EFFECT OF PRE- AND POSTHARVEST APPLICATION OF 1-METHYLCYCLOPROPENE ON THE MATURATION OF YELLOW PITAHAYA (*Selenicerus megalanthus* Haw)

EFECTO DE LA APLICACIÓN EN PRECOSECHA Y EN POSCOSECHA DE 1-MCP EN LA MADURACIÓN DE PITAHAYA AMARILLA (*Selenicerus megalanthus Haw*)

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ABSTRACT

The effect of pre- and postharvest applications of 200 and 400 μgL^{-1} aqueous solutions of 1-methylcyclopropene (1-MCP) on yellow pitahaya (maturity stage 3) was assessed. Changes in respiratory rate, color, firmness, soluble solids content, titratable acidity, maturity index, weight loss and commercial preservation were measured. Results showed that the preharvest application of 400 μgL^{-1} 1-MCP enhanced fruit color, preserved firmness, and reduced weight loss and maturity index of fruits. It is suggested that these results were explained by the reduction of available membrane receptors able to bind ethylene, thus increasing ethylene sensitivity and response magnitude. The preharvest application of 1-MCP could potentially be used to accelerate pitahaya fruit ripening. The preharvest application of 200 μgL^{-1} 1-MCP resulted in smaller changes in color and titratable acidity *vs.* control. Total soluble solids and pH were not significantly affected by the treatments. The postharvest application of 1-MCP maintained the texture of fruits by three additional days when compared to the untreated control.

Keywords: Tropical fruits, ethylene, respiratory rate, firmness, color.

RESUMEN

Se evaluó el efecto de la aplicación en precosecha y en poscosecha de soluciones acuosas de 200 y 400 μgL^{-1} de 1-MCP, con tiempo de exposición de 10 minutos, sobre la maduración de pitahaya amarilla entera en grado de madurez tres. Se midieron cambios en la respiración, pérdida de peso, color, firmeza, contenido de azúcares solubles, acidez, índice de madurez y tiempo de vida comercial. Los resultados demostraron que la aplicación de 400 μgL^{-1} de 1-MCP en precosecha acelera los cambios de color de la fruta, conserva su firmeza, disminuye la pérdida de peso y disminuye su índice de madurez. Lo anterior se explicó por la disminución en los receptores de membrana disponibles para interactuar con el etileno, lo que provoca incremento en la magnitud y sensibilidad de la respuesta del etileno. La aplicación de 1-MCP en precosecha podría tener aplicaciones en la aceleración de la maduración de frutas. La aplicación de 200 μgL^{-1} de 1-MCP en precosecha disminuyó los cambios de color y conservó la acidez. Los sólidos solubles, azúcares totales y pH no fueron influenciados significativamente por los tratamientos. La aplicación de 1- MCP en poscosecha mantiene la textura de la fruta durante 3 días más, comparada con el tratamiento control.

Palabras clave: frutas tropicales, etileno, tasa respiratoria, firmeza, color.

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INTRODUCTION

Ethylene is a volatile hormone that affects the development of the entire plant (1), from seeds germination to leaves formation and growth, development and maturation of fruits, and plant senescence (2). The metabolic processes known as maturation are regulated by the binding of ethylene to a family of receptors with histidine kinase activity (3).

Ethylene analogs can compete for ethylene membrane receptors and modify the physiology of maturation and senescence, and also the preservation of fruits and vegetables (4). 1-methylcyclopropene (1-MCP) is a cyclopropene ethylene antagonist that exhibits excellent stability properties and effectiveness to control ethylene effects (5). Additionally, 1-MCP inhibits the biosynthesis of ethylene by reducing the activity of the enzymes carboxylic acid synthetase (ACC synthase) and carboxylic acid oxidase (ACC oxidase) (6).

Previous studies reported the postharvest application of 1-MCP to control ripening and delay senescence of a large number of fruits, with results varying from delay to lack of fruit ripening. In most cases, the response to 1-MCP depended on concentration and moment of application, but varied for different species, in physiology and morphology of the fruit, variety, maturity stage, crop and storage conditions (7). The most common reported effects were the decay in softening and color development, reduction in respiratory activity and ethylene production, reduction in weight loss and fungi damage, and delay of processes related to ripening and senescence (7). A recent formulation (Harvista™, AgroFresh, Inc., Dow Chemical Co.) was developed for the preharvest application of 1-MCP in the field (8). This formulation improved fruit firmness and reduced the generation of ethylene, but did not have significant effect on fruit color, total soluble solids, and respiratory rate (8-10).

The use of pre- and postharvest applications of 1-MCP has not been studied in yellow pitahaya, an exotic cactus with worldwide flavor acceptance and good selling price in the international market (11). The pitahaya is a perennial plant with two harvest seasons (12) and only refrigeration has been studied to extend the commercial preservation of whole fruits.

Since enzymatic browning, skin necrosis, and skin softening are the main factors that negatively affect the commercial value of yellow pitahaya (13), it was hypothesized that the pre- and postharvest application of 1-MCP should favorably delay fruit softening, color development, weight loss, and other ripening related processes.

The objective of this study was to assess the effect of pre- and postharvest applications of 200 and 400 μgL^{-1} aqueous solutions of 1-MCP on the maturation of yellow pitahaya fruits. Fruit ripening was determined by the changes in respiratory rate, weight, color, firmness, soluble solids content, acidity, maturity index and commercial preservation.

MATERIALS AND METHODS

Plant material

Experiments were done on a 500 m^2 parcel of yellow pitahaya (5000 plants/ha density) located in the municipality of Roldanillo, in the "Valle del Cauca" Department, Colombia (4° 24´ 08¨ North latitude; 76° 09´ 00¨ West longitude; 1450 m altitude). For the preharvest application, 15 days prior to collection, 80 fruits per treatment were randomly selected from the same row. For the postharvest application, fruits with a maturity stage 3 were selected. Maturity was determined using the NTC 3554 standard classification (14).

1-MCP preparation and application

A powder 1-MCP formulation (3.8%) obtained from Rohm and Haas (Philadelphia, Pennsylvania) was used. Solutions of 1-MCP at 200 and 400 μgL^{-1} in distilled water were prepared. For the preharvest experiments, the solutions were prepared in the field and applied by uniformly spraying the fruits on the trees, using a manual sprayer (2 bar operating pressure, 5 cm distance from the fruit). Fifteen days after application, the fruits were collected and rinsed in distilled water for one minute, dried outdoors, placed in plastic baskets (27 fruits per basket, arranged in a single layer), and stored in a controlled environment chamber (Model 1000L, Dies, Colombia) set at 25 ± 2°C and 75% relative humidity. For the postharvest application, the harvested fruit, with a maturity stage 3 (14), were first washed using distilled water and dried outdoors. Then, the fruits were submerged in aqueous solutions of 1-MCP with concentrations of 200 and 400 μgL^{-1} for 10 minutes, rinsed with distilled water, dried outdoors, placed in plastic baskets, and stored in the same conditions as described before. The same

procedure was followed for the control treatment, using fruits with a maturity stage 3 but no application of 1-MCP. The following abbreviations will be used throughout the text: 200-PRE (200 μgL^{-1} preharvest application of 1-MCP), 400-PRE (400 μgL^{-1} preharvest application of 1-MCP), 200-POS (200 μgL^{-1} postharvest application of 1-MCP), 400-POS (400 μgL^{-1} postharvest application of 1MCP), and control (no application of 1-MCP).

Physiological, physical, and chemical analysis

Physiology of the fruits was evaluated by measuring respiratory rate. Physical properties were evaluated by measuring fruit weight loss, color, and firmness, and chemical properties by measuring soluble solids, and titratable acidity. All determinations were done in three replicates.

Respiratory rate measurement

The respiratory rate was measured by titration, using a modification to the method reported by Montes *et al.*, 2001 (15), in figure 1. A refrigerated chamber externally equipped with a compressor and CO_2 traps was used. Three hermetically sealed containers equipped with input and output hoses were placed inside the chamber. Each container held three previously weighed pitahayas. The compressor allowed external air to flow into a CO_2 trap, containing 50 ml of 2N KOH to eliminate the CO_2 present in the air by neutralization with a base. Then, the CO_2-free air continuously flew to the hermetically sealed containers for 30 minutes. The air expelled from the desiccators, containing CO_2 as a result of fruit respiration, was collected in secondary CO_2 traps containing 50 ml of 0.1 N NaOH. The secondary CO_2 traps were removed from the system and immediately sealed. Then, a 20 ml aliquot from each trap was mixed with 15 ml of 10% w/v $BaCl_2$ (to form $BaCO_3$), and 4 drops of phenolphtalein. The solution was immediately titrated with 0.1 N HCl using phenolphtalein as an indicator. Respiratory rate estimation was carried out daily during the first six days of storage, and then every three days. The respiratory rate (RR) expressed in mg of CO_2 kg^{-1} h^{-1} was determined using equations 1 and 2.
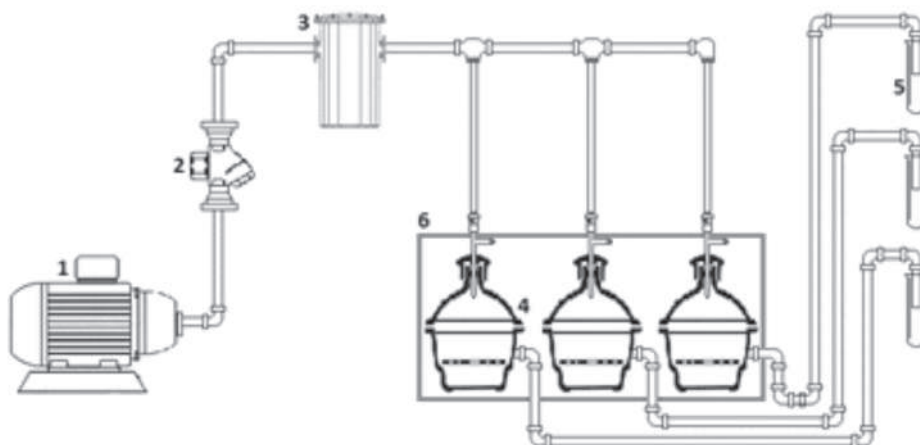
Figure 1. Diagram of the device used to estimate respiratory rate. 1. Compressor, 2. CO_2 Trap (2N KOH), 3. Humidity trap (silica gel), 4. Desiccators, 5. Secondary CO_2 Traps (0.1 N NaOH), 6. Refrigerated chamber.

Physical Properties

The wet weight of three pitahayas in each treatment was measured using a three-digit decimal precision scale (Mettler Toledo 1200, Columbus, Ohio). Then, the pitahaya fruits were placed in an environment controlled chamber (1000L Dies, Colombia) set at 25 ± 2°C and 85% relative humidity. Fruits were weighted daily during the first six days, and every three days subsequently. Weight loss was analyzed using the relative weight percent variation (ΔY) using equation 3.

Color was measured in the 400-700 nm reflectance spectrum using a Colorflex colorimeter (HunterLab, Reston, Virginia). Color coordinates L*a*b* for each fruit were obtained at five points in the equatorial zone, separated approximately by

72º, using the D65 standard illuminant and 10º observer. Three fruits per treatment were analyzed every three days for color determination. Color parameters were estimated by measuring total color change (ΔE) as shown in equation 4 (16).

Firmness was measured in three fruits per treatment every three days. Firmness was evaluated by measuring the maximum force required to penetrate 10.0 mm into the fruit, using a texture analyzer (model EZ-Test, Shimadzu, Somerset, New Jersey) equipped with a 2.0 mm diameter cylindrical penetrometer moving at 10 mm/min speed.

$$RR \left[\frac{m \ g}{k \ g} \ _h^2 \right] = \frac{(V_b - V_m)*N_{HCl}*22*f}{w*t}$$ **Equation 1.**

$$f = \frac{V_{NaOH}}{V_{aliquot}}$$ **Equation 2.**

where: V_b = Volume (ml) of HCl used in blank titration; V_m = Volume (ml) of HCl used to titrate the sample; N_{HCl} = Normality of HCl; w = simple weight (Kg); t = time (hours); 22 = milliequivalent weight of CO_2 (g-meq); f = sample factor = (volume of NaOH / volume used for the sample).

$$\Delta Y = \left(\frac{Y_j - Y_0}{Y_0} \right) *100$$ **Equation 3.**

where: Y_0 = initial fruit weight; Y_j = weight of fruit at time j.

$$\Delta E = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2}$$ **Equation 4.**

where: $L*$ = Luminosity; $a*$ = red to green color; $b*$ = blue to yellow color.

Chemical Properties

The flesh from three pitahayas was mashed and used to determine total soluble solids (°Brix) and acidity. Total soluble solids were estimated using AOAC official method 932.12 by placing the liquid from the mashed fruit into a refractometer (Hand Held 500 HRS, Atago, Bellevue, Washington) (17).

Titratable acidity was measured using AOAC method 942.15A (18). NaOH 0.1 N was used to titrate to pH 8.1 and results were expressed as equivalent grams of citric acid.

The maturity index was determined as the ratio between total soluble solids and titratable acidity of fruit.

Evaluation of fruit preservation

Fruit preservation was determined by a daily evaluation of the physical appearance of the fruit and the quantification of the percent fruit that lost commercial value. The commercial preservation of individual fruit was defined as the number of days in storage before observing browning, necrosis of mammilla, or skin softening (firmness below 12 N). The percent loss was calculated as the ratio of damaged fruit over total fruit.

Experimental design

To determine the effect of the pre- and postharvest application of different 1-MCP aqueous solution on the ripening of fruit, a completely randomized factorial design with three factors and a control was used. Factors were moment of 1-MCP application at two levels (pre- and postharvest), 1-MCP concentration at two levels (200 and 400 μgL^{-1}), and storage time at 10 levels (0, 1, 2, 3, 4, 5, 6, 9, 12, and 15 days). All determinations were done in triplicates.

Analysis of variance was done using the Minitab Statistical Program version 15.1 (Minitab, State College, Pennsylvania). When treatment effects were detected by ANOVA, multiple comparisons for the mean were done using the Tukey test (alpha=0.05).

RESULTS AND DISCUSSION

Respiratory rate

The respiratory rate of yellow pitahaya treated with 1-MCP aqueous solutions and the pre- and postharvest control treatments are shown in figure 2. All fruits exhibited a climacteric respiratory curve, in agreement with Rodríguez *et al*., 2005 (19), and Baquero *et al*., 2005 (20), and in contrast with reports by Nerd *et al*., 1997 (21, 22), who stored fruits at 20°C and found low CO_2 generation and absence of a climacteric peak. The observed differences could be explained by differences in cultivar (23, 24), pre- and postharvest practices (24), and weather and agronomical conditions. Wills *et al*., 1998 (25) and Chitarra *et al*., 2005 (26), defined climacteric fruits as those exhibiting a sudden increase in the respiratory rate, which is typical of stored yellow pitahaya.
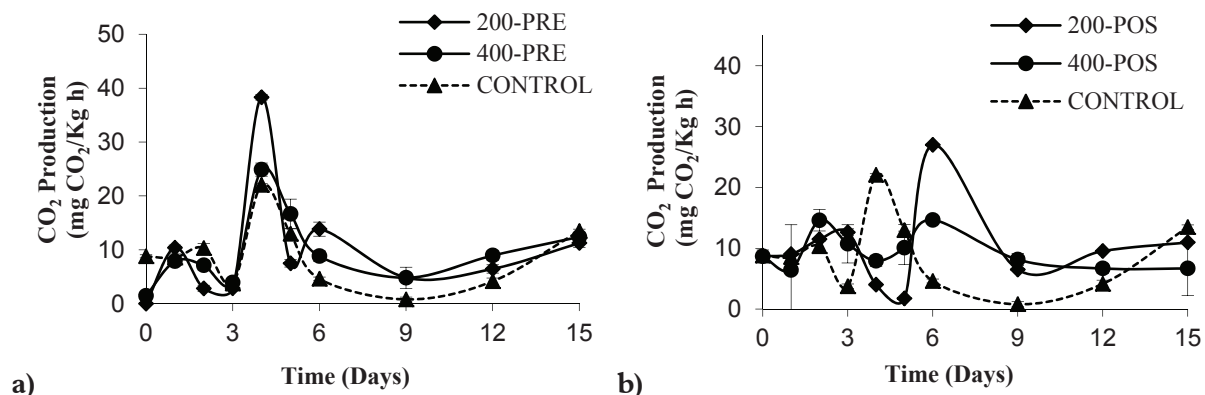
Figure 2. Respiratory rate in yellow pitahaya fruits treated with 200 and 400 μgL^{-1} of 1-MCP at preharvest (a) and postharvest (b). PRE: preharvest; POS: postharvest. Values are means ± S.D.

Preharvest application of 1-MCP enhanced fruit respiration. The maximum respiratory rate (38.3 mg CO_2 $kg^{-1}h^{-1}$) was observed after four days of storage in fruit treated with 200 μgL^{-1} 1-MCP, whereas the control treatment exhibited the lowest respiratory rate in figure 2a. The use of 1-MCP at 200 μgL^{-1} in postharvest displaced the climacteric peak to the sixth day of storage (26.9 mg CO_2 $kg^{-1}h^{-1}$) and fruit receiving a postharvest application of 400 μgL^{-1} showed respiratory peaks during the second and sixth day of storage and lower respiratory rates that fluctuated between 5.9 and 14.60 mg CO_2 $kg^{-1}h^{-1}$. Since the climacteric peak occurred during the initial days of storage, it was not related to the beginning of the senescence. However, it was considered to have an effect on the beginning or acceleration of the maturation metabolic processes (27).

The ANOVA showed a significant effect of storage time on the respiratory rate of yellow pitahaya fruit (p < 0.002). However, 1-MCP levels and time of application were not significant. These results were similar to reports by Dong *et al.*, 2002 (28), where the application of 1000 nL L^{-1} of 1-MCP did not significant affect the respiratory rate of apricots. Dong *et al.*, 2001 (29), also found similar results when 1 μgL^{-1} of 1-MCP was applied to nectarines. Defilippi *et al.*, 2007 (8), found that the preharvest application of 1-MCP (Harvista^{TM}) did not affect the respiratory rate of apples. In this study, the observed respiratory rate values were lower than those reported by Rodríguez *et al.*, 2005 (19), in yellow pitahaya.

Weight loss

All treatment factors had a significant effect on weight percent loss (p < 0.05; figure 3). The lowest weight percent loss was observed in fruit exposed to 400 μgL^{-1} 1-MCP preharvest in figure 3a and the highest weight loss in fruit treated with postharvest 1-MCP applications. The postharvest use of 1-MCP resulted in similar weight percent losses of 15.6 and 16.3% for 200 and 400 μgL^{-1} 1-MCP applications, respectively.
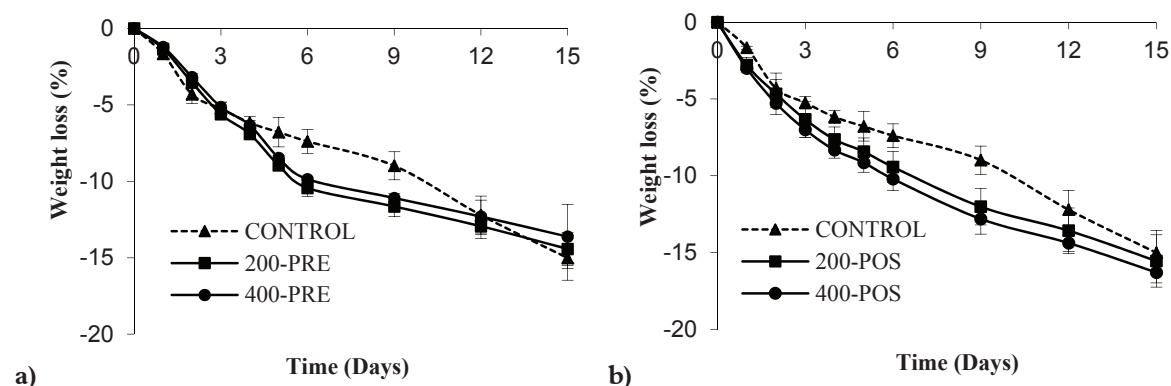
Figure 3. Weight loss during storage in yellow pitahaya fruits treated with 200 and 400 μgL^{-1} of 1-MCP at preharvest (a) and postharvest (b). PRE: preharvest; POS: postharvest.

Nerd *et al.*, 1997 (22), reported that yellow pitahaya exhibited a maximum 23% weight loss when stored at 20°C and 70% RH. These results were higher than those obtained in our study where control fruit showed a 15% maximum weight loss during storage. Weight percent loss in fruit after postharvest treatments in figure 3b was not in agreement with results by Massoloa *et al.*, 2011 (30), where the postharvest application of 1-MCP in eggplant resulted in the lowest weight percent loss. Valero *et al.*, 2007 (31), also observed the lowest weight percent loss in plums treated with postharvest 0.3 and 0.5 $\mu g L^{-1}$1-MCP and stored at 1 and 10°C. Other authors did not observed significant treatment effects for the case of apricots treated with 1-MCP (32).

The water balance in fruit is determined by the entrance of sap through the xylem and phloem and the loss of water by transpiration. Storage conditions play an important role in the fruit water balance since cuticular transpiration is determined by the difference between vapor pressure in the fruit surface vs. its surroundings (33). Transpiration by fruit during storage generates loss of water and therefore weight loss (34). Our results showed that the postharvest application of 1-MCP in yellow pitahaya caused a negative effect on weight, increasing postharvest economic losses.

Color

The major color changes in fruit were observed with the preharvest application of 1-MCP in figure 4, where the 200-PRE treatment resulted in the highest color percent change in figure 4a. Significant differences among control and treated samples ($p < 0.05$) were found after the sixth day of storage. At the end of the storage time, total changes in fruit color for the CONTROL, 200-PRE and 400-PRE treatments were 41.09, 52.68, and 42.31% respectively.
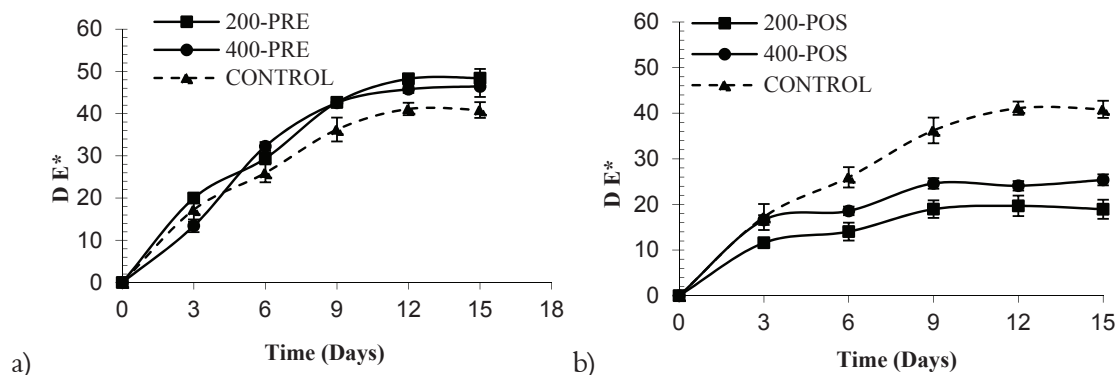
Figure 4. Color changes in yellow pitahaya fruits treated with 200 and 400 $\mu g L^{-1}$ of 1-MCP at preharvest (a) and postharvest (b). PRE: preharvest; POS: postharvest.

All treatments resulted in color changes after prolonged storage, but faster changes were observed in yellow pitahaya treated with preharvest 1-MCP. Gutiérrez *et al.*, 2008 (4), found similar behavior in pears, where fruit subjected to 1-MCP at concentrations of 0.4 and 0.8 $\mu L \ L^{-1}$, showed the biggest change in luminosity and color. Their results were different from reports in the preharvest applications of 1-MCP (Harvista[TM]) in apples (8, 9) and pears (10) where no significant differences in color were observed. Changes in fruit color are explained by the metabolism of green pigments and the exposure of typical previously masked colors of fruit in the early stage of maturity.

Fruit treated with postharvest applications of 1-MCP, showed minor changes in color (figure 4b). The average change in color (See equation 4) at the end of storage was 41.6, 19.22 and 28.69% for fruit treated with 0 (control), 200, and 400 $\mu g L^{-1}$ postharvest 1-MCP, respectively. The postharvest application of 200 $\mu g L^{-1}$ 1-MCP yielded fruit with color attributes similar to freshly harvested fruit, but with longer storage preservation. Studies in broccoli (35), and grapefruit (36), reported that the postharvest application of 1-MCP delayed color changes in fruit, maintaining their characteristics during storage. It was also reported that postharvest applications of 1-MCP in watermelon retarded adverse changes in color, pH, and soluble solids content caused by ethylene (37). Although ANOVA showed that concentration of 1-MCP, storage time, and moment of application had all significant

effect on total color change (p < 0.05), the last two factors were the most important in determining total color change.

Firmness

All yellow pitahaya fruits (treated and controls) exhibited firmness losses during storage. However, faster loss of firmness was observed in control *vs.* treated fruit in figure 5. In fruit treated with pre-harvest 1-MCP applications, firmness remained similar to that of freshly harvested fruit for up to 12 days of storage in figure 5a. The preharvest application of 1-MCP (Harvista™) retained firmness in apples (8, 9) and pears (10). The decline in firmness occurred earlier in fruit receiving postharvest 1-MCP applications, with significant differences between treated and control samples observed by the 15th day of storage in figure 5b.
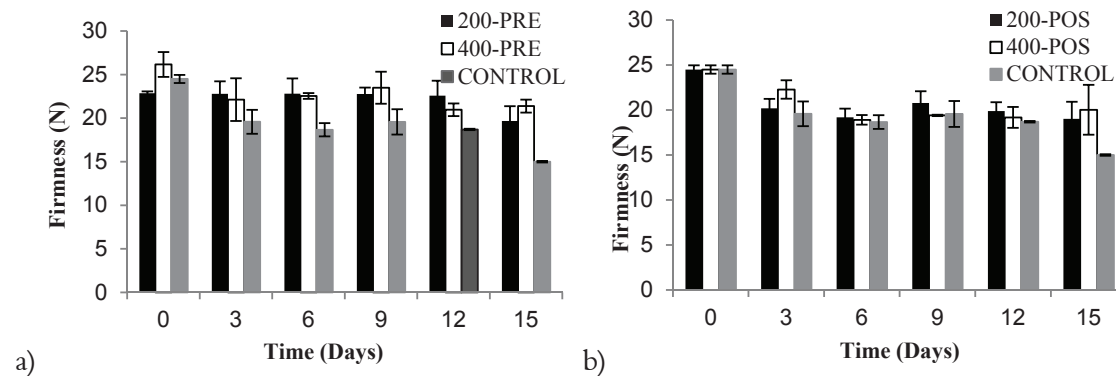
Figure 5. Changes in firmness for yellow pitahaya fruits treated with 200 and 400 μgL^{-1} of 1-MCP at preharvest (a) and postharvest (b). PRE: preharvest; POS: postharvest.

Fruit treated with 400-PRE showed an 18.27% relative firmness loss during storage time vs. 19.26% in fruit treated with 200-PRE. Significant differences in firmness were observed due to moment of 1-MCP application (p < 0.019), and storage time (p < 0.001). Similar results were observed in tomatoes by Mostofi *et al.*, 2003 (38), where the application of 250 nL L^{-1} of 1-MCP reduced firmness loss. Similarly, 1-MCP at 20-30 nL L^{-1} concentration levels, reduced the softening of plums harvested at two maturity stages (31).

The firmness of fruit is related to cell properties including adhesion between neighboring cells, cell brittleness, and cell turgor pressure (39). The cell wall is mainly formed by rigid cellulose microfibers held together by a network of glucans (hemicelluloses) and pectin arrays, and small quantities of structural proteins and aromatic compounds (40). During ripening, various enzymes degrade pectin and glucan arrays, affecting the structural integrity of the cell wall (41).

The hydrolysis and degradation of structural polymers, accumulation of osmotic solutes in the cell wall (41, 42), environmental conditions affecting the turgidity (42), and loss of water during ripening (41, 43) are all factors potentially affecting the texture of fruit by promoting changes in cell dimensions, intercellular adhesion, and cell wall composition

(41). The use of 1-MCP reduces the activity of enzymes promoting pectin and hemicelluloses degradation, resulting in less significant changes in fruit firmness during storage (23).

Soluble solids

The soluble solids content in control samples varied from 17.1 °Brix at day one after harvest to 16.4 °Brix after 15 days of storage, and exhibited a peak of 18.4 °Brix on the fourth day of storage. These results differ from experiments by Nerd *et al.*, 1997 (22), who found that yellow pitahaya fruits harvested green and mature exhibited constant soluble solids contents that ranged from 19 to 21 °Brix when stored at 10 and 20°C.

Fruit treated with preharvest applications of 1-MCP showed overall reductions on soluble solids during storage in figure 6a. The control and 400-PRE treatments exhibited an increase in soluble solids up to the second day, but subsequent reductions during storage. The reduction in soluble solids was coincident with the beginning of the respiratory climacteric peak. In contrast, a constant reduction in soluble solids during storage was observed in fruit treated with 200-PRE. Similar behavior was evident when fruit was treated with postharvest applications of 1-MCP in figure 6b.
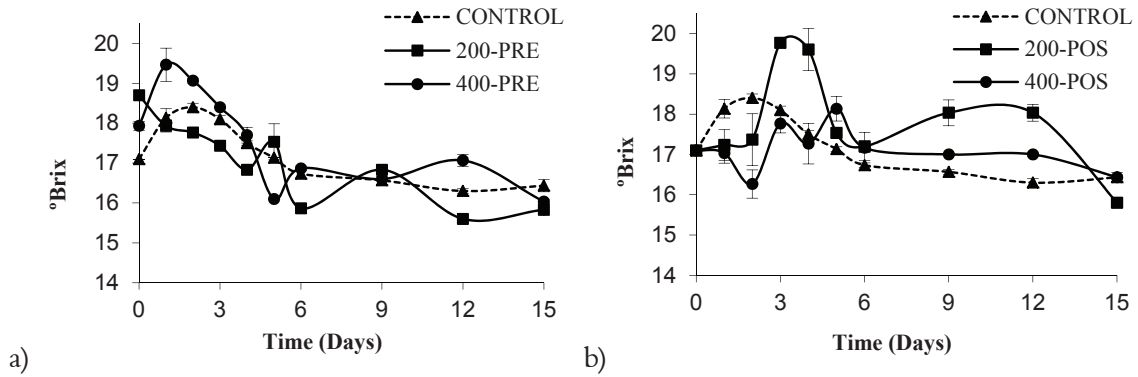
Figure 6. Soluble solids evolution during storage in yellow pitahaya fruits treated with 200 and 400 μgL^{-1} of 1-MCP at preharvest (a) and postharvest (b). PRE: preharvest; POS: postharvest.

The observed reductions in soluble solids are mainly explained by the use of simple sugars trapped inside vacuoles as substrates for respiration, via the glycolytic, pentose phosphate, or tricarboxylic acid pathways (44). The oscillating variation in soluble solids may be due to the existence of a different sugar source available for respiration as reported by Nerd *et al.*, 1997 (21). Similar behavior was reported in onions by Chope *et al.*, 2007 (45). Rodríguez *et al.*, 2005 (19), measured the °Brix in yellow pitahaya fruits (maturity stages 3 and 5) and reported soluble solids between 14 and 16 °Brix for fruit stored at 19 °C and fluctuating values from 12 and 18 °Brix when fruit was stored at 8 °C. These values differed from our results and those reported by Nerd *et al.*, 1997 (22).

The postharvest applications of 1-MCP generated a strong variability in soluble solids in figure 6b. Although significant differences (p < 0.001) were found due to moment of application, concentration and storage time. A similar behavior was observed in onions treated with 0.1 μL L^{-1} 1-MCP vs. untreated controls, where soluble solids yielded significant treatment effects (45). Previous experiments also showed significant effects due to the application of 1-MCP in pineapple (35).

Acidity

All studied factors had a significant effect on the total titratable acidity (TTA) of yellow pitahaya fruits. The postharvest application of 1-MCP resulted in the least reduction in TTA in fruit up to the 12th day of storage. However, at the end of the storage time, lower TTA was observed in treated vs. control samples in figure 7a. Although control and 1-MCP treated fruit exhibited the same trend towards the reduction in total titratable acidity, sharp peak variations were observed during storage. These peaks were mostly evident in fruit receiving postharvest applications of 1-MCP and during the 2nd and 10th days of storage in figure 7b.
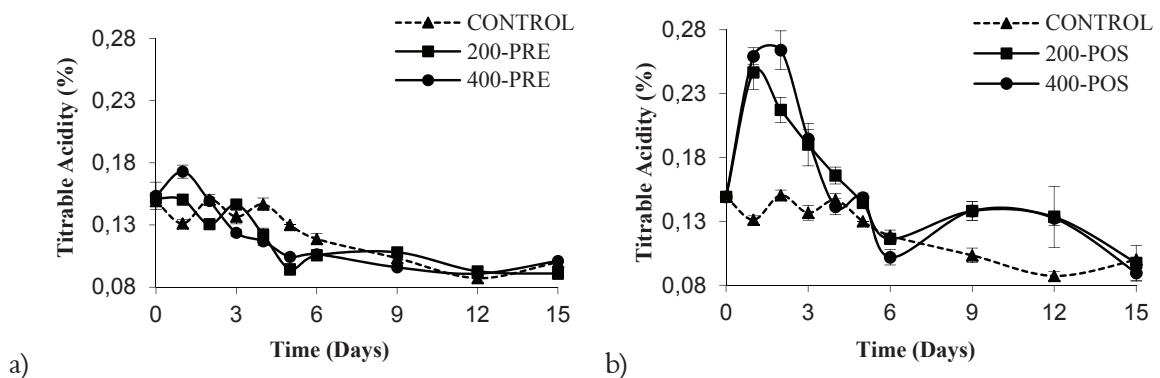
Figure 7. Total titrable acidity (TTA) during storage in yellow pitahaya fruits treated with 200 and 400 μgL^{-1} of 1-MCP at preharvest (a) and postharvest (b). PRE: preharvest; POS: postharvest.

Titratable acidity of pitahaya decreases because organic acids are metabolized during the storage of fruit. Citric acid is metabolized to sugars, aminoacids, and non volatile organic acids that are used in oxidative reactions during maturation (46). The sudden increases in TTA could be explained by citric acid synthesis from glucose during the Krebs cycle (47). Rodríguez *et al.*, 2005 (19), harvested yellow pitahaya fruits with maturity stage 3 and observed that TTA ranged from 1.5 to 2.54% after 15 days of storage at 19°C and from 1.3 to 3% after 23 days of storage at 8°C. According to these authors, fruit harvested with maturity stage 5 and stored at 8 and 19 °C showed negligible changes in TTA during storage.

Our results agreed with data reported by Servarajah *et al.*, 2001 (35), who found that the application of 1-MCP delayed the reduction of ascorbic acid content in stored pineapples. Dong *et al.*, 2002 (28), reported similar behavior in plums and Bassetto *et al.*, 2005 (48), found high total acidity levels in 1-MCP treated guava fruits stored at 25°C, due to the delay in the maturation process. It must be noted that the effect of the 1-MCP is limited in advanced stages of ripening (32) and studies in apricots showed no effect of 1-MCP treatments on the total acidity and soluble solids in mature fruit (28).

Maturity index

All studied factors promoted increments in the maturity index of yellow pitahaya fruits. Control fruit exhibited 115 and 200 maturity index at the beginning and end of the storage period, respectively. Fruit treated with preharvest application of 1-MCP showed initial and final maturity index of 123 and 174 for 200-PRE and 116 and 153 for 400-PRE treatments. Postharvest applications of 200 μgL^{-1} and 400 μgL^{-1} 1-MCP resulted in final maximum maturity index of 181 and 162, respectively. The maturity index was significantly affected by the moment of application and the concentration of applied 1-MCP (p < 0.05). It also showed significant changes due to the maturation process during storage. The maturity index followed the pattern control-fruit > fruit with postharvest applications of 1-MCP > fruit treated with preharvest applications of 1-MCP. Valero *et al.*, 2007 (31), found that the maturation of plums stored at 20°C was delayed by increasing concentrations of 1-MCP, which in turn improved the fruit organoleptic properties.

Fruit quality preservation

Treated samples were evaluated for their overall appearance to verify that the whole fruit was suitable for consumption. The control fruit was acceptable for consumption for up to 12 days, after which basal decay, browning, and peduncle detachment were observed. Rodríguez *et al.*, 2005 (19), reported that yellow pitahaya fruit harvested at maturity stage 3 and stored at 19 °C retained their quality for 15 days. Likewise, Janick *et al.*, 2008 (49), reported high quality preservation of yellow pitahaya fruits stored for 14 days at 10°C or 17 days at 5°C. The postharvest application of 200 μgL^{-1} 1-MCP delayed in three days the signs of aging in fruit. After 15 days of storage, 47.3% of the treated fruit lost their commercial quality *vs.* 84.2% for control fruit. Fruit receiving the postharvest application of 400 μgL^{-1} 1-MCP showed signs of aging after 12 days of storage and 50% of the fruit lost their commercial value after 15 days of storage. Although control fruit and fruit receiving the preharvest application of 1-MCP (200 and 400 μgL^{-1}) simultaneously began their commercial decay at day 12 of storage, 68% of fruit treated with 400 μgL^{-1} lost their commercial value by day 15.

A series of physical, chemical, and physiological changes occur in the fruit after harvesting due to the sudden end of water and solids circulating from the plant into the fruit (33) and the increase in activity of hydrolytic enzymes generating plant metabolites. The application of 1-MCP inhibits the production of ethylene (6) and the interaction between ethylene and its receptors (5). However, in preharvest applications of 1-MCP, metabolic processes responsible for shorten the yellow pitahaya preservation are triggered. This is because the magnitude and sensitivity to ethylene rises as a lower number of receptors are present (2, 3). The increase in the ethylene sensitivity together with the production of ethylene by untreated fruit and plant organs increase the response of stored fruit to the hormone.

CONCLUSIONS

The pre- and postharvest applications of 200 and 400 μgL^{-1} 1-MCP aqueous solutions affected the preservation of the yellow pitahaya fruits during storage. The physical, physiological, and chemical effects depended on the concentration of the com-

pound, the moment of application, and the storage time. Preharvest applications of 200 and 400 μgL^{-1} 1-MCP could be used to accelerate external changes in yellow pitahaya fruits by promoting epicarp coloration, maintaining firmness, and delaying weight loss and maturity index. However, the maximum concentration of 1- MCP used in preharvest (400 μgL^{-1}), yielded a high percent of pitahaya fruits showing undesirable signs of senescence.

The postharvest application of 200 μgL^{-1}1-MCP extended the commercial preservation of pitahaya fruits in three days by reducing maturity index, color changes, and fluctuations in titratable acidity. In contrast with similar reports in tropical fruits, our experiments indicated that postharvest applications of 1-MCP promoted greater weight losses in fruit during storage. Total soluble solids were not significantly affected by the use of 1-MCP.

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