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agrocolfabog@gmail.com
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Pinzón-Gómez, Lida Paola; Deaquiz, Yuli Alexandra; Álvarez-Herrera, Javier Giovanni
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Comportamiento poscosecha de tomate de árbol (*Solanum betaceum* Cav.) tratado con $CaCl_2$ bajo diferentes temperaturas de almacenamiento

Lida Paola Pinzón-Gómez[1], Yuli Alexandra Deaquiz[1], and Javier Giovanni Álvarez-Herrera[1]

ABSTRACT

The tamarillo, or tree tomato, produced in Colombia, has great potential for commercialization in the global market for tropical exotic fruits, but suffers quality losses during the postharvest phase due to the use of inappropriate technologies. In order to extend the postharvest life of these fruits, the effect of calcium chloride ($CaCl_2$) and different storage temperatures was evaluated. A completely randomized design was used, where the block criterion was the temperature with three treatments (control and calcium chloride doses of 570 and 862 mM) and three blocks (6, 9°C and ambient temperature [20°C]), for a total of nine experimental treatments monitored every five days for 20 days. The $CaCl_2$ treatments delayed softening over time, as compared to the control but did not affect the other quality attributes. Generally, the fruits stored at low temperatures lost less fresh weight and had a lower respiration rate as compared with the fruits stored at the ambient temperature. During the postharvest, it was observed that the fruits had a pH between 3.84 and 4.36, total acidity between 0.57 and 1.6% and 9.79°Brix on average. The physicochemical properties of the tamarillo were more affected by the ambient temperature than by the application of $CaCl_2$. The temperature of 9°C is recommended for maintaining the quality of this fruit for 20 days.

Key words: exotic fruits, firmness, weight loss, respiration, refrigeration.

RESUMEN

El tomate de árbol, producido en Colombia tiene un gran potencial para ser comercializado en el mercado mundial de frutas tropicales exóticas, pero durante su vida poscosecha se presentan pérdidas debido al uso de tecnologías inadecuadas que no contribuyen a mantener la calidad de los frutos. El objetivo del trabajo fue prolongar la vida poscosecha de estos frutos mediante la aplicación de cloruro de calcio ($CaCl_2$) y almacenamiento a diferentes temperaturas. Se utilizó un diseño en bloques completos al azar, donde el criterio de bloqueo fue la temperatura, se contó con tres tratamientos (testigo, dosis de $CaCl_2$ 570 y 862 mM) y tres bloques (6, 9°C y ambiente [20°C]), para un total de nueve unidades experimentales. Se realizaron mediciones cada 5 días por 20 días. Los tratamientos con $CaCl_2$ disminuyeron el ablandamiento a lo largo de la conservación comparados con el testigo pero no afectaron el resto de atributos de calidad. En general, frutos almacenados a bajas temperaturas perdieron menos masa fresca y presentaron una tasa respiratoria menor comparada con los almacenados al ambiente. Durante el almacenamiento se observó que los frutos presentaron pH entre 3,84 y 4,36, acidez total de 0,57 a 1,6% y °Brix de 9,79 en promedio. Las características físico-químicas de los frutos de tomate de árbol fueron más afectadas por la temperatura de conservación que por los tratamientos con $CaCl_2$. La temperatura de 9°C se recomienda para mantener la calidad de estos frutos durante 20 días.

Palabras clave: frutas exóticas, firmeza, pérdida de peso, respiración, refrigeración.

Introduction

Tamarillo, or tree tomato, (*Solanum betaceum* Cav.) is considered an exotic fruit. In Colombia, it is widely cultivated in departments such as Cundinamarca, Boyaca, Santander, Antioquia, Caldas, Quindio, Risaralda, Tolima, Valle and Nariño (Bonnet and Cárdenas, 2012). Colombia stands out in production, seed commercialization and crop technology development, so it has great potential for exporting this fruit. However, the quality standards for exporting this product include fruits without mechanical or phytosanitary damage (Contreras *et al.*, 2007). For this reason, new technologies for maintaining the quality and extending the postharvest life of these fruits should be developed.

Fruit ripening is characterized by a sequence of physical and chemical changes associated with processes such as respiration, transpiration, ethylene production and other volatile substances (Balaguera *et al.*, 2009; Ayala *et al.*, 2013). These processes are influenced by internal and

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[1] Group of Agricultural Research (GIA in spanish), Faculty of Agricultural Sciences, Universidad Pedagógica y Tecnológica de Colombia (UPTC). Tunja (Colombia). jgalvarezh@gmail.com

external factors that increase or decrease their activity, in which calcium plays a fundamental role. Calcium is a nutrient associated with fruit ripening and storage life. The main role of calcium in the ripening and senescence of fruit is to maintain the integrity of the membranes and stabilize the structure of cell walls (Roman and Gutiérrez, 1998). High levels of calcium in fruit tissue cause a decrease in processes such as ethylene production, respiration rate, weight loss and firmness (Ernani *et al*., 2008).

Fruit is an organ with a high metabolic rate and its growth depends on a continuous supply of calcium. However, the concentration of this element within fruits decreases during fruit growth (Awang *et al*., 2011); whereby, the application of calcium before storage is recommended in many zones of fruit production around the world as a strategy to protect fruit from stress and mechanical and chilling damage (Serrano *et al*., 2004).

Moreover, temperature is the most determinant factor in the rate of deterioration of harvested products (Kader, 2013) because it influences the action of gases such as oxygen, carbon dioxide and ethylene. The manipulation of temperatures during the storage of fruits is one of the main methods used to maintain postharvest characteristics (Rolz, 2011). In the absence of chilling injury or associated damages, cold storage temperatures decrease the respiration rate, ethylene production, weight losses through transpiration, microbial growth and, in general, ripening processes and deterioration in quality (Knee, 2002).

In this regard, the manipulation of storage temperatures and postharvest calcium applications could be a viable alternative for maintaining the quality and postharvest life of tamarillo. The objective of this investigation was to extend the postharvest life of these fruits through the application of calcium chloride ($CaCl_2$) and storage at different temperatures.

Materials and methods

This study was carried out at the Laboratory of Plant Physiology of the "Universidad Pedagógica y Tecnológica de Colombia", Tunja, which has an average temperature of 20°C and average relative humidity of 65%. The fruits were harvested from a commercial crop in the municipality of Jenesano (Boyaca department), located at 2,100 m a.s.l., 5°23'18'' N and 73°22'05'' W, with an average annual rainfall of 1,095 mm, average temperature of 18°C and relative humidity of 85%.

The tamarillo fruits were harvested at maturity stage 5, as classified by the standards set by Icontec 4105 (Bonnet and Cárdenas, 2012). The fruits were chosen for uniform size, lack of mechanical damage and good phytosanitary conditions.

A completely randomized block design was used. The block criterion was temperature (6, 9°C and laboratory ambient temperature [20°C]) with three treatments consisting of different $CaCl_2$ doses (control and $CaCl_2$ 570 and 862 mM), for a total of nine experimental units (10 fruit per treatment).

After the fruits were harvested and selected, they were transported to the laboratory where they were disinfected with a sodium hypochlorite solution at 2% and washed with distilled water. Then, the treatments were applied to the respective fruit batches. For the $CaCl_2$ treatments, the fruits were immersed for 15 min and allowed to dry at the ambient temperature for 1 h. Finally, the fruits were stored in refrigerators at 6 or 9ºC and at the ambient temperature in the laboratory (20°C and relative humidity of 65%).

The variables evaluated were weight loss (WL, in %), respiration rate (mg kg^{-1} h^{-1} of CO_2), firmness (N), skin color (L*, a* and b* color indices [CI]), pH, total titratable acidity (TTA, in %), total soluble solids (TSS, in ºBrix) and maturity index (MI), or ratio obtained by dividing TTA by TSS. These variables were measured every 5 d and ended after 20 d, in accordance with the study realized by Contreras *et al.* (2007).

The data were subjected to exploratory data analysis and normality tests to determine the existence of outliers and deviation from normality. Later, a longitudinal analysis of variance (ANOVA) was carried out to determine the statistical differences between the treatments according to calcium dose and storage temperature. To establish the best treatments, a Duncan test ($P \leq 0.05$) was conducted. For the analysis, the statistical program SAS® v. 9.2 was used (SAS Institute, Cary, NC).

Results and discussion

Weight loss

The continuous increase of weight loss (WL) of the fruits showed no significant differences over time between the tamarillos immersed in different doses of calcium chloride. This may have occurred principally because the main reason for WL in fruits is water loss, which is caused by transpiration and it is mediated by the vapor pressure deficit between the fruit moisture and humidity of the environment (Kader, 2013). The average WL of the fruit in the 20 d of storage was 5.33%, which means that, at this moment, the fruits had a high loss of quality because, according to Ávila *et al.* (2006), fruits lose consumption quality when they lose more than 5% of their weight. So, the applied calcium treatments probably did not have a strong impact on the WL variable. Even so, the entry of this element into the fruit depends on factors such as the maturity stage, the fruit structure, the dose and time of dip in the Ca-solution (Saure, 2005). Similarly, the soil and climate conditions, variety and maturity stage affected the Ca accumulation in the fruits (Galvis *et al.*, 2003).

The highest fruit WL occurred with the highest concentration of $CaCl_2$ (862 Mm) for all the storage temperatures. This is similar to findings for pineapple guava (*Acca sellowiana*) by Galvis *et al.* (2005), who reported the highest WL when the fruits received the highest doses of calcium (10 and 15%), which was attributed to the fact that, during the dipping of the fruits, a difference in the water potential was generated, being lower in the solution due to the osmotic activity of the calcium chloride, which caused water loss and, therefore, a reduction in the weight of the fruits. Contrary to these results, Galvis *et al.* (2003) found, in the mango fruit (*Mangifera indica*) variety Van Dyke, that the percentage of WL decreased with an increasing concentration of $CaCl_2$ in the treatments, because the control fruits showed the highest losses, while the fruits with 20% $CaCl_2$ dips had smaller losses.

Similarly, when the effect of the temperature factor was analyzed, the analysis of variance showed significant differences between the blocks in all of the evaluations, with the WL being lower when the storage temperature was colder. Throughout the postharvest period, the fruits stored at the ambient temperature had the highest percentage of WL (Fig. 1), whereas no significant differences between the temperatures of 6 and 9°C were seen, but they had significantly less WL compared with the fruits stored at the ambient temperature.

The results in this study are consistent with the findings of Contreras *et al.* (2007), who found that tamarillos stored at ambient temperatures (18°C) lost less weight, and are similar with reports for fruits such as passion fruit (Sáenz *et al.*, 1991; Téllez *et al.*, 2007), mango (Lizana and Ochagavia, 1998; Lúquez and Manzano, 2003), lulo (Casierra-Posada *et al.*, 2004), pineapple guava (Galvis *et al.*, 2005) and guava (Suárez *et al.*, 2009).

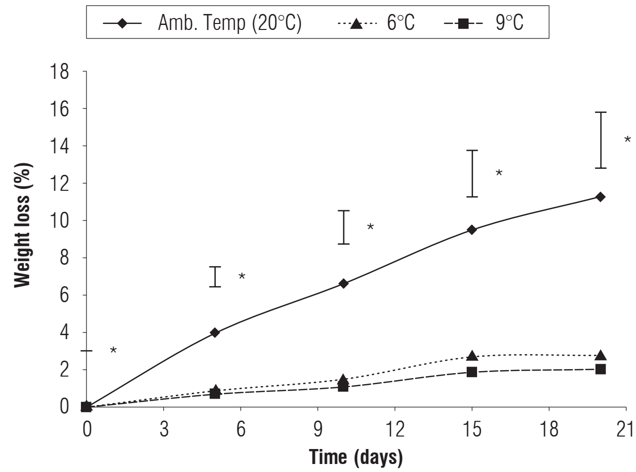

FIGURE 1. Weight loss of tamarillo fruits stored at different temperatures. * Indicates significant differences between temperatures, calculated with Duncan test ($P \leq 0.05$) ($n=9$). Error bars indicate standard error.

Respiration rate

The tamarillo fruits showed a typical behavior of non-climacteric fruits, presenting a decrease in CO_2 production, coinciding with previous reports (Pratt and Reid, 1976; Márquez *et al.*, 2007).

The respiration rate was unaffected by the applied doses of $CaCl_2$, probably because the dose was too low. Calcium is associated with the ripening process of fruits and high concentrations of this element reduce the transpiration process and CO_2 emission, thus reducing the respiration rate (Roman and Gutiérrez, 1998; Awang *et al.*, 2011), because calcium maintains the stability of the cell membrane (Galvis *et al.*, 2005). Also, high calcium levels in cell walls reduce the activity of the enzymes responsible for fruit softening, such as polygalacturonase, pectinmethylesterases and glycosidases, reducing the respiration rate because there is less solubilizing of substances that can serve as substratum for the respiratory process (Huber *et al.*, 2001), as observed by Saftner and Conway (1998), who found that the postharvest application of calcium chloride helped to reduce the respiration rate in apples.

The storage temperature factor showed significant differences starting at the fifth day (Fig. 2). A higher production of CO_2 during the experiment was seen in the tamarillos stored at ambient temperatures (Tab. 1) because high temperatures accelerate chemical reactions and respiration rates (Jayas and Jeyamkondan, 2002; Suárez *et al.*, 2009). Similarly, storage at low temperatures delayed the occurrence of the climacteric peak (Villamizar *et al.*, 1993).

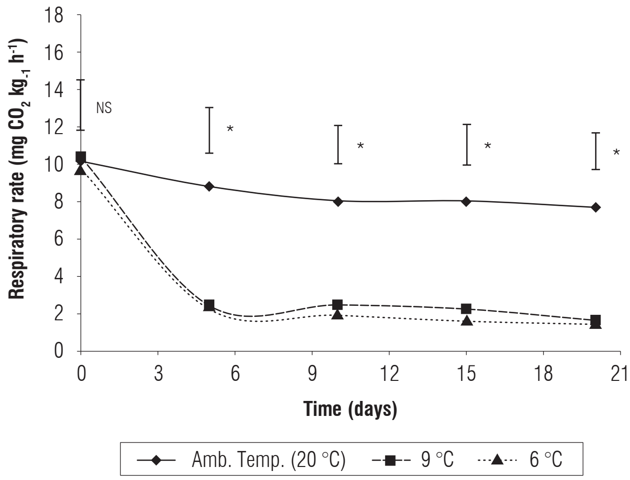

FIGURE 2. Respiration rate of tamarillo fruits stored at different temperatures. NS: not significant differences. * Indicates significant differences between temperatures, calculated with Duncan test ($P \leq 0.05$) ($n=9$). Error bars indicate standard error.

TABLE 1. Respiration rate (mg kg^{-1} h^{-1} of CO_2) during storage of tamarillo fruit under three storage temperatures.

Day	Temperature		
	20°C	9°C	6°C
0	10.173 a	10.415 a	9.787 a
5	8.8175 a	2.4453 b	2.2558b
10	8.0561 a	2.4860 b	1.9312 b
15	8.0470 a	2.2613 b	1.6122 b
20	7.7008 a	1.6577 b	1.4440 b

Means with different letters indicate significant differences according to the Duncan test ($P \leq 0.01$) ($n=9$).

Firmness

The fruits lost firmness during the storage time in all the treatments; this decrease was more noticeable after 10 d of storage. This variable presented statistically significant differences for the calcium dose factor (Fig. 3A) as well as the storage temperature factor (Fig. 3B).

The calcium dose factor presented significant differences for fruit firmness during the storage time. In general, according to the calcium dose, a lower loss of firmness occurred when the fruits were immersed in $CaCl_2$, and, according to the storage temperature, a lower loss of firmness was registered in the refrigerated fruits. The lower loss of firmness in the fruits with an application of $CaCl_2$ was probably due to the fact that calcium inhibits the activity of the polygalacturonase (PG) enzyme, which degrades pectates, constituents of cell walls (Fallani *et al.*, 1997; Marschner, 2002).

A similar case occurred in pineapple guava fruit, where the highest concentrations of calcium (10 and 15%) generated firmer fruits and these fruits were stored at ambient temperature these presented the less loss of firmness (Galvis *et al.*, 2005). Similarly, guava fruits treated with calcium chloride at 2% had higher firmness compared with untreated fruits (Castellano *et al.*, 2005). Furthermore, Galvis *et al.* (2005) reported that in the mango (*M. indica*) variety Van Dyke treated with solutions of 15 and 20% $CaCl_2$, the fruit firmness was maintained as high throughout storage. In Loquat (*Mespilus germanica*), the maximum firmness was found with 3% $CaCl_2$, as compared with control fruits (Akhtar *et al.*, 2010). In the kiwi (*Actinidia deliciosa* cv.

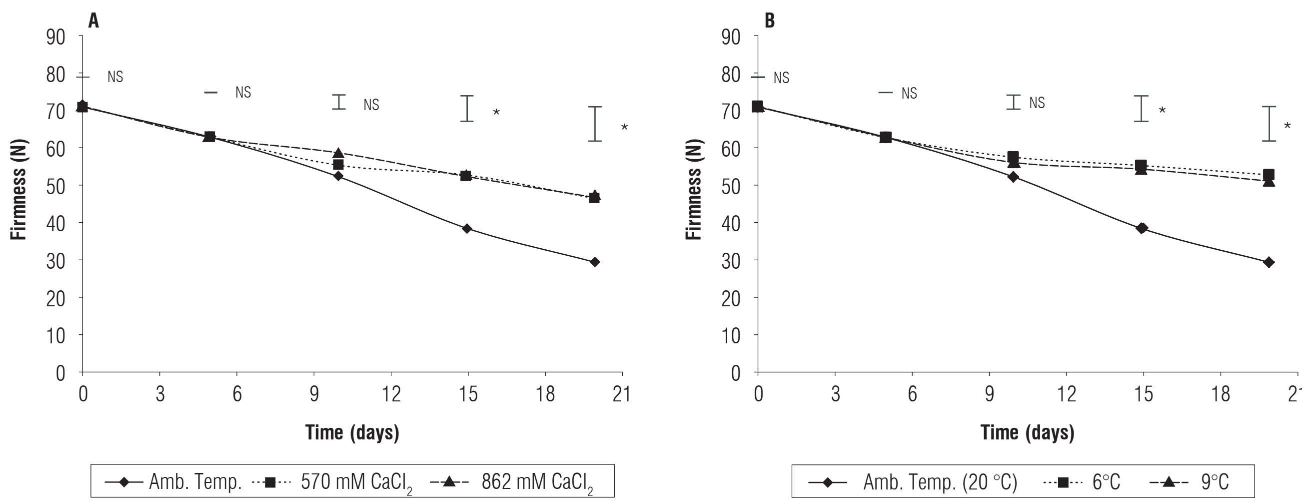

FIGURE 3. Flesh firmness of tamarillo fruits under different treatments. A, $CaCl_2$ doses; B, storage temperatures. NS: not significant differences. * Indicates significant differences between temperatures, calculated with Duncan test ($P \leq 0.05$) ($n=9$). Error bars indicate standard error.

Hayward), the fruits dipped in 4% calcium chloride had higher firmness values as compared with untreated fruits (Kazemi *et al*., 2011).

The results obtained by different authors confirm that the retention of firmness in the fruits after applications of calcium may be due to its accumulation in cell walls, which leads to facilitating the crosslinking of pectic polymers, which increases cell cohesion and resistance of the cell wall (Kazemi *et al*., 2011).

Color

When the values of lightness (L*), chroma green to red (a*) and chroma blue to yellow (b*) in the fruits were analyzed during the postharvest phase, the calcium treatments and the storage temperatures did not have a significant influence, and all of the treatments had similar values for this period. The L* values for the five measurements showed that these fruits gradually lost their lightness during postharvest, perhaps due to water loss through transpiration and to the tissue oxidation that can occur through the degradation of chlorophylls caused by chlorophyllase, peroxidase (Cogo *et al*., 2011) and feofitinase (Schelbert *et al*., 2009). The a* values demonstrated that these fruits tend to lose the green color and gain red color intensity and that this occurs due to the natural maturation process where the loss of green color is a consequence of the degradation of the chlorophyll, which is due to changes in pH, oxidative processes and the action of chlorophyllase (Kader, 2002), and the gain of red color results from the appearance of carotenoids and anthocyanins (Balaguera and Herrera, 2012). Altogether, b* had a steady increase in values during the storage time, which shows that the tamarillo fruits tended to gain yellow color in postharvest, possibly because of degradation or synthesis processes in which there are decomposition of chlorophyll and formation of carotenoid pigments, such as lutein, neoxanthin and violaxanthin (Agusti, 2000), which are responsible for giving a yellow color to some fruits.

As for the color indices [CI], the Anova did not show significant differences for the storage temperature in the five samplings.

Márquez *et al.* (2007) reported that lightness in tamarillo epidermis had a tendency to increase when passing from 43 to 57, while a* and b* tended to increase in the red and yellow colors; this behavior can be attributed to the increase in the concentration of carotenoid pigments, which, in addition to the presence of anthocyanins, generate the natural color of the epidermis of tamarillo fruits during ripening. Moreover, Mwithiga *et al.* (2007) evaluated the effect of ripening on the physical properties of tamarillo fruits, including color and found that, during storage, the L* values decreased from 46.3 to 22.1, the b* values decreased from 28.4 to 4.9 and a* increased from 4.9 to 28.3; these results contrast with the results obtained in the present investigation because the L*, a* and b* values did not show drastic changes. During the postharvest phase, several authors have studied the effect of calcium applications and of storage temperature on the process of color change. For calcium applications, the epidermis color of mango fruits treated with different sources and doses of calcium was almost the same when compared with untreated fruits (Akbar and Ali, 2004). Similarly, high temperatures affect the development of a red color in tomatoes (Feng and Paull, 1990). In peaches, Gorny *et al.* (1998) reported that cold storage of the fruits at 5 and 10°C helps to increase lightness. In tamarillo, a temperature of 5±2°C helped to maintain the color of the fruit and ensured the conservation of quality for a longer time in storage (Manzano and Díaz, 2002). Likewise, Suarez *et al.* (2009) found that refrigeration temperatures retard color change, thus retarding the ripening process in guava fruits.

pH

The Anova did not show significant differences for the temperature or for the different calcium doses ; however, when the statistical analysis of the pH behavior was performed over time, the fruits treated with calcium chloride showed significant differences for the doses of 570 mM and 862 mM between the first day of the measurements and during the entire evaluation (Tab. 2), which demonstrated that the different calcium doses influenced the pH values of the fruits; this may result from the fact that calcium is involved in the regulation of cell pH (Galvis *et al*., 2005) because a too high or low pH causes a decrease in the activity of enzymes, such as polygalacturonase (Marschner, 2002), which delays the normal maturation of the fruit (Galvis, 2003).

The fruits that were not immersed in the calcium chloride solution generally showed lower pH values during the storage when compared to the fruits that received applications of calcium, which may be related to the action of calcium, which decreases the catalytic activity of the enzymes, which could explain the lower pH values. A similar decrease in pH values occurred in anon (*Annona squamosa* × *Annona Cherimola*) (Abi *et al*., 2009). The pH values for the control treatment ranged over time from 4.09 to 3.84, while the fruits treated with 6% of $CaCl_2$ changed from 4.34 to 3.85 and the treatments with 9% $CaCl_2$ passed from 4.36 to 3.89; this contrasts with the findings of Contreras *et al.* (2007) and Manzano and Díaz (2002) for tamarillo, where the

TABLE 2. Changes of pH of tamarillo fruits after storage at different temperatures.

$CaCl_2$ dose (mM)	Time (days)				
	0	5	10	15	20
0	4.09 a	3.99 a	3.94 a	3.87 a	3.84 a
570	4.34 a	4.03 b	3.87 b	3.92 b	3.85 b
862	4.36 a	3.92 b	3.96 b	3.93 b	3.89 b

Means with different letters indicate significant differences according to the Duncan test ($P \leq 0.01$) ($n=9$).

pH increased. Similarly, Mwithiga *et al.* (2007) reported increases in the pH of tomatoes during postharvest with changes from 3.35 to 3.85. This situation has also been seen in pitahaya (Rodríguez *et al.*, 2005), pineapple guava (Galvis *et al.*, 2005), curuba (Téllez *et al.*, 2007) and guava (Suárez *et al.*, 2009), fruits that presented an increase in the pH value during postharvest.

Total soluble solids, total titratable acidity and maturity index

The behavior of these variables was not statistically significant between the treatments of $CaCl_2$ concentrations or storage temperature. The average values presented for the five sampling points over time were 9.73, 10.45, 9.70, 9.51 and 9.55%, respectively consistent with the findings of Márquez *et al.* (2007), who mentioned that the TSS in tamarillos tends to increase until day five and later the behavior is constant but with high variability. This was attributed to the hydrolysis of starches, which are broken down into simpler disaccharides and monosaccharides as sucrose, fructose and glucose (Kan, 2008). The stability of the TSS in the last phase of fruit storage agrees with the findings of pineapple guava, probably because, during maturation, large changes of carbohydrates to sugars do not occur; consequently, the TSS contents did not increase, which is why the percentage of soluble solids did not rise either (Galvis *et al.*, 2005). Furthermore, the application of $CaCl_2$ leads to greater stability in the TSS change, because calcium has an effect on the inhibition of pectic enzymes and stability of the metabolic rate of fruit (García and Praderas, 2010).

According to Castellano *et al.* (2005), an effect of storage time was observed in guava fruits and lower values of TSS were found as the postharvest phase progressed; the fruits submitted to immersions in $CaCl_2$ at 2% had higher values without being significant. In the mango variety Van Dyke, the TSS content increased during storage, however, the fruits treated with $CaCl_2$ showed lower quantities of TSS (Galvis *et al.*, 2003).

The total titratable acid contents of the tamarillo fruits showed no significant differences. The average values presented for the five sampling points over time were 0.94, 1.11, 1.05, 1.05 and 1.20, respectively. This behavior is due to the fact that, during maturity, fruits go under a change in the amount of acids, which generally decreases because, during respiration, it is normal for various substances, such as sugars and acids, to be degraded and, therefore, if the respiratory rate increases, then the acid consumption is greater (Galvis *et al.*, 2005).

The MI decreased as the storage time increased. This decrease occurred due to the increase that was presented in the TTA in the first 5 d of storage. In this regard, MI is important because it determines the palatability or taste of the fruit and juice because, when the fruit has a high sugar content, the acid level should be high enough to satisfy the taste of consumers (Téllez *et al.*, 2007).

Conclusions

The $CaCl_2$ treatments maintained the fruit shelf-life for 20 d by reducing the softening of the tamarillo fruits without compromising other fruit quality parameters. Both storage temperatures of the refrigerated tamarillo fruits reduced the respiration rate and fruit weight loss and maintained flesh firmness longer. A temperature of 9°C is recommended for maintaining the quality of tamarillo fruit.

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