Revista Internacional de Investigación e Innovación Tecnológica
Página principal: www.riiit.com.mx

Study of marketing simulation in jackfruit (*Artocarpus heterophyllus* Lam) treated with 1-methylcyclopropene

Estudio de la simulación de mercadeo en yaca (*Artocarpus heterophyllus* Lam) tratada con 1-metilciclopropeno

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Technological innovation: Characterization of fruits treated with 1-methylcyclopropene at different concentrations with marketing simulation.

Industrial application areas: Handling and post-harvest treatment for jackfruit in packinghouses in the region for export purposes.

Received: December 06th, 2020
Accepted: April 12th, 2021

Resumen

La yaca es altamente apreciada en el continente asiático debido a sus propiedades nutricionales y funcionales. En México la yaca juega un papel muy importante en la economía, ya que más del 93% de la producción nacional es destinada a la exportación, no obstante, su naturaleza climatérica y su elevada producción de etileno lo hacen un fruto altamente perecedero con un mercado limitado. El objetivo de este estudio fue evaluar el efecto del 1-metilciclopropeno en frutos de yaca almacenados con simulación a mercadeo para alargar la vida de anaquel. Se utilizaron frutos en madurez fisiológica y se les aplicó 1-MCP a diferentes concentraciones (300, 600 y 1000 nL/L), así mismo se almacenaron frutos control a 13 ºC durante 5 días, posteriormente, se almacenaron a 25 ºC, para simular la comercialización del producto; hubo un grupo control absoluto permanente a 25 ºC. Se realizaron análisis fisicoquímicos y fisiológicos, se determinó capacidad antioxidante, fenoles solubles totales, vitamina C, carotenoides y se realizó una evaluación sensorial. En los resultados de velocidad de respiración para los frutos control almacenados a 13 ºC y los tratados

con 1-MCP (300, 600 y 1000 nL/L) se observó un pico máximo con valores de 179.22, 163.02, 231.68, y 266.72 mL de $CO_2 \cdot kg^{-1} \cdot h^{-1}$ respectivamente. Para la producción de etileno los frutos control y tratados con 1-MCP presentaron valores máximos de 52.34, 51.53, 34.07, y. 81.14 $\mu L \cdot kg^{-1} \cdot h^{-1}$ respectivamente. El tratamiento con 1-MCP a 600 nL/L prolongó la vida útil del fruto presentando el desarrollo de las propiedades fisicoquímicas, componentes y características sensoriales atractivas, lo que permitirá ofrecer una alternativa de manejo poscosecha de yaca para mejorar sus condiciones de exportación.

Palabras clave: Capacidad antioxidante, Condiciones de mercadeo, Fenoles solubles totales, Parámetros fisiológicos y fisicoquímicos, Yaca.

Abstract

Jackfruit is highly appreciated in Asia due to its nutritional and functional properties. In Mexico, jackfruit plays a very important role in the economy, since more than 93% of the national production is destined for export, however, its climacteric nature and its high ethylene production make it a highly perishable fruit with a limited market. The aim of this study was to evaluate the effect of 1-methylcyclopropene (1-MCP) on stored jackfruit with marketing simulation in order to extend their shelf life. Fruits in physiological maturity were used and 1-MCP was applied to them at different concentrations (300, 600 and 1000 nL/L), likewise control fruits were stored at 13 ºC for 5 days, then, were stored at 25 ºC, to simulate the product marketing; an absolute control group at 25 ºC was used. Physicochemical and physiological analyzes, determination of antioxidant capacity, total soluble phenols, vitamin C, carotenoids and a sensory evaluation were carried out. Respiration rate of the control fruits stored at 13 ºC and fruits treated with 1-MCP (300, 600 and 1000 nL/L) appeared their maximum peak with values of 179.22, 163.02, 231.68, and 266.72 mL of CO_2•kg-1•h-1 respectively. For the production of ethylene, the control fruits and those treated with 1-MCP present maximum values of 52.34, 51.53, 34.07, and 81.14 $\mu L \cdot kg^{-1} \cdot h^{-1}$ respectively. Treatment with 600 nL/L with 1-MCP at 13 ºC prolonged the useful life of the fruits and achieved the development of physicochemical properties, components and attractive sensory characteristics, thus to allow to offer an alternative for postharvest handling of jackfruit to improve its export conditions.

Keywords: Antioxidant capacity, Jackfruit, Marketing conditions, Physiological and physicochemical parameters, Total soluble phenols.

1. Introduction

Jackfruit (*Artocarphus heterophyllus* Lam) is an exotic fruit originating from the southeast of India distributed in different parts of the world, including Mexico in the American continent [1]. There, the state of Nayarit is the main producer of this fruit with more than 93% of the production reported in 2019 [2]. Among 2011 and 2016, jackfruit export volumes increased by 114% [3]. However, despite its success in production, there is a lack of scientific information for its postharvest handling, generating significant losses to producers [4]. Jackfruit is highly perishable, this by their characteristics as a multiple fruit-climacteric and its sensitivity to cold; in addition, its respiration rate and ethylene production are considered high, reported a maximum peak of CO_2 production of 90.7 mL•kg-1•h-1 and 22.5 µl•kg-1•h-1 of

ethylene [5]. Nowadays, postharvest technologies help to extend the shelf life of fruits; 1-methylcyclopropene (1-MCP), as one of them, has innovated in its mechanism of action for its effect [6]. At standard temperature and pressure, 1-MCP is a gas, which allows it to have mobility in the fruit tissues [7], in this way, the molecule can occupy the ethylene receptors permanently, and thus, control the signaling cascade that induces gene expression, a process that is related to the response to ethylene and maturation [8]; This slows down the respiration rate, the ripening process and the weight loss of the fruit. 1-MCP is nontoxic, it is stable at room temperature and has an easy application that has been used successfully in different agricultural species [9], such as bananas [10], apple [11], "Kingston pride" mango [12], nectarine [13], "Ataulfo" mango [14], kiwi [15], among others.

2. Materials and Methods

The methodology was divided into two parts: part 1 with all the treatments (physicochemical and physiological analysis) and part 2 which was carried out to the treatment that presented the most suitable results for the marketing simulation (antioxidant capacity, total soluble phenols, vitamin C, total carotenoids and sensory evaluation).

2.1 Obtaining fresh-cut material and applying treatments

Jackfruits were collected at physiological maturity in the season of May-June 2019, using "Agüitada" as a work material. All fruits came from "El Llano", San Blas and "Estación Nanchi", Santiago Ixcuintla both belonging to the state of Nayarit, Mexico. After collection, fruits were washed by immersion and an antifungal treatment was applied for 3 min. Once dried, the peduncle was sealed with a saturated solution of copper oxychloride. The fruits were divided into 2 groups: controls (13 ºC and absolute control at 25 ºC) and fruits treated with 1-MCP at different concentrations (300, 600 and 1000 nL/L). 1-MCP was applied in 512 L containers and hermetically closed, exposing the fruits this gas for 12 h. At the end of this time, fruits were stored at 13 ºC and after 5 days, were stored at 25 ºC simulating the marketing chain.

2.2 Physicochemical analysis

The physicochemical analyzes were carried out on days 0, 3, 5, 8, 11, 14, 17 and 21 of storage. The determination of total soluble solids was carried out by the 932.14 method, the pH measurement by the 981.12 method, the titratable acid with the 942.15 method, all according to the AOAC [16]. Firmness was determined using a texturometer (Stable Micro Systems®, TA.TXPlus, U.K.) with a 5 mm tip for the peel and a 2 mm tip for jackfruit bulbs. Measurements were carried out at three different points of the equatorial diameter of each fruit, the average of the results was expressed in Newton (N). For color determination, a colorimeter (Minolta®, CR300, Japan) was used and the hue angle (h), chroma (C) and luminosity (L) were reported.

2.3 Physiological Analysis

Physiological analyzes were carried out on a daily basis until the end of the shelf life of the fruits. Respiration rate (RR) and ethylene production (EP) were worked with the methodology proposed by Tovar et al. [17] with some modifications. Individual fruits were placed in hermetic containers for 1 h for RR and EP. 1 ml of gas was taken from the headspace and analyzed in a gas chromatograph (Hewlett-Packard®, GC6890 Series, USA) fitted with an HP-PlotQ column (15 mx 0.53 mm and 40 µm film thickness), a flame ionization detector (FID) and a thermal conductivity detector (TCD). The

temperature of the injection port and the detectors was 250 ºC. Within this same system, H_2 (30 ml/min) and purified air (400 ml/min) were used. The carrier gas was N_2 with a flow of 7 ml/min. The oven temperature had a ramp from 60 to 80 ºC, which changed at a speed of 30 ºC/min. The RR was expressed in mL of $CO_2 \cdot kg^{-1} \cdot h^{-1}$ and the EP in $\mu L \cdot kg^{-1} \cdot h^{-1}$.

Weight loss was determined daily using a digital scale (Torrey®, L-PCR, Mexico); the difference in weight with respect to the original was expressed as the percentage of weight loss [18].

2.4 Sample extract

An extract of the sample was made as follows: 1 g of ground jackfruit pulp was mixed with 5 ml of acidified methanol (1.6%), then centrifuged (10,000 rpm at 4 °C for 10 min). The supernatant (extract) was recovered in a 10 mL volumetric flask and 5 mL of acetone was added to the precipitate, it was stirred, centrifuged, and the supernatant was recovered again, this being the sample extract.

2.5 Antioxidant capacity

The antioxidant capacity was determined by two methods, the ferric reducing antioxidant power (FRAP) and by the 2,2-diphenyl-1-picrylhydracil (DPPH) radical scavenging method.

The FRAP determination in microplates was carried out following the methodology proposed by Benzie & Strain [19] with modifications from Álvarez-Parrilla et al. [20] on microplate (Biotek®, Microplate reader 800TS, USA). To analyze the sample extract, 180 µL of the FRAP solution [Ratio 10: 1: 1 (v/v/v) sodium acetate buffer (0.3 M; pH 3.6), TPTZ-HCl (10 mM, 40 mM) and ferric chloride hexahydrate (20 mM)] was dispensed into the wells of the microplate in triplicate and 24 µL of the sample extract was added, then the plate was left to stand for 30 min in dark. The absorbances were measured at 595 nm (Biotek®, Gen 5™, USA) and the values were reported as mmol TE/g on fresh weight (FW) using a standard Trolox curve (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic).

The DPPH radical scavenging method followed was that proposed by Prior & Cao [21] on microplate (Biotek®, Microplate reader 800TS, USA). Sample extract of 30 µL was taken and deposited on the microplate in triplicate, followed by 200 µL of DPPH radical at a concentration of 190 mM and incubated in the dark for 10 min. The absorbance at 517 nm (Biotek®, Gen 5™, USA) was measured and the results were expressed as mmol TE/g on fresh weight (FW). A standard Trolox curve (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic) was used.

2.6 Total soluble phenols content

Total soluble phenols (TSP) were quantified using the Folin-Ciocalteu reagent according to the methodology described by Montreau [22] with modifications by Álvarez-Parrilla et al. [23] in a microplate reader (Biotek®, Microplate reader 800TS, USA). 250 µL of the sample extract were taken and mixed with 1250 µL of Folin-Ciocalteu reagent, subsequently, the mixture was incubated in tubes for 5 min. Then, a sodium carbonate solution (1000 µL, 75 g/L) was added and the tubes were incubated in a water bath at 50 °C for 15 min. Subsequently, 270 µL was placed in each well of the plate and the absorbance was measured at 765 nm (Biotek®, Gen 5™, USA). Calculations were carried out with a gallic acid standard curve, expressing the results as mg GAE/100g on fresh weight (FW).

2.7 Sample preparation for vitamin C and total carotenoids

The bulbs obtained from jackfruit treated with 600 nL/L of 1-MCP were lyophilized (Labconco®, Freezone 2.5L -50°C, USA) at -50 ºC and 0.125 mbar for 72 h and subsequently stored at -20 ºC, until their analysis.

2.8 Quantification of vitamin C

The determination was made using the technique proposed by Barbosa-Gámez et al. [24], so 0.1 g of lyophilized sample was taken and placed in a teflon tube for centrifugation and mixed with 20 mL of phosphoric acid (H_3PO_4) using an orbital mixer for 30 min. The mixture was subsequently centrifuged at 6,000 rpm for 20 min at 4 °C, the supernatant was collected and filtered (0.20 µm, Millex GN, USA). 20 µL were sampled and injected into an HPLC (Agilent Technologies®, 1260 Infinity, Germany) where the stationary phase used was a C18 column (Agilent Technologies®, 4.6 x 100 mm ZORBAX Eclipse plus, USA) with separation isocratic. The mobile phase was monobasic sodium phosphate (NaH_2PO_4) with a pH of 2.7 to 0.5 mL/min. Ascorbic acid detection was at 250 nm with a UV-VIS photodiode array detector, calculating the concentration using an ascorbic acid standard curve expressing the results as mg AA/g on fresh weight (FW).

2.9 Total carotenoids

The quantification methodology proposed by Philip & Chen [25] was used with some modifications. Briefly, 2 g of lyophilized jackfruit pulp were taken, 0.5g of magnesium carbonate ($MgCO_3$) and 10 mL of acetone-ether (80-20) were added and the mixture was subsequently stirred and centrifuged for 30 min at 4 ºC at 15,000 rpm. The supernatant was stored refrigerated and in the dark. Moreover, acetone-ether (80-20) was added to the precipitate, stirred and centrifuged under the same conditions. At the moment that the sample did not show coloration, the washes were suspended. Once the supernatants had been collected, were decanted into a separatory funnel where 20% sodium chloride was added, the mixture was left to settle until an organic layer had formed. The aqueous phase was drained and the organic phase was washed with distilled water, the aqueous phase was drained again. The ether and carotenoid extract were treated with anhydrous sodium sulfate (Na_2SO_4). After 1 minute of contact, the carotenoids were decanted, and ether was added to the sodium sulfate until it was gauged. The absorbance was measured at 448 nm using ether-ketone as a blank and the values were reported as µg/100 g of carotenoids, on fresh weight (FW).

2.10 Sensory analysis

An affective sensory analysis was applied as recommended by Pedrero & Pangborn [26], using an evaluation format with an unstructured scale with the participation of 30 untrained judges.

2.11 Statistical analysis

The data obtained from each variable were expressed as the mean ± standard deviation (n = 3) and were analyzed using the Prisma program (GrapPad®. Prism 8, USA), under a one-factor design.

3. Results and discussion

3.1 Physicochemical and physiological analysis

3.1.1 Total soluble solids

The analysis of the total soluble solids (TSS) (Table 1) carried out for the absolute control fruits showed an initial value of 8.33 TSS and during the storage increased until reaching day 8 and reporting 29.55 TSS. Similar values were found in control fruits at 13 ºC on day 11, reaching 26.85 TSS. The fruits treated with the different concentrations of 1-MCP

show statistically similar values, starting with the treatments with 300 nL/L, 26.68 TSS was found, in 600 nL/L 29.3 TSS and finally for 1000 nL/L 28.43 was quantified of TSS. These results can be compared to those found in "Kent" mango by Osuna-García et al. [27] where they did not find statistically significant differences ($p < 0.05$) in TSS, in fruits treated with different concentrations of 1-MCP (100, 200, 300, 600 and 900 nL/L). However, effect observed in jackfruit is due to the fact that the application of 1-MCP promotes a positive effect for the expression of phosphorylase, causing the degradation of starch and an increase in TSS [28].

Table 1. Physicochemical analysis of different concentrations of 1-MCP during storage in jackfruit (FW).

Storage days	Control		1-MCP		
	25 ºC	13 ºC	300 nL/L 13 ºC	600 nL/L 13 ºC	1000 nL/L 13 ºC
			Total soluble solids (ºBx)		
1	8.33±1.53^{a}	8.3±0.14^{a}	8.3±0.14^{a}	8.3±0.14^{a}	8.3±0.14^{a}
3	20.98±0.95^{a}	13.33±0.05^{b}	10.9±0.61^{c}	12.25±0.61^{bc}	12.1±0.08^{bc}
5	27.05±0.95^{a}	25±0.23^{a}	15.33±0.05^{b}	15.23±0.05^{b}	13.65±0.06^{b}
8	29.55±3.52^{a}	30.13±2.41^{a}	17.7±0.4^{b}	17.53±0.38^{b}	16.13±1.48^{b}
11		26.85±1.12^{b}	18.98±1.88^{c}	20.2±1.85^{c}	18.35±2.14^{c}
14			20.08±2.34^{b}	17.08±1.36^{c}	20.7±1.72^{b}
17			26.68±1.31^{b}	27.6±0.48^{b}	24.68±0.34^{b}
18				29.3±1.34^{b}	28.43±0.81^{b}
			Titratable acid (%)		
1	0.17±0.05^{a}	0.17±0.05^{a}	0.17±0.05^{a}	0.17±0.05^{a}	0.17±0.05^{a}
3	0.45±0.13^{a}	0.28±0.02^{b}	0.23±0.04^{b}	0.3±0.07^{b}	0.3±0.05^{b}
5	0.32±0.06^{a}	0.51±0.12^{b}	0.33±0.08^{a}	0.28±0^{a}	0.31±0.03^{a}
8	0.25±0.06^{a}	0.33±0.04^{a}	0.32±0.09^{a}	0.33±0.07^{a}	0.33±0.05^{a}
11		0.33±0.03^{b}	0.32±0.09^{b}	0.36±0.09^{b}	0.34±0.03^{b}
14			0.27±0.04^{b}	0.34±0.03^{b}	0.3±0.07^{b}
17			0.55±0.11^{b}	0.5±0.09^{b}	0.51±0.09^{b}
18				0.46±0.1^{b}	0.41±0.06^{b}
			pH		
1	5.88±0.15^{a}	5.88±0.15^{a}	5.88±0.15^{a}	5.88±0.15^{a}	5.88±0.15^{a}
3	4.73±0.07^{a}	4.81±0.05^{a}	5.38±0.3^{b}	5.18±0.05^{b}	5.19±0.1^{b}
5	4.83±0.05^{a}	4.47±0.21^{b}	5.16±0.06^{c}	5.09±0.07^{c}	5.04±0.05^{c}
8	5.46±0.29^{a}	4.9±0.08^{b}	5.1±0.23^{bc}	5.28±0.02^{c}	5.22±0.1^{c}
11		5.17±0.03^{b}	5.29±0.21^{b}	4.94±0.16^{c}	5.34±0.15^{b}
14			5.42±0.06^{b}	5.3±0.18^{b}	5.06±0.08^{c}
17			4.99±0.16^{b}	4.81±0.05^{b}	
18				5.14±0.02^{b}	5.19±0.03^{b}
			Peel Firmness (N)		
1	300.68±34.36^{a}	294.34±30.7^{a}	294.34±30.7^{a}	294.34±30.7^{a}	294.34±30.7^{a}
3	298.96±32.06^{a}	340.41±24.46^{ac}	328.21±39.18^{ac}	354.22±60.34^{ac}	367.83±46.96^{bc}
5	266.49±35.68^{a}	334.59±67.56^{b}	364.54±59.55^{b}	363.36±45.65^{b}	347.45±39.7^{b}
8	238.68±23.8^{a}	296.1±32.84^{ac}	373.51±39.18^{b}	333.43±44.69^{bc}	349.07±37.94^{bc}

11		234.83±33.48^{b}	365.91±51.05^{c}	357.94±33.78^{c}	338.96±17.72^{c}
14			363.47±54.86^{b}	355.89±34.23^{b}	355.9±34.21^{b}
17			282.15±18.76^{b}	316.42±39.07^{b}	352.29±78.15^{b}
18				300.33±31.34^{b}	255.13±26.52^{b}
			Bulbs Firmness (N)		
1	16.91±4.16^{a}	16.91±4.16^{a}	16.91±4.16^{a}	16.91±4.16^{a}	16.91±4.16^{a}
3	11.92±1.77^{a}	22.79±3.67^{b}	33.02±3.82^{c}	26.59±4.16^{bc}	26.91±5.46^{bc}
5	7.22±2.51^{a}	13.16±1.71^{b}	30.33±2.74^{c}	27.34±3.06^{c}	27.08±6.3^{c}
8	6±2.6^{a}	5.87±1.17^{a}	20.89±2.46^{b}	24.18±6.68^{b}	21.68±5.52^{b}
11		5.62±2.95^{b}	17.67±8.01^{c}	14.62±2.28^{c}	18.9±6.17^{c}
14			14.68±2.92^{b}	14.85±2.13^{b}	14.8±2.25^{b}
17			8.53±1.15^{b}	11.79±2.76^{b}	8.52±2.33^{b}
18				4.91±2.57^{a}	4.19±1.34^{a}
			Peel Color (ºHue)		
1	106.25±1.52^{a}	106.69±0.81^{a}	106.69±0.81^{a}	106.69±0.81^{a}	106.69±0.81^{a}
3	103.47±2.44^{a}	104.37±1.67^{a}	103.1±12.94^{a}	107.41±2.26^{a}	105.57±2.31^{a}
5	98.68±5.91^{a}	102.27±3.4^{ab}	107.1±1.37^{ab}	107.39±1.48^{ab}	110.74±15.36^{b}
8	84.45±8.33^{a}	94.88±5.61^{ac}	107.16±1.88^{b}	106.54±3.36^{b}	102.18±3.71^{bc}
11		85.89±6.9^{b}	105.18±3.68^{c}	96.25±32.67^{bc}	103.86±1.98^{c}
14			96.23±3.07^{b}	92.4±3.53^{b}	94.17±1.31^{b}
17			89.15±5.65^{b}	84.36±4.65^{b}	86.77±1.56^{b}
18				87.83±2.26^{b}	88.87±1.28^{b}
			Bulbs Color (ºHue)		
1	80.5±10.73^{a}	80.5±10.73^{a}	80.5±10.73^{a}	80.5±10.73^{a}	80.5±10.73^{a}
3	73±7.71^{a}	70.04±2.16^{a}	74.41±3.17^{a}	69.41±1.16^{a}	70.47±2.61^{a}
5	64.86±2.62^{a}	70.79±2.03^{b}	71.14±2.42^{b}	72.93±1.46^{b}	74.14±1.62^{b}
8	64.06±4.48^{a}	68.25±1.59^{ac}	74.32±0.96^{b}	70.76±1.22^{bc}	74.74±2.49^{b}
11		63.5±4.17^{b}	73.3±0.49^{c}	72.48±0.85^{c}	72.35±2.26^{c}
14			68.35±2.08^{b}	70.03±1.57^{b}	70.46±2.78^{b}
17			67.74±3.29^{b}	68.17±2.38^{b}	64.84±3.37^{b}
18				64.86±1.67^{b}	62.76±2.06^{b}

The day of the refrigeration temperature change was on day 5, at a temperature of 25 ° C. The values are presented with their mean ± standard deviation (n = 3). Lower case letters represent the effect of days in storage. Different letters indicate a significant difference (α = 0.05).

3.1.2 Titratable acid

The titratable acid (TA) values obtained in control fruits and fruit treated (Table 1), showed fluctuations throughout their storage. No significant effect was found between the different concentrations of 1-MCP applied and the control fruits. The initial values of the absolute control fruits and 13 ºC were 0.17, culminating their shelf life with 0.25 and 0.33 respectively. In the fruits treated with 1-MCP at 300 nL/L, 0.55 was found, those treated with 600 nL/L 0.46 and those of 1000 nL/L 0.41, at the end of the storage time. Similar values are reported by Mata-Montes de Oca et al. [5] for jackfruit treated with 1-MCP (100 and 300 nL/L) where at the end of the shelf life of the fruits there were no significant differences ($p < 0.05$) between the values of their control and treated fruits. This behavior is closely related to the respiration of the fruit; the parameters of TA and pH are also related

to each other, so the observed variability may due to the fact that the organic acids contained in the fruit are degrading as the fruit respiration [29].

3.1.3 pH

These results maintain a relationship with the TA data (Table 1), since they did not present significant differences ($p < 0.05$) between the different concentrations of 1-MCP applied and the control fruits. The initial value found for the absolute control fruits and 13 ºC was 5.88. The final values are statistically similar due to the fact that in the absolute control a pH of 5.46 was observed and the fruits subjected to marketing simulation at 13 ºC presented a pH of 5.17. In the case of jackfruits treated with 1-MCP, showed pH values in their first concentration (300 nL/L) of 4.99, 5.14 for the second concentration (600 nL/L) and 5.19 for 1000 nL/L. Vargas-Torres et al. [30] report for jackfruit bulbs treated with 1-MCP at 1000 nL/L stored at 5 ºC that they did not present significant differences ($p < 0.05$) in the pH values with respect to the control. This variability in the pH values that increase or decrease are dependent on the metabolism of each fruit species [31], which explains the variability of the results found.

3.1.4 Peel Firmness

The firmness of the fruit peel (Table 1) gradually begins to decrease over the days of storage. However, the fruits treated with 1-MCP managed to exercise control over the loss of this parameter since values higher than those of the initial day were observed, indicating that the loss of firmness in treated fruits is minimal. The control fruits showed 238.68 N for the absolute control and 234.83 N in the control at 13 ºC on their last day of storage. The 1-MCP treatments presented 282.15 N in 300 nL/L, approaching the initial firmness value; the concentration of 600 nL/L obtained values of 300.33 N and finally 255.13 N in 1000 nL/L. Similar values were found in the research of Mata-Montes de Oca et al. [5] in jackfruit treated with 1-MCP (100 and 300 nL/L), showing initial values of 340 N and 60 N on the final day in the 300 nL/L treatments. The variation in firmness can be explained because the degradation process of cell wall polymers involves a coordinated action of cell wall modifying enzymes and proteins such as polygalacturonase (EC 3.2.1.15), pectinmethylesterase (EC 2.4.1.207), β-galactosidase (EC 3.2.1.23), xyloglucan endotransglycosylase (EC 2.4.1.207) and expansins [32], and 1-MCP by exerting a control on the expression of genes of these enzymes, the values are maintained or decreased moderately, behavior observed in table 1.

3.1.5 Bulbs Firmness

Compared with the results of firmness in peel (Table 1), firmness in bulbs in all treatments had a decrease. The initial firmness values indicated 16.91 N for the absolute control and 13 ºC. The 1-MCP treatments at its different concentrations did not show significant differences among themselves ($p < 0.05$), it was only possible to observe how 1-MCP delayed the decrease in the firmness value, however, similar values were obtained on the final days to those of the controls. For the treatments stored with 1-MCP at 300 nL / L, 600 nL/L and 1000 nL/L values of 8.53, 4.91 and 4.19 N were registered respectively, however, this same behavior does not occur in all fruits. In the research by Razzaq et al. [12] where they worked with "Kensington pride" mango using 1-MCP at 10 µL/L reported significant differences ($p < 0.05$) between their treated and control fruits. Otherwise, Amornputti et al. [33] report that the firmness of the durian pulp treated with 1-MCP at 500 nL/L subjected to marketing simulation did not have significant differences ($p < 0.05$) with its control fruit stored at 25ºC. So, it can be interpreted, that

the behavior of 1-MCP will depend of the nature of the fruit. In general, pulp softening is one of the most important parameters that define the quality of fruits in storage after harvest, the effect of 1-MCP is attributed to the control of gene expression for the production of enzymes that hydrolyze starch into sugars [34].

3.1.6 Peel Color

The degradation of chlorophyll in the fruits treated with 1-MCP (Table 1) was only delayed, because at the end of the shelf life of the fruits they presented the same tones as the control fruits, this is a highly attractive result, since achieves a longer shelf life, presenting desirable peel color variations. The initial shades that the control fruits presented were around 106.25 º Hue, reflecting a bright green color. At the end of the shelf life the fruits reported ºHue of 84.45 for the absolute control and for 13 ºC values of 85.89, developing an olive green color.

As mentioned above, the fruits treated with 1-MCP only delayed the loss of color in the peel, since the fruits showed values of 89.15, 87.83 and 88.87 ºHue in the order from lowest to highest concentration of 1-MCP. Data obtained in the investigation of Osuna-García et al. [27] for avocado fruits treated with 200 nL/L of 1-MCP with a marketing simulation of 12 days at 22 ºC and 6 days at, 6ºC, shown differences in the loss of the green coloration of the avocado peel. Although ethylene is responsible for inducing the degradation of chlorophylls, it is also known to affect the functionality of chloroplasts, due to the decrease in the fluorescence of chlorophyll [35]. The mechanism by which 1-MCP delays the degradation of chlorophylls is related to the mitigation of expression of genes that encode enzymes that degrade chlorophylls [9].

3.1.7 Bulbs Color

The absolute control and control fruits at 13 ºC (Table 1) had initial values of 80.5ºHue showing a bright yellow color and ended their shelf life with values of 64.06 and 63.5ºHue respectively, denoting saffron yellow tones. The fruits that were treated with 1-MCP presented similar values to those of the control of 13 ºC, because at the end of the shelf life of the fruits at 17 and 21 days values of 67.74 ºHue were reported in 300 nL/L, 64.86 ºHue for 600 nL/L and 62.76 ºHue for the 1000 nL/L treatment. In other investigations similar results have been found, in plums treated with 500 nL/L of 1-MCP and stored at 20 ºC, there were no significant differences ($p < 0.05$) with respect to the control fruits [36]. In this sense, it has been reported that the phytoene synthase and phytoene desaturase genes are regulated by ethylene, because they are found cascading above the signaling to generate phytoene and phytofluene, however, β-carotene, ξ-carotene desaturase they are independent, therefore the staining under the control of 1-MCP can occur without interruptions [37].

Overall, the application of 1-MCP allows the physicochemical characteristics to be equal to those fruits that are not treated, this being very important since it indicates that the quality of the fruits is not affected by this technology.

3.1.8 Respiration and ethylene production rate

The RR values obtained (Figure 1A) for the absolute control fruits presented fluctuations throughout their storage, reaching the end of their shelf life on day 8; in addition, the climacteric peak was presented on day 3 with 103.49 mL of $CO_2 \bullet kg^{-1} \bullet h^{-1}$. Moreover, the control fruits stored at 13 ºC presented lower values compared to those obtained by the absolute control and it is on day 7 where the climacteric peak occurs with 179.22 mL of

$CO_2 \bullet kg^{-1} \bullet h^{-1}$ (Figure 1 B) Later, the CO2 values did not decrease. The fruits treated with 300 and 600 nL/L coincide on day 13 of storage with the generation of the climacteric peak, reporting 179.22 and 241.86 mL of $CO_2 \bullet kg^{-1} \bullet h^{-1}$ respectively. Interestingly, the treatment with 1-MCP at 600 managed to prolong the shelf life of the fruits up to 21 days and the 300 nL/L treatment only 17.

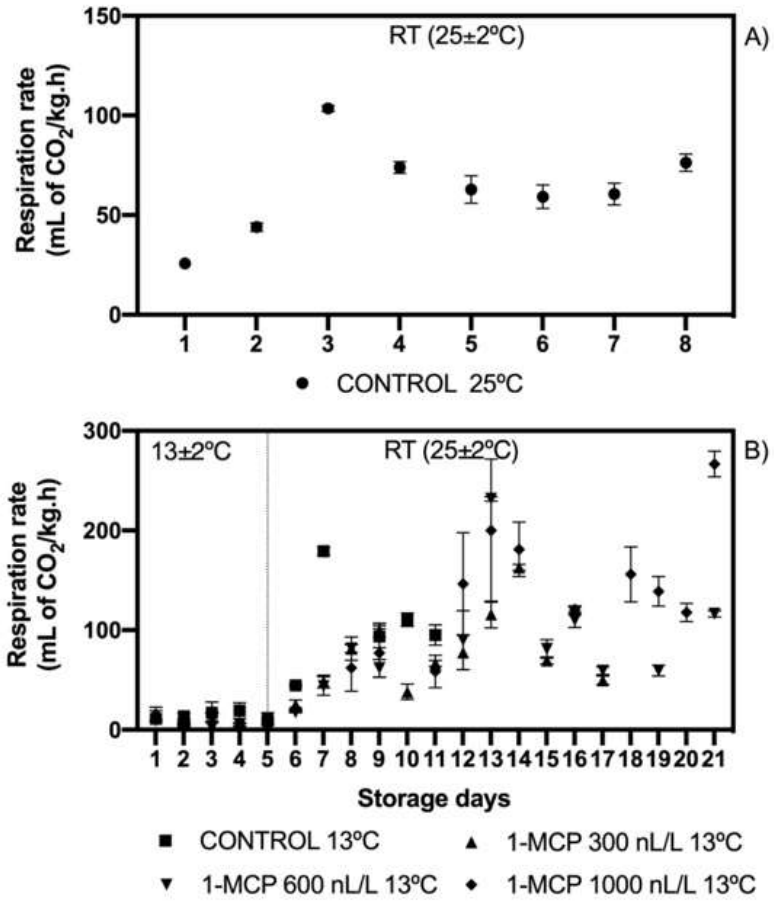

Figure 1. Respiration rate of jackfruit treated with 1-MCP at different concentrations and stored at temperatures of 25 ± 2 ºC (A) and 13 ± 2 ºC (B). The dotted line indicates the marketing simulation day, the data are presented as means ± standard deviation.

Mata-Montes de Oca et al. [5] reported similar behavior for jackfruit treated with 100 and 300 nL/L of 1-MCP stored at 20 ºC where a significant reduction in RR was obtained. A similar behavior is also reported by Ortiz-Franco et al. [38] in "Ataulfo" mango fruits with 0, 300 and 600 nL / L of 1-MCP applying a marketing simulation (stored for 20 days at 13 ± 1 ºC and later at 25 ± 2 ºC) showing that by increasing the storage temperature in the simulation, climacteric peaks are higher. The action of 1-MCP on respiration lies in the ethylene biosynthesis pathway, since 1-MCP as an antagonist controls the production of ethylene, a mechanism that is carried out by inhibiting the expression of the enzyme 1-aminocyclopropane- 1-carboxylate synthase (ACC synthase) and the enzyme 1-aminocyclopropane-1-carboxylate oxidase (ACC oxidase), the latter being dependent on oxygen, therefore, the inhibition of ethylene

production influences the low consumption of oxygen and low production of CO_2 [39].

The maximum peak of EP produced by the fruits of absolute control (Figure 2 A) was found on the third day of storage with 45.55 $\mu L \cdot kg^{-1} \cdot h^{-1}$ coinciding with the climacteric peak. Control fruits stored at 13 ºC (Figure 2 B) show significant differences ($p < 0.05$) with respect to the absolute control, since they showed their maximum ethylene peak on day 7 of storage with 52.34 $\mu L \cdot kg^{-1} \cdot h^{-1}$. The fruits treated with 1-MCP on average show the maximum peak of EP 10 days after control fruits (Figure 2 B). The fruits treated with 300 nL/L present their maximum peak with 51.53 $\mu L \cdot kg^{-1} \cdot h^{-1}$ on day 16, on day 15 those of 600 nL/L with 34.06 $\mu L \cdot kg^{-1} \cdot h^{-1}$ and for fruits with 1000 nL/L at 18 days of storage with 81.14 $\mu L \cdot kg^{-1} \cdot h^{-1}$. The results reported by Mata-Montes De Oca et al. [5] were similar, since the application of 1-MCP managed to delay the appearance of the maximum ethylene peak by 15 days, and in the case of the present investigation, together with a marketing simulation, there is an average of 14 control days at peak ethylene production. The effect that 1-MCP exerts on the control of ethylene is due to the fact that it affects the autocatalytic synthesis of ethylene by reducing the expression of genes that code for the enzymes 1-aminocyclopropane-1-carboxylic acid (ACC) synthase and ACC oxidase [9].

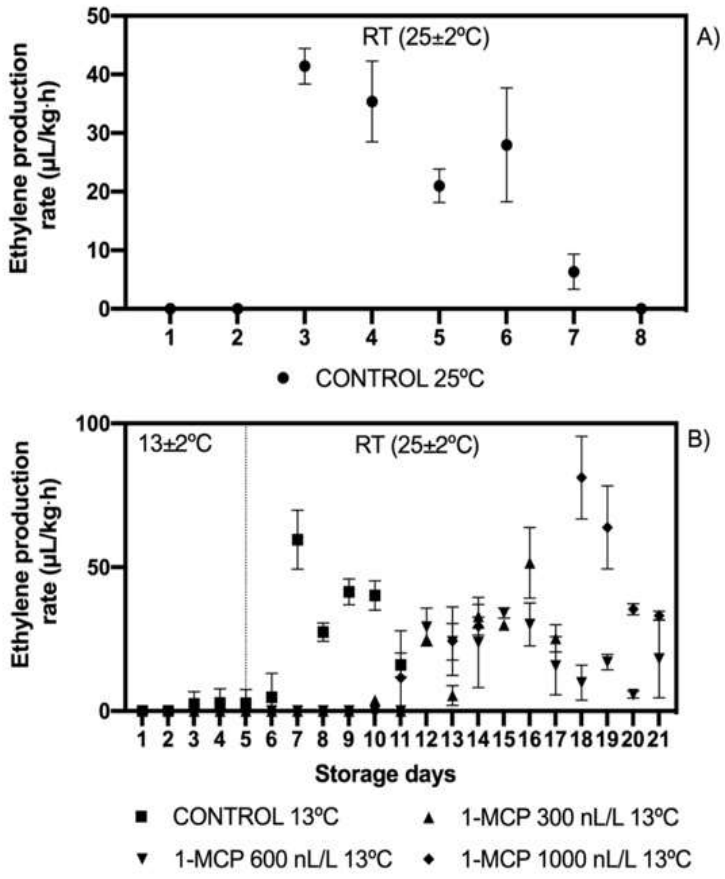

Figure 2. Ethylene production rate of jackfruit treated with 1-MCP at different concentrations and stored at temperatures of 25 ± 2 ºC (A) and 13 ± 2 ºC (B). The dotted line indicates the marketing simulation day, the data are presented as means ± standard deviation.

3.1.9 Physiological weight loss

In the analysis of physiological weight loss (FWL) data, an exponential weight loss can be observed in all the fruits used in this experiment. Taking as a reference, absolute control fruit (Figure 3 A) for each day of storage that elapses, it loses more than 1% of the weight, reaching up to 8 days of shelf life with a FWL of 11.96%. The control fruits submitted to marketing simulation (13 ºC) showed a slow and moderate loss, showing values of 7.61% on day 8 (Figure 3 B). For the fruits treated with 1-MCP (Figure 3 B), FWL values were obtained below both controls, averaging 7.2%, highlighting the concentration of 600 nL / L with 6.93% on day 8 of storage. In the research carried out by Tovar et al. [40] using soursop fruits treated with 1-MCP (1000 nL/L) and stored at 13 ºC, a decrease of 22.6% of FWL was reported compared to the control fruits. The low FWL in fruits treated with 1-MCP in this research is related to the decrease in RR and EP, resulting in a decrease in gas exchange in the fruit [41].

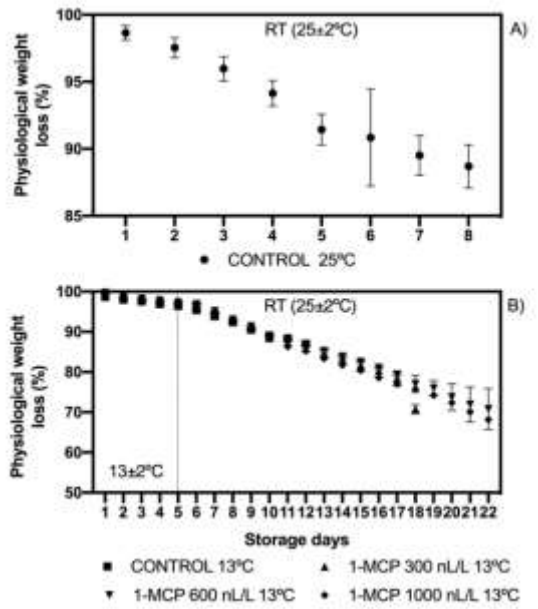

Figure 3. Physiological weight loss of jackfruit treated with 1-MCP at different concentrations and stored at temperatures of 25 ± 2 ºC (A) and 13 ± 2 ºC (B). The dotted line indicates the marketing simulation day, the data are presented as means ± standard deviation.

The results obtained from the physiological analyzes as well as the physicochemical ones allow us to observe that the treatments with 1-MCP manage to control the ripening processes of the fruits. In the case of physiological processes, significant control is achieved in all of these, prolonging the shelf life of the fruits until 21 days of storage. Figure 4 shows the appearance of the treated fruit at the end of the storage life of the control at 25 ºC, day 8.

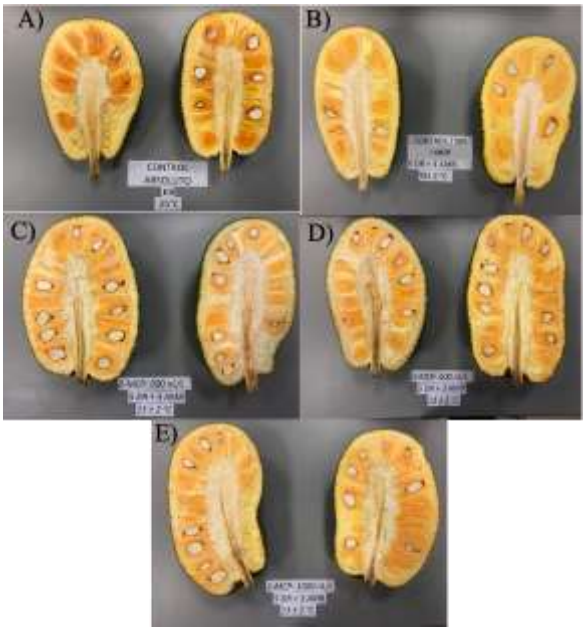

Figure 4. Final day of storage of control at 25ºC (A) vs. control at 13ºC (B) and fruits treated with 1-MCP 300 nL/L (C), 600 nL/L (D) and 1000 nL/L (E).

3.2 Antioxidant capacity, total soluble phenols, vitamin C, total carotenoids and sensory evaluation

3.2.1 Antioxidant capacity by FRAP

The antioxidant capacity is presented by the FRAP method (Table 2) where fluctuations in the results of control fruits could be observed. In the absolute control, the antioxidant capacity decreased on the last day of storage (from 4.35 to 2.84 mmol TE/g FW). In the control bulbs at 13 ºC, the antioxidant

capacity kept constantly decreasing until reaching 3.28 mmol TE/g FW. The fruits treated with 600 nL/L of 1-MCP presented lower values than the controls, because they reported a decrease in the antioxidant capacity between the first and last day (4.35 to 1.29 μmol TE/g FW). Liu et al. [42] reported in peaches without treatment (control) an increase in antioxidant capacity at the end of their shelf life stored at 20 ºC, however, when applying a concentration of 5000 nL/L of 1-MCP, this parameter decreased. The same behavior was found in this study in the bulbs with a concentration of 600 nL/L. The variability of the results obtained in this determination can be related to the values obtained from TSP. One of the reasons for this behavior is due to the fact that 1-MCP can influence the antioxidant capacity of a fruit during the ripening period, generating changes in the TSP content [43]. However, even so, the results obtained are important.

3.2.2 Radical scavenging by DPPH

In the antioxidant capacity by the DPPH method (Table 2), variability could be observed in the results of the control fruits and those treated with 1-MCP at 600 nL/L. The absolute control presented a decrease in DPPH activity with respect to the first day of storage (3.89 to 2.87 mmol TE/g FW), in the same way, the control at 13 ºC had a decrease (10.85 to 9.82 mmol TE / g FW). In the 600 nL/L 1-MCP treatments, the DPPH antioxidant capacity did not have significant differences ($p < 0.05$) between the first and last days (3.89 to 3.94 mmol TE/g FW). Saxena et al. [44] reported a decrease in DPPH activity in control bulbs, which was similar to what happened with controls at 13 ºC. The decrease in DPPH radical scavenging activity can be attributed to a decrease in the concentrations of phenols, ascorbic acid and flavonoids during fruit storage, since the antioxidant capacity is related to the presence of these compounds [45].

Table 2. Antioxidant capacity and total soluble phenols in jackfruit fruits (FW).

Storage days	Control		1-MCP
	25 ºC	13 ºC	600 nL/L 13 ºC
	FRAP (mmol TE/g)		
1	4.35±0.61[a]	3.77±0.92[a]	4.35±0.61[a]
3	6.51±4.35[a]	4.30±0.22[a]	1.25±0.09[b]
5	6.16±0.54[a]	5.21±0.53[a]	1.62±0.23[b]
8	2.84±0.36[a]	5.03±0.54[a]	3.59±0.40[a]
11		3.28±2.82[a]	1.26±0.34[a]
14			1.95±0.12[a]
17			3.23±0.27[a]
21			1.29±0.24[a]
	DPPH (mmol TE/g)		
1	3.89±0.30a	10.85±0.24b	3.89±0.30a
3	2.69±0.39a	3.75±0.09b	4.23±0.39b
5	3.97±0.09a	9.07±0.31b	5.34±0.81c
8	2.87±0.40a	9.97±0.04b	4.15±0.36c
11		9.82±0.12a	4.05±0.49b
14			3.86±0.43a

17			2.32±0.78a
21			3.94±0.12a
	Total Soluble Phenols (mg GAE/100g)		
1	1168.27±60.36[a]	1292.91±216.13[a]	1168.27±60.36[a]
3	1313.65±94.04[a]	1121.62±30.8[b]	1125.08±5.31[b]
5	1685.73±88.50[a]	1440.11±78.27[b]	1188.24±115.79[c]
8	1174.864±44.855[a]	1424.104±59.04[b]	1249.53±66.59[a]
11		1453.56±129.09[a]	1091.79±36.73[b]
14			1320.48±137.34[a]
17			1228.39±33.04[a]
21			1141.18±53.32[a]

The day of the refrigeration temperature change was on day 5, at a temperature of 25 ° C. The values are presented with their mean ± standard deviation (n = 3). Lower case letters represent the effect of days in storage. Different letters indicate a significant difference (α = 0.05).

3.2.3 Total soluble phenols

Variable behavior could be observed in the results of the control at 25 ºC (Table 2) and the control at 13 ºC, as well as in the treatment with 600 nL/L of 1-MCP. In the absolute control, an increase in this parameter was reported between the last day of storage with respect to the initial day (1168.27 to 1174.86 mg GAE/100g FW). The control at 13 ºC did not present significant differences ($p < 0.05$) with respect to the initial and final day (1292.91 to 1453.56 mg GAE/100g FW). In the case of the fruits treated with 1-MCP, there were no significant differences ($p < 0.05$) in the TSP content between the first and last day (1168.27 to 1141.18 mg GAE/100g FW). Shafiq et al. [46] reported in jackfruit bulbs (untreated) from Lahore, Pakistan, a TSP content of 239.87 mg GAE/100g in the mature state of consumption. Jagtap et al. [47] reported in control jackfruit bulbs (without treatment with storage at -20 ºC) from Ghats, India a content of 21 mg GAE/100g. Vargas-Torres et al. [30] reported values close to 900 mg GAE/100g in jackfruit bulbs treated with 1000 nL/L of 1-MCP. When comparing these values with those obtained in this study, it was found that these were higher than those from the authors. The increase in TSP observed in this study in the bulbs treated with 1-MCP in the first 8 days of storage may be due to the fact that the fruit ripening process promotes the synthesis of polyphenols [30]. Furthermore, it could be related to the potential capacity of the fruits to activate the production of defense mechanisms, such as phenolic compounds [48].

3.2.4 Vitamin C

The statistical analysis for the values obtained for the content of ascorbic acid (Table 3) did not show significant differences between the control fruits and those treated with 1-MCP. In the absolute control bulbs, it decreased considerably from day 1 to 8 (19.80 to 1.36 mg AA/g FW), the control bulbs of 13 ºC did not show any effect in delaying the loss of these values, in addition the lowest value of all the fruits evaluated (19.80 to 0.90 mg AA/g FW). Treatment with 1-MCP at 600 nL/L prolonged the shelf life of the bulbs up to 21 days and a higher prevalence was observed in the content of ascorbic acid (19.80 to 2.23 mg AA/g FW) compared to the controls. Xu et al. [49] reported higher content of ascorbic acid in kiwis treated with 1-MCP (0.9 µl/L) on the last day of storage compared to the control without treatment (1.02 to 1.46 mg AA/kg FW), otherwise than those reported by Du et al. [50] in green chilies with 1 µL/L the parameter decreased

significantly (0.85 to 0.72 g/kg FW); which coincides with the results obtained.

Table 3. Quantification of vitamin C and carotenoids in jackfruit bulbs (FW).

Storage days	Control		1-MCP
	25 ºC	13 ºC	600 nL/L 13 ºC
	Vitamin C (mg AA/ g)		
1	19.80±4.00[a]	19.80±4.00[a]	19.80±4.00[a]
5		4.29±0.41[a]	6.78±0.96[a]
8	1.36±0.21[a]		
11		0.90±0.03[a]	
14			
17			
21			2.23±0.42[a]
	Carotenoids (µg/100g)		
1	3927.10±859.74[a]	3927.10±859.74[a]	3927.10±859.74[a]
5	3833.60±212.64[a]	5684.83±344.115[b]	7399.02±159.28[c]
8	8902.30±533.18[a]		
11		5634.84±212.97[a]	
14			
17			
21			6651.27±459.39[a]

The day of the refrigeration temperature change was on day 5, at a temperature of 25 ° C. The values are presented with their mean ± standard deviation (n = 3). Lower case letters represent the effect of days in storage. Different letters indicate a significant difference (α = 0.05).

It has been reported that 1-MCP has significant effects on the delay of the maturation processes, generating a response in the content of ascorbic acid preserving it for longer times [51]. Wang et al. [52] mention that 1-MCP, in addition to delaying the maturation process, protects the reactive oxygen species (ROS) scavenger system, which is related to the metabolism of ascorbic acid, since it is a critical component in the processes antioxidants of plant cells and can interact enzymatically and non-enzymatically with ROS [53].

3.2.5 Total carotenoids

In the quantification of total carotenoids (TC), fluctuations (Table 3) could be observed in the controls, as well as in the fruits treated with 600 nL/L of 1-MCP. In the absolute control, significant differences were found ($p < 0.05$) between the first and last day of storage (3927.10 to 8902.30 µg/100g FW). The control at 13 ºC increased the content of TC by 5634.84 µg/100g FW on the last day storage. In the fruits treated with 1-MCP at 600 nL/L, an increase in the TC content from 3927.10 to 6651.27 µg/100g FW was observed from the first to the last day. Karunakaran et al. [54] reported for jackfruit 'Siddu' a content of 4430 µg/100g of TC (FW), likewise, De-Faira et al. [55] reported 107.94 µg/100g (FW) in jackfruit from unspecified work material, both authors carried out the evaluation at consumption maturity. No reports of TC were found in whole jackfruit with the application of 1-

MCP, however, Wisutiamonkul et al. [56] reported in Durian an increase from 22 to 33 µg/100g (FW) in TC when applying 500 nL L of 1-MCP, which coincides with the effect that occurred in the jackfruit bulbs treated with this compound. Carotenoids have been extensively studied in various plant sources, however, the results of the effect of 1-MCP on the levels of this compound have not been consistent in many horticultural products [57]. Marty et al. [37] reported in their investigation of 1-MCP for the regulation of ethylene and its relationship with the accumulation of carotenoids in peaches that 1-MCP managed to inhibit ethylene production, however, the effects on pigment accumulation were minimal. These results were similar to those of this investigation, since the production of TC in the bulbs occurred according to the days of storage.

3.2.6 Sensory evaluation

Once the results of the sensory test were obtained, the average of acceptance among the judges who evaluated was calculated. The fruits used were the absolute control and the fruits treated with 1-MCP at 600 nL/L, all on their last day of shelf life.

During the ripening process of the fruits, the photosynthetic apparatus is degraded and the thylakoid membrane ruptures, in this way the chloroplasts become chromoplasts; subsequently, carotenoids are generated, giving the fruit red, yellow or orange colors [58]. In the color analysis, a greater preference could be observed in the bulbs treated with 1-MCP, showing a mean acceptance 9.53±2.67. 1-MCP does not affect carotenoid generation, because pigment synthesis is not affected by ethylene receptor blockade [59].

Ethylene production is highly related to the generation of volatile compounds characteristic of jackfruit bulbs. However, in the odor evaluation it was observed that the highest degree of acceptance occurred in the fruits treated with 1-MCP at 600 nL/L with a mean 8.8±3.01. The control that 1-MCP exerts over ethylene affects its dependent maturation processes, including the production of volatile aromatic compounds. However, the development of aromatic compounds in fruits treated with 1-MCP depends on the concentration at which this technology is applied [60]. The flavor of a fruit is made up of various volatile compounds such as aldehydes, esters, alcohols, and non-volatile compounds such as organic acids, sugars and various amino acids [61] [62] [63]. The values obtained from the flavor analysis showed that the bulbs from the fruits treated with 1-MCP at 600 nL/L were the ones with the highest acceptance with a mean of 9.33±2.75. TSS and TA are related to the general sensory quality of the fruit [64], and since 1-MCP does not have interference on synthesis or degradation, this parameter is not affected.

The softening of the fruit pulp is mainly attributed to the hydrolysis of sugars and starches in the fruit, leading to a degradation of the cell wall by pectin, a product of maturation [34]. The sensory analysis of texture in the evaluated fruits showed that the bulbs of the different samples had the same degree of acceptance with a mean of 8.4±3.54 and 8.4±2.84 respectively. It has been mentioned previously that 1-MCP prevents or delays softening, which is closely related to ethylene production [65].

4. Conclusions

The physiological and physicochemical parameters showed significant differences *(p* <0.05) between the control fruits and the treated fruits. A delay effect in maturation was observed in the fruits treated with 1-MCP. The concentration at 600 nL/L presented the most convenient results for the

marketing chain, increasing the useful life of the fruits to 22 days.

The analysis of antioxidant capacity, TSP, vitamin C and carotenoids showed statistically significant differences (p <0.05) between the control fruits and the fruits treated with 1-MCP at 600 nL/L. The sensory evaluation showed that the application of 1-MCP at 600 nL/L does not affect the sensory parameters of the bulbs, a greater preference for treated fruits was even observed when compared to controls.

The results obtained are of the utmost importance since they allow us to consider this technology as an excellent alternative for the treatment of the fruit that can give producers a longer time to place the fruits for sale with quality characteristics and thus obtain a better price.

5. Acknowledgments

The authors thank CONACYT for financing through the SAGARPA-CONACYT project (code no. 291472). Likewise, the authors thank CONACYT (Mexico) for the scholarship awarded to David Antonio Morelos Flores (scholarship number: 287441) and the Tecnológico Nacional de Mexico / Instituto Tecnológico de Tepic for the support provided for the development of this project.

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