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Efecto de diferentes dosis de 1-metilciclopropeno sobre la poscosecha de frutos de pitahaya (*Selenicereus megalanthus* Haw.)

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ABSTRACT

Key words:
Storage
Total carotenoids
Climacteric fruit
Ripening

Colombia is one of the leading producers of yellow dragon fruit, but exports of this fruit is low when compared to the domestic production because most do not meet the requirements of international markets in terms of quality and preservation. As a result, this study aimed to determine the effect of the application of 1-methylcyclopropene (1-MCP) on the preservation and quality of dragon fruit, given that it has been effective in the conservation and postharvest quality of many agricultural species allowing longer life, using a completely randomized experiment design with three treatments: 0, 300 and 600 mg L^{-1} of 1-MCP, with four replications. The 600 mg L^{-1} of 1-MCP dose was able to maintain the quality of the dragon fruit longer (28 days after harvest (dah)) because it managed to reduce the respiratory rate. The application of 1-MCP did not affect the firmness, loss of mass, total soluble solids, total titratable acidity, or total carotenoids in the fruits. The application of 1-MCP slowed the loss of fruit quality in terms of color because the 600 mg L^{-1} dose maintained the lightness of the fruits longer, reduced the color changes as expressed in a* and b* values and decreased the chlorophyll degradation.

RESUMEN

Palabras claves:
Amacenamiento
Carotenoides totales
Fruto climatérico
Maduración

Colombia es uno de los principales productores de pitahaya amarilla, pero las exportaciones de este fruto representan un bajo porcentaje en comparación a la producción nacional, debido a que la mayor parte de los frutos no cumplen con los requisitos de los mercados internacionales, en cuanto a calidad y conservación. Por lo cual, esta investigación tuvo como objetivo determinar el efecto de la aplicación de 1-metilciclopropeno (1-MCP) en la conservación y calidad de frutos de pitahaya, dado a que ha sido eficiente en la conservación y calidad poscosecha de muchas especies agrícolas lo que permite prolongar su vida útil, para lo cual se utilizó un diseño experimental completamente al azar con tres tratamientos 0, 300 y 600 mg L^{-1} de 1-MCP, con cuatro repeticiones. La dosis de 600 mg L^{-1} de 1-MCP logró mantener la calidad de los frutos de pitahaya por más tiempo (28 días después de cosecha (ddc)), debido a que logró disminuir la tasa respiratoria. La aplicación de 1-MCP no afectó la firmeza, la pérdida de masa, los sólidos solubles totales, la acidez total titulable, ni los carotenoides totales de los frutos de pitahaya. La aplicación de 1-MCP retarda la pérdida de calidad de los frutos de pitahaya en cuanto al color, debido a que la dosis de 600 mg L^{-1} mantiene por mas tiempo la luminosidad de los frutos y disminuye los cambios de color expresados en los valores de a* y b*, así mismo disminuyó la degradación de la clorofila.

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The yellow dragon fruit is one of the more exotic fruits from Colombia and, currently, it has a growing international market thanks to its nutritional content, sodium, potassium and vitamin A, flavor and aroma (Le Bellec and Vaillant, 2011), mainly with high demand for quality, flavor and nutraceutical properties (ICA, 2010); however, proper technology production packages and postharvest management that would allow this crop to be competitive do not exist, which implies the need to apply advanced techniques that have proven effective in maintaining the quality of fruits after harvesting, such as the application of 1-MCP (Selvarajah *et al.*, 2001), thermal treatments (Dueñas *et al.*, 2008), controlled atmospheres and wax (Hu *et al.*, 2011; Hu *et al.*, 2012), among others as packaging and use of potassium permanganate.

1-methylcyclopropene (1-MCP) has been widely used to control senescence in minimally processed fruits and vegetables (Toivonen, 2008; Watkins, 2008), which can delay ripening and maintain fruit quality longer during storage (Jiang *et al.*, 2014). It also reduces the respiratory rate and ethylene production and helps inhibit the activity of 1-aminocyclopropane-1-carboxylic (ACC) oxidase (Amornputti *et al.*, 2016). 1-MCP has been tested in many fruits, as reported in the nectarine (Öskaya *et al.*, 2016), apple (Xiaotang *et al.*, 2016), guava (Cerqueira *et al.*, 2009), kiwi (Mao *et al.*, 2007), plum (Khan and Singh, 2007), banana (Zhu *et al.*, 2015), melon (Han *et al.*, 2015) and broccoli (Ma *et al.*, 2009) among others, where the best results have been observed in climacteric fruits (Serek *et al.*, 2006). It has also been used in the preservation of flowers and foliage, increasing the postharvest shelf-life (Cerqueira *et al.*, 2009).

The concentration of 1-MCP needed to block the action of ethylene varies by species, variety, degree of ripeness, production of new ethylene receptors, exposure time and temperature (Amornputti *et al.*, 2016). The greater the time of exposure to the product, the lower the concentration needed to achieve the desired effect because there is an interaction between the concentration and exposure time. In this regard, Bassetto *et al.* (2005) applied concentrations of 900 nL L^{-1} and 100 nL L^{-1} of 1-MCP for 3 and 12 h on 'Pedro Sato' guava fruits and observed the same results,

indicating that a 1-MCP application alone does not guarantee preservation of fruits.

Although the dragon fruit is a climacteric fruit and water loss does not exceed 4.3% during the first three weeks of storage, during ripening, the fruit loses a lot of its peel firmness at the time of harvest, making it a highly perishable fruit when stored under ambient conditions (Le Bellec and Vaillant, 2011).

Therefore, the objective of this research was to determine the effect of 1-MCP applications on the postharvest behavior of yellow dragon fruit (*Selenicereus megalanthus* Haw.) in an attempt to maintain fruit quality longer during storage.

MATERIALS AND METHODS
Ubication
The study was conducted in the postharvest laboratory of the Faculty of Agriculture Sciences of the Universidad Nacional de Colombia, Bogotá. The fruits were collected from a commercial orchard (Piedras Verdes farm) in the municipality of Miraflores (Boyacá, Colombia), located at an altitude of 1600 m, latitude 5°11' and longitude 73°08', with an average annual rainfall of 2500 mm, a temperature ranging between 18 and 24 °C and an average relative humidity of 87%.

Vegetable material
The plant material used was yellow dragon (or pitahaya) fruits (*Selenicereus megalanthus* Haw.), which were collected in maturity grade 3 (4580 norm of Icontec, 1996). The fruits presented uniform size, no mechanical damage and good phytosanitary condition. 1-MCP (powdered form from Rohm and Haas, Bogotá) was used.

The experimental design was completely randomized with three treatments that corresponded to the doses of 1-MCP (0, 300 and 600 mg L^{-1}) with four replications, for a total of 12 experimental units (EU). Each EU was composed of six fruits.

The fruits were disinfected with a solution of 2% NaCl and washed with distilled water, then subjected to the treatment applications. The 1-MCP was vaporized according to the methodology of Herrera (2007), where 300 and 600 mg L^{-1} of 1-MCP was weighed in a 10 mL glass tube, which was

sealed with a rubber stopper, through which the hot water (45-50 °C), provided by the manufacturer, was injected. The dissolution of 1-MCP in the hot water generated the release of gaseous 1-MCP in the headspace of the tube. This was introduced into a 2 L sealed chamber containing the fruits; then the chamber was opened to release the compound and immediately sealed for 24 h.

Variables

The evaluated variables were: fruit firmness (N), determined with a digital PCE-PTR200 penetrometer (PEC Ibérica SL, Albacete, Spain); fresh mass loss (%), by measuring the fresh weight of the fruits with a 0.0001 g precision balance (Ohaus, Ohio, OH); total soluble solids (TSS), using a digital Hanna refractometer (Hanna Instruments, Woonsocket, RI), 0 to 85% range at 20 °C; total titratable acidity (TTA; % citric acid), using the formula: % Acidity = (A* B* C)*100/D, where: A = volume of NaOH used, B = normality of NaOH (0.097), C = equivalent weight in g of predominant acid in the fruit (citric acid 0.064 meq g^{-1}), D = weight in grams of the sample used (5 g). The maturity index (MI) was calculated with the TSS /TTA ratio. The color was measured using a Minolta CR-300 reflectance colorimeter (Minolta Co., Japón). Three replications were performed on three fruits directly on the surface at the equatorial axis. CIELab system parameters "L", "a" and "b" were determined. L indicates brightness, where 0 is black and 100 white; values "a" < 0 indicate trend towards green and > 0 into the red; "B" has the same range but values < 0 indicate a tendency towards blue and > 0 towards yellow.

For the extraction and quantification of total carotenoids, approximately 1 g of pulp was weighed, 5 mL of acetone was added, vortexed for 1 min and then centrifuged for 10 min at 4,000 rpm. The supernatant was poured into a 25 mL flask; acetone was added to the pellet, vortexed and then centrifuged. This procedure was repeated three times. Acetone was added to the obtained supernatant to obtain a volume of 25 mL. The absorbance was measured in a spectrophotometer at 450, 663 and 645 nm.

Respiratory rate was measured taking approximately 300 g of fruit which were placed in an airtight 2 L chamber VER BC-2000 (Vernier Software & Technology, United States), in which an infrared CO_2 sensor VER CO_2-BTA (Vernier Software & Technology, United States) was located,

which was connected to a LabQuest2 (Vernier Software & Technology, United States). Every 4 sec for 5 min, CO_2 values were recorded. With these values, the slope was calculated, which corresponded to the respiration rate. Also, the fruit weight and volume of the chamber were taken into account to convert the data to mg CO_2 kg^{-1} h^{-1}.

Statistic analysis

An analysis of variance (Anova) was conducted to determine statistical differences between the treatments and to classify them with a Tukey test ($P \leq 0.05$). Analyses were performed using SAS statistical software v. 9.1e (SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION
Firmness

In the case of yellow dragon fruit, the loss of firmness at 15 and 22 days after harvest (dah) showed significant differences between the doses of 300 and 600 mg L^{-1} of 1-MCP; however, these doses did not differ significantly from the dose control, where the fruits only maintained quality for 15 dah (Figure 1a). Still, only the fruits of treatment than received the dose of 600 mg L^{-1} reached the 28 dah, whereas treatment of 300 mg L^{-1} only reached 26 dah.

This indicates that the yellow dragon fruit responded to the application of 300 mg L^{-1} doses of 1-MCP during the first 22 dah, while the dose of 600 mg L^{-1} extended life 6 more days (until 28 dah); day from which the fruit quality consumer is lost due that this continue to mature normally, with the respective softening. This effect occurs due to the inhibition of the enzymes involved in the degradation of cell walls, such as cellulose, pectin methyl esterase, polygalacturonase, β-1,4-D-glucanase, β-galactosidase, exopolygalacturonase, endopolygalacturonase and polyphenol oxidase (Öskaya *et al.*, 2016; Khan and Singh, 2007), which has been observed in apples (Gago *et al.*, 2015), where applications of 1-MCP reduced the softening of stored fruits, as well as in nectarines (Öskaya *et al.*, 2016) and pears (Li *et al.*, 2016). On the other hand, Rizzolo *et al.* (2015) reported that pear fruit firmness only began to decline after 20 d of storage, similar to what was found by Li *et al.* (2016).

Mass loss

This variable showed no significant difference during the storage time, notwithstanding the fact that the application

of 1-MCP extended the postharvest shelf-life of the fruits 28 dah, as compared with the control fruits, which only reached 15 dah with consumption quality. The 600 mg L^{-1} dose showed the greatest loss of mass (9.84%, 11.89%, 13.01% and 16.09%) at 22, 24, 26 and 28 dah. However, this dose was not significantly different from the 300 mg L^{-1} dose or the control (Figure 1b).

This indicates that the 600 mg L^{-1} dose of 1-MCP could generate a negative effect on the fruits, increasing the processes of transpiration and respiration and causing further losses of water as compared to the 300 mg L^{-1} dose, in agreement with the results reported by Serna

et al. (2011) for the sweet yellow pitahaya, where an application of 1-MCP had the highest loss of mass. Likewise, Gago *et al.* (2015) found that the mass loss in apple fruits increased during the storage period equally in treatments with 1-MCP and in untreated fruits. In this regard, Aguayo *et al.* (2006) found that 1-MCP in pineapples did not affect the values of mass loss and firmness. In addition, it has been proven that when applications of 1-MCP are carried out on fruits stored at room temperature, treatments tend to be less effective against the responses of ethylene (Serek and Sisler, 2005), which coincides with the results found in dragon fruit.
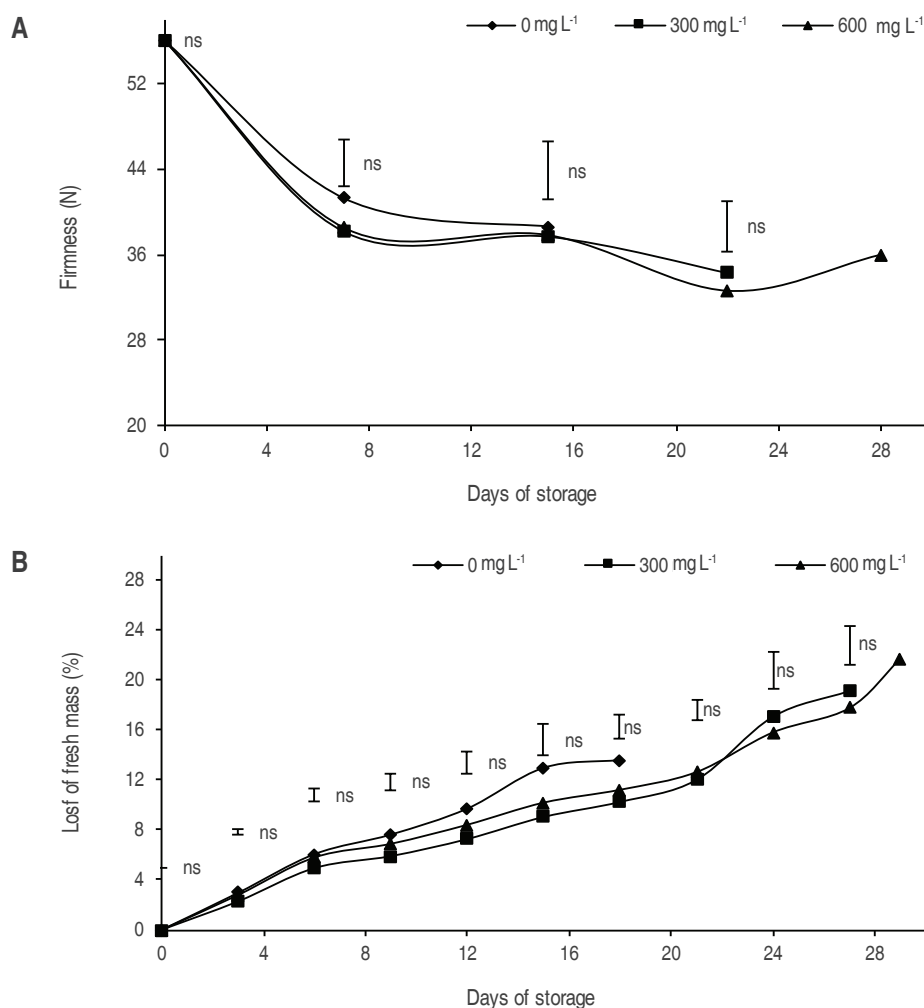

Figure 1. Postharvest behavior of firmness (A) and Loss of mass (B), under the application of different doses of 1-MCP in fruits of pitahaya. The vertical bars indicate the minimum significant difference according to the Tukey test ($P \leq 0.05$) (n=4). * 5% statistical differences, ns: no differences.

Total soluble solids (TSS)

The behavior of the TSS did not show significant differences during storage (Figure 2a), which implies that the application of 1-MCP does not affect the sugar content of dragon fruit during storage, which is similar to results observed with applications of 1-MCP in the apple (Gago *et al.*, 2015), pear (Rizzolo *et al.*, 2015), plum (Khan and Singh, 2007) and feijoa (Rupavatharam *et al.*, 2015), where 1-MCP had little or no effect on the content of TSS.
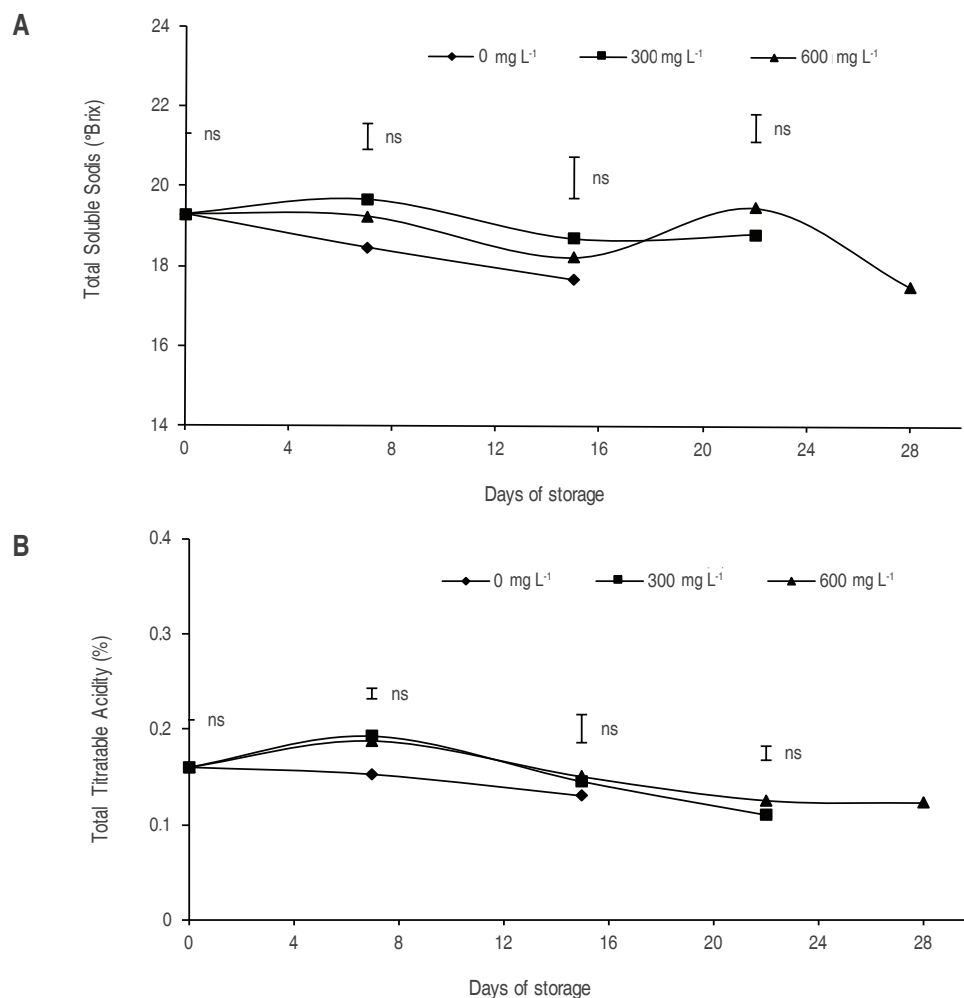

Figure 2. Postharvest behavior of Total Soluble solids (A) and Total titratable acidity (B), under the application of different doses of 1-MCP in fruits of pitahaya. The vertical bars indicate the minimum significant difference according to the Tukey test ($P \leq 0.05$) (n=4). * 5% statistical differences, ns: no differenes.

It is known that, during the ripening of fruits on the tree, the TSS content increases due to the conversion of organic acids to sugars and the biosynthesis or degradation of polysaccharides in cell walls (Cerqueira *et al.*, 2009), forming part of simple sugars such as glucose, fructose and sucrose, which generates an increase in the content of soluble sugars. Still, the TSS in the fruits decreased after 28 dah in all of the treatments, which probably occurred due to the use of sugars as a respiratory substrate (Paliyath and Murr, 2008).

Contrasting results have been reported for the effect of 1-MCP on TSS because, according to Hofman *et al.* (2001), 1-MCP increased soluble sugars in papaya, contrary to the results found for the nectarine (Öskaya

et al., 2016), guava (Cerqueira *et al.*, 2009), *Durio zibethinus* (Amornputti *et al.*, 2014), apple (Marin *et al.*, 2009), kiwi (Mao *et al.*, 2007) and melon (Han *et al.*, 2015), where 1-MCP delayed the conversion of organic acids to sugars and maintained fewer TSS throughout storage when compared to the control.

Total titratable acidity (TTA)

Statistically significant differences ($P<0.05$) were obtained during the first two postharvest measurements at 7 and 15 dah between the doses of 300 and 600 mg L^{-1} of 1-MCP, but they did not show significant differences from the control. The 600 mg L^{-1} dose had the highest values of TTA (Figure 2b). Similarly, it was observed that the TTA values decreased as the storage time passed, similar to that seen by Obenland *et al.* (2016) in dragon fruit, which is attributed to the activity of dehydrogenases because organic acids are used as respiratory substrates (Paliyath and Murr, 2008); it has also been shown that 1-MCP affects the metabolism of polymeric carbohydrates (peptic and hemicellulose substances) and decreases the TTA in the apple (Marin *et al.*, 2009), guava (Bassetto *et al.*, 2005), pineapple (Selvarajah *et al.*, 2001), pear (Rizzolo *et al.*, 2015) and tomato (Beckles, 2012); however, the efficiency of 1-MCP may depend on the endogenous levels of ethylene (Zhang *et al.*, 2009).

Maturity index (MI)

This characteristic only had significant differences at 15 dah, where the application of the 600 mg L^{-1} dose of 1-MCP (MI = 12.6) significantly reduced the MI values as compared with the fruits in the control treatment (MI = 14). The behavior of the MI during storage presented initial values of 12 at harvest and then decreased at 7 dah with a value of 10.4 (probably at the climacteric peak); then it began to increase during the storage period to a value of 16.7 at 28 dah. Increasing MI occur when fruits reach maximum respiratory intensity, associated with energy consumption in the form of ATP and other compounds in order to maintain the homeostasis of the fruits (Piriyavinit *et al.*, 2011), which includes conversion processes for starch into glucose and fructose that are used as respiration substrates (Lima *et al.*, 2011).

Color

In general, the different color parameters measured in the fruits showed no significant differences in the 1-MCP applications (Table 1), similar to that found in apples (Gago *et al.*, 2015) and feijoa (Rupavatharam *et al.*, 2015); however, it can be seen that the treatments with a dose of 600 mg L^{-1} had fruits with more lightness because the postharvest shelf-life (7 and 15 dah) was prolonged, indicating that the 1-MCP applications

Table 1. Color evolution in fruits of pitahaya under the application of different doses of 1-MCP.

dah	1-MCP (mg L^{-1})	Colour parameters			
		L*	a*	b*	IC
0	0	46.28 a	-2.98 a	38.90 a	-1.77 a
	300	47.30 a	-4.23 a	37.37 a	-2.46 a
	600	42.74 a	-4.05 a	38.54 a	-2.61 a
7	0	52.92 a	3.81 a	44.80 a	1.53 a
	300	51.48 a	1.72 a	42.46 a	0.79 a
	600	55.86 a	1,32 a	44,00 a	0,55 a
15	0	54.85 a	5.12 a	42.44 b	2.18 a
	300	53.51 a	5.38 a	44.26 ab	2.29 a
	600	58.02 a	4.39 a	44.91 a	1.68 a
22	0				
	300	61.83 a	5.94 a	50.55 a	1.89 a
	600	58.51 a	6.26 a	47.58 a	229 a
28	0				
	300				
	600	59.98	6.39	47.83	2.16

dah: days after harvest. L: lightness; a *: chromaticity from green to red; b *: chromaticity from blue to yellow; CI: color index. Averages with different letters in the same column and classified for days after harvest indicate statistically significant differences between factor levels, according to the Tukey test ($P \leq 0.05$).

resulted in fruits that had higher luminosity, which slows the loss of quality, which agrees with the results of Villalobos *et al.* (2011), who stated that 1-MCP is important for increasing the postharvest shelf-life and delaying color changes in the peel.

Total carotenoid content

The content of total carotenoids in the fruits had no significant differences between the 1-MCP doses and the control during the first 15 dah (Figure 3a). However, they continued to increase throughout the storage period, reaching values of 179 mg g^{-1} PF, which means that the application of 1-MCP prolonged the postharvest shelf-life of the fruits, which retained their nutraceutical properties.

Because the fruits were stored under ambient conditions, it is likely that the total carotenoid content increased due to the accelerated loss of chlorophyll, which was expressed as total chlorophyll, from 0.068 mg g^{-1} PF at the beginning of storage to 0.014 mg g^{-1} PF at 28 dah, which coincides with that reported in citrus fruits stored at 12 °C (Carmona *et al.*, 2012). Rubinowska *et al.* (2012) stated that an increase in the synthesis of
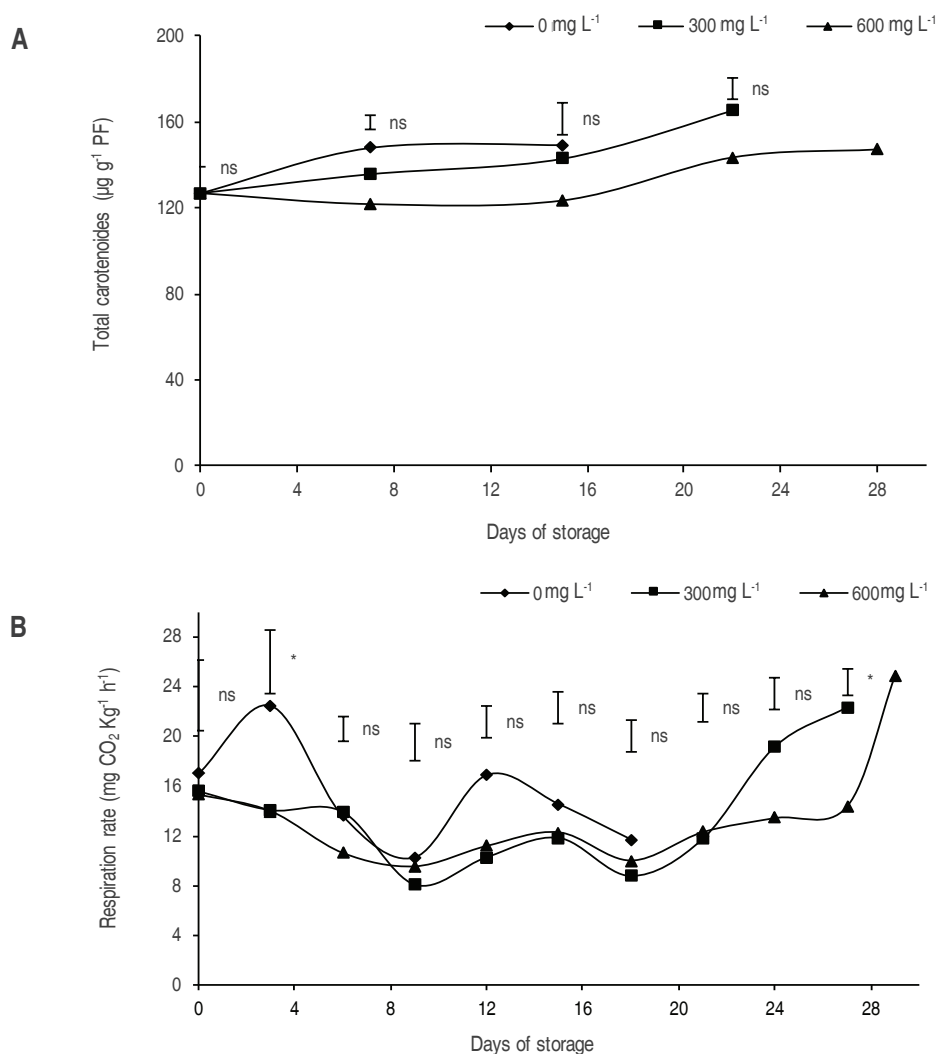

Figure 3. Postharvest behavior of Total carotenoids (A) and Respiration rate (B), under the application of different doses of 1-MCP in fruits of pitahaya. The vertical bars indicate the minimum significant difference according to the Tukey test ($P \leq 0.05$) (n=4). * 5% statistical differences, ns: no differences.

carotenoids (β-carotene and lycopene) is associated with the ability to scavenge free oxygen radicals that are generated in greater amounts during the oxidative stress seen in the postharvest phase of fruits. However, 1-MCP applications likely slow the increase in carotenoids, which coincides with that reported by Guillén *et al.* (2007) who showed that ripening tomatoes require the application of much higher levels of 1-MCP in order to extend the shelf life.

Respiratory rate (RR)

This variable showed significant differences between the control and the doses of 300 and 600 mg L^{-1} of 1-MCP (Figure 3b), with an increased RR in the fruits. Similarly, the 1-MCP doses had similar results during the first 22 dah; towards the end of the postharvest period, differences (27 dah) occurred between the doses of 300 and 600 mg L^{-1} 1-MCP, where the higher doses preserved fruit quality longer. This occurred because, in prolonged periods of storage, fruit tissues synthesize more ethylene receptors, which increases the RR at the end of storage (Serek *et al.*, 2006). However, the 1-MCP greatly reduced the RR during the storage time of the fruits. Similarly, this decrease in CO_2 production is consistent with that found in the nectarine (Öskaya *et al.*, 2016), guava (Cerqueira *et al.*, 2009), and melon (Han *et al.*, 2015), where 1 -MCP decreased the respiration rate and significantly delayed the onset of the climacteric peak.

CONCLUSIONS

The 600 mg L^{-1} dose of 1-MCP was able to maintain the quality of the fruits longer (28 dah), which was reflected in a decreased respiration intensity in the fruits. The application of 1-MCP did not affect the firmness, loss of mass, TSS, TTA, or carotenoids of the fruits. The application of 1-MCP slowed the loss of fruit quality in terms of color because the 600 mg L^{-1} dose maintained the lightness of the fruits longer and reduced the color changes expressed as a* and b* values.

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