

# Chemical and fruit skin colour markers for simple quality control of tomato fruits

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original scientific paper

DOI: 10.17508/CJFST.2015.7.2.03

## Summary

The orientation of this research was to evaluate the classic parameters regarding the external and internal quality of tomato fruits cv. 'Brilliant' at different stages of maturity and to define the dynamics of their changes during the ripening in storage at 18 °C. Principal component analysis (PCA) and multivariate canonical discriminant analysis (DA) were used to classify tomato samples according to quality (internal and external) and nutritional value based on fruit mass, fruit skin colour, contents of soluble solids (SS), total titratable acids (TTA), ascorbic acid (AA), and total antioxidant potential (TAP). Several methods are used for determining AA content and TAP in plant samples. A simple routine method, direct redox titration with iodate solution and spectrophotometric determination of TAP<sub>SP</sub>, as described by Singleton and Rossi, also called total phenols, were used respectively. The results show that the stage of maturity (based on fruit skin colour) strongly determines the quality and nutritional value of the tomato fruit. Tomatoes harvested at table maturity (red colour, index  $a^*/b^* \geq 0.85$ ) have a significantly higher nutritional value (in terms of antioxidants - TAP<sub>SP</sub> and AA content) and overall quality than those harvested at an earlier maturity stage and then ripened in storage. This brings out the importance of short food supply chains and, from the viewpoint of overall fruit quality, it raises doubt about harvesting before reaching table maturity. On the other hand, it is necessary to be extremely attentive when determining optimal maturity, because when the plant becomes over-ripe or when stored, the nutritional value and overall quality decrease drastically. Besides the colour parameters, AA content is the most important chemical marker for a simple quality control. By using a simple and reliable analytical method for determining AA content, such as direct redox titration, the monitoring of tomato fruit quality could also be easily performed in situ.

**Keywords:** chemical markers, quality control, antioxidant, tomato, discriminant analysis

## Introduction

Tomato is a climacteric fruit that allows harvesting before it reaches table maturity. This is a very convenient property that is of the greatest importance for growers and retailers. It provides extra time for handling, transport, it prolongs the shelf-life, and minimizes risks. Accordingly, there are only a few growers concerned about the connection between the early harvesting, post-harvest methods, and the overall quality of the tomato fruit.

Being an important source of the income, while on the other hand having health components that have been proven to minimize the risk of cancer (Giovanucci et al., 2002), tomato fruit has become a frequent research topic over the recent decades. In many of the published research work, conflicts have occurred regarding the early harvesting of premature fruit, antioxidant potential (Kader et al., 1977; Jimenez et al., 2002), fruit growth (Fanwoua et al., 2013), and standard ripening/quality parameters (soluble solids, titratable acids, firmness) of the tomato fruit (Beckels, 2012; Dijk et al., 2006; Dobricevic et al., 2007). The influences of some post-harvest treatments on overall quality should also not

be overlooked, since the negative effects of low temperature on the kinetics of ripening regarding sugars, organic acids, phenolic antioxidants and lycopene were reported by Gomez et al. (2009).

Nowadays, several methods are used for determining the total antioxidant potential of the fruit. In this way we can quickly characterize the antioxidant content by taking into consideration the mutual synergistic effects, as well as the effects of other components such as transition metals, the effect of which may be pro-oxidative. The results of analyses are usually reported as equivalents of gallic acid or another antioxidant model solution. It is well-known that tomatoes contain different classes of substances with antioxidant properties such as carotenoids, ascorbic acid (AA), phenolics, and tocopherols. From the chemical point of view, the main antioxidants in food samples are polyphenols. By comparing different methods of analysis for determining the TAP, some authors (Weingerl et al., 2009; Weingerl et al., 2011) have previously demonstrated that the use of routine methods for determining the levels of total phenols by Singleton-Rossi was very much in place. Singleton et al. (1965) published a method for the

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determination of total phenols, which is based on the oxidation of phenolic compounds in an alkaline medium with the Folin-Ciocalteus reagent. This mentioned spectrophotometric method was used for determining the total antioxidant potential (TAP<sub>SP</sub>) of the tomato fruit.

Several analytical methods such as fluorometric methods, chromatographic methods, chemiluminometric, and electrochemical methods have been proposed for determining AA in different matrices. Most of the above mentioned methods are time-consuming, costly, they lack sensitivity or selectivity, and usually specially trained staff is needed. Although separation techniques such as liquid chromatography (Nováková et al., 2008; Spínola et al., 2012; Tarrago-Trani et al., 2012), are regarded as more accurate, direct titrimetric determination is often used, as it is simple, fast, reliable and inexpensive (Suntornsuk et al., 2002). Sankhyan et al. (2013) reported on comparisons between three analytical methods for the determination of AA; titration, enzymatic, and HPLC. The results showed that all three methods are appropriate for the quantification of AA.

By direct titration of the tomato fruit sample we avoid complex sample preparation and the possibility for low efficiency of the extraction, as well as the possibility for instability of the analyte. We can assume that direct titration using iodate solution is a simple and reliable analytical method for monitoring tomato fruit quality, especially for in situ determinations, which could be easily performed by the grower.

Lycopene (red pigment, a major carotenoid and a precursor to the production of alpha- and beta-carotene) stands out amongst health components. Various methods have been used for determining lycopene content in tomato fruit, mostly HPLC. Several studies have been performed in order to determine the correlation between colour parameters and lycopene. Seroczynska et al. (2006) suggested that the more preferred methods for objectively measuring colour are the tristimulus Hunter and the CIE L\*a\*b\* systems. According to D'Suza et al. (1992), Arias et al. (2000), Brandt et al. (2006) and Stinco et al. (2013) correlation coefficient between the colour parameter a\* (or colour indexes a\*/b\*) and lycopene varies between 0.75 and 0.93.

In most cases the colour of the tomato fruit is a single parameter used by the growers for determining the harvesting date. The change in fruit colour during ripening is mainly related to a chlorophyll degradation, as well as the synthesis of lycopene, as it is responsible for the red colour, and other carotenoids

such as chloroplasts are converted into chromoplasts (Arias et al., 2000). Kacjan-Maršić et al. (2011) reported that colour is significantly influenced by the maturity stage associated with the climatic conditions.

As the connection between the fruit skin colour and lycopene content has been confirmed, it is still an open question what happens to the chemical and skin colour quality markers in the cases when tomato fruits are harvested at different stages of maturity (green, green-orange, orange, red; these are in compliance with the technological maturities of harvested fruits in the different countries of Europe) and then stored at 18 °C and left to ripen. The main hypothesis the authors have followed is that the nutritional value and the overall fruit quality depend significantly on the ripening stage of tomato fruit at the time of harvesting.

## Materials and methods

### *Plant material and sample preparation*

In the presented experiment, the tomato cultivar 'Brilliant' (*Lycopersicon esculentum* Mill.), grown in a greenhouse (surface area 6 ha, 6 m high), was used. The plants were planted in hanging gutters in an organic substrate mixture of peat and coconut to a final density of 3.75 plants/m<sup>2</sup>. The average daily temperature was 19 °C, average relative air humidity (RAH) 80.6%, average illumination 1787 J (Source: Meteorological station Paradajz Ltd., Renkovci, Slovenia).

### *The design of the experiment*

#### *Assessing the quality parameters at different maturity stages of the tomato fruit (on-plant: P)*

Sixty fruits (always the third fruit in the cluster) at different maturity stages (that represent different treatments) were harvested from the plant. The maturity stages were associated with fruit colours: green (G, colour index a\*/b\* ≥ -0.05), green-orange (GO, colour index a\*/b\* ≥ 0.05), orange (O, colour index a\*/b\* ≥ 0.4) and red (R, colour index a\*/b\* ≥ 0.85). The quality and maturity parameters were analysed immediately after the harvesting.

#### *Monitoring quality parameters of tomato fruit stored (S) at 18 °C*

500 tomato fruits at maturity stage G, 360 fruits at maturity stage GO, 260 fruits at maturity stage O, and 160 fruits at maturity stage R were removed from the

plant and stored at 18 °C and 70.8% RH. After zero (S0), three (S3), six (S6), eight (S8), ten (S10) and fourteen (S14) days after harvesting 21 fruits from each of the four maturity stages (treatments) were taken from storage and analysed for different quality and maturity parameters. The samples' labelling numbers from 0 to 14 represented the number of days in storage (from the moment of harvesting until the day they were analysed).

#### *Determination of fruit colour*

Immediately after harvesting, the colours on three different spots of the equatorial section of the fruits, were determined. The skin colour was recorded using a Minolta CR-400 tristimulus colour analyser (Minolta Co., Ltd., Osaka, Japan). The chromaticity was expressed in  $L^*$ ,  $a^*$ ,  $b^*$  colour space coordinates (CIELAB). The  $L^*$  coordinate indicated the darkness or lightness of the colour and ranged from black (0) to white (100). Coordinates  $a^*$  and  $b^*$  indicated colour directions:  $+a^*$  was the red direction,  $-a^*$  the green direction,  $+b^*$  the yellow direction, and  $-b^*$  the blue direction. (Darrigues et al., 2008)

Colour index  $a^*/b^*$  was calculated in order to evaluate (express numerically) the differences in skin colours of the fruits after different treatments, thus representing the 'starting point' of the experiment.

#### *Determination of fruit maturity and quality parameters*

Concentrations of the different quality parameters often vary within individual fruits (often being higher at the stem and lower at the calyx), and for this reason, longitudinal slices of the fruit (from end to end) were used. All the samples were thermostated at room temperature before the analysis. The fruit mass was determined using a precision balance KE-PL420-3N (Kern & Sohn GmbH, Balingen, Germany). After that, the fresh tomatoes were cut and homogenised in ultraturax at 24000/min for 3 min, 25 g homogenised samples were centrifuged for 15 minutes at 9500/min (4 °C), and the clear liquid was poured off for the analysis.

#### *Chemical analysis*

The following parameters, regarding quality and ripeness, were analysed: soluble solids' content (SS), content of total titratable acids (TTA), content of ascorbic acid (AA) and total antioxidant potential ( $TAP_{SP}$ ).

#### *Determination of $TAP_{SP}$*

In technical terminology used in food chemistry, there are several different terms for antioxidant content,

such as antioxidant potential, antioxidant efficacy, antioxidant capacity, and the like. Due to the compliance with the professional terminology, the term 'potential' was used, although it is not the most suitable from the chemical point of view. Determination of  $TAP_{SP}$  was performed according to the Singleton-Rossi procedure (Folin and Ciocalteu, 1927; Singleton and Rossi, 1965). Briefly, 250  $\mu$ L of homogenised, centrifuged tomato sample, 15 mL of distilled water, 1.25 mL of diluted (1:2) Folin-Ciocalteu reagent, and 3.75 mL of a sodium carbonate solution (20%) were mixed and distilled water was added to make up the total volume of 25 mL. The solution was agitated and left to stand for 120 min for the reaction to take place. The calibration curve was prepared with gallic acid solutions in concentrations from 0 to 1000 mg/L. The absorbance was measured after the reaction at 765 nm using a Cary 1E spectrophotometer (Varian, California, USA). The Folin-Ciocalteu reagent was purchased from Merck (Darmstadt, Germany).

#### *Determination of ascorbic acid*

Determination of AA content by redox titration using iodate solution is a routine method, which is simple, fast and reliable (Balan et al., 2005). Determination of AA in the tomato fruit (according to web reference: University of Canterbury, 2015): 20 mL of homogenised, centrifuged tomato fruit sample was pipetted into a 250 mL conical flask and about 150 mL of distilled water, 5 mL of 0.6 mol/L potassium iodide, 5 mL of 1 M HCl and 1 mL of starch indicator solution were added. The sample solution was titrated with 0.002 M  $KIO_3$ .

#### *Determination of titratable acids*

In regard to determining TTA in the tomato fruit samples, the concentrations of titratable hydrogen ions contained in each tomato fruit sample were measured by neutralisation with a strong base solution to a fixed pH. The TTA value included all the substances of acidic nature present in the tomato fruit: free hydrogen ions, organic acids, acid salts and cations. 5 mL of centrifuged tomato fruit juice was weighted into a 100 mL Erlenmeyer flask; 50 mL of deionised water was added and then titrated with 0.1 M NaOH to an end point of pH 8.2 (phenolphthalein). The milliequivalent factor for malic acid in tomato fruits (0.067) was used for calculating TTA.

### *Determination of soluble solids content*

The SS content was measured with the use of a Atago 4487 PAL-87S (Atago Co. Ltd., Tokyo, Japan) refractometer, and expressed in °Brix.

### *Statistical analysis*

Data were expressed as means  $\pm$  standard deviations (SD) of three replicate determinations and then analysed by SPSS 21.0 for Windows (SPSS Inc., Chicago, USA). Factor and multivariate canonical discriminant analyses were carried out with the evaluated compounds. The number of variables was 8: fruit weight, colour of the epidermis (colour parameters L\*, a\* and b\*), SS content, content of TTA, content of AA and TAP<sub>SP</sub>. All variables were mean averaged prior to the analysis. The principal component method (PCA) was used as a factor extraction method and a varimax rotation was carried out to obtain a better interpretation of the factors. The determined internal and external tomato fruit quality parameters were processed by analysing a variance as independent variables. Sample type, stage of maturity, and the score factors obtained during the factor analysis were used as dependent variables. Further discriminant analysis, a multivariate technique, was used to describe a group separation in which discriminant functions were used to elucidate the differences between the groups, leading to identifying the relative contributions by all variables prior to the group separation and for predicting or allocating observations in which the linear or quadratic functions of the variable was used to assign an observation to one of the groups (Hair et al., 2009).

## **Results and discussion**

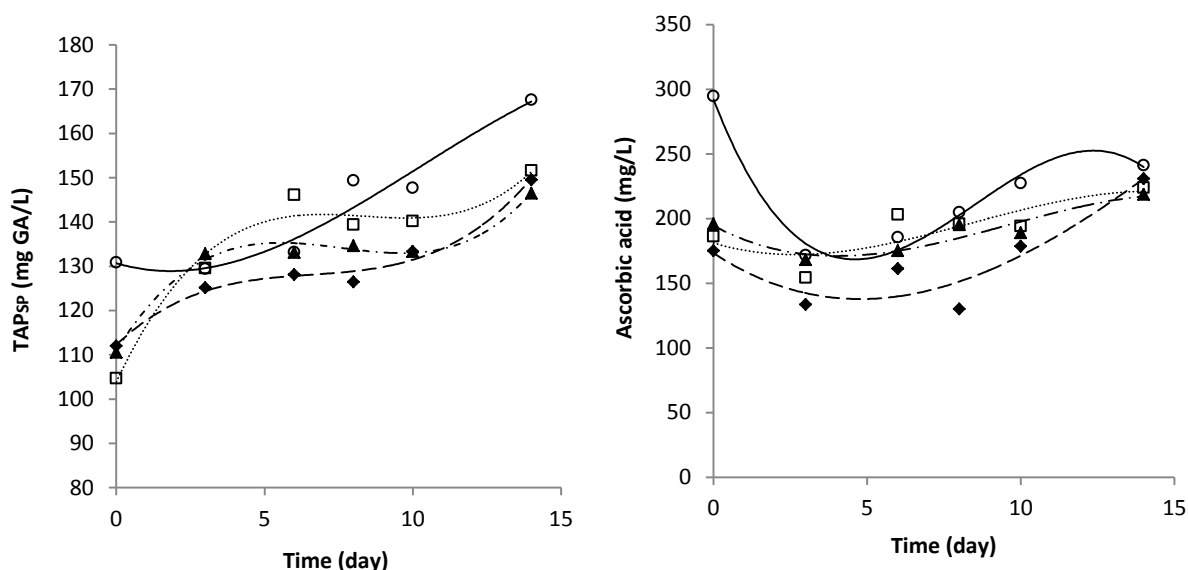
### *Ascorbic acid and total antioxidant potential*

AA is one of a number of antioxidants that are found in tomato fruit. It was included in the study because it is better known to the general public, and also because it is frequently mentioned within the context of conceiving the antioxidant potential. It is a representative of the primary antioxidants and it traps free radicals. In addition to lycopene, beta-carotene and AA, tomatoes contain further flavonoids and phenolic antioxidants.

AA contents for the analysed tomato samples varied between 130 and 300 mg/L. As is evident from Fig. 2, the content of AA depends significantly on the maturity stage of the tomato fruit. It reaches its maximum value at optimal - table maturity of the fruit. Contents of AA in the tomato samples at other maturity stages were on average 40% lower, with smaller differences between maturity stages. On the other hand, the AA levels decline was evident with every day of on-plant over-ripening, already starting two days after the optimal table maturity.

Tracking the dynamics of AA content during the storage provided interesting information: the moment of harvesting affects the fruit significantly, resulting in AA levels, at each of the maturity stages of the tomato fruit. After three days of storage, the content of AA was reduced by 25 to 50%. After 6-8 days of storage the fruit at maturity stages G, GO and O managed to catch up with the decline and to overcome the values at the time of harvesting. After 14 days of storage there were practically no differences in AA content between individual treatments. Nevertheless, tomatoes, harvested and stored when less mature, could not reach the AA contents in the tomatoes harvested at table maturity (R).

Total antioxidant potential is the sum of the individual contributions of synergistic antioxidants, carotenoids, polyphenols, terpenoids, and trace elements. As is evident from Fig. 1, TAP<sub>SP</sub> in the tomato fruit varied in regard to the different maturity stages and reached values between 104 and 131 mg of GA/L. TAP<sub>SP</sub> of the fruit harvested at table maturity (R) was the highest and exceeded on average by 17% the TAP values of other maturity stages. During each treatment TAP<sub>SP</sub> slightly increased over days in storage. After 14 days of storage, when all the fruits had reached table maturity (R) (according to fruit skin colour), the TAP<sub>SP</sub> values for all the tomatoes harvested at different stages of maturity increased up to a maximum level, as determined in samples after individual treatments. Despite the TAP<sub>SP</sub> values of table mature tomatoes also remaining the highest after 14 days of storage, the TAP<sub>SP</sub> values of other treatments (G, GO and O) were practically identical. After 14 days of storage the absolute difference between the treatments remained unchanged, although the tomatoes of all stages of maturity gained on average 7% of the TAP during storage.



**Fig. 1.** AA content and TAP<sub>SP</sub> and their dynamics in tomato fruit samples of different maturity stages, stored in storage at 18 °C (◆ G, □ GO, ▲ O, ○ R)

There was a reasonable correlation between the contents of AA and TAP<sub>SP</sub> for tomato fruit samples harvested at different maturity stages and stored for 0-14 days (T = 18 °C) (R<sup>2</sup> = 0.82).

*Soluble solids content (SS)*

Soluble solids content of tomato fruits at different maturity stages varied between 3.7 and 4.0 °Brix, so the absolute differences between treatments were

small. Still, it is obvious from the data presented in Table 1 that the maturity stages directly influence the values of SS, being the highest in tomato fruits of table maturity, app. 5% lower after treatment O, and app. 7% lower after treatments GO and G. The dynamics of changes in SS content in tomato fruit at different maturity stages is evident from Table 1. After 14 days of storage, differences in table mature tomatoes were negligible, while other treatments exhibited minimal increases of SS.

**Table 1.** Quality parameters (soluble solids - SS, total titratable acids - TTA and fruit masses) of tomato fruits at different maturity stages and their changes in storage at 18 °C

Storage time (day)	Stage of maturity			
	G	GO	O	R
TSS (Brix):				
0	3.69 ± 0.02	3.69 ± 0.02	3.78 ± 0.00	3.96 ± 0.09
3	3.83 ± 0.05	3.78 ± 0.02	3.91 ± 0.04	3.95 ± 0.09
6	3.83 ± 0.11	3.78 ± 0.03	3.95 ± 0.16	3.98 ± 0.14
8	3.90 ± 0.11	3.84 ± 0.05	3.87 ± 0.12	3.85 ± 0.02
10	3.75 ± 0.03	3.85 ± 0.15	3.85 ± 0.00	4.01 ± 0.11
14	3.94 ± 0.07	3.90 ± 0.07	3.90 ± 0.05	3.95 ± 0.02
TTA (g/L):				
0	0.55 ± 0.01	0.49 ± 0.00	0.42 ± 0.06	0.39 ± 0.02
3	0.54 ± 0.02	0.49 ± 0.00	0.44 ± 0.02	0.38 ± 0.02
6	0.47 ± 0.06	0.47 ± 0.01	0.43 ± 0.01	0.36 ± 0.01
8	0.46 ± 0.01	0.41 ± 0.01	0.40 ± 0.03	0.38 ± 0.02
10	0.45 ± 0.01	0.44 ± 0.02	0.39 ± 0.01	0.35 ± 0.02
14	0.45 ± 0.03	0.42 ± 0.01	0.35 ± 0.04	0.37 ± 0.02
Mass (g):				
0	133.67 ± 1.97	141.62 ± 4.50	141.05 ± 7.37	142.19 ± 7.48
3	132.08 ± 5.82	141.45 ± 5.71	143.71 ± 1.87	143.48 ± 6.15
6	132.86 ± 3.95	142.32 ± 1.94	142.38 ± 5.74	143.35 ± 3.38
8	133.27 ± 1.79	142.00 ± 3.44	140.36 ± 3.00	142.49 ± 3.77
10	132.73 ± 2.58	143.37 ± 3.55	142.89 ± 3.10	142.35 ± 4.51
14	130.29 ± 3.47	141.89 ± 2.71	141.76 ± 4.46	142.47 ± 4.76

### Total titratable acid content (TTA)

Data in Table 1 show the initial values and the dynamics of the change of TTA during the storage of tomato fruits at different maturity stages (treatments). It is obvious that the TTA contents significantly differed between treatments; they varied between 0.39 and 0.55 g/L, being in an inverse correlation with the maturity stages of the tomato fruit. During storage, the TTA content of treatment R changed minimally, while changes in treatments G and GO were more pronounced (app. 16%). After 14 days of storage, the absolute differences between the treatments did not change significantly; TTA treatments G and GO were still app. up to 18% higher than in other treatments.

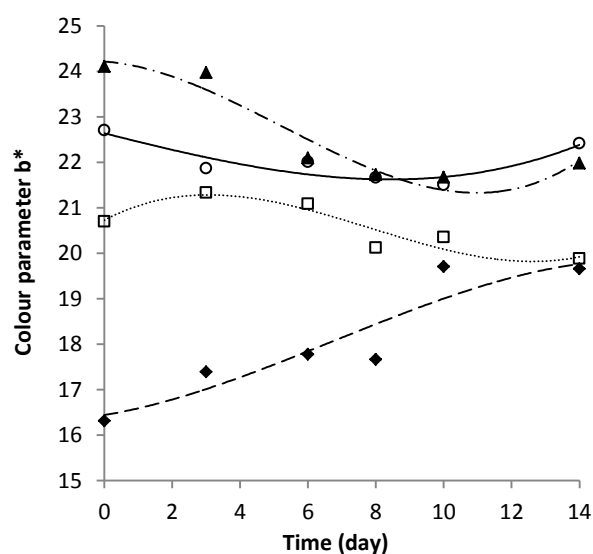
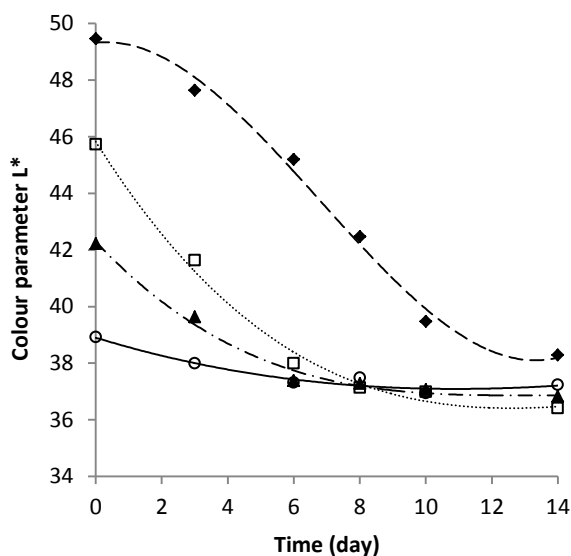
### Fruit mass

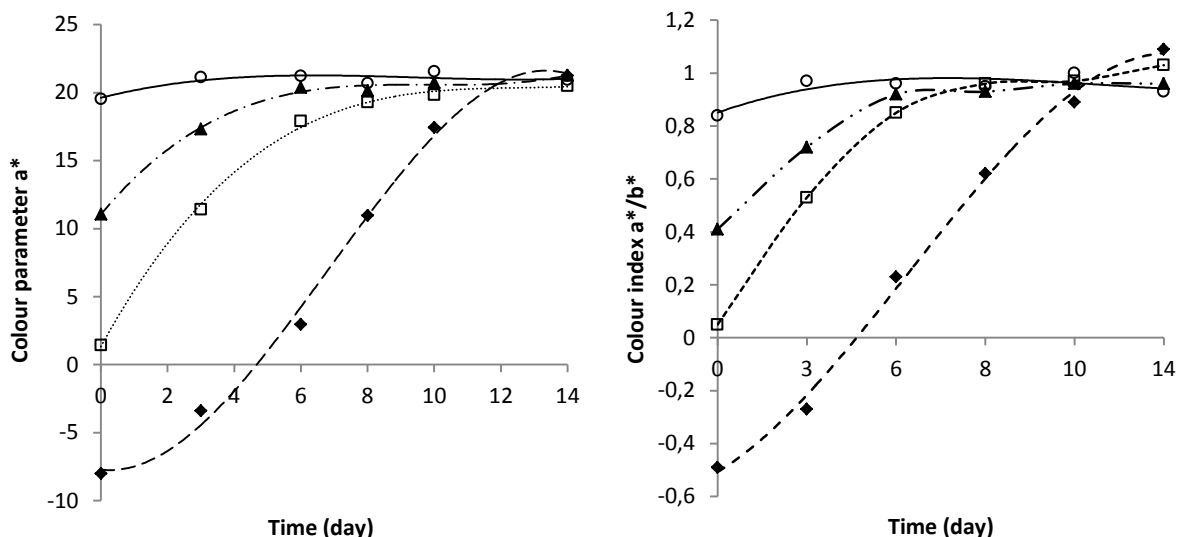
Fruit mass at the time of harvesting and its dynamics during the 14 days storage are shown in Table 1. It correlated well with fruit maturity and varied between 133 g and 144 g, being significantly the lowest in treatment G. After 14 days of storage, no changes in the fruit masses of R, O and GO treatments were detected, while the mass lost in treatment G was more pronounced and reached app. 5 g per fruit or 4% of initial total yield.

### Colour parameters

The dynamics of colour parameters  $L^*$ ,  $a^*$ ,  $b^*$  and the ratio between  $a^*/b^*$  for tomato fruits harvested at different maturity stages during 14 days of storage, are presented in Fig 3. At the time of harvesting, the values

of colour parameter  $a^*$  differed significantly amongst treatments, being in a positive correlation with the maturity stage of the tomato fruit. At the time of harvesting, the absolute differences between treatments were high ( $\Delta a^*=28$ ). During storage, the degradation of chlorophyll allowed intensification of the red colour, and after 14 days in storage no visible differences in the values of a parameter  $a^*$  were noticeable. Data in Fig. 2 show that the comparable values of the colour parameter  $a^*$  were reached after 12 days during the treatment G, after 8 days during the treatment GO and after 6 days during the treatment O. A specific sigmoid-shaped curve for a parameter  $a^*$  was highly-visible in treatment G, while the fruits from other treatments were shown only on a part of this curve. This coincided with the research by Tijssens et al. (2009), who applied the standard logistic model expressed in the biological shift factor system, describing the behaviour of the  $a^*$  value depending on the season and the experimental set-up. Data in Fig. 2 also present the initial values of the colour parameter  $L^*$  and its changes during the 14 days of storage. It is obvious that the value of this colour parameter correlated negatively with the maturity stage of the tomato fruit. At harvesting time, the differences between all treatments were large, but after 14 days of storage only the fruits from the treatment G still differed significantly from the other treatments. The most evident change of parameter  $L^*$  could again be seen in the treatment G. As a result of the early start of measuring, it displayed the complete dynamics of the fruit darkening during maturation and ripening. The time delay in the change of a colour parameter  $L^*$  between different treatments was similar to a parameter  $a^*$ .





**Fig. 2.** Colour parameters  $L^*$ ,  $a^*$ ,  $b^*$  and colour indexes  $a^*/b^*$  at different maturity stages of tomato fruits and their changes during storage ( $T=18^\circ\text{C}$ );  $\blacklozenge$ G,  $\square$ GO,  $\blacktriangle$ O,  $\circ$ R

Colour parameter  $b^*$  represents the transition of colouring from blue to yellow. It is evident from Fig. 2, that parameter  $b^*$  depended on the maturity stage of the tomato fruit, being the lowest for the treatment G. During storage, the fruits from different treatments showed different development patterns of the colour parameter  $b^*$ ; there was no drastic change in the value of a parameter  $b^*$  for the treatment R. In the treatments O and GO a slight decrease was recorded while in the treatment G, the values of a parameter  $b^*$  increased significantly. After 14 days of storage, the absolute differences between treatments were much smaller (app. 50%) than at the time of harvesting. In contrast, the situations for the colour parameter  $a^*$ , tomato fruits from the treatments G and GO did not reach the end-values of a colour parameter  $b^*$  regarding the treatments O and R.

According to the literature (Kacjan et al., 2011), colour indexes  $a^*/b^*$  should represent the colour intensities in a better way than each parameter individually. Data in Fig. 2 show the initial colour intensities of tomato fruits at different maturing stages. Absolute differences between treatments, regarding the times of sampling (harvesting), varied between -0.5 and 0.85, being -0.5 in the treatment G, 0.05 in the treatment GO, 0.4 in the treatment O and 0.85 in the treatment R, representing green, green orange, orange, and red colours. According to the data in Fig. 2 colour indexes  $a^*/b^*$ , confirmed the dynamics of the fruit skin colour change during storage and were in compliance with the time schedule discussed in the cases of colour parameters  $L^*$  and  $a^*$ .

#### Determining chemical markers

PCA was performed in order to obtain a better overview of the overall fruit quality, to reduce the

number of variables, and to investigate the extent of a correlation between the determined tomato fruit quality and maturity parameters (Fig. 3).

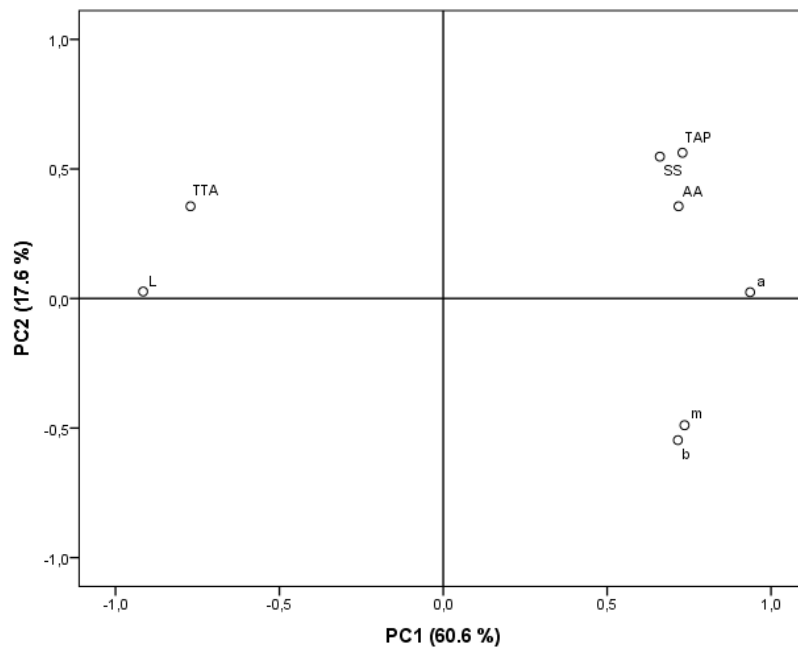
Even though 60.6% of the variation can be explained by PC1 and another 17.6% by PC2, loading factors were compared to investigate co-correlations between different variables. The contents of AA and  $\text{TAP}_{\text{SP}}$  were very strongly co-correlated and most strongly affected by the contents of SS and slightly less by the colour parameter  $a^*$ . Very strong co-correlation could be seen between the colour parameter  $b^*$  and the tomato fruit mass, and the connection with TTA content was also evident.

Differences between groups of variables were further explained by discriminant analysis (DA). As is evident from Fig. 4, the strongest deviation, according to quality and maturity, can be observed for the sample group no. 1, which represents green tomatoes stored in storage (GS), and sample group no. 5, which represents red tomatoes, freshly harvested at table maturity (RP). The first discriminant function, that contributed most to the distinction between the GS treatment and all other sample types of tomato fruit ( $\text{DF1} = 69.1\%$ ), was associated with the colour parameter  $b^*$ , fruit mass, and content of AA. The second DF contributed considerably to the differentiation between RP and treatments GOS, OS, and RS ( $\text{DF2} = 24.2\%$ ), and it is linked to the contents of AA, TTA and  $\text{TAP}_{\text{SP}}$ . The percentage of the original grouped cases that were correctly classified was 92.9%.

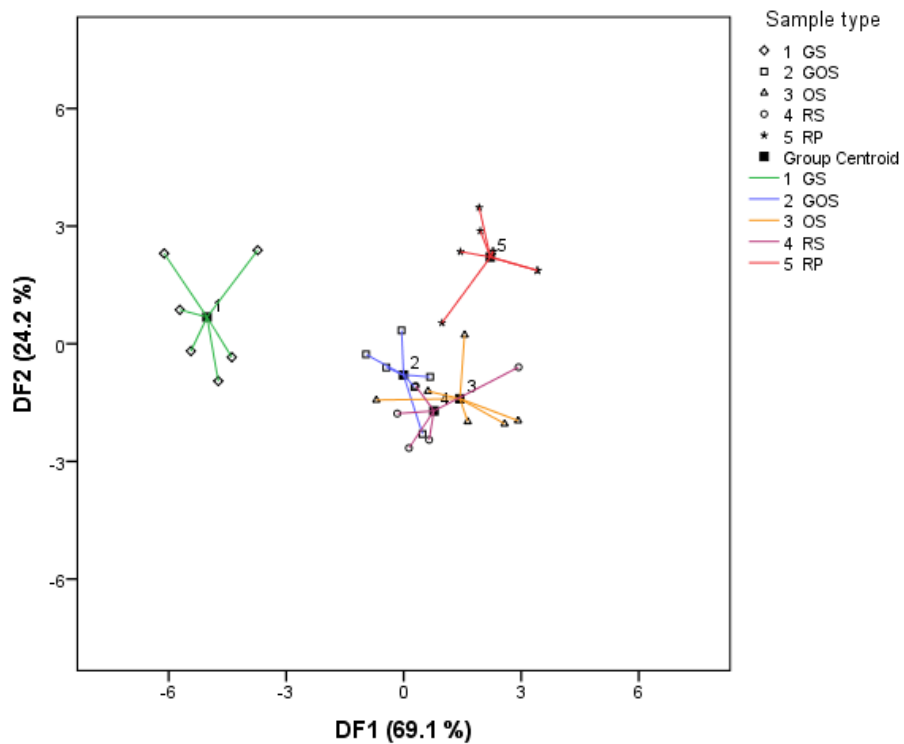
Therefore, the more important chemical and fruit skin colour markers for distinguishing individual treatments were the colour parameter  $b^*$  and the content of AA. Regarding overall quality, there were no statistically significant differences between the treatments GOS, OS, and RS.

The requirements of the market (consumers) reflect the tendency towards a higher content of AA and higher TAP, because such fruit has higher nutritional value.

Regarding quality, the optimum time for harvesting tomato fruit at the moment is when it reaches its full colouration and table maturity on the plant.



**Fig. 3.** Loading plot for PCA performed with all measured variables: internal and external tomato fruit quality and maturity parameters



**Fig. 4.** Scatterplot in the space of the first two discriminant functions for tomato fruit quality parameters, considering the stage of maturity at harvesting time



## Conclusions

Aside from the obvious differences in fruit skin colours, tomato fruits at different maturity stages exhibited large differences in internal fruit qualities and nutritional values. During storage at 18 °C, tomatoes harvested at earlier stages of maturity reached their full red colouration (table maturity) with delays of 12, 8 or 6 days respectively for the treatments G, GO, and O.

Fresh, table mature tomato fruits differed from those that ripened in storage (T = 18 °C) after harvesting at different maturity stages, mostly because of AA content and TAP<sub>SP</sub>, both being key parameters for higher nutritional values of tomato fruits. Freshly harvested, table mature tomato fruits also differed from tomatoes over-ripened on the plant and harvested too late. The grower must be especially attentive when determining the optimal harvesting date, because the quality declines either with over-maturity or with early harvesting and storage. Considering the nutritional value, the tomato is better if it is over-matured on the plant than if it is stored. AA content and TAP depend on the maturity stage of the tomato fruit, the with fresh tomato fruit harvested in time for table maturity having the highest value. There was a good correlation between the contents of AA and TAP<sub>SP</sub> in those tomato fruit samples in storage at T = 18 °C. The content of SS depended directly on the maturity stages of the fruits; absolute differences between individual maturity stages were very small. The content of TTA was in inverse correlation with the maturity stage of the tomato fruits. AA content is clearly the most important chemical marker for simple quality control of tomato fruits. By using a simple and reliable analytical method for determining AA content such as direct redox titration, monitoring of tomato fruit quality could also be easily performed in situ by every person included in the food supply chain.

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Received: September 25, 2015

Accepted: November 18, 2015