

Fruits from each repetition were washed, cut and mixed and the juice samples were refrigerated at –18°C until analysis. The Brix° was examined with a refractometer (AST 1230, Tokyo, Japan) according to the Hungarian Standard (MSZ EN 12143, 1998). Acid content of fruits was determined according to a Hungarian Standard and expressed as g kg^{-1} citric acid in fresh weight (MSZ EN 750, 1998). Carbohydrate content was measured after an acidic hydrolysis with HCl at 65°C for five minutes by the classical Schoorl-Regenbogen method (*Sarudi*, 1961). Lycopene content was determined from tomato juice after extraction with hexane by spectrophotometrically at 502nm (*Sadler* et al., 1990; Merck Co., 1989). The analyses of total polyphenols were conducted according to the Folin-Denis method by spectrophotometrically at 760 nm (AOAC 1990). Beside the above mentioned antioxidant compounds also HMF was quantified by colorimetric method based on the thiobarbituric acid color reaction measured out 443 nm (*Guzmán* et al., 1986).

Statistical analysis. The results were expressed as the average plus/minus standard deviation. The statistical analysis was carried out by t-student test and the correlation analyses were made by using the linear regression-analysis module of software MicroSoft Excel 2002.

Results

Soluble solids (Brix°) content of tomato fruit is determined by variety, method of cultivation and environmental conditions, occurring during the growing process. There was no significant difference among the first five maturity stages (from mature green to red) in soluble solids (Brix°). However, the value of Brix° is significantly higher (12%) in deep-red (6^{th}) stage compared to the previous maturity stages (*Figure 1*). It has been established that the higher the refraction value of tomato fruit, the higher level of valuable nutritive components in the fruit and the better the flavor.

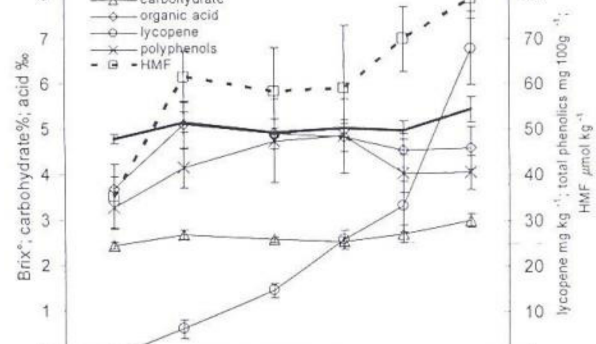

Fig. 1. Formation of tomato fruit components in relation of a*/b* ratio in the six maturity stages (mean±SD; n=72)

According to our results carbohydrates account for 50–55% of the soluble solids in tomato fruit. Average of carbohydrate content of fruits show the same tendency as Brix°, although 1^{st} (mature green) and 6^{th} (deep red) maturity stages differ significantly from other stages. Similar to Brix°

Table 1. Average of color readings of tomato fruits at different maturity stages with correlation coefficients (mean±SD, n=216)

	Maturity stages						
	mature green	breaker	turning	pink	red	deep red	R^2
L*	60.5±1.91	58.0±3.20	51.6±2.53	47.1±2.69	43.4±1.07	39.9±0.16	0.89***
a*	−6.8±0.89	3.8±5.90	14.6±3.13	22.4±1.75	27.3±2.16	28.8±2.21	0.88***
b*	26.2±0.72	29.0±1.87	28.9±1.07	27.6±1.18	26.6±0.91	21.6±1.41	0.24***
a*/b*	−0.3±0.02	0.1±0.21	0.5±0.09	0.8±0.10	1.0±0.08	1.3±0.09	0.94***
chroma	27.1±0.85	29.9±2.23	32.6±2.44	35.6±0.72	38.3±1.75	36.1±2.32	0.64***

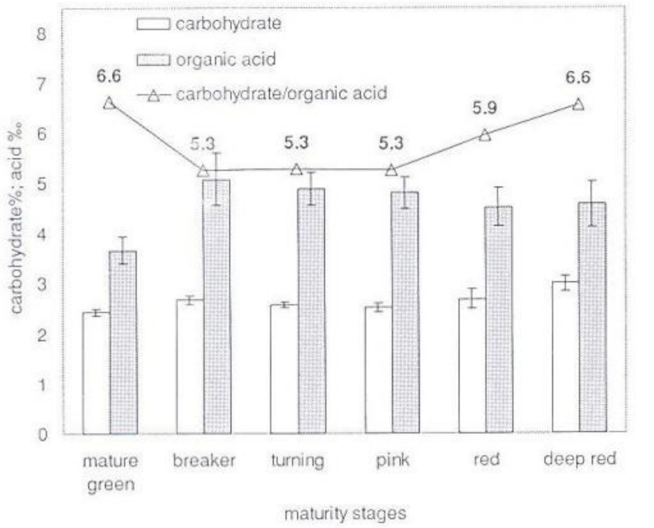

Fig. 2. Average of carbohydrate and organic acid content and carbohydrate/organic acid ratio in different maturity stages of tomato fruit (mean±SD; n=72)

Table 2. Correlation coefficients of linear regression between investigated ingredients and parameters (n=72; *** P<0.001; ** P<0,01; * P<0,05)

R	Brix	carbo-hydrate	organic acid	poly-phenols	lyco pene	HMF	a*/b*	chroma
Brix°		0.68***	0.44	−0.22	0.5*	0.08	0.42	0.32
carbo-hydrate			0.32	−0.03	0.62***	0.39	0.49*	0.34
organic acid				0.44	0.23	0.12	0.3	0.35
poly-phenols					−0.06	0.61**	0.05	−0.07
lycopene						0.47	0.89***	0.67***
HMF							0.49*	0.35
a*/b*								0.85***
chroma								

carbohydrate content of fruits was the highest in the 6th stage (3%). This value was higher by 23% compared to the same value in the first stage (*Figure 1*).

Organic acid content was the lowest in the mature green phase (3.7‰); later in the following stages acid content remained almost the same during the ripening process (averagely 4.7‰). Tomato fruit flavor is basically determined by the ratio of carbohydrate to acids. This value ranged from 5.3 to 6.6 during the ripening process. The average carbohydrate/acids ratio in the 1th (mature green) and 6th (deep-red) stages were the same (6.6). However, this ratio was calculated using higher carbohydrate and higher acid values in the deep-red stage; thus the flavor of the fruits was much better and harmonious in this last stage (*Figure 2*).

Figure 1 shows the average values of polyphenols at each maturity stage. Based on the average of all the samples, the polyphenol content of the fruits ranged from 33 to 48 mg 100 g^{-1}. The lowest value was found in the 1st stage and the highest value in the 4th stages. These findings show that the polyphenol content of fruits during the ripening process does not change significantly.

The biosynthesis of pigments is under genetic control, and the red color of the tomato fruit results from the accumulation of lycopene the level of which relates to genetic potential of the variety and the environmental circumstances (mainly temperature and light). In this study, the fruit contained little lycopene in the mature green stage and was hardly detectable. In later maturity stages, lycopene content is continuously increased in the fruits. Almost half (46%) of the lycopene content, is synthesized and accumulated in the 6th maturity stage (*Figure 1*). The color of the fruits is an important consumer quality with a strong preference for the deep-red color of ripe tomatoes. Many tomatoes, produced for fresh consumption, are sold at less than full maturity (4th and 5th ripening stages), and relatively few are marketed as completely deep-ripe-red-colored tomatoes. *Table 1* shows the color evaluations performed with Sheen chroma meter in relation of sensory classification of maturity stages (*Yamaguchi*, 1983). Linear regressions of color readings and maturity stages showed, that a*/b* ratio produced the best fit (R^2=0.94).

Figure 1 shows the quantity of HMF in the fruits ranging from 35 and 79 µmol kg^{-1} depending on maturity stages. The value of HMF was doubled from mature green stage to deep-red stage. It should be emphasized that this HMF value does not represent any risk in aspect of human consumption. Intake of harmful quantities of HMF only occurs only by consuming very high amounts of processed tomato products.

In summarizing, correlation coefficients of each investigated component parameter can be found in *Table 2*.

Conclusions

The color parameter a*/b* ratio correlated positively with carbohydrate, lycopene and HMF (P>0.05). Linear regression of the a*/b* ratio and maturity stages and lycopene content (*Table* 2) produced a good fit (R=0.89), which agrees with finding of *Arias* et al. (2000), although the a*/b* ratio and lycopene exponential regression produced the best fit.

Brix° only correlates positively with lycopene at P>0.05. Polyphenols were highly correlated only with HMF content and less significantly with other components P>0.05. HMF can originate not only during processing, because fresh tomato also consists detectable quantity of HMF, but it does not represent any risk in aspect of human consumption.

These results show that a*/b* ratio is a suitable parameter with which to characterize maturity stages and lycopene content of tomato fruit. Brix° might also be used to characterize the other measured components in different maturity stages.

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