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Study of the quality and antioxidant properties of tomatoes (*Solanum lycopersicum* L.) under different postharvest and dehydration conditions

Luna-Guevara María Lorena[1]; González-Sánchez Teresita[1]; Delgado-Alvarado Adriana[2]; Ramos-Cassellis María Elena[1]; Pérez-Luna José Guillermo[3]; Luna-Guevara Juan José[1*]

[1]Benemérita Universidad Autónoma de Puebla, Facultad de Ingeniería Química, Colegio de Ingeniería de Alimentos, Puebla, México. [2]Colegio de Postgraduados, Campus Puebla, Puebla, México. [3]Benemérita Universidad Autónoma de Puebla Centro de Investigaciones en Dispositivos Semiconductores, Instituto de Ciencias, Puebla, México.

***Corresponding author**: juanj.luna@correo.buap.mx

ABSTRACT

Objective: To study the effect of storage temperatures and dehydration conditions (solar and convective drying; SD, CD), on the quality, physicochemical parameters and antioxidant properties of tomato fruits.

Methodology: The physicochemical characteristics pH, titratable acidity, soluble solids (°Bx) and color parameters (*L**, *a** and *b**), were evaluated. The lycopene, carotenoids and antioxidant activity percentages retention of tomatoes fruits stored at 7 and 22 °C for 5 days and subjected to SD (Temperature (T) of 67 °C and luminescence of 685 lum/sqf) and CD (T 70 °C, flow rates 0.5, 1.0 and 1.5 m/s), were analyzed.

Results: The fruits reached humidities of 17 and 15% for SD and CD. The parameters pH, °Bx, *L**, *a**, *b** were highest with 22 °C and CD (1.5 m/s). The value of the carotenoids was higher in fruits stored at 7 °C and subjected to CD (1.0 and 1.5 m/s) and SD with values of 83.85, 85.98 and 99.43%, respectively. The CD (0.5 m/s) and SD improved lycopene (94.37 and 95.14%) and the antioxidant activity with values of 73.06 and 97.21%.

Implications: The application of solar dehydration depends on luminescence condition; however, it is inexpensive and environmentally friendly alternative.

Conclusions: The results derived in a viable alternative for the conservation and commercialization of tomato fruits in rural communities.

Keywords: dried tomato, solar dehydration, lycopene, carotenoids, antioxidant activity.

INTRODUCTION

The tomato (*Solanum lycopersicum* L.) of the Solanaceae family, is one of the essential vegetables due to its consumption and economic relevance, with a cultivation area of 4.6 million hectares worldwide (FAO, 2017). In 2017, fresh tomato production in Mexico was 4,243,058 tons (Servicio de Información Agroalimentaria y Pesquera,

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2016), being Sinaloa, San Luis Potosí, Michoacán, Jalisco and Puebla, states with the highest production. However, the increase of the production and sometimes the low demand of the market propitiate alterations in the commercialization affecting the fresh tomato conservation, due to its high moisture content (92%), which result in the physical-chemical and microbiological changes. Dehydration is one of the most used processes in the conservation of fruits and vegetables (Ibarz and Ribas, 2005), highlighting drying as one common operation in the processing of food products, to increase their shelf life. The demand for dehydrated tomatoes has increased internationally, due to its use for the preparation of different dishes (Catalano *et al*., 2013). Additionally, the application of solar drying is being promoted as a conservation alternative, inexpensive, and friendly to the environment (Ojike *et al*., 2010). Moreover, several studies highlight the nutritional composition of tomatoes and the presence of lycopene, β-carotene, vitamins C and E, and phenolic compounds (Leonardi *et al*., 2000; Luna-Guevara and Delgado-Alvarado, 2014). The antioxidant properties of these compounds are associated with the prevention of carcinogenic and cardiovascular diseases (Juroszek *et al*., 2009; Luna-Guevara *et al*., 2019). Similarly, some physicochemical properties of tomato are essential because they are related with the selection criteria by the consumer, they are also crucial as quality factors during processing (Ghavidel and Davoodi, 2010).

This research aimed to study the effect of storage temperatures, dehydration conditions and the influence of dehydrator types (solar and convective), on the quality, physicochemical parameters and antioxidant properties of tomato fruits.

MATERIALS AND METHODS

Vegetal material

In a greenhouse with a fertirrigation system, 100 fruits of tomato cv Reserva-vilmorin were harvested in the Aquixtla region, Puebla, Mexico. The second and third bunch of five flowering plants located in the center of the greenhouse were marked to guarantee the degree of physiological maturity (PM). The PM degree is considered by the local producers for commercialization and corresponds to the slightly red coloration (color chart No.5) (USDA, 2019).

Pretreatments

The fruits were selected with similar size, washed, and disinfected with a sodium hypochlorite solution 5% (v/v). Subsequently, the tomatoes were divided into four lots, two of them were stored at 7 °C ± 2 °C and the other two lots at 22 °C ± 2 °C, both remained for 5 days.

Dehydration processes

Preparation of the sample

The stored fruits were cut into four portions of approximately 20 g and submitted to the drying conditions. For solar dehydration (SD) treatments was used an SSB-2008 dryer (1.4 m × 0.8 m × 0.4 m dimensions), which consists of a collector, air channel and tray sample, hot air extractor and thermoelectric cell for electric power generation. The samples were exposed to sunlight during the month of June, and the environmental conditions (average temperature of 67 °C and luminescence of 685 lum/sqf) were monitored with a data logger (HOBO Mod. H08-004-00). While a cabinet dryer was considered for convection drying (CD) treatments, which operated at 70 °C and air flows of 0.5, 1.0 and 1.5 m/s conditions, the samples were weighed every 30 min for 5 h until a constant weight was reached (Montiel-Ventura *et al*., 2018).

Physicochemical and composition characterization of dehydrated fruits

Color

The parameters of Hunter scale color L^* (luminosity, white-black), a^* (red-green) and b^* (yellow-blue) were analyzed with a colorimeter (Minolta Mod CR-300) and were used to calculate total color difference (ΔE) with equation:

$$\Delta E = \left(\left(L_1^* - L_2^*\right)^2 + \left(a_1^* - a_2^*\right)^2 + \left(b_1^* - b_2^*\right)^2\right)^{(1/2)} \quad (1)$$

Other physicochemical properties

The dried tomatoes were pulverized in a coffee grinder (KRUPS, Mod GX410011V73). The physicochemical properties such as pH, total soluble solids (°Brix) and titratable acidity (% citric acid) were evaluated in dehydrated fruits according to the methods of the AOAC 918.12, 932.012 and 942.15, (AOAC, 2010).

Lycopene content

The content was analyzed according to Sadler *et al*. (1990), in 0.1 g of the dried product previously homogenized in 1 mL of water. To each sample were added 19 mL of the mixture hexane, acetone and ethanol (2:1:1) (v/v), vigorously shaken for 15 min and the non-polar phase was collected. Finally, the absorbance was evaluated at 503 nm, and the concentrations were calculated according to the following expression:

$$L = \frac{Abs \times EC}{TS} \quad (2)$$

Where: L is the lycopene content (mg of lycopene/kg), *Abs* absorbance, and *EC* is the extinction coefficient (31.2), *TS* is the dried sample (g).

Total carotenoids

These compounds were evaluated according to the Lichtenthaler and Wellbum (1983) methodology. One sample was macerated with 5 mL of acetone (80% v/v), 2 g of calcium carbonate and 2 g of sea sand, and the mixture was centrifuged at 3500 rpm for 10 minutes. The absorbance was evaluated at 470, 645, and 662 nm, the acetone was used as blank, and the carotenoids contents were calculated with the following equations:

$$C_c = \frac{1000\ Abs_{470} - 2.27C_a - 81.4C_b}{227} \quad (3)$$

$$C_a = 11.75\ Abs_{662} - 2.35\ Abs_{645} \quad (4)$$

$$C_b = 18.61\ Abs_{645} - 3.96\ Abs_{662} \quad (5)$$

Where: *Abs* is the absorbance, C_a is chlorophyll a, C_b is chlorophyll b, and C_c is the content of carotenoids (μg of carotenoids / 100 g of sample).

Antioxidant activity (AA)

The AA was evaluated according to the methodology proposed by Mongkolsilp *et al*. (2004), by neutralizing the DPPH radical (1,1-diphenyl-2-picrylhydrazyl). The extracts were obtained with 0.5 mL of sample mixed with 3 mL of methanol (80% v/v), which were stirred at 125 rpm by 12 h at 40 °C. 2 mL of DPPH (0.1 mM) (Sigma-Aldrich, MO, USA) were added to 500 μL of extract and the mixture was stored by 30 minutes in dark conditions. The absorbance was measured at 517 nm using methanol as the blank. The AA was expressed in percentages of inhibition and was calculated using the following equation:

$$I = \frac{\left(Abs_b - Abs_s\right)}{Abs_s} \times 100 \quad (6)$$

Where: I is the% inhibition, Abs_b is absorbance of the blank, and Abs_s is the absorbance of the methanolic extract.

Percentages of retention

The results of the antioxidant compounds were expressed as percentages of retention of lycopene, carotenoids and antioxidant activity, which were calculated in the ratio of the concentrations of dehydrated fruits on the concentrations of fresh fruits * 100.

Statistical analysis

The analysis were performed by triplicate, the averages and ± SD were calculated. Likewise, the experimental data were analyzed through a randomized block experimental design, with the Minitab Statistical Software version 18.1 (Inc. All Reserved) program using ANOVA analysis and Tukey test means with a significance level of 0.05.

RESULTS AND DISCUSSION

Dehydration conditions

The fresh fruits with an approximate initial moisture content of 90 ± 0.30% were subjected to the dehydration processes. From the CD (70 °C with flow rates of 0.5, 1.0 and 1.5 m/s) conditions and according to Mariem *et al*., 2014, the final moisture content of 15% was determined. While the fruits exposed to SD showed a moisture percentage of 17% with 67 °C and drying time of 7 h. These moisture contents were higher than those reported by Ghavidel and Davoodi (2010) with values of 5.9-6.9% (T 65 ± 2 °C and flow rate of 1 m/s) and 4.5-6.0% with CD and SD, respectively. The differences in moisture content with SD can be related to variations in drying temperature or the season to guarantee solar radiation.

Effect of the dehydration treatments on physicochemical properties

The highest pH values were obtained in the fruits exposed to CD with 70 °C and flow rate 1 m/s. While the tomatoes with SD were more acids with pH 3.91 and 4.02 in fruits previously stored at 7 and 22 °C, respectively (Table 1).

The quality of dehydrated fruits depends on many factors such as the tomato variety, the content of soluble solids (°Brix), the sizes and shapes of the fresh fruit segments subjected to dehydration treatments (Gallo *et al*., 2010). While Coste *et al*. (2010) mention that T close to 50 °C during CD allows the preservation of product and increase the production of certain enzymes related to the sensory profile and level of acceptance of dried tomato. Specifically, the SD treatments increased the acidity of the dehydrated products due to the partial fermentation that occurred in samples and the activity of the pectic enzymes in the first hours of the drying process (Okanlawon *et al*., 2002). A similar trend was observed with the °Bx; this parameter was higher in the fruits submitted to CD. The drying conditions can produce a more significant loss of water, resulting in major levels of soluble solids in dehydrated tomato fruits (De Abreu *et al*., 2014). While the lowest values of titratable acidity (TA) observed in stored fruits at 22 °C with CD at 70 °C are related to the decrease in the content of organic acids in tomatoes, which is due to the fact that these compounds are used as substrate in the processes of respiration of the fruit (Sanchez-Moreno *et al*., 2006).

Concerning the color parameters of dehydrated fruits; the values of *L** reflected higher luminosity with tomatoes preserved at 22 °C and CD (flow rate of 1.5 m/s) and with SD, while an increase in darkness (decrease in the *L** value) was observed with CD and flow rate of 0.5 m/s (21.07 and 21.31).

The values of the parameters *a** and *b** increased in conditions of 7 °C and CD (1.5 m/s), the increase in the values of *b** indicate yellow colorations in the fruits, while the parameter *a** is an indicator of the red color (Brandt *et al*., 2006).

Additionally, the values of ΔE (calculated in relation to the color parameters of the fresh fruit) were lower in the fruits with CD and with higher flow velocities (1.0 and 1.5 m/s) with both storage, while the results of the fruits subjected to solar dehydration (SD) did not differ from each other (P≥0.05).

Table 1. Physicochemical parameters of tomato fruit subjected to different storage temperature and treatments to dehydration by convection and solar.

Parameter	Convection drying			Solar drying
	70 °C/0.5 m/s	70 °C/1.0 m/s	70 °C/1.5 m/s	T 65 °C
Temperature of storage: 7 °C				
pH	4.29±0.09^{abc}	4.35±0.11^{a}	4.25±0.05^{abc}	3.91±0.20^{d}
°Brix	4.96±0.35^{ab}	5.36±0.92^{ab}	6.00±0.55^{a}	5.53±0.11^{ab}
AT%	0.48±0.01^{a}	0.50±0.02^{a}	0.47±0.03^{a}	0.49±0.01^{a}
*L**	21.31±1.24^{d}	28.81±0.22^{abc}	27.27±0.79^{c}	29.14±0.23^{ab}
*a**	13.56±0.16^{f}	23.52±0.49^{b}	25.80±0.65^{a}	21.61±0.14^{c}
*b**	7.91±0.79^{d}	12.57±0.49^{ab}	13.12±0.57^{a}	12.47±0.18^{ab}
ΔE	11.76±0.90^{a}	2.00±0.06^{c}	4.50±0.63^{b}	1.15±0.29^{c}
Temperature of storage: 22 °C				
pH	4.29±0.16^{ab}	3.99±0.06^{bcd}	3.97±0.03^{cd}	4.02±0.05^{bcd}
°Brix	4.23±0.32^{b}	4.90±0.34^{ab}	5.66±0.25^{a}	4.13±0.66^{b}
AT%	0.49±0.01^{a}	0.48±0.01^{a}	0.44±0.01^{a}	0.48±0.02^{a}
*L**	21.07±0.88^{d}	27.73±0.19^{bc}	29.77±0.18^{a}	27.45±0.11^{bc}
*a**	13.66±0.60^{f}	20.01±0.82^{d}	18.45±0.41^{e}	20.22±0.62^{cd}
*b**	7.26±0.40^{d}	10.27±0.86^{c}	11.44±0.14^{bc}	10.68±0.46^{c}
ΔE	10.16±0.98^{a}	1.79±0.67^{c}	1.29±0.11^{c}	1.88±0.29^{c}

Values reported as the average ± Standard Deviation (n=3). Equal letters do not present significant differences (P≥0.05).

Some processing conditions of tomato affect the color due to the formation of brown pigments; according to Okanlawon *et al*. (2002) the color change (red to dark red) might be due to Maillard reactions, which are caused by dehydration conditions. Even though for De Abreu *et al*. (2014), the darkening is a chemical process that relates the T, the dehydration time and the structure of the dehydrated material, generating changes in the sensory and nutritional quality of the dehydrated products. Another report mentions that the increases in the values of the *b** parameter indicate yellow colorations in the fruits, which can be favored in conditions of refrigeration and may be due to the synthesis of flavonoids such as quercetin (Luna-Guevara and Delgado-Alvarado, 2014). While, the parameter *a** is an indicator of the red color in fresh and processed tomatoes, and a determining factor in the quality and commercialization of the fruit (Juroszek *et al*., 2009).

Effect of treatments on antioxidant properties

In this study, the Figure 1 shows the percentages of retention for carotenoids, lycopene, and AA of the fruits subjected to the different conservation treatments. Retention of carotenoids was higher in fruits stored at 7 °C and subjected to CD (air flow rates of 1.0 and 1.5 m/s) and SD with values of 83.85, 85.98 and 99.43%, respectively (Figure 1A).

Concerning the values of lycopene, these were higher in tomatoes stored at 22 °C, flow rate 0.5 m/s and SD conditions with results of 94.37 and 95.14% (Figure 1B). The results obtained with the retention percentages of the AA, were constant with the different storage conditions and drying treatments, with values of 73.06 to 97.21% (Figure 1C).

According to Andritsos *et al*. (2003) and Azeez *et al*. (2019), the conditions of T 45-55 °C are recommended for the dehydration of tomato due to the better protection of antioxidant compounds and quality aspects such as color. Another study carried out by Montiel-Ventura *et al*. (2018), the fruits subjected to CD maintained the highest contents of lycopene under conditions of 40 °C and 50 °C with 540, 390 min.

The highest antioxidant potential of tomato is due to the content of phenolic compounds, ascorbic acid, and lycopene. However, several dehydration techniques used during the conservation of this fruit can significantly influence these compounds (Yahia *et al*., 2007). While, Veillet *et al*. (2009) considered that the AA of dehydrated tomatoes depends on some carotenoids that are released due to the degradation of cellular components during thermal processing. De Abreu *et al*. (2014) mentioned that the differences of the antioxidant properties vary due to the cultivar, process variables such as T, the incidence of light, and drying time.

Concerning the values of lycopene, these were higher in tomatoes stored at 22 °C, this temperature promotes the maturation of the fruit and increases the contents of this antioxidant compound (Giovanelli *et al*., 1999). In this study, the low flow rate of CD and SD conditions increased lycopene retention, according to Periago *et al*. (2007), the lycopene contents rise during CD, because of the rupture of tomato cells throughout dehydration inducing the availability of this antioxidant. However, Demiray et al. (2013) suggested that conditions of 70 to 80 °C can significantly affect the loss of lycopene, which can be related to the lower retention values obtained in this study with higher flow velocities (1.0 and 1.5 m/s). While Bechoff et al. (2010) consider that the stability of the carotenoids during the SD compared with the CD, is due to the UV radiation only affects the surface and does not penetrate the inner part of the tissue, preventing its degradation.

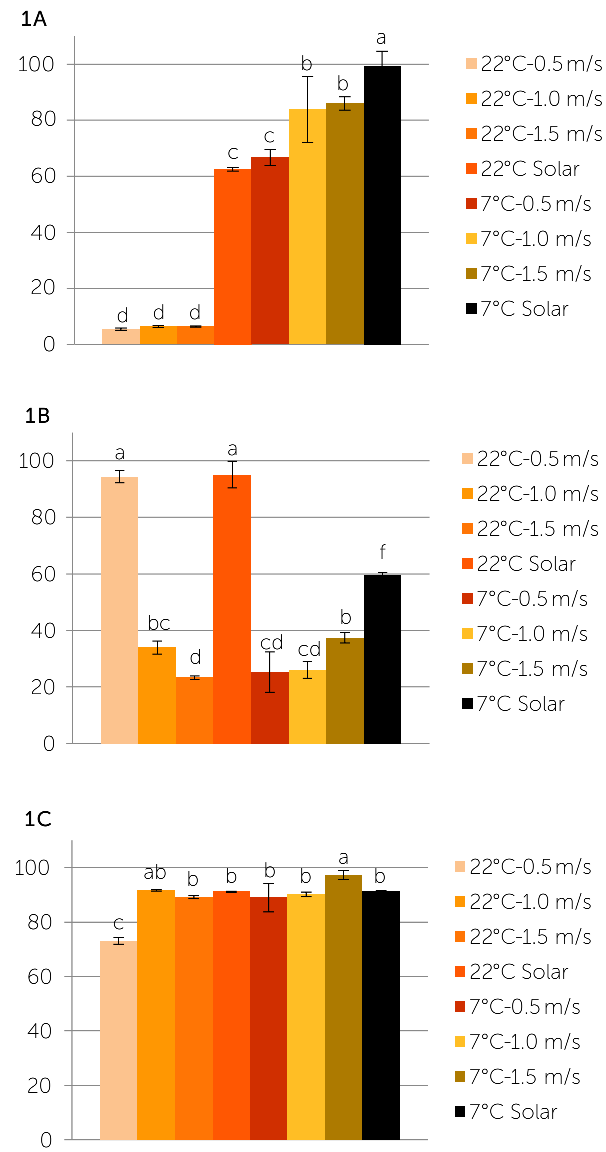

Figure 1. Percentages of retention of antioxidant compounds in tomato fruits subjected to dehydration by convection and solar dehydration. 1A) Total Carotenoids, 1B) Lycopene and 1C) Antioxidant Activity. Values reported as the mean ± standard deviation (n=3). Same letters do not present significant differences (P≥0.05).

CONCLUSION

The results showed that storage and drying conditions influenced the physicochemical and functional properties. The processes of convection dehydration were more effective in preserving color specifically with parameter a*, which is related to the red tones of dehydrated fruit. However, fruits stored at room temperature (22 °C) and subjected to solar dehydration presented the highest percentages of lycopene, this being the main antioxidant of tomato fruit. Finally, the proposed storage conditions and solar dehydration treatments can be a viable alternative for conservation and commercialization for tomato farmers in rural communities.

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