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Physicochemical Parameters for Obtaining Prediction Models in the Postharvest Quality of Tomatoes (*Solanum lycopersicum* L.)

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Abstract. This study aimed to determine physicochemical parameters for obtaining prediction equation in order to evaluate the postharvest quality of tomatoes (Solanum lycopersicum L.). A imaging system was used to measure L*a*b* color space. In tomatoes (variety Caiman) were evaluated weight loss, ºBrix, pH, titrable acidity, firmness and ºHue over 17 days of storage. The experimental results demonstrate that imaging system is feasible and most significant changes were observed in a correlation between firmness and ºHue= $27.04e^{(0.017\text{firmness})}$ with R^2=0.99. The lycopene content showed values from 0.15 to 8.21 mg/100g in a state of maturity USDA Nº 2 (breaker) y USDA Nº6 (deep red), respectively. Logarithmic models between color and lycopene content were much better fitted for °Hue and a*/b* vs. Lycopene with R^2=0.96.

Keywords: Tomato, postharvest quality, firmness, ºHue, image analysis, lycopene.

1 Introduction

Historically, tomato has been always important food for Mexican diet such as salsa, guacamole, shrimp cocktail, etc. In Mexico, as well as other countries, consumers have recognized the fresh tomatoes has more beneficial health effects of vitamins and minerals than cooked ones, so they are trying eating more fresh tomatoes than before. As this fact makes the distribution demand higher quality of fresh tomato, the cultivation in greenhouse has a rapid expansion for keeping the quality of them.

The average Mexican tomato fruit yield is about 160 and 31 ton ha-1 harvested from greenhouse and open field, respectively. In particular, greenhouse tomato production in this country in 2004 was 160 thousand metric tons, 8% of national production; nevertheless, most of this productivity is leaded to the USA market. In fact, The United States Department of Agriculture (USDA, 2004) reported that Mexico provides 84% of the tomatoes imported by the United States, which is about 700 thousand metric tons per year. In Mexico, there are 18, 127greenhouse production units, representing a total area of 12.540 ha (INEGI, 2007); whereas, in Nuevo Leon, a northeast state of Mexico, there are 106 production units with a greenhouse area of 95.53ha.

In other hand, the visual appearance of the fruits and vegetables is one of the characteristics of quality considered by the consumer, if fruits or vegetables are not attractive, the consumer will reject them immediately. Among these quality characteristics evaluated by a consumer are color and texture. The perception of color depends on three factors: a) type and intensity of light, b) chemical and physical characteristics of the fruit, and c) the person's individual ability to characterize the color (Mitcham et al., 1996).

2 Color measurement, image processing and lycopene of tomato

The color arises from the presence of light and higher intensities at certain wavelengths than others. The selective absorption of different numbers of wavelengths is what determines the color of the object (Sahin and Gülüm, 2009).This absorption is composed of different radiation wavelengths. However, visible light is the most important in relation to the appreciation of color and corresponds to wavelengths between 380 and 750 nm which is a very small portion of the electromagnetic spectrum (Delgado-Vargas & Paredes-López, 2003).

Image processing is a technique that can be used to measure the internal quality of fruits and vegetables through the collection of spatial information (X, Y) (Gómez-Sanchis et al., 2008). The fruit firmness can be estimated with an texturometer by using fruit deformation strength and speed of instrument. Other important parameters in the postharvest quality of fruits and vegetables are the Brix degrees (ºBrix), total soluble solids (TSS), pH and titratable acidity (TA) because they undergo changes with advancing the state of fruit ripeness (Mitcham et al., 1996).

The main pigments of the tomato fruit are carotenoids, which are responsible of tomato red color. Lycopene is the primary carotenoid found in tomatoes, accounting for 90% of total carotenoids (De Nardo et al., 2009). The lycopene molecular formula C40H56 is an open-chain acyclic polyene with 13 double bonds in the chain, it has 11 conjugated double bonds in a linear array, making it larger than any other carotenoid (Fig. 1) (Xianquan et al., 2005).

3 Physicochemical techniques

For the actual study, Caiman tomato fruits variety (breaking stage) were collected from a greenhouse located at Autonomous University of Nuevo Leon selecting a total of 36 fruit free of defects. The fruits were washed with a chlorine solution of 100 ppm, dried and sorted into groups of three. Subsequently stored in a shelf-life chamber, brand Lumistell, simulating marketing conditions at a temperature of 20 º C and relative humidity (RH) of 90%.

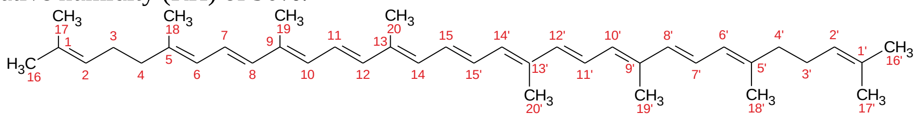

Fig. 1. Chemical structure of trans-lycopene (Bramley, 2002).

The experiment was carried out for 17 days. From first to seventh day, tomato physical-chemical properties were measured daily, whereas from the ninth day to the seventeenth day, the physicochemical measurements were made every two days. Groups of three tomatoes were sampled per day and destructive tests (texture, total soluble solids, pH, acidity) plus non-destructive tests (weight loss, and imaging) were conducted on them.

For lycopene content, measurements were made every two days. For the measurement of texture, a texture analyzer (TA.XT Plus, Stable Micro System) was used. This equipment was calibrated daily during the experiment. We measured the strength of the fruit to a deformation of 5 mm, using a rate of 1 mm s^{-1}. The fruit hardness at the maximum applied strain was recorded in Newtons (N). In a second group of tomato fruits, it was determined by accumulative loss of weight, recording daily the weight of each fruit, using a scale (Salter Brecknell, accuracy of 1 g). The accumulative weight loss per day was obtained using the following formula:

$$\%\text{Accumative Weight Loss} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} * 100 \qquad (1)$$

where the initial weight is the weight of the fruit at the beginning of the experiment and final weight is the weight of fruit in each sampling day.

The color determination was made by processing images obtained from three tomatoes which were placed on a flat surface with a black background and using a camera (Sony Cyber-shot), with a 4.1-megapixels resolution. The camera was placed at a height of 40cm, whereas, light source, in the laboratory, was a 4100K lamp (F32738CPX41, Ecolux model). From obtained images, there were only processed those that corresponded 1,3,5, 7,9,11,13,15,17 days. The imaging scanning was performed using a program developed in Matlab to obtain the RGB color space (red-green-blue) of the fruit and from which were took 24 pixels in a given area for each fruit. The R, G and B obtained from each pixel could transformed to the color space CIEL* a *b *Color Metric Converter (Release 2007). The true color (°Hue) was obtained using the following equations:^{0}Hue= tan-1 (b * /-a *) + 180 (used for ripening stages from green to breaking) and the equation ^{0}Hue= tan-1 (b * / a*) (used for ripening in red color).

After that tests were carried out about the measurement of strength. Tomato fruits were divided into four equal parts and stored at -20 ° C to carry out the measurements of ° Brix, pH, acidity and lycopene content. The º Brix were measured using a refractometer (Atago model) with scale from 0 to 32%. This equipment was calibrated daily during the experiment. A sample of the fruit juice was measured directly on the refractometer. For TA and pH measurement were taken 15 g of tomato sample without seed, were added 60 ml of water, and the mixture was homogenized for a period of approximately 25 s using a blender (Osterizer), and finally was filtered through fabric organza. The pH was directly measured in an aliquot of 25 ml of fruit juice with a pH meter (Orion Company). This pH meter was calibrated daily during the experiment. TA was measured in,an aliquot of 25 ml, it was added to 2% phenolphthalein indicator and titrated with 0.1 N NaOH until a pH of 8.2. The result was expressed as a percentage of TA using the following formula:

$$\%\ \mathrm{TA} = \frac{\mathrm{mL\ consumed\ of\ NaOH{*}N{*}meq}}{\mathrm{ml\ tomato\ juice\ analyzed}} * 100 * FD \tag{2}$$

where N normality of NaOH. mEq milliequivalents of citric acid (0064), DF dilution factor.

On the other hand the maturity index, was determined using the following equation:

$$\mathrm{MI} = \frac{°\mathrm{Brix}}{\mathrm{AT}} \tag{3}$$

4 Determination of Lycopene

Hexane, acetone and ethanol (spectrophotometric grade, Teddy brand) were the organic solvents for lycopene extraction from tomato samples. Lycopene with a purity of 95% was purchased from Sigma-Aldrich. Tomato fruit stored at -20 ° C, were lyophilized on a Labconco Freezone 4.5. For the extraction of lycopene, 1g of freeze-dried tomatoes was mixed with 25 mL of water and blend for a period of 90 s (Osterizer) for tomato juice extraction. Eventually, this suspension was added to a mixture of hexane-acetone-ethanol in 2:1:1 ratio, the mixture was stirred for 5 min and allowed to stand until the separation (Fig. 1). An mL aliquot was recovered from the upper layer of hexane, which was evaporated at a temperature of 45 º C in a water bath, purged with argon flow, a process carried out under low light conditions. Once the solvent evaporates, the extract was covered with aluminum foil and stored at -20 ° C to carry out its spectrophotometric analysis. Lycopene samples were suspended in 3 mL of hexane (Fig.2) and homogenized by vortex agitation, readings were made using a spectrophotometer (21 D Spectronic, cells of 1 cm in length and 2.5 mL volume), determining the absorbance of the sample at 503 nm. The calculation of lycopene concentration in samples was performed using a standard calibration curve at 0.033, 0.016, 0.008, 0.004 and 0.002 mg mL-[1], using hexane as pattern.

Fig. 2. Top layer of hexane

5 Weight loss, total soluble solids, firmness obtained in laboratory

Weight loss is related to the metabolic process of respiration of the fruit, as a final product of this process. With only a 5% loss of weight in fruits and vegetables, it is considered that these are a bad product at a commercial level due to withered appearance (Wills *et al*., 2007). Tomatoes showed up weight loss during storage, at the end of the experiment a value of 4.97% was observed. A conducted study by Javanmardi and Kubota (2006), reported a weight loss of 4.8% over a period of six days of storage at temperature of 26 °C. The behavior of weight loss in the actual study were different values than those reported. These differences can be attributed mainly to the storage conditions used. Generally, it was observed a rising trend, with least significant difference (LSD) throughout the storage period, except on days 11th and 15th with values of 3.18 and 4.37, respectively. This is attributed to the process of respiration and transpiration of the fruit during the storage period.

The main components of the total soluble solids are sugars and they are used as a substrate for energy production during the respiration process. Therefore once the fruits are harvested, the º Brix value decreases during storage (Wills et al., 2007& Bartz et al., 2003). This behavior was observed during the experiment showing a initial and final value of 5.6 of 5.0, respectively. Tomatoes showed an increase in pH during the storage period. The initial value was 4.18 and for the seventeenth day was 4.34. Hernandez-Suarez et al., (2008a) reported pH values of 4.17 in Thomas tomato cultivar, which was analyzed at maturity 6 (USDA), significant difference were found on days 5, 11 and 15 with values of 6.07, 4.67 and 4.67, respectively.

Organic acids decline during ripening, as some of them are converted to sugars, for latter reason organic acids are an alternative source to carry out the process of respiration. Wills et al., (2007) and Hernandez-Suarez et al., (2008b) have reported values of total acid (TA) of 0.48 in the variety of tomato Dorothy, the pH is higher compared to values obtained in this experiment, which showed maximum values of 0.33 and minimum values of 0.29.There was no significant minimum difference for each of the days of fruit storage.

The firmness affects the texture of the fruit. The pattern in the firmness of tomatofruits was downward during the storage period with an initial value of 79 N and a final value of 33 N (Fig.3). The final values of firmness are different to those reported by Artes et al., (1999), and this can be attributed to cultivar and storage conditions used.

The Figure 3 shows the data of tomato firmness analyzed for the study period; there occurred a descending of firmness, finding greater least significant difference (LMD) on days 1, 3, 5, 7, 9 and day 17 with values of 79.64, 64.19, 53.28, 43.48, 39.82 and 33.12, respectively. This is due to weight loss in together with the degradation of cell walls of the fruit.

6 Color of tomato fruits obtained by imaging

Color is the most obvious change in fruits and therefore the best criterion for determining quality, color changes are mainly associated with chlorophyll degradation and biosynthesis of diverse pigments. In the case of tomatoes these pigments are mainly carotenoids, particularly lycopene (Wills *et al.*, 2007). At the beginning of the experiment there was an increase of 104.92°Hue and a final value of 49.95 ºHue which is manifested in the change of color of tomato fruits (Figure 4). On the other hand Choid *et al.*(2008), worked with fruits of tomato breaker stage of maturity which obtained initial values of 115 °Hue and end of the experiment were 45 °Hue values Lopez *et al.*(2004), conducted an experiment with tomato fruits at maturity from green to red were 113.3°Hue values for breaking stage and a final value of 64.9. These results are close to those obtained in this experiment.

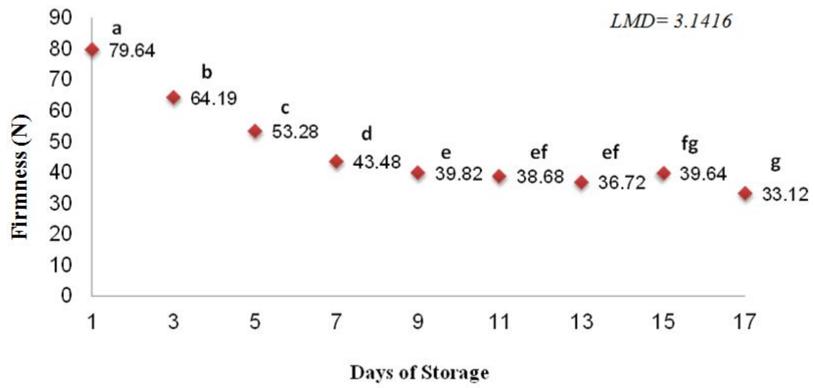

Fig. 3. Firmness in tomato fruits obtained in a period of 17days of storage. Same letters indicate no significant difference between treatments (α =0.05).

Figure 4 shows the behavior of the variable ºHue in the fruits analyzed during the study period, there was an overall decrease, with the greatest significant difference for days 1, 3, 5, 7, and 9 with values of104.92, 79.20, 69.08, 53.19. Figure 5 shows changes of color occurred in all long period of storage.

Figure 5 shows processed images of the color change in tomato fruit during 17 days of storage obtained by Matlab and Color Metric Converter.

The correlation ºHue-Firmness was modeled with the prediction equation $Hue = 27.04e^{0.017firmness}$ which had a coefficient of determination $R^2 = 0.99$ (Fig. 6). Therefore, the correlation º Hue-firmness can be used as a tool to predict the postharvest quality of tomato fruits in the supply centers, and thus plan the time that the product should be sent to stores to sale to consumers.

The maturity is a physiological stage in which physical-chemical changes are manifested in the color, respiration rate and carbohydrate composition (Wills et al., 2001). Hernández-Suárez et al., (2008a, 2008b) found a maturity value of 9 in the Boludo cultivar on the 7-8 maturation stages, according to the classification of Kleurstadiatomaten in Holland, these values are lower compared to those reported in our study, which were 17.17 and 17.5 as the initial and final value, respectively.

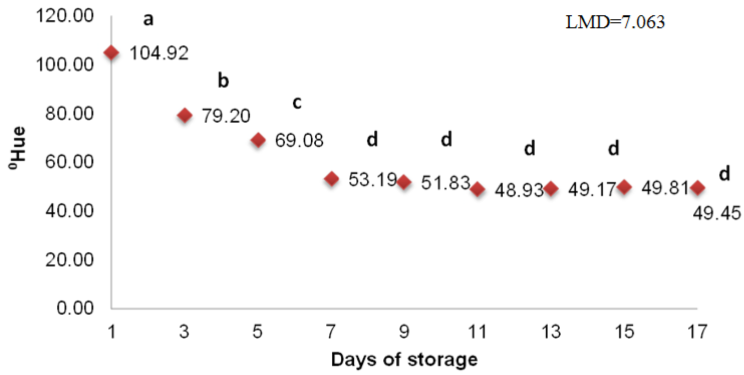

Fig. 4. . °Hue in tomato fruits obtained in a period of 17 days of storage.

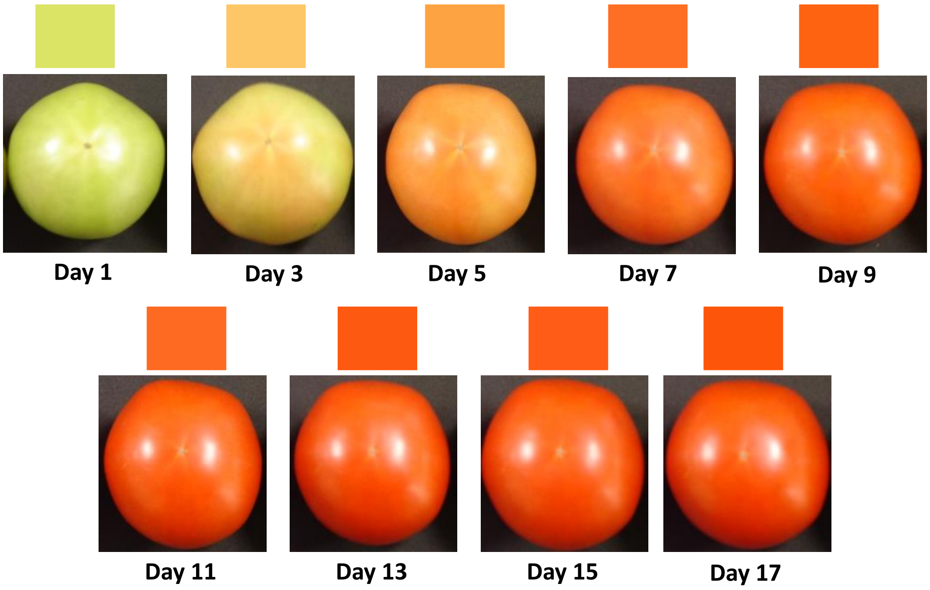

Fig. 5. Images of the color change in tomato fruit during 17 days of storage: a) true color (Hue°) of the tomato fruit, b) perception of tomato fruit color seen by the human eye.

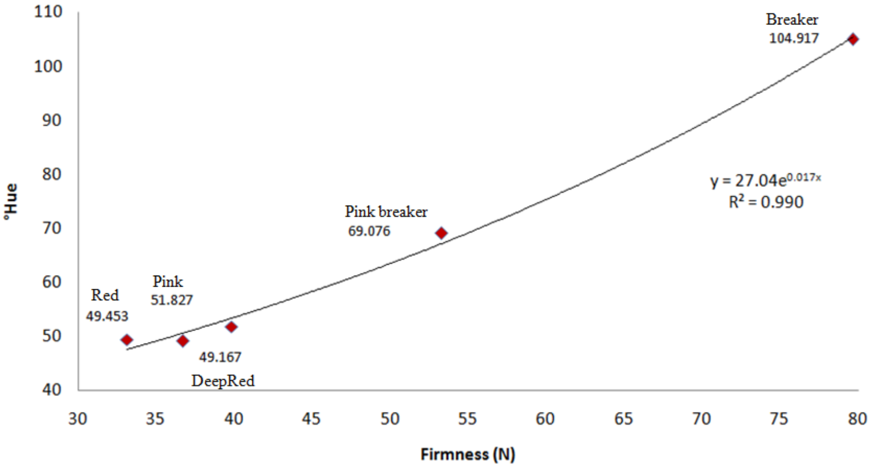

Fig. 6. Correlation ° Hue-Firmness in five maturity stages in tomato.

7 Content of lycopene obtained in tomato laboratory tests

The prediction model (R2 = 0.96) obtained for the determination of lycopene is as follows:

$$\text{Lycopene}\left(\frac{\text{mg}}{\text{mL}}\right) = \frac{A_{503}-0.0808}{19.419} \quad (4)$$

Where:A_{503} is the absorbance measured by a spectrophotometer at a wavelenght of 503 nm to avoid interferences from other carotenoids present in the specimen.

The lycopene contents obtained for different stages of maturity are shown in Fig.7. The average value at the beginning of the experiment was 0.15mg/100g for maturity stage, USDA Number 2 (breaking), whereas the average value at the end was 8.21mg/100g for maturity stage, USDA Number. 6 (deep red) (Bartzand Brecht, 2003). The lycopene content in tomato fruits in the USDA Number 5 mature stage (light red) was 3.36mg/100g whereas in stage of maturity USDA Number 6 (deep red) was 8.21mg/100g. The trend of the lycopene content of fruits analyzed during the research showed a general upward shaped behavior and finding the most least significant difference for days 1, 3, 13 and 17 with valuesof 0.15, 0.68, 5.01 and 8.21, respectively. Similar results were obtained by por Toor y Savage, 2006.This occurred due to the number of double bonds during the ripening process.

Clement et al., (2008), obtained lycopene concentrations of 0.18 and 7.2 mg/100g at maturity stages USDA No. 1 (green) and USDA No. 6 (deep red), respectively. These results are similar to those found in this experiment with initial values of 0.15 mg/100g and final values of 8.21 mg/100g .

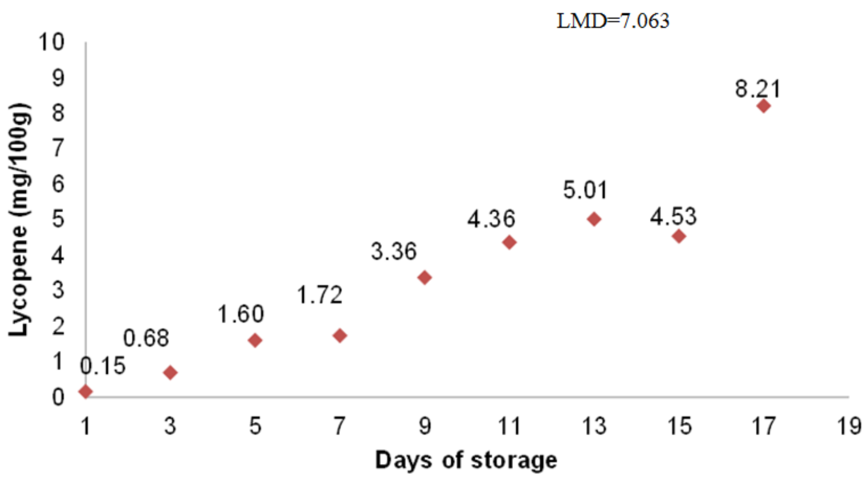

Fig. 7. Changes in lycopene content during storage at 20 °C and a RH of 90%.

Correlations were made between linear and logarithmic color parameters (a *, b *, a * / b *, °Hue) and the lycopene content during different stages of ripeness of tomatoes.

The coefficients of determination for linear correlations showed values of 0.60 to 0.67 whereas for the logarithmic correlation values were 0.94 to 0.96. Linear regression showed that parameters a * and a * / b * had the highest values in the coefficient of determination R2 = 0.67 and 0.64, respectively, whereas for the logarithmic regression, parameters a * / b * and ° Hue presented the highest coefficient of determination (R2 = 0.96). Logarithmic prediction equations that include a * / b * and ° Hue allowed obtaining more accurate prediction content of lycopene in tomatoes.

8 Conclusion

The most outstanding changes of tomato fruits were observed in parameters of firmness versus ° Hue. They can be used as a good index for predicting the postharvest quality of tomato. As for the content of lycopene in the tomato fruit is concluded that increases as the maturity of the tomato fruit changes from maturity stage USDA Number. 2 to maturity stage USDA Number 6. From maturity stage USDA Number 5, lycopene content continues to increase, but the value of º Hue remains constant.

Color parameters correlated against the content of lycopene, the data obtained from a * / b * and ° Hue, the a logarithmic model adjusted much better. On the other hand, data from a * and a*/b* vs. lycopene adjusted better to a linear model.

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