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TOMATO BIOCHEMICAL COMPOSITION AND QUALITY ATTRIBUTES IN DIFFERENT MATURITY FRUITS

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Abstract. Maturity at harvest is very important attribute to tomatoes quality. This research showed that fully ripen tomato fruits had the highest amount of lycopene and β-carotene respectively 46.68 and 6.22 g kg^{-1}. Therefore, it was determined correlation between amount of carotenoids and tomato ripening stages. Tomato fruit flesh lost it's firmness through ripening period from 82.54 till 15.24 N cm^{-2}. Fruit ripeness stage at harvest determines tomatoes biochemical composition and quality. Carotenoids (β-carotene, lycopene) syntheses during fruit ripening were the results of tomato colour and nutrition value changes, which results to correlation between colour indexes and tomato fruit quality attributes such as: hue angle (h°) and lycopene, colour index a* and lycopene, flesh firmness and hue angle (h°), skin firmness and chroma (C).

Key words: carotenoids, maturity, firmness, colour, fruit.

INTRODUCTION

In currently years, people are more interested in environmental problems caused by agricultural activities. Special attention is focused on the health risks resulting from the use of various chemicals and plant growing systems. Otherwise, the growing phytosanitary problems and unrelenting use of pesticides lead to new challenges in food safety. Unfortunately old farming systems, like tomato growing on natural soil has a markedly negative effect on the yield and these fruits have more visible defects in comparison to tomatoes growth using mineral nutrient solutions in water (hydrophonic) [Hallmann and Rembialkowska 2007, Gonzalez-Cebrino et al. 2010]. But consumers expect organic

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and natural growth food to have a higher nutritional value, to be healthier or simply to be safer and less risky to human. However, experiments showed that relative impact of adapting production methods on food quality and safety may change over time, according to changes of soil characteristics and plant cultivars [Niggli and Leifert 2007].

The fruit ripening processes gives attractiveness and better taste to a variety and seed dispersing organisms. Because of the dual role of flash fruits as both a unique aspect of plant development and the source of a large

However, most of the researchers describe tomato portion of the human diet, the molecular basis of development and ripening of fleshy fruits has received considerable scientific attention in recent years [Giovannoni 2001].

During ripening processes fruit demonstrate changes in colour, flavour, texture, and pathogen susceptibility. Tomato ripening is a highly coordinated developmental process that coincides with seed maturation. Regulated expression of thousands of genes controls fruit softening as well as accumulation pigments, sugars, acids, and volatile compounds [Klee and Giovannoni 2011]. Typical and advanced mature-green tomatoes will usually attain a much better flavour at the table-ripe stage then those picked at the immature or partially mature stages. Tomatoes accumulate β-carotene, lycopene, acids, sugars, ascorbic acid and other components during ripening on the vine, so ripeness stage at harvest affects fruit nutritional value and quality [Brandt et al. 2006, Urbonavičienė et al. 2012].

fruit nutritional and external quality at technical fruit maturity. So, the aim of our investigation was to evaluate tomato nutrition growth on natural soil and fruits quality changes during ripening.

MATERIALS AND METHODS

Investigation was carried out at the Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestry. Tomatoes were grown under the same conditions (according to tomato growing technology adopted by Institute of Horticulture [Jankauskienė and Survilienė 2003] in the natural soil (*Endohypoglei-calc*(*ar*)*ic Luvisol*) in not heated greenhouse covered with polymeric film. Tomato seeds were sown on the 1st of April and sprouts were planted (distance – 0.7 × 0.3 m, 4.7 plants m^{-2}) on the 17th of May in 2013. Tomatoes harvesting period started on the 25th of July and vegetation period ended on the 21st of September. Tomato fruits for analysis were picked at peak of the fruit ripping period on the 17–19th of August.

In order to determine tomato ripeness influence on fruit quality, tomatoes were harvested at six different ripening stages: I – degree of ripeness means 100% green tomato fruits; II – up to 10% coloured tomato fruits; III – 10–30% coloured tomato fruits); IV – 30–60% coloured tomato fruits; V – 60–90% coloured tomato fruits, VI – 90% coloured tomato fruits [Kader 2011].

The research objective was five tomato (*Lycopersicon esculentum* Mill.) varieties: ‘Rutuliai’ (Lithuanian, own seeds), ‘Saint perrie’ (French, bought seeds), ‘Money maker’ (English, bought seeds), ‘Tamina’ (German, bought seeds), ‘Promyk’ (Polish, bought seeds) and five hybrids: ‘Adam’ (Polish, bought seeds), ‘Brooklyn’ (Dutch, bought seeds), 'Benito' (Dutch, bought seeds), 'Tocayo' (Dutch, bought seeds), 'Tolstoi' (Dutch, bought seeds) from different countries.

The following fruit quality parameters at different ripening stages were evaluated: amount of dry matter, lycopene, β-carotene, soluble solids in fresh tomato matter, also were determined fruit skin and flesh firmness and colour indexes (CIE L* a* b*) with calculated hue angle (h°) and chroma (C). For every replication, 10 tomatoes of each cultivar were harvested at random. As the fruits were harvested from different plants, the experiment design was completely randomized. Primarily, spectroscopic measurements and texture analysis were made and afterwards tomatoes were cut in small pieces and homogenized, immediately, using Bosch Easy Mixx blender and filtered. The quality of harvested tomato fruits was evaluated at the Laboratory of Biochemistry and Technology applying chemical and physical methods of investigations.

Carotenoids (β-carotene and lycopene) content was determined by high performance liquid chromatography (HPLC) method. Dry matter content was determined gravimetrically by drying tomatoes to a constant weight at 105°C. Soluble solids were established using NIR (Near Infrared) method, by transmittance principle using the near infrared spectrophotometer ("NIR Case NCS001A", Sacmi Imola, S. C. Imola, Italy). Tomato texture measured with texture analyser ("TA.XTPlus", Stable Micro Systems, Godalming, England). Colour indexes in the space of even contrast colours were measured with spectrophotometer "MiniScan XE Plus" (Hunter Associates Laboratory, Inc., Reston, Virginia, USA) and calculated chroma (C = (a*2 + b*2)1/2) and hue angle (h° = arctan(b*/a*)). The volumes L*, C, a* and b* are measured in NBS units, hue angle h° – in degrees from 0 to 360°. NBS unit is a unit of USA national Standard Bureau and corresponds to one threshold of colour distinction power, i. e. the least distinction in colour, which the trained human eye can notice.

All analyses were conducted in four replications. The data are presented as an average of ten investigated cultivars. So, one point of ripeness stage is composed of 40 values (10 cultivars and 4 repetitions). Statistical software's (SAS and MS Excel) were used for data calculation and significance evaluation.

RESULTS AND DISCUSSION

One of the most noticeable characteristics of tomato ripening is the huge increase of the carotenoid content in the fruit. The change in pigmentation is caused by a massive accumulation of lycopene within the plastids and the disappearance of chlorophylls. The chloroplasts of the mature green fruit change into chromoplasts, which accumulate lycopene in membrane-bound crystal [Brandt et al. 2006, Radzevičius et al. 2009, Takayuki et al. 2014]. Gonzalez-Cebrino [2010] reported that lycopene contents changed widely among all investigated cultivars during ripening, increasing significantly from 6.57 mg kg^{-1} (III ripeness stage) to 132.64 mg kg^{-1} (VI ripeness stage). In general, β-carotene was highly accumulated at the fifth ripeness stage, ranging the concentrations between 5.66 and 16.75 mg kg^{-1}.

According to figure 1, it was found that amount of lycopene and β-carotene had sequentially increased during tomato fruit ripening. The least amount of carotenoids was found in green tomatoes (I ripening stage) where content of lycopene was 2.86 g kg^{-1} and content of β-carotene – 0.10 g kg^{-1}. The fully ripe tomato fruits (VI ripeness stage) had the biggest amount of lycopene and β-carotene, respectively 46.68 and 6.22 g kg^{-1}. Therefore, it was established correlation between amount of carotenoids and tomato ripening stages. Exponential trend line of lycopene and fruit ripening stage showed that coefficient of determination (R^2) reached 0.985. Exponential trend line of β-carotene and fruit ripening stage showed that coefficient of determination (R^2) had almost the similar value – 0.9797. Exponential trend line is most useful when data values rise or fall at increasingly higher rates.

Soluble solids are very important contribution in fresh tomato production because sugars and acids determine flavour of the fruit [Stevens et al. 1977, Young et al. 1993, Qianqian et al. 2015]. Scientists reported that dry matter per cent decreased for all genotypes throughout maturation of the tomato fruit when it was expressed on a fresh weight basis [Young et al. 1993, Viskelis et al. 2015]. But, different tendencies were obtained with content of dry matter in our experiment (fig. 2). The least amount (39.88 g kg^{-1}) of dry matter was found in the green tomato (I ripening stage) and had tendency to increase up to 78.59 g kg^{-1} (III ripening stage) and then started slow decrease until 68.27 g kg^{-1} (VI ripening stage). For that reason polynomial regression was used which is a form of linear regression in which the relationship between the independent variable (ripeness stage) and the dependent variable (dry matter) is modelled as an 2^{th} order polynomial. Determination coefficient (R^2) of dry matter and tomato ripening stage was 0.9023.

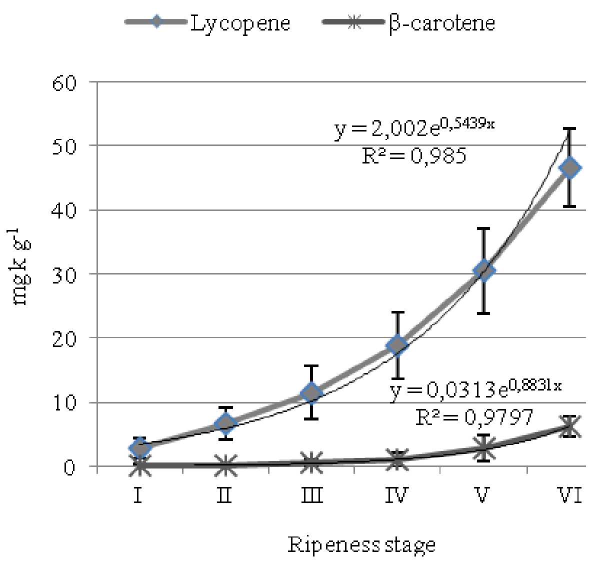

Fig. 1. Lycopene and β-carotene changes during tomato fruit ripening

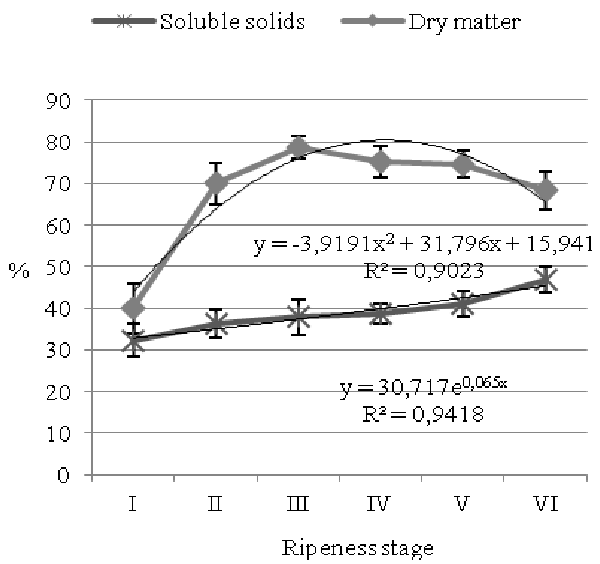

Fig. 2. Soluble solids and dry matter changes during tomato fruit ripening

Total soluble solids content is significantly influenced by the combined effect of fruit maturity and ripening conditions during the whole period of ripening. Moneruzzaman et al [2008] found that full ripen tomato contained the highest amount of soluble solids (68.2 g kg^{-1}) while lowest (58.5 g kg^{-1}) was detected in mature green tomatoes at harvest. For all maturity stages, soluble solids increased gradually with the advancement of ripening process. Similar trends of such results reported and other scientists [Karki 2005, Majidi et al. 2011]. That can confirm and our experiment, where amount of soluble solids had tendency to increase during tomato ripening (fig. 2). The least content (32.26 g kg^{-1}) of soluble solids was detected in absolutely green tomato fruits (I ripening stage) and the highest amount (46.88 g kg^{-1}) of soluble solids was in fully ripen fruits (VI ripening stage) and differences between these two ripening stages were statistically significant. Exponential trend line of soluble solids and fruit ripening stage showed that coefficient of determination (R^2) reached – 0.9418. This, soluble solids decrease in the per cent presumably could be explained by dilution in concentration resulting from fruit water uptake during ripening [Young et al. 1993].

Quality of tomato texture is determined by tomato fruit skin and flesh firmness and their relationship. Skin and flesh firmness of tomato fruits are influenced by plant genotype and ripeness stage [Voisey et al. 1970, Radzevičius et al. 2012]. Karapanos et al. [2015] reported that fruit ripened naturally on the plant exhibited a uniform colour and were firmer than those ripened on the shelf. Previous studies showed that different factors affect tomato textural properties, among them – cell wall composition composed of protein and three major polysaccharides (pectin, hemicelluloses and cellulose) [Campbell et al. 1990, Fischer and Bennett 1991]. Our experimental evidence indicated that tomato fruit lost his firmness through ripening (fig. 3) period from 82.54 N cm^{-2} in green fruits (I ripeness stage) to 15.24 N cm^{-2} in fully ripen fruits (VI ripeness stage). Linear regression of flesh firmness during it ripening showed that coefficient of determination (R^2) was 0.8992. Different trends were observed with tomato skin firmness. In the green (I ripeness stage) tomato skin firmness reached 225.62 and increased till the IIIth ripeness stage up to 302.91 N cm^{-2} and then began to decline till the VIth ripeness stage 201.27 N cm^{-2}. For this reason polynomial regression was used and obtained determination coefficient (R^2) reached 0.9841. Such results could be related with ethylene biosynthesis during tomato fruit ripening and respiration undergo a climacteric rise, tissues lost their firmness, extractable activities of specific hydrolytic enzymes increase and cell wall fractions change their composition [Campbell et al 1990].

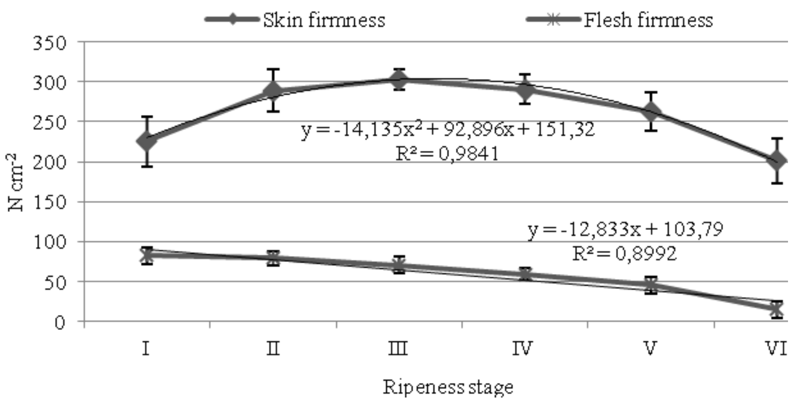

Fig. 3. Skin and flesh firmness changes during tomato fruit ripening

The green to red colour transition typical of ripening tomato fruit is largely due to the developmental transition of chloroplasts to chromoplasts, as photosynthetic membranes are degraded, chlorophyll is metabolized, and carotenoids, including β-carotene and lycopene, accumulate. The regulation of carotenoid biosynthesis during ripening is due, at least in part, to ripening-related and ethylene-inducible gene expression in tomato [Grierson et al. 1987, Ronen et al. 1999, Giovannoni 2001]. Our research data showed that chlorophyll degradation and carotenoids syntheses during tomato fruit ripening were the results of colour changes in the values L*, a*, b*. Values of colour index L* and hue angle (h°) went down during tomato fruit ripening (tab. 1) and that leaded to tomato colour darkening. Colour index L* ranged from 39.92 in the fully ripe tomato to 55.00 in the green fruits, meanwhile hue angle decreased from 105.79 (I ripeness stage) to 44.22 (VI ripeness stage). Colour index a*, which indicates the ratio of red and green colour, at the beginning of fruit ripening (I ripeness stage) was negative (-8.72), but red colour started to dominate during tomato ripening period and reached 27.34 in fully ripen fruits (VI ripeness stage). Colour index b* and chroma varied during fruit ripening respectively from 26.19 (III ripeness stage) to 30.86 (I ripeness stage) and from 26.24 (III ripeness stage) to 28.22 (VI ripeness stage).

Table 1. Tomato colour indexes changes during tomato fruit ripening

Ripeness stage	Colour index (NBS units)				
	L*	a*	b*	C	h°
I	55.00	-8.72	30.86	32.07	105.79
II	54.55	-1.12	29.98	30.03	92.09
III	52.38	1.05	26.19	26.24	88.14
IV	50.66	4.14	28.73	29.20	81.99
V	49.33	12.89	29.77	32.51	66.64
VI	39.92	27.34	26.64	38.22	44.22
Standard deviation (SDev)	±5.54	±12.64	±1.90	±4.04	±21.63

Previous studies compared colorimetric analysis and carotenoid content in vegetable crops and controversial results were obtained in reliability of colour indexes and carotenoid content [Arias et al. 2000, Logendra and Janes 2000, Reeves 2006].

Simple linear regression model we used to relate chromaticity values to tomato fruit quality attributes. In order to determine regression coefficient, average values were calculated from ten different tomato cultivars for each ripeness stage (total number of ripeness stages – 6). The negative correlation was observed between hue angle and lycopene measured in this study (fig. 4) and it suggests that decrease of hue angle is determined by lycopene content increase. Regression coefficient (R^2) between these two parameters was very high and reached 0.9803.

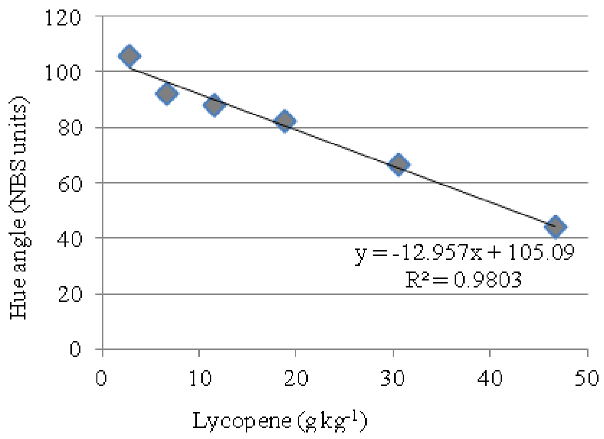

Fig. 4. Hue angle (h*) and lycopene content correlation

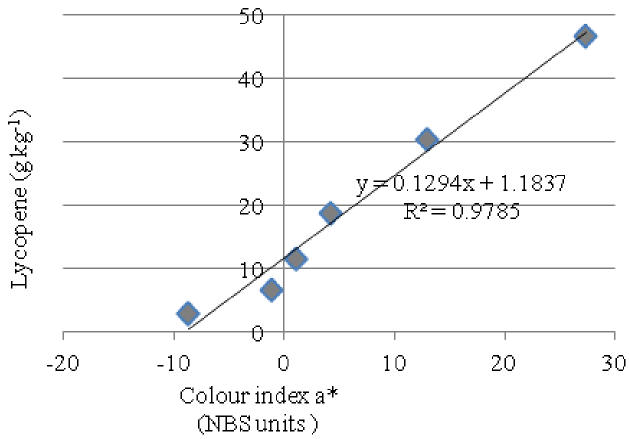

Fig. 5. Colour index a* and lycopene content correlation

Also, it was established positive correlation between colour index a* and lycopene content (fig. 5). Lycopene content increase determined rise of fruit colour index a*. Established determination coefficient (R^2) was very high – 0.9785.

We found that hue angle value increase was closely linked with tomato fruit flesh firmness (fig. 6). So, it was established positive correlation (R^2 = 0.969) between hue angle and tomato fruit flesh firmness. As well, chroma value was a fairly good predictor for tomato fruit skin firmness (fig. 7). Chroma value increase had resulted in decrease of tomato skin firmness and that negative dependence has been expressed by regression coefficient R^2 = 0.8344.

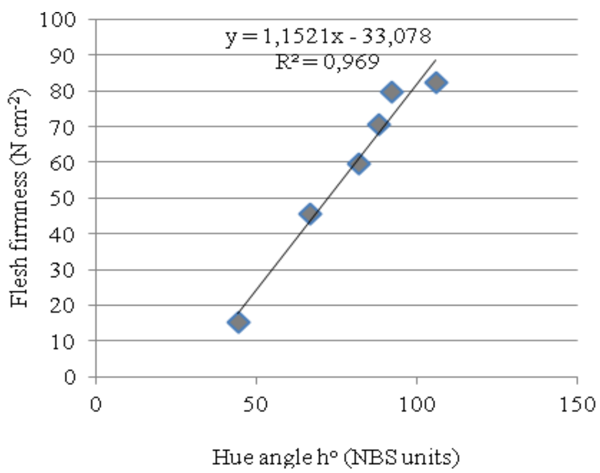

Fig. 6. Flesh firmness and hue angle (h°) correlation

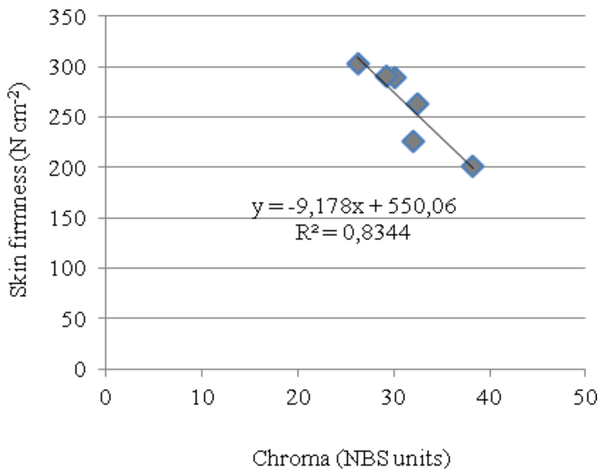

Fig. 7. Fruit skin firmness and chroma (C) correlation

CONCLUSIONS

1. Tomatoes biochemical composition and quality was determined by fruit ripeness stage at harvest, because during tomato ripening was obtained fruit flesh firmness loss and steady increase of lycopene, β-carotene and dry matter.

2. Carotenoids (β-carotene, lycopene) syntheses during fruit ripening were the results of tomato colour and nutrition value changes, which results to correlation between colour indexes and tomato fruit quality attributes such as: Hue angle (h*) and lycopene; Colour index a* and lycopene; Flesh firmness and hue angle (h°); Skin firmness and chroma (C).

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SKŁAD BIOCHEMICZNY I JAKOŚCI OWOCÓW POMIDORA W OKRESIE DOJRZEWANIA

Streszczenie. Dojrzałość jest bardzo ważnym atrybutem jakości pomidorów. Wyniki prezentowanych badań wykazały, że owoce pomidora w pełnej dojrzałości miały największą ilość likopenu i β-karotenu, odpowiednio 46,68 i 6,22 g kg^{-1}. W związku z tym stwierdzono korelacje między ilością karotenoidów i etapami dojrzewania pomidorów. Miąższ owoców pomidora stracił jędrność podczas dojrzewania (od 15,24 do 82,54 N cm^{-2}). Stopień dojrzałości owoców w czasie zbioru określa biochemiczny skład i jakość. Synteza karotenoidów (β-karoten, likopen) podczas dojrzewania owoców była wynikiem zmiany odżywiania i barwy, co doprowadziło do powstania korelacji pomiędzy indeksami barw i jakości owoców pomidora, jak: *hue angle* (h°) i likopen, indeks a* i likopen, miąższ pomidora i *hue angle* (h°), jędrność skóry i *chroma* (C).

Słowa kluczowe: karotenoidy, dojrzałość, jędrność, barwa, owoce

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