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Ripening and postharvest quality of guavas treated with plant regulators

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ABSTRACT

Purpose: Guava is a tropical and subtropical fruit recognized for its nutritional quality. However, o it is a climacteric fruit, that is, with high respiratory activity and ethylene production during ripening, it becomes extremely perishable under environmental conditions, requiring conservation technologies that allow its commercialization without compromising post-harvest quality during storage. Therefore, the objective of this study was to evaluate the effect of plant regulators (gibberellic acid – GA_3 and ethephon) on ripening and quality preservation during storage at room temperature. **Research method**: Physiologically mature guavas (stage 3) were harvested in a commercial orchard, selected and sanitized in a chlorinated solution, and immersed in the following solutions: distilled water (control), GA_3, and ethephon (150 $mg.L^{-1}$) for a period of 10 minutes and subsequently stored under room temperature conditions (28 ± 2 ºC) for 12 days with physical-chemical quality assessments carried out every three days. **Findings**: Treatment with GA_3 provided lower values of mass loss, soluble solids, titratable acidity, and total sugars, in addition to higher values of firmness and vitamin C of the fruits analyzed, while the opposite effect was observed in guavas treated with ethephon. In general, the postharvest application of GA_3 delays ripening, making it possible to extend marketing for up to 9 days, on the other hand, ethephon anticipates ripening, making them fully ripe after 6 days of storage. **Research limitations**: There were no limitations to carrying out this research. **Originality/Value**: This research's results support staggering the ripening of guava over time, allowing the fruit's commercialization period to be extended.

INTRODUCTION

Guava (*Psidium guajava* L.) is a tropical and subtropical fruit belonging to the Myrtaceae family and recognized for its high nutritional content, such as minerals (Ca, Mg, K, P), vitamins (A, thiamine, riboflavin), bioactive compounds (phenolic, flavonoids, ascorbic acid), pectin and fibers, among others (Shao et al., 2023). However, all this nutritional potential is limited by the postharvest physiology of the fruit, which is classified a climacteric fruit, and has high perishability, and limits its commercialization potential.

Knowledge of fruit physiology is important, as it provides technical support for extending storage time without altering their physical, sensory, and nutritional characteristics (Karagiannis, 2024). In the case of guava, loss of quality is generally associated with immediate softening and color change from green to yellow during postharvest storage (Anjum et al., 2020; Supa et al., 2024). Therefore, postharvest technologies such as the application of plant regulators must be adopted to increase storage potential and preserve quality.

Studies have shown that the application of plant regulators postharvest can reduce physiological disorders, improve quality, increase shelf life, and standardize ripening (Mostert et al., 2024). Gibberellins, such as gibberellic acid (GA_3), are essential plant hormones in regulating the growth and development of fruits (Kamiab et al., 2023). Recent studies have demonstrated that gibberellins are important in delaying the ripening and senescence of horticultural crops, improving internal and external quality, and resistance to stress and disease (Zhang et al., 2023). In turn, ethylene is an important regulator of various aspects of development and physiological processes: from seed dormancy to germination, fruit ripening, defense against biotic and abiotic stresses. Regarding its role in ripening, ethylene accelerates the deterioration of vegetable products resulting in a shorter shelf life (Asrey et al., 2023), but depending on management, its application can anticipate maturation allowing marketing in a short period of time.

Considering that the exogenous application of GA_3 and ethylene can delay or anticipate ripening, allowing the expansion of the supply in the commercialization of guava at different times, this study aimed to evaluate the effect of the application of these plant regulators in the standardization of ripening and maintenance of quality during storage under ambient conditions (28 ºC).

MATERIALS AND METHODS

Plant material

Physiologically ripe guavas 'Paluma' were harvested at maturity stage III with light green epicarp color (Azzolini et al., 2004) in a commercial orchard located in the municipality of Marituba, PA, Brazil at 1° 21′ 19″ South, 48° 20 ′36″ West. When harvesting, fruits free from physiological defects or affected by pests and diseases were taken into consideration. These were packed in thermal boxes and transported to the Postharvest Laboratory of the Isacta Institute, Belém, PA, Brazil.

Application of treatments and storage

In the laboratory, the fruits were washed in running water, sanitized in a chlorinated solution (150 $mg.L^{-1}$), and air-dried at room temperature (28 ºC). These were then divided into batches (75 fruits) and immersed in the following solutions: control (distilled water), GA_3 (150 $mg.L^{-1}$) Sigma Aldrich®, and ethephon (150 $mg.L^{-1}$) Ethrel® for 10 minutes, with subsequent drying under a screen nylon to drain excess liquid. The concentration of the regulators was defined after preliminary tests. After drying, the fruits (5 units) were placed in polyethylene styrofoam trays, and stored under ambient temperature conditions (28 ± 2 ºC) simulating points of sale for 12 days.

Evaluation of physical-chemical quality

Evaluations were carried out in triplicate at intervals of three days under the following aspects:

The shelf life of the fruits was measured in days from the initiation of the experiment up to 25% rotting.

Fresh mass loss determined by weighing the fruits on an analytical balance (Mars, model AS 2000, São Paulo, Brazil) at the beginning of the experiment (initial weight) and again at each evaluation period (final weight). The results were expressed as a percentage (percentage) based on the following equation (1):

$$\text{PMF (percentage)} = \text{Initial mass} - \text{Final mass} / \text{Initial mass} \times 100 \qquad (1)$$

Pulp firmness determined with a digital penetrometer (53200 TR Turoni, Italy), with an 8 mm tip, taking 2 readings on opposite sides in the region with the largest diameter of the fruits. The fruit peel was previously removed with the help of a manual peeler. The data were expressed in Newtons (N), considering the average of the two readings per fruit.

The color of the peel and pulp was determined using a colorimeter (Minolta, CR-400, Osaka, Japan), positioned in the central region of the opposite sides of the fruit to obtain the variables L*, a* and b*, which were used to calculate luminosity (L*), chromaticity (C*) and hue angle (hº), respectively (McGuire, 1992).

Soluble solid content (SSC) of the liquid obtained by pressing 10 g of pulp was determined using a digital refractometer (Alpha, Atago Co., Ltd, Japan) and the results expressed as °Brix. Titratable acidity (TA) was determined by titrating 10 g of pulp with 0.1 N NaOH, using 0.1% phenolphthalein as an indicator. The results were expressed as equivalent grams of citric acid in 100 g of pulp. The pH of the samples was measured using a pHmeter (Thermo Scientific, Orion 3 Star, USA) directly on the fruit pulp. The vitamin C (AsA) content was determined by titrating a 10 mL aliquot of the extract with 2,6-dichlorophenolindophenol. The results were expressed as mg 100 g^{-1} (AOAC, 2020).

Total sugars determined according to the methodology described by Yemn and Willis (1954). The extract was obtained by diluting 1.0 g of the pulp in 100 mL of distilled water. The samples were prepared in an ice bath, adding 150 µL of the extract, 850 µL of distilled water and 2.0 mL of 0.2% anthrone solution to a tube, followed by shaking and resting in a water bath at 100 °C for 8 minutes. The reading was carried out on a spectrophotometer at 620 nm, using glucose as a reference to obtain the standard curve and the results were expressed in g.100g-1 pulp.

Experimental design and statistical analysis

The experiment was conducted in a completely randomized design (CRD), with a factorial scheme (3×5), with PGR treatments (control, GA_3, and ethephon), and 5 evaluation times (0, 3, 6, 9, and 12 days), with three replications and five fruits composing the experimental plot. The results were analyzed using analysis of variance and presented with mean and standard deviation after Tukey's test at a 5% level of significance, with the aid of the statistical program SAS® version 9.1.

RESULTS

The shelf life of guavas was significantly affected by plant regulators. In general, the longest shelf life was observed in fruits treated with GA_3 (12 days), control (9 days), and the shortest in fruits exposed to ethephon (3 days) (Fig. 1).

There were significant effects of treatments and days of storage ($p<0.05$) on the loss of mass and firmness of 'Paluma' guavas treated with plant regulators and stored under ambient conditions (28 ± 2 ºC) for 12 days (Table 1).

There was an increase in mass loss, regardless of the treatments applied throughout the storage period. Generally, guavas treated with GA_3 showed the lowest mass losses up to the 12th day of storage (8.96%). On the other hand, fruits treated with ethephon exhibited the greatest losses with an average percentage exceeding 10% after 6 days of storage (Table 1).

Firmness was significantly affected by treatments and storage time ($P<0.05$). It was observed that fruits treated with GA_3 presented the highest firmness values and that this regulator kept the fruits firmer until the 12th day (26.62 N). On the other hand, the lowest firmness was observed in guavas treated with ethephon, which on the 3th day of storage already stood out from the different treatments with lower values (53.89 N), showing total softening on the 6th day of storage (17.65 N) (Table 1).

There was a significant effect of regulators ($P<0.05$) on the color of the peel and pulp during storage (Table 2).

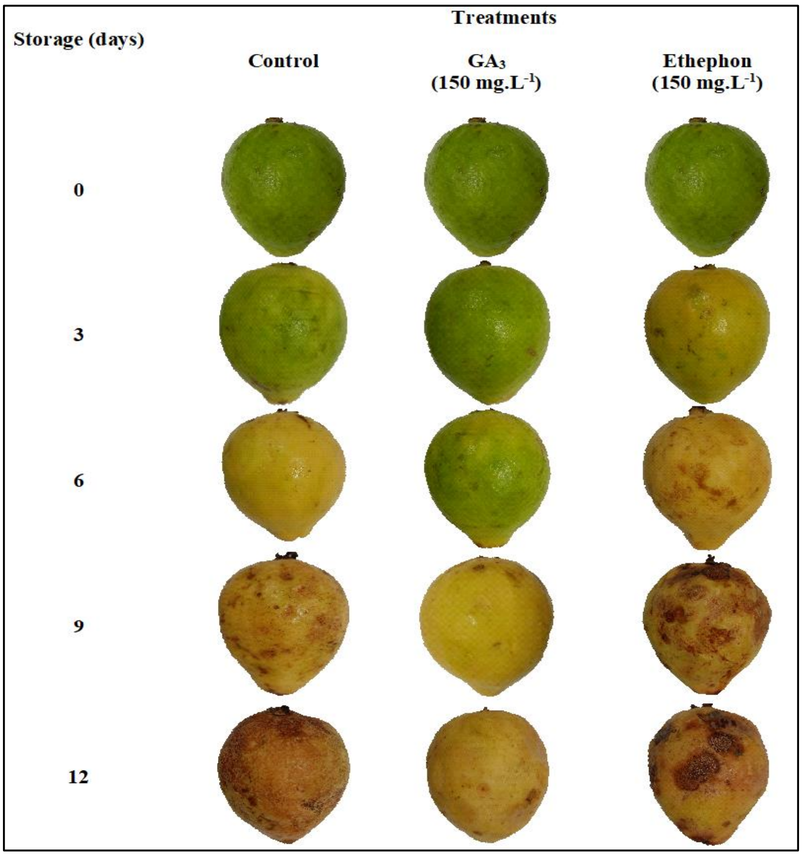

Fig. 1. Shelf life and visual quality of guavas treated with GA_3 and ethephon during storage at ambient conditions (28 ± 2 ºC) for 12 days.

Table 1. Evolution of mass loss (%) and reduction in firmness (N) in guavas treated with GA_3 and ethephon during storage under ambient conditions (28 ± 2 ºC) for 12 days.

Storage (days)	Treatments		
	Control	GA_3 (150 mg.L^{-1})	Ethephon (150 mg.L^{-1})
	Mass loss (%)		
0	0.00 ± 0.00 aA	0.00 ± 0.00 aA	0.00 ± 0.00 Aa
3	2.89 ± 0.36 bB	1.69 ± 0.06 bA	3.86 ± 0.31 bC
6	5.54 ± 0.29 cB	2.74 ± 0.19 cA	10.05 ± 0.33 cC
9	9.31 ± 0.43 dB	4.07 ± 0.33 dA	*
12	*	8.96 ± 0.41 eA	*
CV (%)	4.11		
	Firmness (N)		
0	86.11 ± 2.10 aA	86.11 ± 2.10 aA	86.11 ± 2.10 aA
3	80.19 ± 2.05 bA	84.05 ± 2.83 aA	53.89 ± 1.28 bB
6	52.18 ± 1.94 cB	63.89 ± 2.11 bA	17.65 ± 1.92 cC
9	21.07 ± 3.65 dB	41.77 ± 1.98 cA	*
12	*	26.62 ± 3.71 dA	*
CV (%)	3.91		

Means followed by the same letter in the row (treatments) and in the column (storage days) do not differ from each other using the Tukey test ($p<0.05$). *not evaluated.

Regarding luminosity (L*), a reduction of more than 65% was observed in the values of the peel and pulp of fruits treated with ethephon and control on the 6th and 9th days of storage, respectively, while the treatment with GA_3 maintained the L* with higher values in the peel (16.86 L*) and pulp (21.05 L*) for up to 12 days (Table 1).

In the peel, chromaticity (C*) reduced by 40.63% in fruits treated with ethephon after 6 days of storage, while in the pulp there was an increase of 38.82% for the same period (Table 2). In turn, fruits treated with GA_3 exhibited higher and lower C* values in the peel (29.77 C*) and pulp (54.04 C*) up to the 9th day of storage in relation to the control (16.74 and 65.32), respectively ($p<0.05$).

Likewise, the hue angle (hº) reduced in the peel and increased in the pulp at different fruit storage periods. In the peel of guavas treated with ethephon, a sharp reduction of around 78.47% was observed between day 0 and day 6 of storage, while in the pulp an increase (35.49%) was observed for the same period (Table 2). In contrast, fruits treated with GA_3 exhibited a slower reduction in peel hº, approximately 48.67% lower than control fruits over 9 days. In the pulp, a smaller increase (8.45%) was also observed in relation to control fruits for the same period (Table 2).

The effects of regulators on physicochemical quality (soluble solids, titratable acidity, pH, vitamin C, and total sugars) are presented in Table 3.

Regarding soluble solids (SS), there was an increase as storage progressed, regardless of the treatments applied (Table 3). In general, SS levels increased until the 6th (10.41 ºBrix), 9th (10.67 ºBrix), and 12th day (10.52 ºBrix) in fruits treated with ethephon, control, and GA_3, respectively ($p<0.05$).

Table 2. Coloration of peel and pulp in guavas treated with GA_3 and ethephon during storage at ambient conditions (28 ± 2 ºC) for 12 days.

Storage (days)	Treatments (peel)		
	Control	GA_3 (150 mg.L^{-1})	Ethephon (150 mg.L^{-1})
	Luminosity (L*)		
0	74.19 ± 2.05 aA	74.19 ± 2.05 Aa	74.19 ± 2.35 aA
3	63.36 ± 1.97 bB	71.26 ± 1.71 bA	43.86 ± 1.86 bC
6	44.31 ± 3.06 cB	62.50 ± 2.47 cA	25.05 ± 2.38 cC
9	23.39 ± 2.53 dB	44.07 ± 2.76 dA	*
12	*	16.86 ± 3.41 eA	*
CV (%)	4111		
	Chroma (C*)		
0	50.13 ± 1.74 aA	50.13 ± 1.74 aA	50.13 ± 1.74 aA
3	40.11 ± 2.35 bA	46.15 ± 2.31 aA	29.76 ± 2.56 bB
6	31.18 ± 1.44 cB	40.89 ± 2.63 bA	11.04 ± 1.53 cC
9	16.74 ± 2.14 dB	29.77 ± 1.18 cA	*
12	*	13.68 ± 3.02 dA	*
CV (%)	2.83		
	Angle hue (hº)		
0	82.01 ± 2.36 aA	82.01 ± 2.36 aA	82.01 ± 2.36 aA
3	80.11 ± 2.05 bA	84.05 ± 2.83 aA	43.89 ± 1.28 bB
6	52.18 ± 1.94 cB	64.89 ± 2.11 bA	17.65 ± 1.92 cC
9	21.14 ± 3.65 dB	41.77 ± 1.98 cA	*
12	*	23.67 ± 3.71 dA	*
CV (%)	3.05		
Storage (days)	Treatments (pulp)		
	Control	GA_3 (150 mg.L^{-1})	Ethephon (150 mg.L^{-1})
	Luminosity (L*)		
0	58.34 ± 1.81 aA	58.34 ± 1.81 aA	58.34 ± 1.81 aA
3	47.04 ± 2.49 bA	51.04 ± 3.93 bA	35.11 ± 1.21 bC
6	28.76 ± 2.18 cB	42.33 ± 2.06 cA	19.58 ± 2.54 cC
9	16.44 ± 1.71 dB	34.07 ± 1.80 dA	*
12	*	21.05 ± 2.13 eA	*
CV (%)	3.47		
	Chroma (C*)		
0	33.06 ± 1.74 aA	33.06 ± 1.74 aA	33.06 ± 1.74 aA
3	39.61 ± 2.73 bA	37.67 ± 2.54 aA	49.76 ± 2.56 bB
6	51.10 ± 1.41 cB	47.12 ± 2.91 bA	64.04 ± 1.53 cC
9	65.32 ± 2.14 dB	54.04 ± 1.83 cA	*
12	*	65.11 ± 2.19 dA	*
CV (%)	2.86		
	Angle hue (hº)		
0	46.22 ± 2.06 aA	46.22 ± 2.06 aA	46.22 ± 2.06 aA
3	52.91 ± 1.33 bA	50.93 ± 1.47 aA	59.41 ± 2.54 bB
6	66.18 ± 1.61 cB	59.61 ± 1.18 bA	71.65 ± 1.46 cC
9	72.14 ± 2.20 dB	66.04 ± 2.50 cA	*
12	*	73.17 ± 1.03 dA	*
CV (%)	3.72		

Means followed by the same letter in the row (treatments) and in the column (storage days) do not differ from each other using the Tukey test ($p<0.05$). *not evaluated.

Table 3. Soluble solids, titratable acidity, pH, vitamin C, and total sugars in guavas treated with GA_3 and ethephon during storage at ambient conditions (28 ± 2 ºC) for 12 days.

Storage (days)	Treatments		
	Control	GA_3 (150 mg.L^{-1})	Ethephon (150 mg.L^{-1})
	Soluble solids (ºBrix)		
0	8.61 ± 0.26 aA	8.61 ± 0.26 aA	8.61 ± 0.26 aA
3	9.17 ± 0.31 bB	8.87 ± 0.34 aA	9.50 ± 0.35 bC
6	9.95 ± 0.35 bB	9.28 ± 0.21 aA	10.41 ± 0.23 cC
9	10.67 ± 0.26 cB	9.94 ± 0.30 bA	*
12	*	10.52 ± 0.17 cA	*
CV (%)	1.92		
	Titratable acidity (g.100g^{-1} citric acid)		
0	0.61 ± 0.03 aA	0.61 ± 0.03 aA	0.61 ± 0.03 aA
3	0.52 ± 0.05 aA	0.56 ± 0.04 aA	0.37 ± 0.02 bB
6	0.34 ± 0.04 cB	0.48 ± 0.03 bA	0.23 ± 0.03 cC
9	0.27 ± 0.03 dB	0.35 ± 0.04 cA	*
12	*	0.26 ± 0.0 dA	*
CV (%)	0.67		
	pH		
0	4.41 ± 0.12 aA	4.41 ± 0.12 aA	4.41 ± 0.12 aA
3	4.81 ± 0.17 bA	4.65 ± 0.23 bA	4.93 ± 0.18 bB
6	5.08 ± 0.21 cB	4.74 ± 0.21 bA	5.31 ± 0.12 cC
9	5.26 ± 0.14 dB	5.06 ± 0.14 cA	*
12	*	5.29 ± 0.11 dA	*
CV (%)	1.03		
	Vitamin C (g.100g-1)		
0	20.31 ± 0.45 aA	20.31 ± 0.45 aA	20.31 ± 0.45 aA
3	26.56 ± 0.42 bB	24.89 ± 0.30 bA	16.54 ± 0.19 bC
6	19.18 ± 0.21cB	31.03 ± 0.28 cA	11.85 ± 0.22 cC
9	11.06 ± 0.61 dB	21.56 ± 0.26 dA	*
12	*	12.15 ± 0.31 eA	*
CV (%)	3.48		
	Total sugar (g.100g^{-1})		
0	5.83 ± 0.21 aA	5.83 ± 0.21 aA	5.83 ± 0.21 aA
3	6.31 ± 0.17 bA	6.14 ± 0.16 aA	8.46 ± 0.11 bB
6	9.16 ± 0.14 cB	7.40 ± 0.20 bA	9.44 ± 0.22 cC
9	9.75 ± 0.25 dB	9.21 ± 0.13 cA	*
12	*	9.81 ± 0.21 dA	*
CV (%)	2.75		

Means followed by the same letter in the row (treatments) and in the column (storage days) do not differ from each other using the Tukey test ($p<0.05$). *not evaluated.

Regardless of the treatments applied, a reduction in titratable acidity (TA) was observed (Table 3). However, guavas treated with GA_3 presented the highest TA levels, which remained with minimal variations until the 6th day of storage, with values around 0.26 g.100g^{-1} of citric acid at the end of 12 days. In turn, the acidity in fruits treated with ethephon reduced by around 39.43% over 3 days and an average content of 0.23 g.100g^{-1} of citric acid after 6 days (Table 3).

pH values increased during storage periods (Table 3), with a significant interaction between storage periods and treatments ($P<0.05$). In general, pH increased as a result of the reduction in acidity, in fruits treated with ethephon and control, for example, there was an increase of around 16.0% until the 6th and 9th day, respectively (Table 3). For the same period, the pH of fruits treated with GA_3 increased by only 13.51% and reached a percentage of 16.63% at the end of 12 days (Table 3).

The vitamin C content varied during storage, with a significant interaction between storage periods and treatments ($P<0.05$) (Table 3). In fruits treated with ethephon, there was a reduction of around 41.65% with average values going from 20.35 $mg.100g^{-1}$ on day 0 to 11.85 $mg.100g^{-1}$ at 6 days. On the other hand, the control and GA_3 treated fruits showed an increase of 23.53 and 34.56% between the 3th and 6th day, respectively. After this period, a reduction in average levels was noted, with control fruits exhibiting a lower value (11.06 $mg.100g^{-1}$) compared to those treated with GA_3 (12.15 $mg.100g^{-1}$) over 9 and 12 days, respectively (Table 3).

DISCUSSION

Shelf life represents the commercial quality of the fruit during the storage period. In this sense, the longer shelf life of fruits treated with GA_3 is due to the inhibition of ethylene synthesis caused by this regulator, which delayed ripening and extended the marketing period. In turn, exposure to ethephon anticipated the ripening of guavas, allowing them to be sold in a shorter time (Fig. 1). These strategies are important as they provide subsidies for producers and retailers to obtain better prices when selling their fruits. Bananas treated with GA3 (300 $mg.L^{-1}$), for example, had approximately 5 days more shelf life when compared to control fruits during storage at 28 ºC (Ghimire et al., 2021).

The maximum tolerated mass loss to prevent the appearance of wilting and wrinkling on the surface ranges between 5 and 10% for most fresh vegetables (Iakimova et al., 2024). In this study, fruits showed losses above this range after 6 days of storage, especially in those treated with ethephon (Table 1). This fact can be attributed to the effect of ethylene which, after being released into the tissues, causes an increase in respiratory activity favoring water loss due to greater transpiration.

On the other hand, the lower loss of mass in guavas treated with GA_3 can be attributed to the inhibition of ethylene synthesis and consequent delay in the ripening process, caused by the reduction in metabolic activity in the fruits due to the action of GA_3, which acts as an antagonist to the effects ethylene degradative agents (Mukherjee et al., 2022). Similar results were obtained in bananas where the immersion treatment at 300 $mg.L^{-1}$ of GA_3 resulted in less mass loss (3.52%) in relation to the control (9.21%) after 15 days under conditions of room temperature.

The firmness of the pulp is determined by the strength of cohesion between the pectins and as ripening progresses, pectinolytic enzymes act, which transforms insoluble pectin into soluble one, promoting the softening of the fruits (Sanches & Repolho, 2022). In this study, the greatest reduction in firmness in fruits treated with ethephon (Table 1) is due to the accelerated ripening caused by this regulator, which promotes the solubilization of the pectins that make up the cell wall, leading to loss of firmness.

For Mukherjee et al. (2022), GA_3 can partially inhibit the action of ethylene, thereby delaying metabolic processes related to ripening, especially fruit softening. This justified the greater firmness in guavas treated with this regulator throughout the storage period (Table 1). Similarly, Bagnazari et al. (2018) also observed that the firmness of peppers treated with 50 $mg.L^{-1}$ was 21.11% greater than control fruits after 20 days of storage at 10 ºC. In okra, treatment with GA_3 (100 $mg.L^{-1}$) delayed softening, corroborated by the inhibition of genes that regulate cell wall degradation during refrigerated storage (10 ºC) over 12 days (Li et al., 2023).

Regarding the color of the skin and pulp, the reduction in L* with storage time is an indication that the fruits were losing their natural shine with the ripening process, in this case, the lower L* values observed in fruits treated with ethephon are consequences of rapid maturation driven by the effects of ethylene. These results agree with Zhang and Zhou (2023) who relate the loss of brightness and darkening of tissues with ripening in lemon fruits exposed to ethephon (1000 $mg.L^{-1}$) and stored at 20 ºC for 9 days. In turn, the higher L* values up to 9 (control) and 12 days (GA_3) suggest greater preservation of natural brightness and consequent delay in maturation (Table 2).

Chroma (C*) is considered the quantitative attribute of coloring and is used to determine the degree of difference in a shade, the higher the chroma values, the greater the intensity of the color. In this study, the reduction in C* values in the peel, regardless of the treatment applied, indicates that the color intensity decreased in different periods depending on ripening (Table 2). Likewise, the increase in C* in the pulp shows that the color intensity/saturation increased with ripening, changing from pink to red as storage progressed, being more pronounced in fruits treated with ethephon (6 days) and lower in those treated with GA_3 (12 days) (Table 2).

The hue angle (h*) is considered a qualitative attribute of color, according to which colors are traditionally defined as reddish, greenish, etc. In this study, the decrease in hº in the fruit peel with storage time indicates a change from green to yellow, suggesting that treatment with ethephon accelerated this change. In contrast, treatment with GA_3 retained the green color for a longer period (Table 2). In the pulp, the increase in hº values demonstrates that the color became redder in different storage periods due to the metabolic role of regulators in anticipating (ethephon) or delaying (GA_3) ripening.

SS is an important parameter, as in addition to being an indicator of the harvest point, it is the main criterion used in establishing postharvest quality standards for fruit in market regulations (Kyriacou & Rouphael, 2018). In this study, the increase in SS levels during storage is due to the advancement of fruit ripening, associated with the loss of water resulting from respiratory activity or transpiration, as well as the degradation of the cell wall, increasing the concentration of soluble solids levels (Zhao et al., 2024). This would justify the lower and higher SS contents in guavas treated with GA_3 and ethephon, respectively (Table 3), demonstrating the antagonistic capacity of the regulators on ripening.

The presence of organic acids gives the acidity of a fruit and is one of the criteria used to classify the fruit by flavor (Chen et al., 2021). Normally, the content of organic acids tends to decrease during the maturation process due to the oxidation of acids in the tricarboxylic acid cycle as a result of respiration. Thus, the variation in acidity can be an indication of the fruit's ripening stage, as acidity decreases as maturation progresses (Sanches et al., 2021). In this sense, the smaller reduction in TA levels in fruits treated with GA_3 may be an indication that there was a reduction in the metabolism of the fruits, showing few transformations due to the delay in ripening. Regarding the treatment with ethefon, on average, the fruits became less acidic than the other treatments on the 6th day, probably due to the use of organic acids in respiratory metabolism driven by rapid ripening (Table 3).

The increase in pH during storage is related to the reduction in organic acids (TA) that are consumed by the respiratory metabolism of fruits, promoting ripening and senescence (Sanches et al., 2021). Thus, the higher pH values in fruits treated with ethephon (6 days) and control (9 days) are indicative of a greater stage of maturation/senescence of these fruits, in turn, the smaller increases in pH values in fruits treated with GA_3 over 12 days suggests a delay in these physiological events (Table 3). Similar results were obtained in mangos where treatment with 400 $mg.L^{-1}$ of GA_3 delayed ripening in relation to the control, corroborated by lower SS accumulation, higher concentration of organic acids (TA) and lower pH increase during 12 days of storage at room temperature (30 ºC) (Chhetri & Ghimire, 2023).

According to Macedo et al. (2023), vitamin C content can be used as an index of food quality, because it varies in the product according to cultivation, storage, and processing conditions. In the case of fruits treated with ethephon, the reduction in average values results from the acceleration of ripening/senescence, as ascorbic acid is used in oxidative reactions, which are activated by the stresses suffered in cell membranes during storage. In this sense, the increase and preservation of vitamin C levels in control fruits and, especially in those treated with GA_3, may be a reflection of less oxidative damage, mainly from respiration, which caused the delay in ripening (Table 3). Likewise, the application by immersion of 'rabbiteye' blueberries in GA_3 solution (500 $mg.L^{-1}$) was able to delay the degradation of ascorbic acid, maintaining the postharvest quality of the fruits in relation to untreated ones (Zang et al., 2016).

Regarding total sugar levels (Table 3), there was an increase in average values at different storage times between treatments ($P<0.05$). In guavas treated with ethephon a pronounced increase was observed between day 0 and day 3 (32.63%) with a maximum peak at 6 days of storage (9.44 $g.100g^{-1}$). In control fruits and those treated with GA_3, this most significant increase was obtained on the 6th and 9th days, with an average percentage of 36% and a maximum peak on the 9th and 12th days (9.75 and 9.81 $g.100g^{-1}$), respectively (Table 3).

According to Wee et al. (2023) during the fruit ripening process, one of the main changes in their characteristics is the accumulation of sugars, reaching their maximum at the end of ripening. In this study, treatment with GA_3 provided the lowest total sugar values up to 12 days of storage, this fact is possibly related to the delay in fruit maturation due to the reduction in metabolic rate and consequent decrease in sugar conversion. On the other hand, the opposite occurred for fruits treated with ethephon up to the 6th day of storage, with increased fruit metabolism corroborated by greater sugar synthesis.

CONCLUSIONS

The postharvest treatment of guavas with GA_3 delayed ripening, making it possible to extend commercialization for up to 12 days under room temperature conditions (28 ± 2 ºC), due to the preservation of firmness, less loss of mass, less accumulation of SS, the content of vitamin C and total sugars.

Ethephon anticipated ripening, allowing the fruits to be commercialized in up to 6 days, without compromising the physical-chemical quality during the storage period.

Conflict of interest

The authors have no conflict of interest to report.

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