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Effect of different methods and doses of 1-methylcyclopropene applications on postharvest feijoa fruits (*Acca sellowiana* Berg)

Efecto de diferentes métodos y dosis de aplicación de 1-metilciclopropeno en la poscosecha de frutos de feijoa (*Acca sellowiana* Berg)

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Feijoa fruit.
Photo: G. Fischer

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ABSTRACT

Feijoa is an aromatic fruit with high nutraceutical value and great economic potential because of its versatility in industrial processing, in addition to being climacteric. However, the postharvest life of these fruits is relatively short. The application of 1-methylcyclopropene (1-MCP) delays the production of ethylene, maintains firmness, and prolongs shelf-life; however, the efficiency of 1-MCP depends on the application method (liquid or gaseous), and different feijoa have not been tested on feijoa. Therefore, the objective of this study was to evaluate the effect of different methods and doses of 1-MCP applications on the postharvest behavior of feijoa fruits stored at room temperature (16°C). A completely randomized design was used with seven treatments made up of control plus six treatments with a 3×2 factorial structure, where the first factor was the application method (immersion, gaseous, and spray), and the second factor was the dose of 1-MCP (30 or 60 mg L^{-1}). The doses and methods of the 1-MCP applications did not affect the loss of mass (16.38%). Firmness decreased by 67.9% during the first 4 days after harvest (dah) in all treatments. The 1-MCP maintained higher levels of soluble solids (10.63 °Brix) than the control (7.6 °Brix) at the end of storage. All 1-MCP application methods decreased the respiratory rate in the feijoa fruits. The 60 mg L^{-1} of 1-MCP application via immersion generated the highest values of total phenol content and total antioxidant activity (TAA) during the first 8 dah, while the TAA decreased and the total phenolic content increased.

Additional key words: antioxidant activity; climacteric; phenols; Myrtaceae; mass loss.

RESUMEN

La feijoa es un fruto aromático de alto valor nutraceútico y gran potencial económico, por su versatilidad en la transformación industrial, además de ser climatérico. Sin embargo, la vida poscosecha de estos frutos es relativamente corta. El 1-metilciclopropeno (1-MCP) retrasa la producción de etileno, mantiene la firmeza y prolonga la vida poscosecha, no obstante, su eficiencia depende del método de aplicación (líquida o gaseosa), y en feijoa no se han probado diferentes métodos. Por lo anterior, el objetivo de este estudio fue evaluar el efecto de diferentes formas y dosis de aplicación de 1-MCP en la poscosecha de frutos de feijoa almacenados a temperatura ambiente (16°C). Se utilizó un diseño completamente aleatorizado con siete tratamientos compuestos por un testigo más seis tratamientos con estructura factorial 3×2, en donde el primer factor fue la forma de aplicación (inmersión, gaseosa y aspersión) y el segundo factor, la dosis de 1-MCP (30 o 60 µg L^{-1}). Las dosis y formas de aplicación de 1-MCP no afectaron la pérdida de masa (16,38%). La firmeza descendió un 67,9% durante los primeros 4 días después de la cosecha (ddc) en todos los tratamientos. El 1-MCP mantuvo elevados los niveles de sólidos solubles (10,63°Brix) frente al control (7,6 °Brix), al final del almacenamiento. Todas las formas de aplicación de 1-MCP disminuyeron la intensidad respiratoria de los frutos de feijoa. La aplicación 60 µg L^{-1} de 1-MCP mediante inmersión generó los mayores valores de contenido de fenoles totales y actividad antioxidante total (AAT) durante los primeros 8 ddc, mientras la AAT disminuyó y el contenido de fenoles totales aumentó.

Palabras clave adicionales: actividad antioxidante; climaterio; fenoles; Myrtaceae; pérdida de masa.

INTRODUCTION

Feijoa fruit is appreciated in international markets (Henao-Ardila *et al.*, 2019) given its high nutraceutical value resulting from the presence of many bioactive compounds, namely, catechin, epicatechin, gallic acid, ellagic acid, procyanidin and quercetin-3-galactoside, among others, which are beneficial for human health (Peng *et al.*, 2020; Guerra-Ramirez *et al*., 2021). This fruit also has many volatile compounds, such as terpenes, esters, alcohols, and aldehydes, which have great potential for industrial use (Baena-Pedroza *et al.*, 2020).

In Latin America, Brazil, Argentina, and Uruguay are the main producers of feijoa; likewise, in Mexico, there are few orchards (Nolasco-Matías *et al*., 2020), while in Colombia, this crop is grown by small producers at altitudes between 1,800 and 2,700 m a.s.l., but planting areas have increased in recent years (Fischer *et al*., 2024; Moretto *et al.*, 2022). Production is concentrated in the departments of Boyaca and Cundinamarca, which, by 2021, had 234 and 74.4 ha cultivated, respectively (MinAgricultura, 2023).

The feijoa fruit has a climacteric behavior and reaches the highest respiratory rate 8 days after harvest (dah) with values of 114.7 mg kg^{-1} h^{-1} of CO_2 in fruits of the 'Clone 41' cultivar stored at room temperature (16°C) (Álvarez-Herrera *et al.*, 2023). Quintero (2012) stated that 'Clone 8-9' had a climacteric peak at 8 dah, and that consumption maturity was reached on day 12, indicating a short shelf-life and making commercialization and export difficult because of the rapid loss of quality (Parra-Coronado *et al.*, 2018).

Different strategies have been tested to increase postharvest duration. Applications of 1-methylcyclopropene (1-MCP) have prolonged the shelf-life of many fruits by maintaining quality, reducing the incidence of physiological disorders (Rupavatharam *et al.*, 2015a), delaying softening and slowing down the degradation of chlorophyll in fruits (Rahman *et al*., 2024). In feijoa, applications of 1-MPC maintained the firmness of Brazil 242 cultivar fruits for up to 30 dah at 4°C (Amarante *et al.*, 2008). Álvarez-Herrera *et al.* (2023) observed that, in 'clone 41', higher doses of 1-MPC generated fruits with greater resistance to penetration. However, Schotsmans *et al.* (2011) stated that 1-MCP did not affect the maturation of feijoa fruits of the Apollo cultivar. The low efficacy of 1-MCP in these studies was attributed to the conditions and methods of the applications and the exposure time of the fruits to this product (Álvarez-Herrera *et al.*, 2023).

Satekge and Magwaza (2022) found that the effect of 1-MCP depends on the method of exposure of fruits to the product and that it can be applied in gaseous or liquid form. Likewise, these authors confirmed that the liquid application method requires a higher concentration than the gaseous method and that the diffusion rate is slower in the immersion method (liquid). For feijoa, there is no information on different application methods that improve the efficiency of 1-MCP, so this study evaluated the effect of different methods and doses of 1-MCP on the postharvest behavior of feijoa fruits to search for strategies to extend postharvest life and improve the commercialization of this fruit.

MATERIALS AND METHODS

Location

The study was carried out at the Universidad Pedagógica y Tecnológica de Colombia (Boyacá, Colombia), Tunja campus, in the Plant Physiology Laboratory of the Faculty of

Agricultural Sciences, with an average annual temperature of 16°C and relative humidity of 65%.

Plant material

The fruits were harvested from a 5-year-old commercial crop planted at a distance of 2.5 m between rows and 2.5 m between plants, located in the municipality of Jenesano-Boyaca, on the 'La Esperanza' farm, 'Palenque' village, which has a rainfall of 1,113 mm in 2021, with an average annual temperature of 17.1°C and relative humidity of 70%, located at 5°21'31" N and 73°21'37" W, at an altitude of 2,121 m. The cultivar corresponds to Clone 41, which was not irrigated, and the harvest was carried out in April, 2021, collecting ripe, uniform-sized fruits with a good appearance and healthy characteristics on April 19, 2021. The transport to the laboratory lasted one hour and was carried out with 10 kg plastic baskets.

Experiment design

A completely randomized design was used with seven treatments: a control plus six treatments with a 3×2 factorial structure, where the first factor corresponded to the application method (immersion, gaseous, and spray), and the second factor was the 1-MCP dose (30 or 60 mg L^{-1}). The immersion treatments and gaseous application had a 30-min exposure time to 1-MCP. Each treatment had four replications, for a total of 28 experiment units (EU), where each EU had 20 fruits, which were stored in T-1 polystyrene trays (Ajover Darnel, S.A.S., Colombia) at laboratory temperature (16°C).

Before applying the treatments, the fruits were sanitized using a 1% sodium hypochlorite solution. For the 1-MCP treatment, the method described by Rupavatharam *et al*. (2015a) was followed, using 1-MCP in the form of a 0.014% soluble powder (Ethylbloc™ Floralife® Inc, OH, USA) to achieve doses of 30 and 60 μg L^{-1}. The fruits were added for immersion in the solution for 30 min, afterward, they were allowed to dry at room temperature (16°C) and kept stored under the same conditions.

The application of gaseous 1-MCP was adapted from the methodology of Ambaw *et al.* (2011), for which a solution of 30 μg L^{-1} of 1-MCP was prepared in a 250 mL Erlenmeyer flask, it was heated to boiling point, and the steam was directed for 30 min through a conduction system to a hermetically sealed 6 L container containing the fruits. Then, the process was repeated with a concentration of 60 μg L^{-1} of 1-MCP. The spray application was done by taking the mixtures obtained by immersion and spraying the fruits with them. Then, they were allowed to dry and deposited in T-1 expanded polystyrene containers to start the postharvest period.

Response variables

The loss of accumulated mass (ML), expressed as a percentage, was evaluated for 14 dah, where the weight of six feijoa fruits was taken using a 0.001 g VîBRΛ AJ220E precision electronic balance (Shinko Denshi Co., Ltd, Japan). The respiratory rate (RR) was evaluated in three fruits deposited in 2 L SEE BC-2000 hermetic containers (Vernier Software & Technology, OR, USA) for 10 min. The amount of CO_2 was determined using a VER CO2-BTA sensor (Vernier Software & Technology, OR, USA) with the LabQuest2 interface (Vernier Software & Technology, USA), and the measurements were expressed in mg of CO_2 kg^{-1} h^{-1} (Álvarez-Herrera *et al*., 2023). Firmness was measured in three fruits per EU using a GY-4 penetrometer (Yueqing Handpi Instruments Co., Ltd, China) with a 3.5-mm-diameter tip, 10-mm pressure depth, and 0.01 N precision.

With a CHNSpec CS-200 Minolta digital colorimeter (Hangzhou CHNSpec Technology Co., Ltd, China), the color of the skin of feijoa fruits was determined on the CIELAB scale (Álvarez-Herrera *et al.*, 2023), for which six fruits per EU and the chromaticity and hue (°*h*) were calculated using the method of Jaime-Guerrero *et al.* (2021). Total soluble solids (TSS) were extracted from the juice of three fruits per EU, from which three drops were taken and measured using a HANNA HI 96803 digital refractometer (Hanna Instruments, Woonsocket, RI), expressed in °Brix. The total titratable acidity (TTA) was measured with the volume of sodium hydroxide (NaOH) incorporated in 5 mL of juice of three feijoa fruits, diluted to 50 mL with distilled water, to which three drops of phenolphthalein were added to determine the final titration point, expressed as the change to pink or violet color in a basic solution, for which the Jaime-Guerrero *et al.* (2021) methodology was used, expressed as a percentage of citric acid (0.064 g meq^{-1}).

Total phenolic compounds (CFT) were determined with the Folin-Ciocalteu technique (Peng *et al.*, 2020): 1 g of feijoa pulp was taken, homogenized in 10 mL of 80% ethanol, and macerated, and the extract was passed through a Unico C858 Model PowerSpin LX centrifuge (Unico Scientific, Hong Kong) at 4,500 rpm for 10 min and 4°C. A 0.5 mL aliquot of the extract was taken and combined with 0.75 mL of 1 N Folin-Ciocalteu reagent, then left to stand at room temperature for 5 minutes. Next, 0.75 mL of 20% sodium carbonate was added, mixed, and allowed to rest for 90 minutes. Finally, the absorbance at 760 nm was measured using a HumanCorp UV/Visible X-ma 1200V spectrophotometer (Human Corporation, Seoul, Korea). The calibration curve was established using gallic acid as the reference standard. Subsequently, solutions were prepared at concentrations of 5, 10, 40, 80, 100, 140, and 200 mg L^{-1}, and the straight-line equation was established based on the gallic acid standard and expressed in mg GAE g^{-1} of fresh weight.

Total antioxidant activity (TAA) was measured with the 2,2'-azino-bis-3-ethylbenzothiazo-line-6-sulfonic acid (ABTS) method (Re *et al.*, 1999) and a stock solution of ABTS (7 mM): 0.0960 g of ABTS was weighed and dissolved in 25 mL of distilled water. In addition, a solution of potassium persulfate ($K_2S_2O_8$) (2.45 mM) was prepared: 0.0165 g of $K_2S_2O_8$ was weighed and dissolved in 25 mL of distilled water. To prepare the ABTS radical, 3 mL of the ABTS mother solution and 3 mL of the potassium persulfate solution were placed in an amber bottle, shaken until homogeneous, and covered with aluminum foil. This solution was incubated for 16 h at room temperature (16°C). Once the ABTS radical was formed, it was diluted in ethanol until obtaining an absorbance between 0.7±1 at 754 nm. A calibration curve with 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) was prepared, starting with a 200 mM Trolox solution made with 0.05 g of Trolox reagent that was weighed and taken to 100 mL with 96% ethanol. Subsequently, aliquots of 2.5, 3.75, 5, 6.25, 7.5, and 8.75 were taken to 25 mL with concentrations of 200, 300, 400, 500, 600, and 700 µmol, respectively. For the measurement, 200 µL of feijoa extract was added to 3.8 mL of ABTS, left to rest for 45 min, placed in 5 mL plastic cuvettes, and measured in the spectrophotometer at 754 nm, and it was expressed in µmol of Trolox per g of extract of fresh weight (TE g^{-1}).

Data analysis

Normality tests of Kolmogorov-Smirnov were performed to guarantee compliance with the assumptions of the analysis of variance (Anova), which was done to establish the statistical differences between treatments and the different measurements over time. Subsequently, comparison tests between Tukey treatments ($P \leq 0.05$) were carried out. The statistical program SAS® OnDemand for Academics (SAS Institute Inc, Cary, NC) was used.

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RESULTS AND DISCUSSION

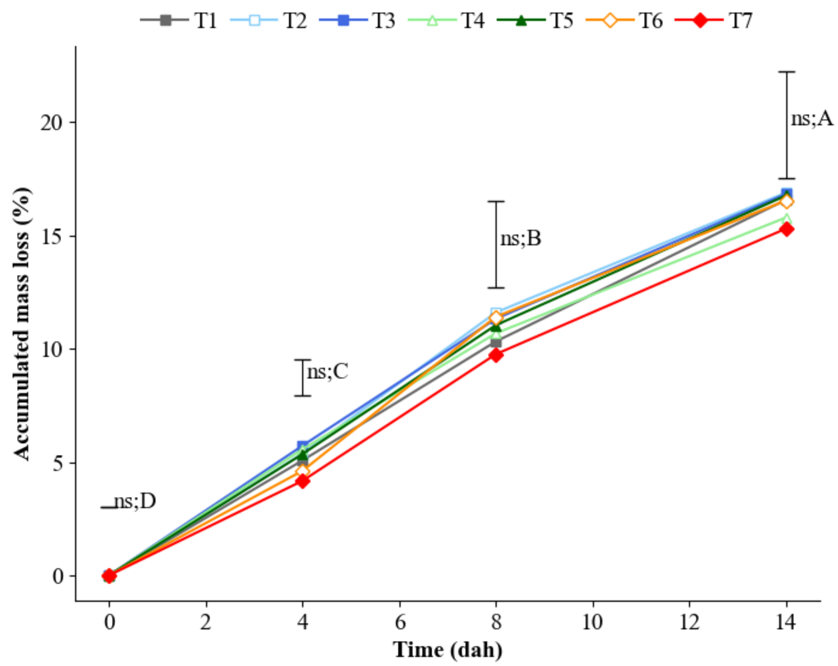
Accumulated mass loss (ML)

The ML did not present significance between treatments; however, applying 60 µg L^{-1} of 1-MCP with the spraying obtained the lowest values (Fig. 1A). Conversely, the measurements over time had significant, statistical differences. In addition, the ML reached average values of 16.38% at the end of storage, and the ML was higher up to 8 dah, subsequently slowing down. The ML was higher than the values of 3.6% found by Amarante *et al.* (2017a) for five feijoa cultivars subjected to refrigerated storage for 21 d. Likewise, Castellanos *et al.* (2016) reported 5.7% and 1.1% ML values for fruits stored at room temperature and packed in polypropylene bags with perforations. ML mainly results from water loss due to transpiration and respiration that generate the output of solutes (Díaz-Pérez, 2019). These authors stated that the permissible ML range for fruits is between 5 and 10%, and higher values indicate the loss of commercial quality, which occurs between 4 and 7 dah at room temperature (16°C) for feijoa. Treatments with 1-MCP did not significantly affect mass loss (ML) since its primary mechanism of action is inhibiting ethylene perception, which delays ripening and senescence but does not directly influence transpiration or water loss (Lv *et al*., 2023). However, the 60 µg L^{-1} spray dose resulted in the lowest ML values, possibly due to better distribution and absorption of the compound, which helped maintain cellular integrity. Nonetheless, ML depends more on factors such as relative humidity and cuticle permeability.

Firmness

No notable differences were observed among treatments in any of the measurements performed on the feijoa fruits (Fig. 1B). However, there were differences between the measurement times, where fruit firmness decreased drastically during the first 4 dah by 67.9%. From 4 to 14 dah, it decreased by only 9.4%, indicating that feijoa fruits should be marketed during the first 4 dah.

A



B

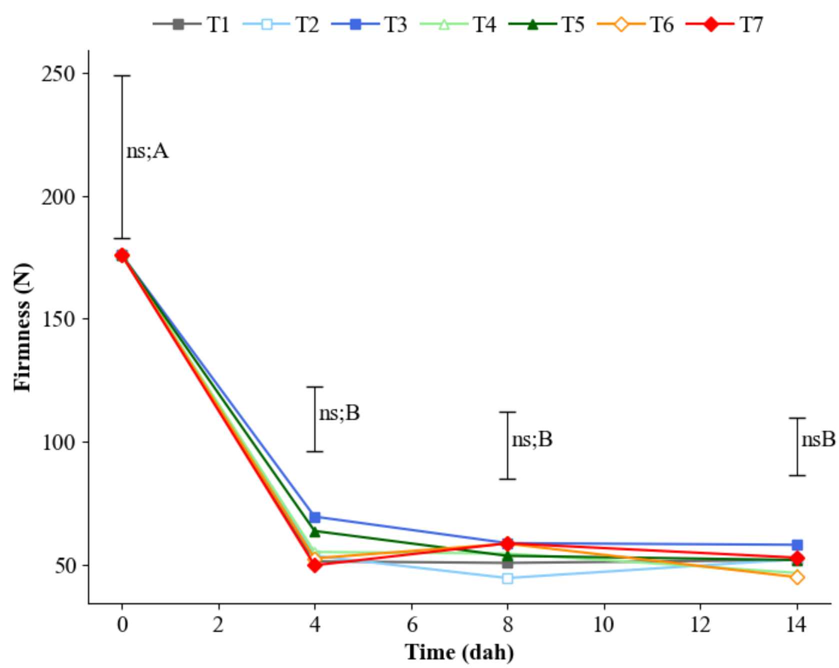


Figure 1. A: accumulated mass loss. B: firmness in feijoa fruits subjected to different 1-MCP doses and application methods. T1: control; T2 and T3: immersion with 30 and 60; T4 and T5: gaseous application with 30 and 60; T6 and T7: aspersion with 30 and 60 mg L^{-1} of 1-MCP. ns: not significant effect according to the Anova ($P≤0.05$) between treatments before the semicolon and different uppercase letters after the semicolon indicate significance between measurements over time according to the Tukey test ($P≤0.05$). dah: days after harvest. Vertical bars indicate the minimum significant difference at each sampling point according to Tukey ($P≤0.05$).

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The absence of significant differences among treatments was probably due to the doses and application methods being inadequate to completely suppress ethylene activity, which regulates the activity of enzymes such as pectinmethylesterase that degrade the cell wall (Bangar *et al*., 2022). Furthermore, the absence of refrigeration accelerated the ripening process, promoting turgor loss and softening. Studies have shown that 1-MCP is more effective when combined with refrigeration (Álvarez-Herrera *et al*., 2023). The averages obtained for all treatments at 14 dah were 51.1 N, similar to Rupavatharam *et al.* (2015a), who found that firmness ranged between 26.9 and 51.5 N for the fruits collected at the time predicted for commercial harvest and 4 weeks prior, respectively. Likewise, Álvarez-Herrera *et al.* (2023) reported values of 70.7 and 44.4 N for refrigerated and non-refrigerated fruits with applications of 1-MCP by immersion. The values in the present study at the end of storage were slightly higher because of 1-MCP applications, delaying fruit softening (Rahman *et al.*, 2024).

Total soluble solids (TSS)

The TSS values remained consistent across treatments, showing no significant variations but did between the different measurement times (Fig. 2A). During the first 8 d, the TSS had constant behavior. Afterward, they began to increase in the treatments with 1-MCP, while in the control they decreased, indicating the beginning of fruit senescence in the last treatment because of the loss of the respiratory substrate (Saltveit, 2019). Notably, the control (7.6 °Brix) had a decrease in TSS at the end of storage when compared to the treatments that received 1-MCP applications regardless of the method (10.63 °Brix). These results are similar to those obtained by Amarante *et al.* (2017a), with averages of 10.12 °Brix for five feijoa cultivars. Likewise, 1-MCP maintained high TSS values for longer, similar to that reported by Chen *et al.* (2020) in apples who stated that applications of nanoemulsions coating of 1-MCP at doses of 1 mL L^{-1} maintained higher TSS values for 140 d in fruits refrigerated at 4°C, as compared with the control treatment. The application of 1-MCP did not significantly affect total soluble solids (TSS) because its main mechanism of action is to inhibit ethylene perception, delaying senescence and degradation of respiratory substrates, but it does not directly influence the accumulation of sugars (Lwin and Lee, 2021).

Total titratable acidity (TTA)

Significant differences were only obtained at the end of storage in the TTA of the feijoa fruits, where the application of 60 mg L^{-1} of 1-MCP with immersion had the highest values, 171% higher than the spray treatment of 30 mg L^{-1} of 1-MCP, which had the lowest values. Similarly, there were significant differences between the various measurements over time for TTA (Fig. 2B), with a descending behavior from 4 dah, where it showed the highest values (2.68%). 14 dah saw values of 1.41%, as reported by Amarante *et al.* (2017a) who stated that TTA decreased during storage in five feijoa genotypes, going from 1.21% at harvest to 0.82% at 21 dah refrigerated at 4°C. The TTA decrease was attributed to the use of acids, which are converted through the decarboxylation of malate and oxaloacetate via the gluconeogenesis pathway into glucose, which is used as a respiratory substrate during the postharvest period (Vallarino and Osorio, 2019).

Respiratory rate (RR)

There were significant differences in the RR between treatments during postharvest for the feijoa fruits (Fig. 3A), where all methods of the 1-MCP applications managed to reduce RR by 64 and 76% at 4 and 8 dah, respectively. This effect was also observed by Rupavatharam *et al.* (2015b), who stated that RR was reduced with 1-MCP treatments. Li *et al.* (2023) stated that 1-MCP delays senescence and the respiratory peak and reduces ethylene production by suppressing the activity of enzymes like 1-aminocyclopropane-1-carboxylate (ACC) synthase, ACC oxidase, ACC catalysts, and ethylene precursors.

The climacteric peak in the feijoa fruits without applications of 1-MCP was reached at 8 dah and registered a value of 46 mg kg^{-1} h^{-1} of CO_2, lower than the 50.7 mg kg^{-1} h^{-1} of CO_2 found on the same day by Álvarez-Herrera *et al.* (2023) in feijoas stored at room temperature without applications of 1-MCP. Likewise, Rodríguez *et al.* (2006) found that the climacteric peak for Quimba cultivar feijoa was reached at 11 dah, with a value of 74.9 mg kg^{-1} h^{-1} of CO_2. One of the characteristics of climacteric fruits is to increase RR during postharvest, which is produced by increases in internal temperature, which increases the production of ethylene and whose purpose is to favor processes such as tissue softening, synthesis of pigments and generation of aromatic compounds, which accompany ripening (Saltveit, 2019).

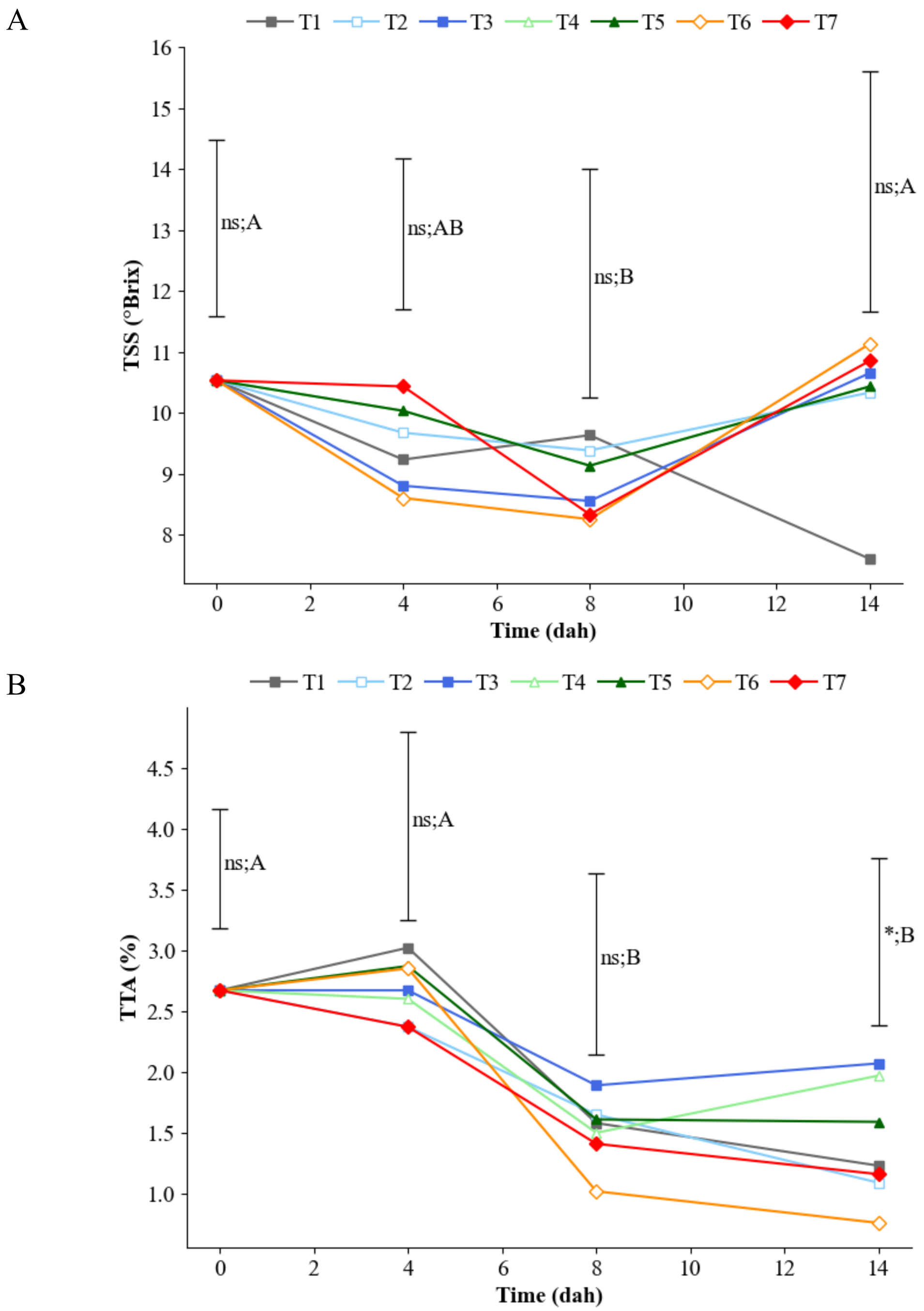

Figure 2. **A: total soluble solids (TSS). B: total titratable acidity (TTA) in feijoa fruits subjected to different 1-MCP doses and application methods. T1: control; T2 and T3: immersion with 30 and 60; T4 and T5: gaseous application with 30 and 60; T6 and T7: aspersion with 30 and 60 mg L^{-1} of 1-MCP. ns: not significant effect according to the Anova (*P*≤0.05) between treatments before the semicolon and different uppercase letters after the semicolon indicate significance between measurements over time according to the Tukey test (*P*≤0.05). dah: days after harvest. Vertical bars indicate the minimum significant difference at each sampling point according to Tukey (*P*≤0.05).**

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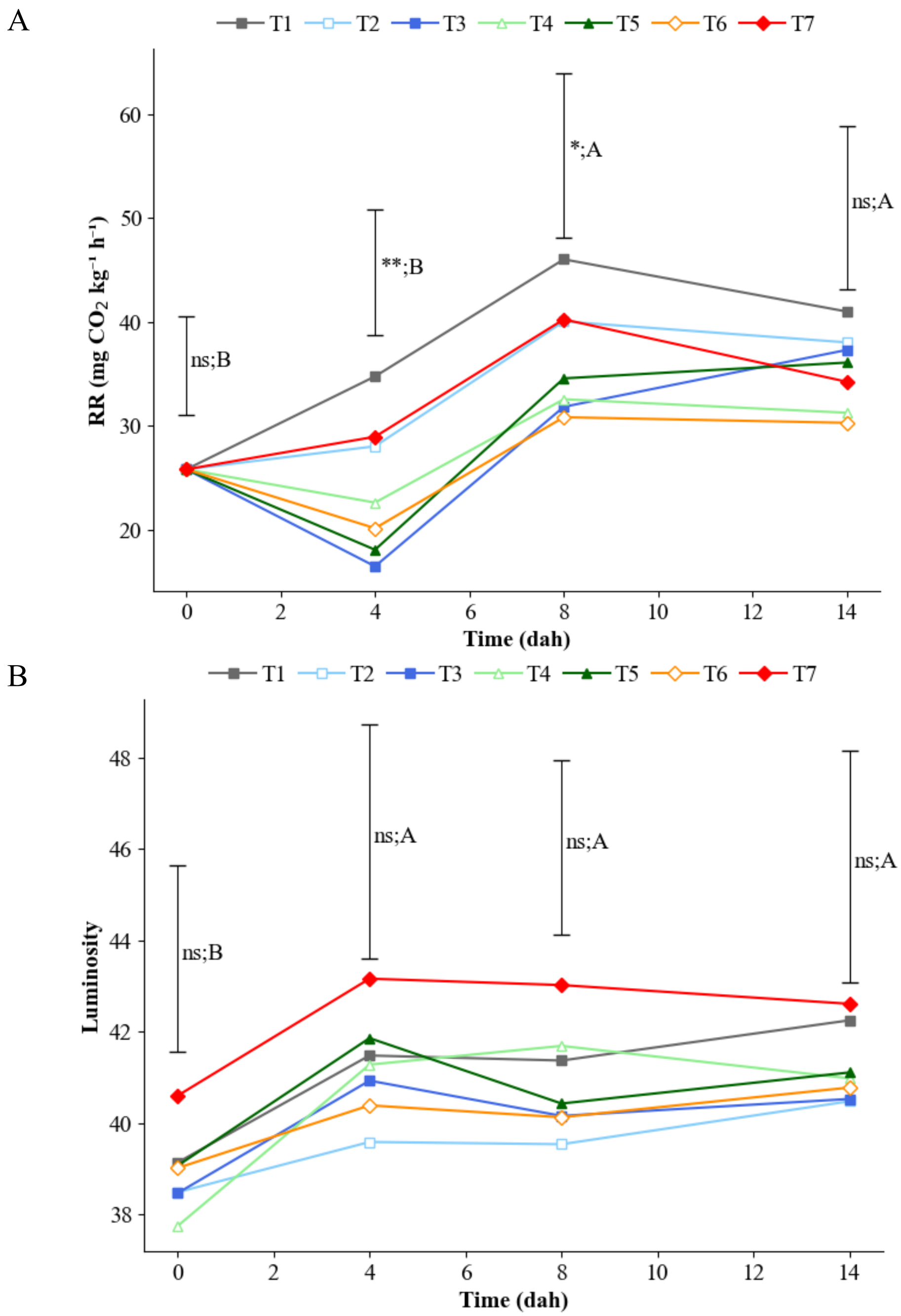

Figure 3. A: respiratory rate (RR). B: luminosity (*L) in feijoa fruits subjected to different 1-MCP doses and methods of application. T1: Control; T2 and T3: immersion with 30 and 60; T4 and T5: gaseous application with 30 and 60; T6 and T7: aspersion with 30 and 60 mg L^{-1} of 1-MCP. ns: not significant effect according to the Anova (*P*≤0.05) between treatments before the semicolon and different uppercase letters after the semicolon indicate significance between measurements over time according to the Tukey test (*P*≤0.05). dah: days after harvest. Vertical bars indicate the minimum significant difference at each sampling point according to Tukey (*P*≤0.05).**

Luminosity of the skin (*L)**

The different doses and methods of application of 1-MCP did not significantly affect the luminosity of the feijoa fruit skin, according to Rupavatharam *et al.* (2015a), who did not find an effect of 1-MCP on the *L** of the skin. However, a significant increase in *L** was observed during postharvest storage, going from 38.93 at harvest to 41.25 at the end of storage (Fig. 3B). Probably, a degreening of the fruits occurred since a change from dark green to light green that was generated by the degradation of chlorophylls was observed, which could have caused a greater *L** at the end of storage (Pasquariello *et al.*, 2015). In contrast, Amarante *et al.* (2017a) reported that the *L** in the skin of different feijoa cultivars decreased on average from 45.4 to 43.8 after 21 dah. Similarly, Pasquariello *et al.* (2015) found an average of 40.11 in *L** for 12 feijoa cultivars, similar to the values found in this study.

Hue (°*h*)

Significant differences were only obtained between treatments at the time of harvest, significance that is attributed to the heterogeneity of the initial color in postharvest of the fruits (Tab. 1). Likewise, there were no significant differences for °*h* between the different measurements over time, and constant behavior was observed with a slight decrease in hue, which went from an average value of 126.5 at harvest to 123.5 at the end of storage. This decrease in the °*h* of feijoa fruits was from 120.1 to 114.9 (Rupavatharam *et al.*, 2015a), similar to the averages of 123.8 and 123.3 reported by Amarante *et al.* (2017a) at harvest and postharvest, respectively. Parra and Fischer (2013) stated that, during postharvest, °*h* decreases in some feijoa cultivars, representing the loss of green color. This decrease in the green hue is caused by the increase in internal temperature suffered by fruits at harvest, which increases the activity of enzymes such as chlorophyllases (Hu *et al.*, 2021).

Chroma (*C)**

There were significant differences between treatments only at 4 dah in the *C** of feijoa fruits. The spray application of 60 μg L^{-1} of 1-MCP maintained the highest *C** values, while the spray application of 30 μg L^{-1} of 1-MCP showed the lowest values (Tab. 1), as reported by Latt *et al.* (2023), who stated that *C** values in the skin were higher in fruits treated with 1-MCP than in the control. They found that 1-MCP delayed the degreening in the skin of pear fruits.

The average behavior over time of the *C** of the feijoa skins had a significant increase, going from 30.1 at harvest to 33.5 at 14 dah, contrary to the decrease described by Amarante *et al.* (2017a), where the fruits of five feijoa cultivars went from 21.5 at harvest to 20.4 at 21 dah. Álvarez-Herrera *et al.* (2023) confirmed that refrigeration maintains higher *C** values in feijoa fruits and more color saturation.

Table 1. Color parameters evaluated in feijoa fruits, subjected to different treatments during the postharvest period.

Parameter	Application method	1-MCP (μg L^{-1})	Time (dah)			
			0	4	8	14
Hue	---	0	127.32±1.17 ab;A	125.16±0.52a;AB	125.17±0.44 a;AB	123.43±0.43 a;B
	Immersion	30	128.08±0.55 a;A	125.81±0.37 a;B	125.61±0.46 a;BC	123.75±0.55 a;C
		60	127.20±0.34 ab;A	126.35±0.45 a;A	126.42±0.48 a;A	125.68±0.61 a;A
	Gaseous	30	126.61±0.91 ab;A	126.31±1.00 a;A	124.37±0.78 a;A	123.26±1.12 a;A
		60	124.28±0.31 b;A	125.72±0.81 a;A	124.97±0.45 a;A	123.41±0.69 a;A
	Spray	30	127.23±0.97 ab;A	125.90±0.61 a;AB	125.94±0.83 a;AB	123.28±1.18 a;B
		60	124.85±0.96 ab;A	124.17±1.15 a;A	125.17±0.94 a;A	121.88±1.22 a;A
Chroma	---	0	29.13±1.46 a;A	32.57±0.93 ab;A	32.39±0.81 a;A	33.75±1.24 a;A
	Immersion	30	28.14±0.59 a;C	30.24±0.40 b;B	31.36±0.23 a;AB	33.07±0.49 a;A
		60	29.75±0.98 a;A	31.36±1.21 ab;A	30.35±1.64 a;A	33.04±1.10 a;A
	Gaseous	30	29.44±1.68 a;A	33.25±0.82ab;A	30.97±1.51 a;A	34.40±1.08 a;A
		60	32.04±1.64 a;A	31.18±0.51 ab;A	30.85±1.00 a;A	32.60±1.02 a;A
	Spray	30	29.11±0.95 a;B	29.98±0.71 b;AB	31.17±0.84 a;AB	32.53±0.40 a;A
		60	33.04±2.03 a;A	34.48±0.67 a;A	31.19±1.40 a;A	35.38±1.94 a;A

Means of 4 replicates ± standard error. Different lowercase letters indicate a significant effect according to the Tukey test ($P<0.05$) between treatments before the semicolon, and different uppercase letters after the semicolon indicate significant between measurements over time according to the Tukey test (P<0.05). dah: days after harvest.

Total phenolic content (TPC)

Significant differences were obtained at 14 dah, where the application of 60 mg L^{-1} of 1-MCP with immersion generated the highest results for the TPC of feijoa fruit pulp, with 2.59 mg g^{-1} of GAE, at the end of the postharvest (Fig. 4A). These values are higher than the 0.86 mg g^{-1} of GAE reported by Amarante *et al.* (2017b) on average for five cultivars and lower than the 7.75 mg g^{-1} of GAE obtained by Oliveira *et al.* (2020). Li *et al.* (2008) reported that applications of 0.5 mL L^{-1} of 1-MCP kept TPC values higher in apples than in the control. However, at the end of storage (4 weeks), the TPC was similar in apples in all treatments. For apples, Lu *et al.* (2012) stated that applications of 1-MCP increased TPC retention. Li *et al*. (2008) observed that 1-MCP preserves high levels of TPC in fruits by inhibiting ethylene action. This mechanism is attributed to the increase in organic acid concentrations induced by 1-MCP, reducing the degradation of phenolic compounds and thereby extending postharvest quality (Chen *et al*., 2023).

When analyzing the behavior of phenols over time, they reached the highest values at 8 dah, with averages of 4.63 mg g^{-1} of GAE, and then decreased until they reached 1.84 mg g^{-1} of GAE, indicating that, when the deterioration of fruits begins, TPC decreases as a result of the degradation process caused by the activation of enzymes such as peroxidase, polyphenol oxidase, lipoxygenase, and laccase, which oxidize monophenols and o-quinones (Vallarino and Osorio, 2019). When oxidized, the latter generates melanin products responsible for fruit browning. Likewise, Tuncel and Yilmaz (2015) found that the TPC increases during the first 4 hours postharvest, going from 11.5 to 13.5 mg g^{-1} of GAE, and mention that in the senescence of the fruits, phenols are degraded by processes of fermentation.

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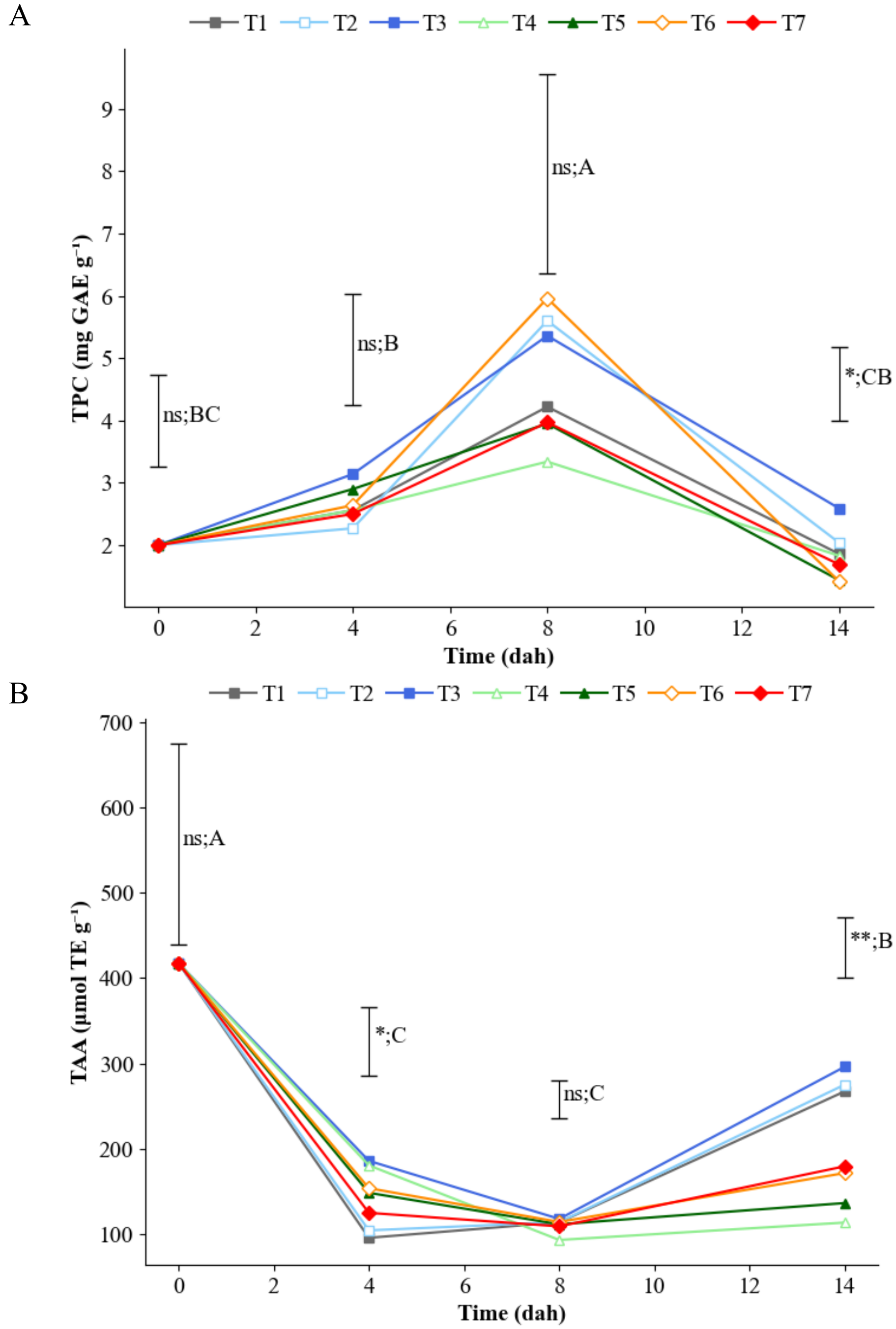

Figure 4. **A: total phenolic content (TPC). B: total antioxidant activity (TAA) in feijoa fruits subjected to different 1-MCP doses and methods of application. T1: control; T2 and T3: immersion with 30 and 60; T4 and T5: gaseous application with 30 and 60; T6 and T7: aspersion with 30 and 60 μg L^{-1} of 1-MCP. ns: not significant effect according to the Anova (*P*≤0.05) between treatments before the semicolon and different uppercase letters after the semicolon indicate significance between measurements over time according to the Tukey test (*P*≤0.05). dah: days after harvest. Vertical bars indicate the minimum significant difference at each sampling point according to Tukey (*P*≤0.05).**

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Total antioxidant activity (TAA)

There were significant differences between treatments for TAA at 4 and 14 dah (Fig. 4B), when the application of 60 µg L^{-1} of 1-MCP with immersion generated the highest value, reaching 296 µmol of Trolox per g of extract (TE g^{-1}). Similarly, Contreras-Calderón *et al.* (2011) found higher values of 320 µmol TE g^{-1}, while Tuncel and Yilmaz (2015) reported lower data, with averages of 123.7 µmol TE g^{-1} for different extractions in feijoa fruits. Lv *et al.* (2023) reported that postharvest applications of 1-MCP increased antioxidant activity, retained TSS, firmness, TTA, and ascorbic acid values for longer, and reduced the production of malondialdehyde, H_2O_2, and singlet oxygen in apricot fruits. In apples, the gaseous application of 1-MCP maintained higher antioxidant activity both in the skin and in the pulp during storage than the control (Ma *et al.*, 2019). On the other hand, Amarante *et al.* (2017b) stated that the main antioxidant agents in feijoa fruits are water-soluble.

It is well known that the application of 1-MCP preserves the TAA due to its ability to inhibit ethylene action, thereby delaying fruit ripening and senescence (Lv *et al*., 223). However, its effectiveness depends on the dose and application method. In this study, the application of 60 µg L^{-1} of 1-MCP via immersion resulted in the highest TAA values, possibly because this concentration and method optimized compound absorption, preserving cellular integrity and antioxidant activity. Lower doses or less efficient methods, such as gaseous application, may not achieve the same effect, leading to greater degradation of phenolic compounds and flavonoids, ultimately reducing TAA.

The TAA values decreased until 8 dah (110 µmol TE g^{-1}) and then increased again until the end of storage (205 µmol TE g^{-1}). This decrease in TAA during storage was caused by the decrease in the concentrations of phenols and flavonoids; TAA correlates with the content of phenolic compounds in apple fruits (Ma *et al.*, 2019). At the end of postharvest, the increase in TAA was attributed to the loss of quality resulting from the beginning of senescence (Álvarez-Herrera *et al.*, 2023).

CONCLUSION

The doses and methods of the applications of 1-methylciclopropene did not affect the accumulated loss of mass, firmness, or luminosity of the skin in the feijoa fruits. Despite the lack of significant differences, applying 1-MCP resulted in total soluble solids values 28.5% higher than those of the control fruits. 1-MCP decreased the respiratory rate of the feijoa fruits in all application methods. Immersion of the fruits in 60 mg L^{-1} of 1-MCP generated the highest values of total phenol content and total antioxidant activity. Applying 60 µg L^{-1} of 1-MCP with the spraying obtained the lowest mass loss values and conserved the hue for more time during storage.

Conflict of interests: The authors declare no conflict of interest.

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