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Preharvest calcium and irrigation regime affects postharvest quality of cape gooseberry fruit (*Physalis peruviana* L.)

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Summary

The cultivation of cape gooseberry in Colombia has increased in recent years, both in terms of export volume and production; however, yield has decreased by 19%. Therefore, it is necessary to evaluate major factors that affect fruit production and postharvest behavior such as irrigation and calcium fertilization. A design with three randomized blocks was used that corresponded to the irrigation frequency (4, 9 and 14 days), each with 12 treatments composed of a factorial arrangement with four irrigation regimes (0.7, 0.9, 11 and 1.3 multiplying factor of the class A tank evaporation) and three doses of calcium (0, 50 and 100 kg ha^{-1}). The calcium dose of 100 kg ha^{-1} resulted in fruits with a lower mass loss (8%), lower total soluble solids (TSS) content (15.74 °Brix) and greater firmness (11.03 N) at the end of storage. The fruits retained better quality with the application of 100 kg ha^{-1} of calcium, along with an irrigation coefficient of 0.9 applied at four days interval; however, the fruits had a lower TSS content. The luminosity of the fruits and the chroma from blue to yellow (b*) decreased during the postharvest period, while the chroma from green to red (a*) and the color index increased. This research provides practical information for farmers, suggesting precise irrigation and calcium nutrition strategies to improve the post-harvest performance of cape gooseberry fruits.

Introduction

Physalis peruviana is native to South America, belongs to the Solanaceae family, and is commercially cultivated in several tropical and subtropical countries (Fischer and Melgarejo, 2020). The fruits have high contents of vitamins (A, B3, B6 and C), carotenoids, flavonoids, and phenolic compounds, along with the capacity to neutralize reactive oxygen species, giving them nutraceutical properties (El-Beltagi et al., 2019).

Colombia is the largest producer and marketer of cape gooseberries in the world and, in 2021, had the highest volume of exports in its history when value increased by 16% (US$ 37.8 million), and production increased by 7% (7.87 t), as compared to 2020. However, yield decreased from 17.79 to 14.41 t ha^{-1} between 2009 and 2020 (Agronet, 2023) because of a lack of modernization in irrigation and fertilization management, along with a large increase in the costs of inputs for production and phytosanitary control (Álvarez-Herrera et al., 2021).

Climate change requires adequate water management in crops (Prasad et al., 2023), along with good fertilization (Michalak, 2019), which are of the utmost importance for cape gooseberry plants and the postharvest-life of the fruits because they are susceptible to cracking (Álvarez-Herrera et al., 2014). In this regard, Fischer and Melgarejo (2020) reported that water deficits affect fruit quality of cape gooseberry, resulting in smaller fruits and physiological disorders (Álvarez-Herrera et al., 2012). Water stress conditions negatively affect the number of fruits developed and their harvest quality (Fischer et al., 2016). The use of rootstocks as protection against biotic and abiotic stress and to increase overall quality in post-harvest as recommended by Prasad et al. (2024) for fruit trees has not yet been applied to cape gooseberry but is being studied.

Álvarez-Herrera et al. (2015) applied an irrigation coefficient of 1.3 and 100 kg ha^{-1} of Ca and reported larger fruits, more production per plant and less cracking. In addition, Fischer (2005) stated that cracking in cape gooseberry fruits is attributed to Ca deficiencies, an essential element in physiological regulation, specifically postharvest, since it plays an important role in development and maturation (Fischer et al., 2021). Furthermore, calcium deficiencies can cause membrane rupture and fruit disorders (Gao et al., 2019).

To avoid fruit cracking, irrigation and fertilization treatments have been visualized that could reduce this physiopathy; however, the effect of these preharvest applications on postharvest fruits should be studied. The objective of this study was to evaluate the postharvest behavior of cape gooseberry fruits from plants exposed to different irrigation regimes and frequencies and calcium doses.

Materials and methods

Location

The postharvest trial was carried out in the Plant Physiology laboratory with fruits obtained from a cape gooseberry crop planted in the greenhouses of the Faculty of Agricultural Sciences of the National University of Colombia, Bogotá campus (4°38'08"N, 74°04'58"W). The environmental conditions in the greenhouse were 18 °C and 60% relative humidity, on average.

Experiment design

A randomized complete block experiment design was used with 12 treatments. The blocks were the irrigation frequencies (4, 9 and 14 days). The treatments included a 4×3 factorial arrangement, where the irrigation levels applied were the first factor (0.7, 0.9, 1.1 and 1.3 of evaporation), and the calcium doses (0, 50 and 100 kg ha^{-1}) were the second, for a total of 36 experiment units (EU), with two plants per EU, which were planted in 20 L pots, with blonde peat as substrate. The measurement of the different parameters was carried out every five days with 10 fruits per EU.

Setup of the experiment in cultivation

The species *P. peruviana* ecotype 'Colombia' was used because it presents fruits with a high sugar content (Fischer et al., 2022). A spatial arrangement of 2 m between plants and 2 m between rows was used, with a high V support system. The edaphic fertilization of the crop (in kg ha^{-1}) was for N: 150; P_2O_5: 220; K_2O: 150; MgO: 60; S: 40 B: 1; Zn: 3; Cu: 2; and Mn: 0.5, divided into five applications throughout the crop: pre-planting, and at three, five, seven and nine months after transplanting.

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The irrigation levels were applied with two drippers per plant, each with a flow rate of 4 L h^{-1}. calcium fertilization was carried out monthly in the form of a crown to the substrate. Every four days, evaporation was measured in a type A evaporimeter tank installed inside the greenhouse, and the data were validated with measurements from the IDEAM weather station. The amount of water to be applied was established following the method used by Álvarez-Herrera et al. (2022).

Response variables

The measurement of the different parameters was carried out every five days with 10 fruits per EU, obtained from the second harvest of the crop, at 19 days after transplanting (DAT), of each treatment, which were determined at 1, 6, 11 and 16 days after harvest (DAH) for the following variables.

Mass loss was measured with an Acculab VIC 612 balance (Sartorius Group, Germany) with a precision of 0.01 g. Fruit firmness was determined with a PCE-PTR200 digital penetrometer (PCE-Iberica, Spain). Total soluble solids (TSS) were expressed in °Brix, with cape gooseberry juice measured in a HANNA HI 96801 digital refractometer (Hanna Instruments, Woonsocket, RI, USA). Total titratable acidity (TTA) was measured according to the methodology reported by Álvarez-Herrera et al. (2022), expressed as a per-centage of citric acid. The maturity index (MI) was calculated using the relationship between the TSS and the TTA. The pH was measured with a HANNA HI 8424 potentiometer (Hanna Instruments, Woonsocket, RI, USA). Color was measured in triplicate in 10 fruits per EU with a PCE-RGB 2 digital colorimeter (PCE-Iberica, Spain). Easy-RGB software (Logicol Color Technology Co.) was used for the conversion to luminosity values (L^*), chromaticity from green to red (a^*) and from blue to yellow (b^*). The color index (CI) was calculated using equation (1), as described by Cayuela and Weiland (2010) for red fruits.

$$CI = \frac{1000 \times a^*}{L^* \times b^*} \quad (1)$$

Data analysis

An analysis of variance (Anova) was performed to determine the significant differences between the factors (irrigation levels [IL], calcium dose [Ca]), their interaction (IL × Ca, treatments), and irrigation frequencies (blocks). Additionally, a Tukey mean comparison test ($P \leq 0.05$) was performed to classify each of the levels in the factors with SAS v. 9.2 (SAS Institute Inc., Cary, NC).

Results and discussion

Accumulated mass loss (AML)

This variable did not show significant differences for the irrigation regime factor or the irrigation regime and calcium dose interaction (Tab. 1); however, irrigation frequency and calcium dose showed significant differences only 6 days after harvest (DAH), while at 11 and 16 days there were no differences between the evaluated treatments (Tab. 2).

The cape gooseberry fruits from plants that received Ca^{2+} doses of 100 kg ha^{-1} had a lower AML than the control treatment and the application of 50 kg ha^{-1} of Ca^{2+}. These results agree with those found for other fruits such as grapes (Martins et al., 2021), pear (Zhang et al., 2019) and guava (Ribeiro et al., 2020), among others, since calcium has the advantage of slowing down cellular respiration, favoring the maintenance of firmness for a longer time (Sajid et al., 2019) and inhibiting the activity of a large number of enzymes such as pectin methylesterase (PME) and polygalacturonase (PG), which maintain tissue firmness and reduce mass loss in fruits (Zhang et al., 2019).

The irrigation frequency of 14 days resulted in fruits with a lower AML at 6 DAH. In contrast, the fruits from plants that received irrigation every 4 days exhibited a higher AML. It is probable that these fruits, receiving a more substantial water supply, reached harvest with an increased water content in the tissue, thereby accelerating the transpiration process due to a higher vapor pressure deficit (Díaz-Pérez, 2019). Consequently, there was a loss of water, dependent on environmental factors (Saroj et al., 2023). The absence

Tab. 1: Fischer values of the analysis of variance of the postharvest variables evaluated in cape gooseberry fruits subjected to different irrigation levels, calcium doses and irrigation frequencies.

DAH	SV	AML	Firmness	TSS	TTA	pH	MI	*L**	*a**	*b**	CI
1	IL	0.36	0.22	0.96	4.57*	0.51	3.45*	1.47	1.24	1.33	1.27
	Ca	0.11	2.20	13.3***	0.14	0.40	2.75	0.87	0.42	0.66	0.96
	IL × Ca	0.84	2.10	0.42	1.42	0.61	0.72	1.19	0.52	0.98	1.61
	IF	1.52	2.80	3.54*	8.06**	10.3***	5.79**	3.46*	0.19	3.17	4.22*
6	IL	0.36	0.69	0.04	5.85**	1.01	2.40	1.60	1.23	1.37	3.04
	Ca	0.14	1.44	0.80	2.39	0.38	0.12	0.75	0.12	0.71	0.88
	IL × Ca	0.79	1.95	2.38	1.42	0.74	1.35	1.11	1.13	1.11	0.50
	IF	1.48	1.49	17.3***	6.36**	1.35	11.5***	1.37	0.22	1.34	1.46
11	IL	0.17	0.78	1.45	3.74*	1.00	6.06**	1.52	1.40	1.35	1.91
	Ca	0.27	0.09	2.04	0.13	0.34	0.70	0.42	0.09	0.39	0.55
	IL × Ca	0.51	2.66*	0.57	0.93	0.36	0.69	0.92	0.79	0.92	0.45
	IF	0.90	0.21	7.07**	0.18	18.9***	1.12	1.03	0.53	1.01	0.84
16	IL	0.39	0.84	1.15	3.57*	0.66	2.01	1.44	1.57	1.34	0.79
	Ca	0.18	0.54	1.96	0.07	0.97	0.77	0.09	0.05	0.08	0.22
	IL × Ca	0.74	1.04	0.48	1.44	0.80	0.60	0.73	0.46	0.74	0.40
	IF	1.41	1.85	5.32*	11.7***	3.52*	7.34**	0.70	0.84	0.67	0.23

DAH: days after harvest; SV: Source of variation; AML: accumulated mass loss; TSS: total soluble solids; TTA: total titratable acid; MI: maturity index; L^*: luminosity; a^*: green to red chromaticity; b^*: blue to yellow chromaticity; CI: color index; IL: irrigation level; Ca: calcium doses; IF: irrigation frequency; *, **, *** indicate significant effect with $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, respectively.

Tab. 2: Total soluble solids (TSS), total titratable acid (TTA), pH, maturity index (MI) and color parameters in cape gooseberry fruits subjected to different irrigation levels, calcium doses and irrigation frequencies.

Parameter	DAH	Irrigation coefficient				Calcium doses (kg ha^{-1})			Irrigation frequency (days)		
		0.7	0.9	1.1	1.3	0	50	100	4	9	14
AML (%)	1	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
	6	3.74a	3.60a	3.61a	3.66a	3.61b	4.02a	3.34b	4.18a	3.60b	3.18b
	11	6.71a	6.41a	7.05a	6.72a	6.78a	7.38a	6.02a	7.49a	6.68a	5.99a
	16	8.90a	8.57a	9.86a	8.63a	9.14a	9.72a	8.11a	10.17a	8.81a	7.99a
TSS (°Brix)	1	16.03a	15.65a	16.02a	15.74a	16.03a	16.38a	15.17b	15.86ab	16.18a	15.54b
	6	15.75a	15.83a	15.80a	15.80a	15.89a	15.83a	15.66a	15.18b	15.98a	16.22a
	11	15.24a	15.51a	15.64a	15.80a	15.78a	15.16a	15.30a	15.10a	15.55ab	16.00a
	16	15.46a	15.95a	15.91a	15.77a	15.85a	15.98a	15.50a	15.40a	15.71ab	16.21a
TTA (%)	1	2.15a	2.06ab	1.95b	2.02ab	2.05a	2.04a	2.02a	2.15a	2.00b	1.97b
	6	2.74a	2.72a	2.57ab	2.46b	2.60a	2.70a	2.56a	2.76a	2.56b	2.55b
	11	2.23a	2.25a	2.07a	2.07a	2.15a	2.17a	2.14a	2.13a	2.16a	2.16a
	16	2.23a	2.08ab	2.14ab	1.97b	2.12a	2.09a	2.11a	2.31a	2.01b	2.00b
MI	1	7.49b	7.59ab	8.23a	7.91ab	7.85a	8.04a	7.53a	7.39b	8.13a	7.90ab
	6	5.71a	6.05a	6.13a	6.43a	6.03a	6.07a	6.14a	5.43b	6.45a	6.36a
	11	6.85b	6.89b	7.59a	7.65a	7.35a	7.20a	7.19a	7.10a	7.21a	7.42a
	16	7.01a	7.65a	8.15a	8.05a	7.99a	7.72a	7.43a	6.72b	8.29a	8.13a
pH	1	3.71a	3.69a	3.69a	3.69a	3.69a	3.69a	3.70a	3.74a	3.67b	3.67b
	6	3.77a	3.75a	3.72a	3.76a	3.75a	3.74a	3.76a	3.78a	3.74a	3.74a
	11	4.08a	4.03a	4.05a	4.04a	4.05a	4.04a	4.06a	4.14a	4.01b	4.01b
	16	4.08a	4.09a	4.07a	4.05a	4.05a	4.09a	4.07a	4.10a	4.04b	4.08ab
*L**	1	26.84a	29.67a	27.46a	30.51a	27.48a	29.81a	28.57a	29.26ab	30.55a	26.05b
	6	26.17a	28.72a	27.46a	28.08a	26.94a	28.23a	27.65a	26.69a	28.42a	27.72a
	11	23.92a	26.91a	25.59a	26.42a	24.94a	26.42a	25.77a	25.16a	27.08a	24.89a
	16	18.75a	21.58a	22.25a	24.26a	21.15a	22.09a	21.90a	21.37a	23.23a	20.53a
*a**	1	17.99a	19.20a	16.30a	18.41a	17.62a	18.69a	17.62a	18.13a	18.29a	17.57a
	6	22.28a	22.80a	21.32a	20.85a	21.73a	22.08a	21.61a	21.48a	22.13a	21.82a
	11	20.52a	22.22a	21.35a	21.51a	21.35a	21.70a	21.15a	21.36a	22.05a	20.79a
	16	16.72a	21.05a	20.83a	21.48a	19.62a	20.15a	20.29a	20.02a	21.42a	18.62a
*b**	1	15.71a	17.33a	15.81a	17.58a	16.03a	17.23a	16.56a	17.01a	17.68a	15.13a
	6	15.57a	17.03a	16.20a	16.51a	15.95a	16.71a	16.33a	15.77a	16.81a	16.40a
	11	14.28a	15.65a	15.12a	16.26a	14.92a	15.78a	15.28a	14.76a	15.99a	15.23a
	16	11.11a	12.98a	13.29a	14.39a	12.60a	13.13a	13.10a	12.70a	13.87a	12.26a
CI	1	43.72a	38.33a	39.45a	35.44a	42.10a	38.53a	37.07a	37.48a	34.91a	45.33a
	6	56.24a	46.76a	48.22a	45.63a	51.76a	47.53a	48.34a	52.45a	46.93a	48.26a
	11	60.07a	52.76a	55.17a	50.07a	57.37a	52.04a	53.71a	57.51a	50.92a	54.84a
	16	91.24a	77.83a	72.15a	70.96a	82.80a	74.82a	76.51a	81.39a	73.14a	79.61a

DAH: days after harvest; AML: accumulated mass loss; *L**: luminosity; *a**: green to red chromaticity; *b**: blue to yellow chromaticity and CI: color index. Means with different letters in the same row and classified by factor indicate significant statistical differences between factor levels, according to Tukey's test ($P \leq 0.05$).

of significant differences in AML among fruits after 11 DAH can be attributed to the fact that this loss is primarily associated with postharvest transpiration and, to a lesser extent, the consumption of substrates used in respiration. Ultimately, these factors become the main contributors to fruit deterioration and a decline in quality (Díaz-Pérez, 2019).

The AML of cape gooseberry fruits was 8,9% on average throughout the 16 DAH, higher than the 4.5% determined by Lanchero et al. (2007) in cape gooseberry fruits stored for 4 weeks or the 6.7% obtained for cape gooseberry fruits stored at 1 °C by Garzón-Acosta et al. (2014). Ávila et al. (2006) reported that the AML cannot exceed 5% since this means product deterioration. The cape gooseberry fruits evaluated in the present study lost commercial quality approximately after 8 DAH. The AML had significant differences between the sampling times (Tab. 2) because of the transpiration process of the fruits and the loss of water as a result of the vapor pressure deficit (VPD) between the internal humidity of the fruits and the relative humidity of the environment (75%) (Díaz-Pérez, 2019).

Fruit firmness

There were no significant differences between irrigation factors and their interaction throughout the storage of the cape gooseberry fruits (Tab. 1). However, the 0.7 irrigation coefficient presented fruits with 5.4% less firmness than fruits from plants irrigated at 1.3 times the evaporation at 16 DAH. Similar results were seen with the irrigation frequency since the fruits irrigated every 14 days had 3.6% less firmness than the fruits irrigated every 4 days, without significant statistical differences. It has been found that, when the amount of water that is applied is decreased, the fruits are softer and tend to wrinkle, which correlates with the loss of turgor and firmness (NARAYANA et al., 2023). This behavior has been observed in grapevine (PORRO et al., 2010) and pear (VENTURI et al., 2021).

The fruit firmness did not present significant differences when the plants were fertilized with different doses of calcium. This may be due to Ca^{2+} being applied in fertilization, which is absorbed by cape gooseberry plants, is accumulated in the leaves and closed fruit calyx, and is relocated towards the fruits at lower quantities, where the concentration of Ca^{2+} remains constant (ÁLVAREZ-HERRERA et al., 2022). Furthermore, SILBER et al. (2003) stated that, when irrigation treatments are carried out, the amount of calcium absorbed by the plant decreases as a result of deficit and excess irrigation applications. Ca^{2+} maintains the stability and integrity of the cell wall by binding to residues of galacturonic acid, the main component of pectins, thereby forming a pectin-calcium gel that positively affects the mechanical properties of the cell wall and confers greater rigidity. Therefore, when the calcium concentration is higher, the pectin pores are smaller due to a greater number of links, and the cell wall is stronger (SAÑUDO-BARAJAS et al., 2019), so the fruits has greater firmness.

When analyzing the firmness of the cape gooseberry fruits over time during postharvest, all the treatments showed an average reduction of 20%, which occurred mainly after 11 DAH with softening and subsequent quality deterioration of the fruits (Fig. 1). This can probably be mediated by an increase in the production of ethylene (BALAGUERA-LÓPEZ et al., 2016; 2017), which promotes in the cape gooseberry fruit the activity of enzymes such as PG, which, according to MAJUMDER and MAZUMDAR (2002), increase starting at stage 3 of maturity and favor degradation of the cell wall; likewise, wall hydrolase enzymes such as PME decrease their activity starting at stage 3. However, ALÓS et al. (2019) reported that the activity of PME occurs in the first stages of fruit growth, breaking the 1.4 bonds of the xyloglucan (XG) chains to later facilitate PG action. SAÑUDO-BARAJAS et al. (2019) stated that degradation of pectic material has a strong correlation with loss of firmness and this begins before separation of the fruits from the plant.

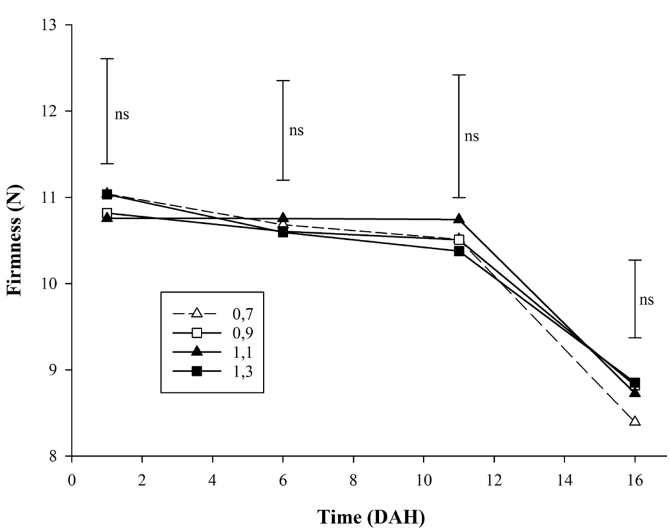

Fig 1: Firmness in cape gooseberry fruits from plants subjected to different irrigation levels. DAH: days after harvest. Vertical bars indicate confidence intervals according to Tukey' test ($P \leq 0.05$). ns: not significant. *: significant effect ($P \leq 0.05$).

Total soluble solids (TSS)

The ANOVA showed significant differences for the irrigation frequency factor during all measurements in postharvest storage (Tab. 2) and for the calcium dose only in the first measurement, a product of the differences in the postharvest stage, while the irrigation level and the interaction of the irrigation level and calcium dose did not significantly affect the TSS of the cape gooseberry fruits.

The 14-day irrigation frequency presented the highest TSS values in all measurements, followed by irrigation every 9 and 4 days. These differences probably occurred because of the osmotic adjustment induced by stress, which generated a greater breakdown of reserve carbohydrates into simpler sugars used in respiration (SALTVEIT, 2019), increasing TSS in the application treatments every 14 d. A dilution effect can occur where the fruits will have a lower moisture content when applying a lower supply of water; therefore, the dry matter in concentration and TSS increase (FALLAHI et al., 2010).

Fruit TSS increases because, during ripening, the activity of the enzymes that hydrolyze starch such as α-amylase, β-amylase and starch phosphorylase increase (YAHIA et al., 2019); likewise, the sucrose synthase activity increases under conditions of water stress, which is why the sucrose concentration gradient between leaves and fruits rises, with a greater transport of photoassimilates to the fruits. The rate of absorption increases transformation of sucrose to glucose and fructose, which ultimately raises TSS levels (TAO et al., 2023).

TSS decreased during storage until 11 DAH, similar to that found in cape gooseberry fruits by ÁVILA et al. (2006) and GARZÓN-ACOSTA et al. (2013). The decrease in postharvest TSS was attributed to the fact that respiration tends to increase during storage at room temperature, and, therefore, the consumption of sugars as a substrate in various metabolic processes increases, among which glycolysis stands out, with conversion to sucrose (SALTVEIT, 2019). After 11 DAH, TSS probably increased because the loss of water through transpiration was greater than the loss of carbohydrates from respiration (REYES-MEDINA et al., 2017), causing a concentration effect.

Total titratable acidity (TTA)

There were no significant differences in the Anova for each of the measurements carried out during the storage of the cape gooseberry fruits for the irrigation level factor or for the irrigation frequency factor, except in the latter for the third measurement at 11 days (Tab. 2). The calcium dose and the irrigation regime and calcium dose interaction were not significant in the TTA variable.

Tab. 2 shows that the irrigation levels of 0.7 and 0.9 presented the highest TTA throughout the 16 days of measurement, which implies that the fruits from plants that were irrigated with less of water presented higher TTA during postharvest. These differences may be because when plants would have little water availability, they suffered water stress, which may increase the production of organic acids as an adaptation mechanism to this hydric stress condition (JUBANY-MARÍ et al., 2010). Acids such as ascorbic increase in the cape gooseberry (ÁLVAREZ-HERRERA et al., 2014). In the same way, it is likely that the fruits from plants that received a higher water supply had a higher water content, which would cause the concentration of acids to decrease because of the dilution effect (FISCHER and MARTÍNEZ, 1999).

The 4-day irrigation frequency generated fruits with a higher TTA, which is a stimulus to vegetative growth and increases the amount of water and photoassimilates that go to the fruits, producing fruits with a higher TTA according to the higher irrigation frequency. The irrigation frequencies of 9 and 14 days caused a very strong stress, where the production of acids decreased, as in the case of ascorbic acid in melon (Li et al., 2012) or in apple (WANG et al., 2019). The decrease in acidity because of severe water stress is accompanied by an increase in the oxidation state, loss of turgor and irreversible oxidative damage (JUBANY-MARÍ et al., 2010).

The application of Ca^{2+} in cape gooseberry plants did not significantly affect the TTA of the fruits; however, AGUAYO et al. (2010) stated that the application of calcium maintained acidity in apple fruits for a longer time since Ca^{2+} delays ripening, so the oxidation process and loss of acids is lessened. In addition, it is likely that there were no significant differences in the cape gooseberry fruits because they do not accumulate a large amount of calcium (ÁLVAREZ-HERRERA et al., 2022).

The acidity increased significantly over time from the beginning of storage and up to 6 DAH, when it also decreased significantly up to 16 DAH. This behavior is similar to that reported in cape gooseberry by ÁVILA et al. (2006) and GARZÓN-ACOSTA et al. (2014). The increase in TTA in postharvest was attributed to increases in the surrounding CO_2, product of the increase in respiration, which caused the cellular environment to be more acidic since carbonic acid is produced (SALTVEIT et al., 2019). On the other hand, the decrease in TTA observed after 6 DAH occurred because many of the organic acids are used as a substrate in the enzymatic reactions of respiration (SALTVEIT et al., 2019). In the case of the cape gooseberry, it is likely that the degradation of sugars to acids continues during postharvest, since the dilution effect in TTA is not as great as with TSS.

Maturity index (MI)

This variable had significant differences for the irrigation frequency factor in the measurements taken at 1, 6 and 16 DAH; likewise, the irrigation depth factor saw differences during the first and third measurement. Even so, neither the application of Ca^{2+} nor the interaction between the irrigation regime and Ca^{2+} dose had an effect on the MI of the cape gooseberry fruits.

Tab. 2 shows that the irrigation levels of 0.7 and 0.9 generated fruits with the lowest MI, while the highest water applications generated fruits with the highest MI during postharvest, clearly related to the TTA since it was higher with the lower water applications, while the TSS was not affected by the amount of water applied to the plants.

The 4-day frequency of irrigation generated fruits with a lower MI than the fruits from plants irrigated every 9 and 14 days in most of the measurements because, when plants are subjected to water stress, MI increases; therefore, a greater amount of applied water decreases TSS to a greater extent than TTA (ÁLVAREZ-HERRERA et al., 2022), similar to that reported in tomato by BECKLES (2012).

Calcium doses did not affect the MI, probably because cape gooseberry fruits assimilate similar amounts of Ca^{2+} despite being fertilized with different doses, which is consistent with that found for cape gooseberry (ÁLVAREZ-HERRERA et al., 2022) and tomato fruits (MELO et al., 2022).

The MI decreased over time from harvest to 6 DAH and then increased until the end of postharvest, as reported by NOVOA et al. (2006) in cape gooseberry fruits stored at different temperatures. This initial decrease was due to the increase in acidity during the first six DAH, and then the MI increased because of the tendency of the TSS to increase, while the TTA decreased, as reported for cape gooseberry by LANCHERO et al. (2007). Similarly, ALÓS et al. (2019) stated that, during maturation, the concentration of sugars increases, and the proportion of acids decreases, resulting in a higher MI.

pH

There were only significant differences for the irrigation frequency factor in the first and third postharvest measurements of the cape gooseberry fruits (Tab. 2). The irrigation frequencies that cause greater water stress (9 and 14 days) kept the pH of the fruits lower during storage; however, the postharvest behavior of the pH correlated with the pH at the time of collection since fruits that start with a low pH also culminated, highlighting the importance of irrigation regimes applied to plants for fruit quality. ABDEL-AL and SAEED (1975) found that the pH decreased significantly in tomato fruits when the crop went from a weekly irrigation frequency to receiving water application every two weeks. However, ZHAO et al. (2022) found that the water regime did not affect the pH of the fruits in tomato plants.

The pH during postharvest increased from 3.70 to 4.08. This trend in cape gooseberry fruits has also been reported by several authors (NOVOA et al., 2006; ÁVILA et al., 2006; LANCHERO et al., 2007), who observed pH values ranging between 3.6 and 4.4 during storage. The increase in pH occurred because, by increasing respiration, the regeneration of the cell membrane slowed down, while the catabolic processes continued, so the activity of Ca^{2+}-ATPase and H^+-ATPase decreased, as did the selective permeability of the membrane, which increased the concentration of cytosolic Ca^{2+}, efflux of H^+ from the cytosol, and acidity (LESTER, 2003).

Color

The values of L^*, a^*, b^*, and CI did not present significant differences during the postharvest period in the cape gooseberry fruits for any of the factors or the interactions, except for the first measurement, where the irrigation frequency affected the L^* and CI values (Tab. 2).

The L^* decreased during the entire postharvest period in the cape gooseberry fruits by 28%, which implied that they darkened probably because of oxidation processes (SOLOVCHENKO et al., 2019), moisture loss and browning, attributed to the degradation of ascorbic acid (ÁLVAREZ-HERRERA et al., 2014). Similarly, VELÁSQUEZ-BARRETO et al. (2022) reported that cape gooseberry fruits stored at three temperatures showed a decrease in L^* during postharvest.

The a^* value increased up to 6 DAH and then remained stable until the end of the postharvest period, which implied that the cape gooseberry fruits in the first week of storage gained red color that remained constant after 6 DAH, which is attributed to oxidation processes in fruit maturation and generates the degradation of chlorophylls caused by chlorophyllases and peroxidases (SOLOVCHENKO et al., 2019). The a^* value had a general average of 20.3 during postharvest for all treatments, similar to the range reported by VELÁSQUEZ-BARRETO et al. (2022) from 14 to 20.1, leading to the conclusion that the fruits in the present study were harvested in a more advanced stage of maturity.

b^* decreased during storage and presented a behavior similar to that reported in cape gooseberry during the first 7 DAH (VELÁSQUEZ-BARRETO et al., 2022). This decrease led to the conclusion that cape gooseberry fruits decrease yellow chromaticity during postharvest, attributed to the instability of carotenoids, which have a highly unsaturated chemical structure that favors oxidation processes (LUCHESE et al., 2015). When determining the a^*/b^* ratio, it increased from 1.07 to 1.63 during storage, suggesting an increase in lycopene and β-carotene according to the correlations reported in tomato by GOISSER et al. (2020).

The CI increased during storage, going from 39.2 to 78.0 at 16 DAH, similar to the increases from 2 to 14 and from 5 to 15 found in the CI by PINZÓN et al. (2015) and REYES-MEDINA et al. (2017), respectively. It can be inferred that the intensity of the dark colors predominates over the light colors in cape gooseberry postharvest. SOLOVCHENKO et al. (2019) observed that color intensity and uniformity determine fruit quality and are frequently used as an indicator of nutritional value, freshness and palatability. On the other hand, despite not finding significant differences in the color of the cape gooseberry fruits with respect to the calcium dose factor, calcium retards coloration changes in some fruits, such as passion fruit (XU et al., 2023) and tomato (SATI and QUBBAJ, 2021).

Conclusion

The postharvest-life of cape gooseberry fruits was increased by applying 100 kg ha^{-1} of calcium with an irrigation coefficient of 0.9 and an irrigation frequency of 4 days; however, the fruits were less sweet. The fruits from the plants that received a greater application of calcium presented a smaller amount of total soluble solids, less mass loss over time and greater firmness. Luminosity and *b** decreased during postharvest life, while *a** and color index increased. The higher irrigation levels caused a greater decrease in TSS than in TTA.

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Conflict of interest
No potential conflict of interest was reported by the authors.

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