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Postharvest behavior and lycopene content of tomatoes at different harvest times

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ABSTRACT. The objective of this study was to evaluate the physical, chemical and bioactive behavior of the tomatoes of the commercialized tomato at the Central of Supply of Goiás at different times of the year and stored for 15 days in ambient conditions and propose the construction of a model to estimate the content of lycopene from the coloring of the fruits. Seven monthly collections of tomatoes were carried out between February and August. The fruits were evaluated for color, firmness, fresh weight loss, titratable acidity, pH, soluble solids, lycopene, total extractable polyphenols, and antioxidant activity. The variation of brightness and firmness were inversely proportional to the storage time. The linear regression model generated from the correlation between the red color and the lycopene content can be used to estimate the lycopene value of the fruits. Future work may be carried out for developing non-destructive models of determination of lycopene for industrial tomato.

Keywords: *Solanum lycopersicum* L., commercialization characteristics, carotenoid compound, coloration, polyphenol compounds, antioxidant capacity.

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Introduction

Tomato (*Solanum lycopersicum* L.) is one of the main vegetables consumed in the world. Its high consumption rate is mainly due to its versatility of use and its sensorial properties like flavor, texture, and aroma (Hernandez, Espinosa, & Galindo, 2014; Iglesias et al., 2015). The fruit is a source of compounds with bioactive properties, such as vitamin C and A, polyphenols and carotenoids, especially lycopene (60%), lutein (10%) and β-carotene (6%) (Meléndez-Martínez, Fraser, & Bramley, 2010; Kotíková, Lachman, Hejtmánková, & Hejtmánková, 2011).

This can be used as a raw material for processing or for in natura consumption in salads and homemade sauces, such as table tomatoes (Hernandez et al., 2014; Iglesias et al., 2015). Hence, the food can be presented to the consumer, both in natura form or its derivatives can be considered as an important source of nutrients with antioxidant properties for the diet. Its consumption is indicated by nutritionists for being a food rich in lycopene (that imparts red color to ripe tomatoes is reported to possess anti-cancerous properties), vitamins A and B complex, as well as minerals such as phosphorus and potassium, as well as folic acid and calcium, among others. It is noteworthy that the more mature the fruit, the higher the concentration of those nutrients. Hence, this can be related to the reduction of the risk of development of diseases, such as cardiovascular disorders, diabetes, obesity and cancer (Palomo, Fuentes, Padró, & Badimon, 2012; Santos, Mattos, & Moretti, 2016).

In tomato consumption, its quality is of vital importance in terms of its commercial value and consumer acceptance (Costa, Guilhoto, & Burnquist, 2015). Ideally, the tomato fruit should exhibit bright red color, firm texture, having no signs of physical damage, diseases, and physiological disorders (Kotíková et al., 2011). The fruit with the desired characteristics will help attract more consumers. However, in the post-harvest phase, if no suitable conservation methods are adopted, for example the use of salicylic acid (Baninaiem, Mirzaaliandastjerdi, Rastegar, & Abbaszade, 2016), temperature control (Viet & Trang, 2015), controlled atmosphere and edible films (Gharezi, Joshi & Sadeghian, 2012), their quality tends to be reduced

(Costa et al., 2015). However in tropical countries, in the retail market, this vegetable is marketed under room temperature conditions and without the use of packaging.

During the growth and development period, there are many chemical and physical changes occurred in tomato that have an impact on fruit quality and ripening behavior after harvest (Dhall & Singh, 2016) and in the storage, either for commercialization or for consumption, the tomato will undergo modifications, resulting in reduced sensorial quality, loss of fresh mass, decrease in firmness and fruit acidification (Ferreira et al., 2010), due oxidative enzymes contribute to changes in taste, texture, color and some nutritional properties of fruits (Mantovani & Clemente, 2010).

Considering the importance of tomatoes in economy, human health and the difficulty in adopting correct techniques by retailers, it is important to understand the change in its physical, chemical and nutritional characteristics when the fruit is stored under commercially defined conditions. Besides that, as for a lot of climacteric fruit ripeness assessment certifies optimal harvest time, which has an effect on the postharvest quality. Harvesting at the full ripening stage results in poor transport and storage capabilities and unacceptable organoleptic quality, while premature harvesting prevents the development of the characteristic flavor and aroma of tomatoes (Pieczywek et al., 2018).

This study investigated the physical, chemical, and bioactive properties of tomatoes marketed for seven months and stored for 15 days under ambient conditions [24 ± 1ºC and 80 ± 5% relative humidity (RH)]. Further, the study proposes the construction of a model to estimate the content of lycopene from the coloring of the fruits.

Material and methods

Plant material

Type 2 long-lived tomatoes (diameter between 60 and 75 cm, having longer post-harvest life, remaining firm for a long period of time) were collected between February to August 2017, a period of seven months covering both the dry and the rainy season. The fruits were purchased from different commercial establishments of the Food Distribution Center of the State of Goiás (Ceasa-GO). The dates of collection in each month were defined by the day of greatest volume of commercialization. Each collection was composed of 88 kg of fresh tomato (from 4 commercial places), physiologically developed, with a color ranging from green to ripe red.

After harvesting, the tomatoes were immediately transported to the Post-Harvesting Laboratory of Vegetables of the Federal University of Goiás (UFG), where 70 units from each collection site were selected, totaling to about 4 lots per month of collection. The selection sought to obtain fruits, free of damage, stains, rot, and any painted coloration (called '*de vez*', i.e., when the yellow, pink, or red color are between 10 and 30% of the fruit surface). Subsequently, they were sanitized with water and sodium hypochlorite at 200 ppm for 15 min. and stored for 15 days under controlled environmental conditions (24 ± 1°C and 80 ± 5% RH).

Experimental design

Physical and chemical characteristics were determined on days 0; 3; 6; 9; 12 and 15 in intact fresh fruits, randomly withdrawn from storage lots. The content of bioactive compounds and total antioxidant activity were determined on days 0; 6 and 15 of storage, in the crushed fruit that was dehydrated by lyophilization (Liotop lyophilizer), packed in vacuum and stored at -20ºC for a maximum of 100 days. Each analysis was performed with a sample size of 36 fruits, subdivided into 12 subsamples, each having 3 experimental replicates with 3 fruits for each batch of fruit storage.

Analysis

Coloring parameters: peel color analysis was performed at two points in the equatorial region of the fruit using a Color Quest XE digital colorimeter (Hunter Association, Reston, Virginia, USA). The color parameters are expressed according to a system proposed by the International Commission of L'Eclaraige (CIE) in L*, a *, b* value. From these determinations the values of hue (h°) and chromaticity (C*) were obtained by McGuire (1992). Firmness of the pulp was measured by the applanation technique (Calbo & Nery, 1995) and the results were expressed in Newton (N). Cumulative loss in fresh weight was determined by comparing the difference in their present weight from day 0. The fruits were weighed in a semi-analytical balance (Marte Slim AD5000 brand, São Paulo) with an accuracy of ± 0.01 g and the value expressed as a percentage (%).

pH was determined in a portable bench pH meter (Technal brand, Piracicaba) which was immersed in about 100 g of crushed tomato pulp (*Instituto Adolfo Lutz* [IAL], 2008). Titratable Acidity was determined in 10 g of the crushed tomato pulp by the titration method, using 0.1(N) NaOH solution and thymol blue as indicator (IAL, 2008) and the results were expressed as percent citric acid. Soluble solids content (SS) was determined using a field refractometer (GoerTek brand, China), and the results were expressed as a percentage (IAL, 2008).

Vitamin C was determined by titration with potassium iodate (0.002 M) which turned light green at the turning point (IAL, 2008), and the results were expressed in mg %. Lycopene content was estimated using a spectrophotometer model V-630 (JASCO, Maryland, United States). According to the analytical methodology of separation and extraction of compounds with organic solvents (Rodriguez-Amaya, 2001), the method involved measuring absorbance at 470 nm and using that value to estimate lycopene content in μg g^{-1}. The results were expressed as mg 100 g^{-1} of the dried tomato.

To estimate the total extractable polyphenolic content, the tomato extract was obtained by the method of Larrauri, Rupérez, and Saura-Calixto (1997), modified by Rufino et al. (2011), from the lyophilized fruit. The total extractable polyphenol contents were determined by the methodology of Obanda and Owuor (1997), modified by Rufino et al. (2011). The results were expressed as mg of gallic acid (mg GAE) per 100 g^{-1} of the dried tomato. The antioxidant activity was determined by ABTS [2,2'-azino-bis-(3-ethylbenz-thiazoline-6-sulfonic acid] and Fe^{3+} reduction (FRAP - ferric-reducing antioxidant power) method as described by Rufino et al. (2011).

Statistical analysis

The data was submitted for regression analysis, in which the behavior of each of the analyzed variables was modeled as a function of storage time. The Pearson correlation coefficient was also calculated. The relationships between the physical and chemical variables, which were statistically correlated with the content of bioactive compounds, were expressed using regression models. Data for the physical and chemical analyses were then used to obtain variance and the means were compared by Tukey test. In all analyses 5% was considered as the critical level of significance. The analyses were performed in Sisvar 5.6 (Ferreira, 2014) and R software.

Results and discussion

The luminosity and hue angle decreased while chromaticity increased during fruit storage in all the months that were evaluated. The modification of fruit color is related to chlorophyll degradation and lycopene synthesis (Arias, Lee, Logendra, & Janes, 2000; Ferreira et al., 2010). Visually, the colors ranged from red-green to rosy red until the 6th day and to intense red until the 15th day (Figure 1).

The firmness of the fruit during its storage was detected in all months of evaluation, with a more intense loss observed until the 6th storage day (Figure 2A). This was similar to the trend observed with color modification. In the months of February and June, the fruits showed less firmness which can be related to the greater luminosity and hue angle of the fruits, in the very same months. The decrease in firmness occurs due to starch degradation and cell wall solubilization that arises from the transformation of insoluble pectins to soluble ones, thereby making the fruits softer (Kerbauy, 2012). The loss of fresh mass increased in all evaluated months and is represented by linear equations (Figure 2B). The accumulated loss ranged from 7.68 in August to 12.89% in February. This modification occurs due to the process of respiration and plant transpiration (Ferreira et al., 2010).

Soluble solids content (SS) varied as a function of storage time (Figure 2C) and time of fruit harvest (Table 1). At the time of collection, the SS content of the tomato was 4.11%, reaching a peak of 4.33% on the 12th day of storage. In the present study we can observe a tendency of increase in the content of SS.

The variation of the SS content in relation to the collection season may be associated with fruit maturation at the time of harvest, since more developed fruits in the plant contain higher levels of soluble solids. The season of the year also causes changes in the solid content of the fruit, and in rainy periods, soluble solids tend to be lower (Chitarra & Chitarra, 2005).

The results of this study were similar to that of the present study in control tomato samples harvested at the turning stage (from 10 to 30% of red color) and stored for 21 days at 9 ± 1°C and 95% RH.

According to Shirahige, Melo, Purquerio, Carvalho, and Melo (2010), high quality fruits should contain more than 0.32 titratable acidity and 3% soluble solids. Taking this parameter of acidity, the fruits sampled in February and May would not be classified as good quality for consumption. The tomatoes had a pH ranging from 4.02 to 4.63 during storage (Figure 3A). This range of variation is common, since in tomatoes the expected pH remains in the range of 4.0 and 4.5, in which the upper value is used to separate the fruits in non-acidic acids (Fontes, Loures, Galvão, Cardoso, & Mantovani, 2004).

The acidity of the samples varied greatly across samples (Figure 3B), but all fruits, regardless of the month of production, showed a decrease in acidity at the end of 15 days of storage. In the present study, the use of organic acids in the production was used of other organic acids and the conversion of organic acids into sugars (Ferreira et al., 2010). Reduction in titratable acidity values during storage of tomatoes was also reported by Andreuccetti, Ferreira, Moretti, and Honório (2007) for the cultivar Andréa.

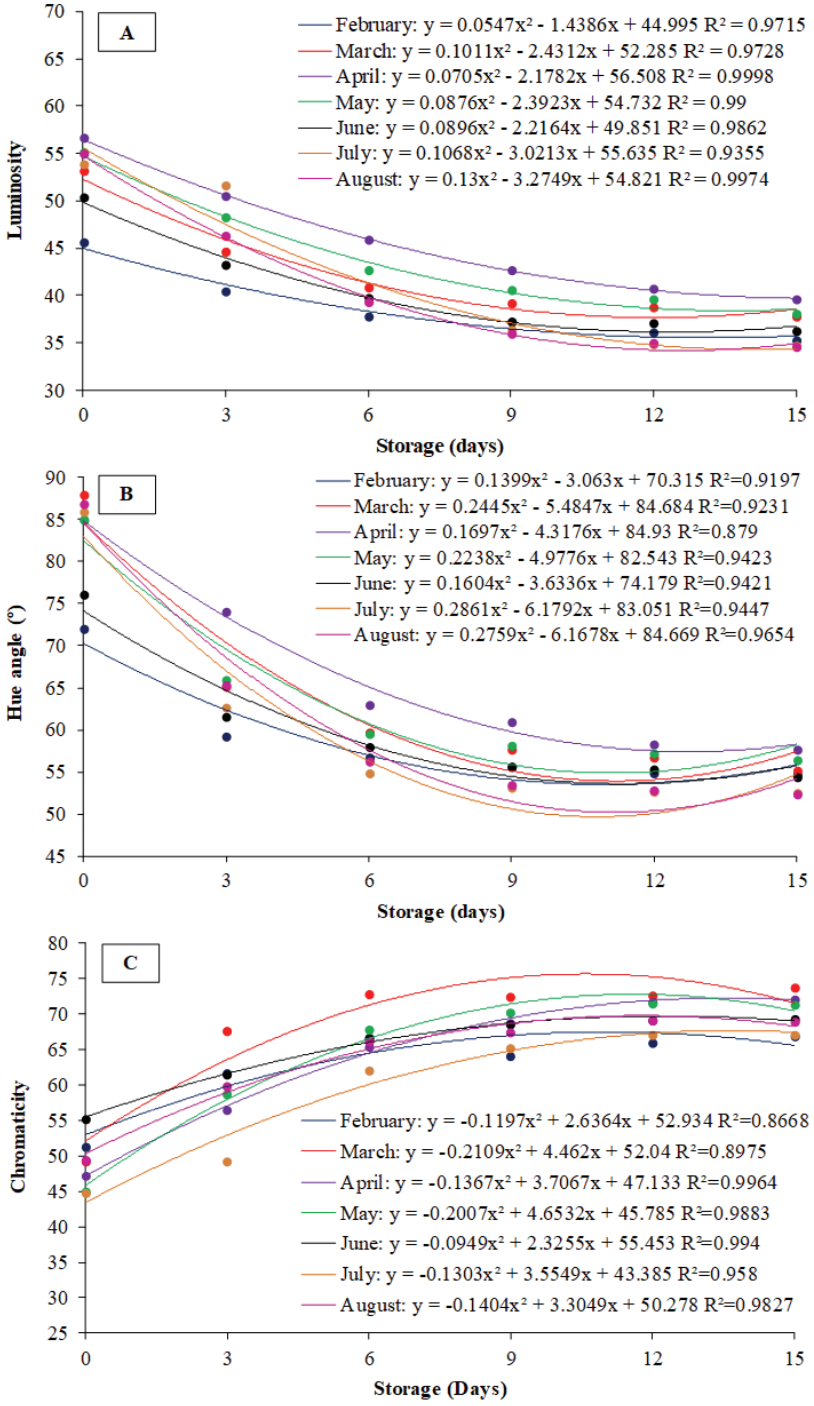

Figure 1. Luminosity (A), hue angle (B) and chromaticity (C) of the type 2 long-lived tomato skin storage for 15 days at 24 ± 1ºC e 80 ± 5 RH during seven days collect.

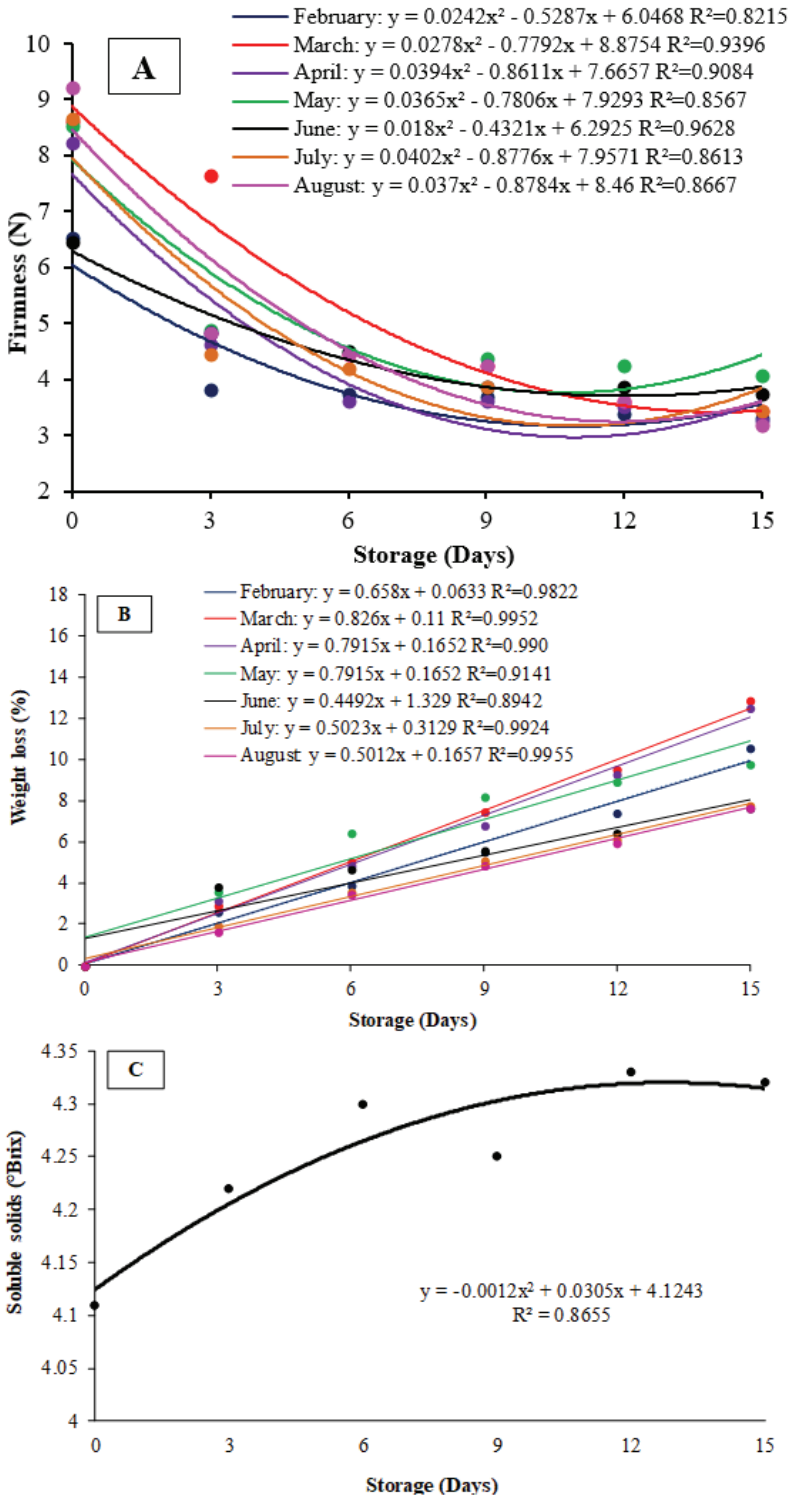

Figure 2. Firmness (A), weight loss (B) and soluble solid (C) in the type 2long-lived tomato storage for 15 days at 24 ± 1ºC e 80 ± 5 UR.

Table 1. Content of soluble solid (SS) in type 2 long-lived tomato in different collect times.

Collect Times	SS (°Brix)
February	4.45 [ab]
March	4.31 [bc]
April	4.12 [c]
May	3.78 [d]
June	4.18 [c]
July	4.51 [a]
August	4.42 [ab]
Dms	0.1889**

Means followed by different letters in the same column differed by Tukey test ($p < 0.05$). ** = significant at 1% probability by test F.

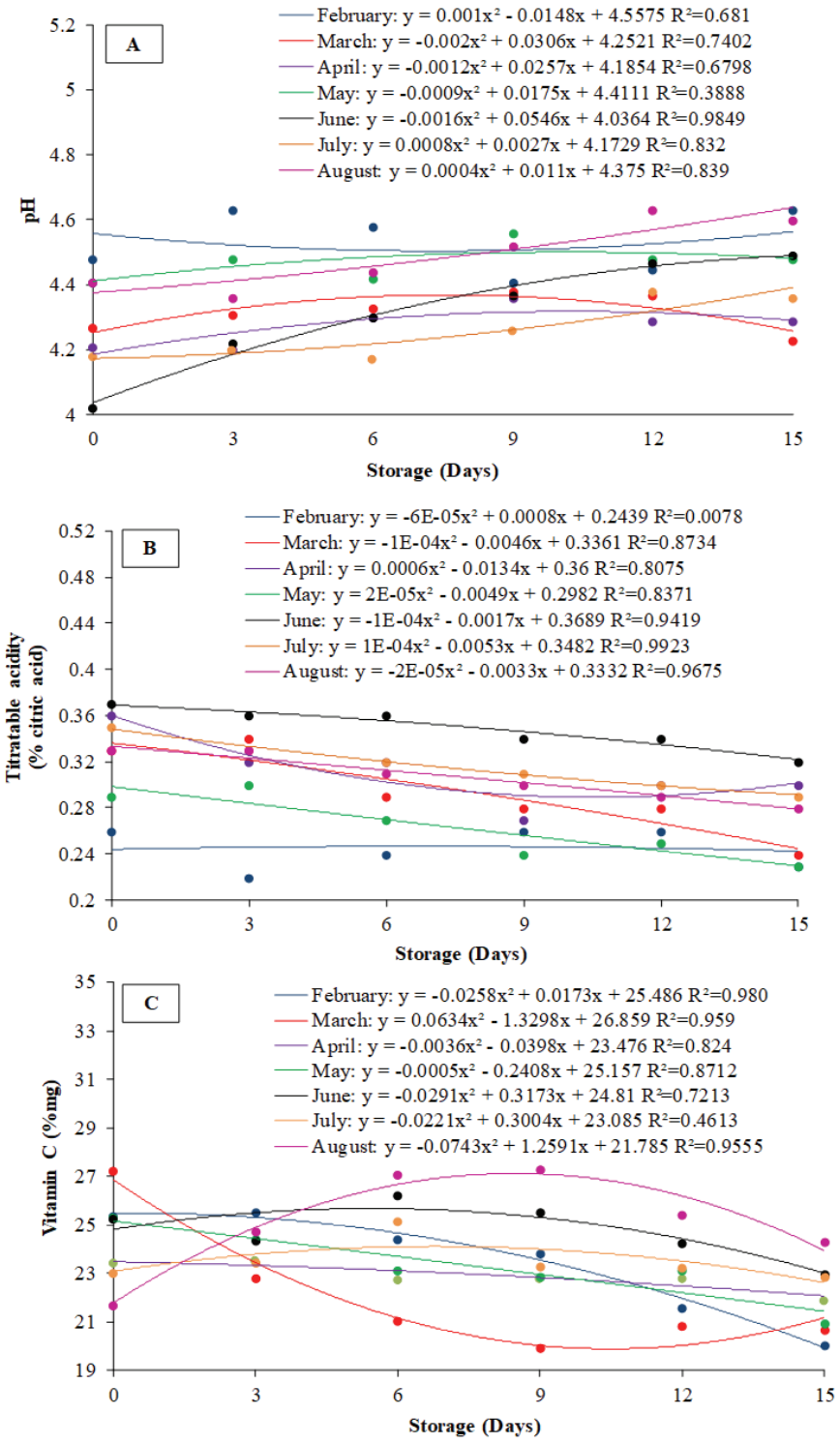

Figure 3. pH (A), tiratable acidity (B), and Vitamin C (C) variation of type 2 long-lived tomato storage for 15 days at 24 ± 1ºC e 80 ± 5 UR.

The content of vitamin C oscillated from between 19.95 and 27.29 mg% (Figure 3C), and was higher than that found in the study by Ferreira et al. (2010), and similar to the study by Vinha, Barreira, Costa, Alves, and Oliveira (2014). The variation in vitamin C content during fruit storage was different in each period. The fruits collected in March showed a greater decrease of vitamin C, whereas in August, on the 9th day of storage, there was a peak in its content. According to Lee and Kader (2000), decrease of vitamin C content after harvest can be considered as an indicator of loss of fruit quality. However, Ferreira et al. (2010) when evaluating conventional and organic table tomatoes in the post-harvest period, observed an increase in vitamin C content proportional to the evolution of the maturation stage, and attributed such variation to the synthesis of L-ascorbic acid resulting from the accumulation of soluble solids and reducing sugars.

The lycopene content increased about 5 times during fruit storage in all evaluated months, however, a linearity of this increase was observed in fruits collected in April, May, and June (Figure 4A). The variation observed in the lycopene content was also similar to the results of the study by Kotíková et al. (2011) that evaluated the lycopene content in tomato during its maturation in the plant. The study found an increase in lycopene content from 17 mg 100 g^{-1} to 69.98 mg 100 g^{-1} in the reddish tomato upon complete maturation.

The increase in the concentration of lycopene occurs in parallel with fruit ripening. More red tomatoes have a higher concentration of lycopene, a pigment responsible for the fruit's characteristic color (Ilahy, Hdider, Lenucci, Tlili, & Dalessandro, 2011; Kotíková et al., 2011). Lycopene continues to accumulate after tomato ripening, becoming the predominant pigment, accounting for about 90% of the carotenoids visible in fruits (Silva, Maciel, Alvarenga, & Paula, 2011).

When the content of phenolic compounds was evaluated, differences were observed in the behavior of the sampled epochs (in the months of June and August), with almost no changes observed in the content during storage (Figure 4B). In the other months of harvest, there was increase from the 6th day of sample storage, more specifically with the fruits collected in May.

There was no significant variation of the antioxidant capacity of the fruit by FRAP method throughout storage, nor in relation to the collection period. The mean value of the antioxidant capacity by the FRAP method was 4.94 µM sulfate ferrous iron g^{-1}, higher than that found in the literature, which ranged from 0.46 to 2.59 µM sulfate ferrous iron g^{-1} (Ilahy et al., 2011; Sulbarán et al., 2011; Kaur et al., 2013).

The ABTS method showed high variation in the antioxidant activity of the fruit during its collection period (Figure 4C). These values also varied throughout the storage period of the fruit. The antioxidant potential determined by the ABTS method was higher than that found in the literature, where the values ranged from 1.87 to 4.60 µmol TE g^{-1} (Ilahy et al., 2011; Sulbarán et al., 2011; Kaur et al., 2013). Only the fruits collected in February showed ABTS values close to those mentioned in previous studies. The variation in the antioxidant potential was however not uniform in all months of fruit harvest. An increase could be observed during March, while in the other collection periods, there was no significant variation in the antioxidant potential.

The variations in the luminosity and the hue angle negatively correlated with variation in lycopene and polyphenol content, loss of fresh mass and pH. However, variation in chromaticity correlated positively with these variables (Table 2). Reversibly, the variables of firmness and acidity positively correlated with luminosity and hue angle, and negatively with chromaticity.

The loss of fresh mass had a positive correlation with pH and showed negative correlation with vitamin C content, titratable acidity, and soluble solids. With increasing mass loss, a decrease in soluble solids content, acidity, and vitamin C were observed, which can be explained by the senescence of the fruit. The decrease in acidity during storage can be attributed to the reduction in the activity of enzymes related to respiratory metabolism. Loss of enzyme activity resulted in increase in the pH of the fruits (Antunes, Filho, & Souza, 2003), thereby justifying the negative correlation between acidity, soluble solids, and pH.

During fruit storage, significant correlations were observed between variation in lycopene content and also in physical variables like staining, firmness, fresh weight loss and chemical variables like pH and vitamin C.

During the process of physiological maturation, rate of carotenoid production (carotenogenesis) directly correlated with increased chromaticity, decreased brightness, similar to lycopene content (Rodriguez-Amaya, Kimura, & Amaya-Farfan, 2008). As maturation occurs the lycopene content increases and tomato fruits pass from the green-mature stage to red (Table 3; Camelo & Gómez, 2004). Such changes occurred in the post-harvest period, given the climacteric nature of fruit (Moura, Finger, Mizobutsi, & Galvão, 2005). The decrease in firmness with fruit ripening is directly related to carotenoid composition. Consequently, decrease in fruit firmness resulted in loss of fresh mass with maturation, increased pH, and decreased vitamin C. Thus, despite the deterioration in physical quality, the lycopene content will be higher in more mature fruits.

Considering the representativeness of the tomato sample used and the sample size being 28, the nutritional value of this fruit is highest at around 6th day of storage (red-pink), when parameters like color, polyphenol and lycopene are found at the apex. During this period, the fruit has maximum levels of polyphenols, high lycopene content, desired firmness, and pink color. The tomato stored for approximately

15 days is in atomized preparations, due to its red color intensity and maximum lycopene content (Table 3). A sensory analysis test performed by Vinha et al. (2014) with tomato consumers of the age range 18-50, showed greater pigmentation of the tomato does not guarantee consumer preference. Thus, pink tomatoes for use in salads is more appropriate.

As a characteristic of large sampling, the equations in Table 4, defined for the staining and lycopene parameters, can be used to estimate the lycopene content, in the absence of conditions for analysis of this bioactive compound in any tomato, since the capacity estimation of the equation is related to a high correlation coefficient, lower error values and better performance in external validation.

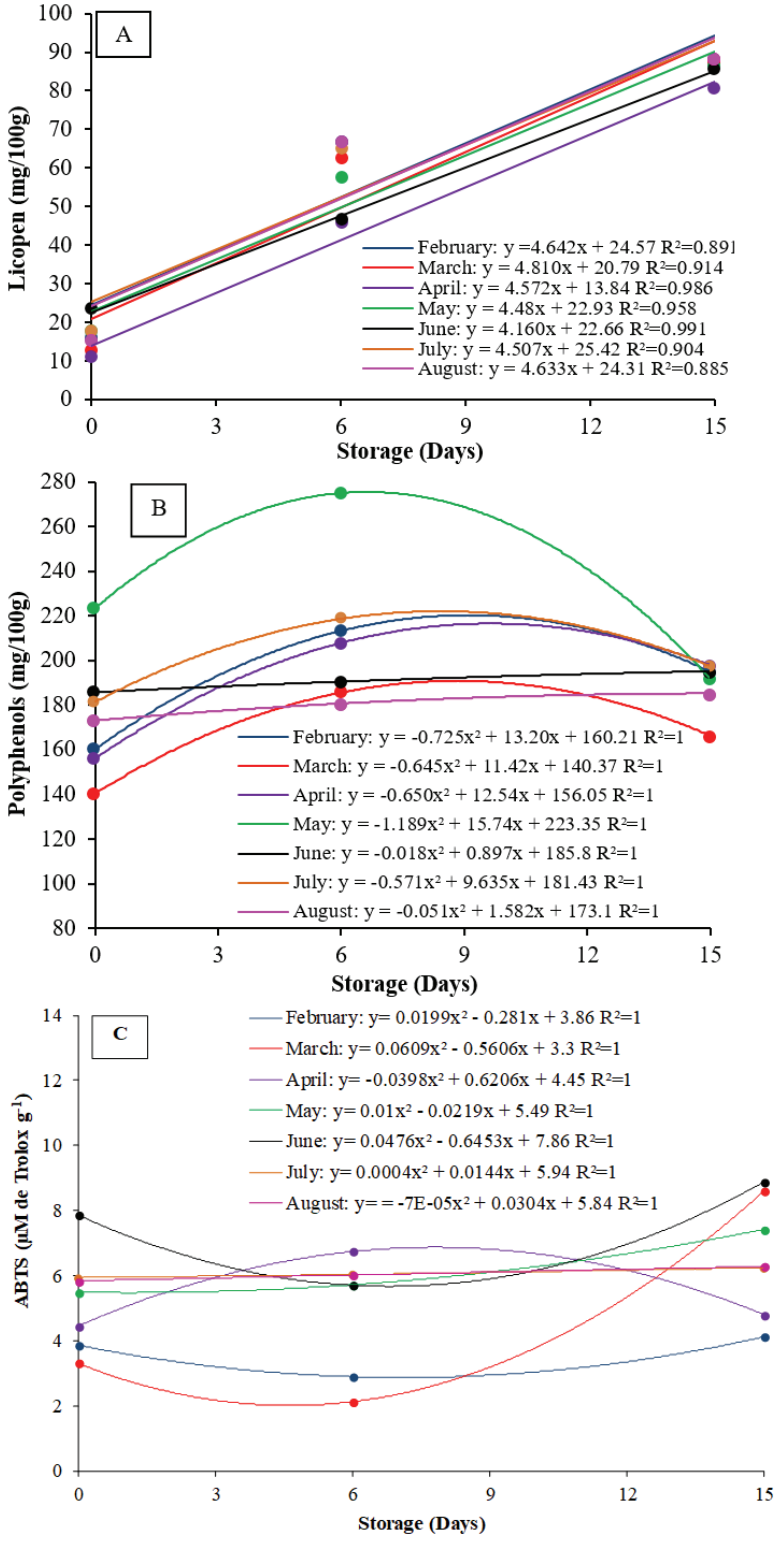

Figure 4. Bioactive compounds of type 2 long-lived tomato storage for 15 days at 24 ± 1ºC and 80 ± 5 UR.

Table 2. Pearson correlations between variables.

	L	Hue	Chroma	Lycopene	Firmness	WL	SS
L	1	-----	-----	-----	-----	-----	-----
Hue	0.9427	1	-----	-----	-----	-----	-----
Chroma	-0.8538	-0.8609	1	-----	-----	-----	-----
Lycopene	-0.9389	-0.9271	0.9070	1	-----	-----	-----
Firmness	0.8368	0.9772	-0.9408	-0.9120	1	-----	-----
WL	-0.7350	-0.7345	0.8618	0.9048	-0.8269	1	-----
SS	0.2014	0.2084	-0.1500	-0.2310	0.1288	-0.2346	1
pH	-0.4947	-0.4062	0.3141	0.4349	-0.3447	0.3140	-0.5030
Acidity	0.4677	0.4219	-0.4963	-0.5887	0.5013	-0.5878	0.3702
Vitamin C	0.1476	0.1674	-0.4073	-0.4518	0.3086	-0.6113	0.1854
Polyphenols	-0.2704	-0.3805	0.3147	0.3005	-0.3652	0.2273	-0.0460
ABTS	-0.1660	-0.2118	0.1918	0.2795	-0.2008	0.2895	0.2885
FRAP	-0.1064	-0.1191	0.1087	0.1712	-0.1239	0.1751	-0.0480
	pH	Acidity	Vitamin C	Polyphenols	ABTS	FRAP	-----
pH	1	-----	-----	-----	-----	-----	-----
Acidity	-0.6616	1	-----	-----	-----	-----	-----
Vitamin C	-0.1776	0.4541	1	-----	-----	-----	-----
Polyphenols	0.1884	-0.2404	-0.1090	1	-----	-----	-----
ABTS	-0.2156	0.1250	-0.1278	0.1134	1	-----	-----
FRAP	-0.2211	0.1135	-0.1783	0.2746	0.1032	1	-----

L: luminosity, Chroma: chromaticity, WL: weight loss, SS: soluble solids.

Table 3. Characteristics of type 2 long-lived tomatoes stored for 15 days at 24 ± 1ºC and 80 ± 5 UR.

Characteristics	Day 0	Day 6	Day 15
			
Color	Green and red	Pink red	Deep red
Firmness	+ firm	firm	- firm
Lycopene	X	↑ 3,5 X	↑ 5,2 X
Polyphenol	Y	↑ 1,2 Y	Y

Table 4. Regression between color and lycopene parameters in type 2 long-lived tomatoes stored at 24 ± 1ºC and 80 ± 5 UR.

	Regression model		
	Luminosity	Hue angle	Chromaticity
Lycopene	Y = 216.33 - 3.743.L (r = 0.8816; p < 0.0000)	Y = 190.76 -2.0981. Hue (r = 0.8595; p < 0.0000)	Y = 115.56+2.737.C (r = 0.8226; p < 0.0000)

Conclusion

The linear regression model generated from the correlation between the red color and the lycopene content can be used to estimate the lycopene value of the fruits. Future work may be carried out for developing non-destructive models of determination of lycopene for industrial tomato.

Acknowledgements

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