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Research article

Treatment effects on the quality and shelf life of the cape gooseberry (*Physalis peruviana* L.) Corpoica Andina

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Abstract: The Cape gooseberry (*Physalis peruviana* L.) is renowned for its distinctive appearance and functional properties. Colombia has emerged as the world's leading producer and exporter of Cape gooseberries, with annual export growth of 1.2%, predominantly to countries such as the USA and the Netherlands. Traditionally sold with its calyx intact to minimize water loss and deterioration, recent interest in selling Cape gooseberries without the calyx to reduce volume has raised concerns regarding shelf life. Consequently, research has pivoted toward post-harvest management to extend shelf life. An experiment was conducted to explore various treatments and temperatures (5, 10, and 18 °C), meticulously monitoring fruit quality over time. Findings underscore that calcium chloride and refrigerated storage at 10 °C preserve the quality of the Cape gooseberry fruit for up to 20 days. Moreover, temperature and time exerted a significant influence on fruit quality and physicochemical properties, with interactions impacting conservation methods. The application of calcium chloride as a barrier method yielded optimal preservation outcomes, safeguarding key fruit properties. Conversely, sodium hypochlorite treatment at 18 °C accelerated fruit ripening owing to heightened respiratory intensity. This study not only sheds light on effective preservation strategies for Cape gooseberries but also underscores the intricate interplay between environmental factors and post-harvest management techniques. By enhancing our understanding of these dynamics, the study catalyzes advancements in fruit preservation practices, thereby fortifying the agricultural and economic sectors, both domestically and internationally.

Keywords: sodium hypochlorite; calcium chloride; quality physicochemical properties; refrigeration

1. Introduction

The Cape gooseberry (*Physalis peruviana* L) is a cold-climate plant that grows in Colombia, where it may be found at elevations ranging from 1800 to 2800 meters above sea level [1]. In 2022, the harvested area was 1514.69 hectares, with a production of 20,430.86 tons and an average yield of 10.61 hectares per ton. The Department of Boyacá had the highest production in 2022, with 6589.37 tons, which is equivalent to 33.68% of the national area [2].

The exports of this fruit were valued at US 35,678,351 FOB (Free on Board), especially in European markets such as Namur, Belgium, which consider them exotic (57.6%) and value its flavor (52%). Between 2016 and 2020, exports increased by 9.1% per year to a net amount of 50,865.7 tons [3,4]. Analdex has also recorded an increasing trend, showing that the Netherlands, USA, and Germany have been the main destinies for the exportation of Cape gooseberry, with an average percentage of exportation of 70.7%, 10.9%, and 6.4%, respectively. Between 2020 and 2021, the total amount of metric tons increased by 1.2% [5]. Those values illustrate the significant importance of seeking strategies for the conservation of fruit from Colombia to Europe and North America.

On the other hand, cape gooseberries exhibit a high nutritional content, including protein (1.88–2.54 g/100 g), lipids (0.25–1.01 g/100 g), carbohydrates (10.23–14.13 g/100 g), carotenoids (13.91–22.36 μg/g), potassium (4043.56–4876.88 mg/kg), iron (7.60–20.91 mg/kg), and magnesium (91.42–455.53 mg/kg). These values were particularly observed in fruits originating from Colombia, as reported by Petkova & Popova [6]. These compounds may be responsible for the health advantages attributed to them.

Post-harvest losses, which account for 21% of all losses, are the main limiting factor in storage and spoilage by microorganisms such as *Cladosporium*, *Phomopsis*, *Pestalotia*, *Botrytis cinerea*, and *Alternaria* spp. [7]. To resolve this issue, a post-harvest strategy should integrate physical methods, which include dehydration, temperature, electricity techniques, and UV-C treatment, chemical treatments, namely fungicides often combined as co-formulations such as calcium chloride or calcium nitrate, and biological treatments, which have been implemented by introducing microbial antagonists such as bacterial or fungal species to control diseases [8].

Regarding chemical treatments, chlorine is the most common chemical sanitizer, mainly due to being the cheapest. The oxidation reaction contributes to pathogen inactivation, with maximum action occurring at a pH from 5 to 7, below the pH of 7.5 of HOCl. The Food and Agricultural Organization (FAO) advised free chlorine doses of 500–200 ppm as Cl_2 for exposure times between 2 and 10 s to control bacteria such as *Salmonella* and *E. coli* [9].

However, some forms of chlorine might not be ideal for vegetal material. Therefore, in this paper, the analyses will be conducted using calcium chloride, which helps preserve quality by controlling physiological disturbances and potentially reducing the respiratory rate and ethylene release rate during post-harvest [10]. For example, studies like Pinzón et al. [11] evaluated the effect of calcium chloride at concentrations of 1% and 2% (w/v) on Cape gooseberry, administering it directly to the solution, both to the fruit and the calyx in pre-harvest, and monitored its effects weekly for a month following harvest. Calcium slowed the ripening of fruit, affecting both physical (diameter, hardness, and color) and chemical characteristics (total soluble solids, total acidity, and calcium content of the fruit).

Besides, treatments with $CaCl_2$ showed delayed ripening by inhibiting the activity of enzymes and genes related to cell wall degradation and ethylene signal transduction [12].

Based on this knowledge, the current study was designed to determine the effect of applying calcium hypochlorite and calcium chloride on Cape gooseberries without calyx at a medium stage of maturity, followed by refrigeration at 10 °C and 5 °C. For 30 days, the quality of Cape gooseberry was monitored every 10 days.

2. Materials and methods

2.1. Vegetal material

Agrosavia provided the Corpoica Andina variety of Cape gooseberry, which was grown in the Department of Cundinamarca of the Tibaitatá Research Centre, located in the municipality of Mosquera (Latitude 4.69541°), at an altitude of 2.516 m above sea level, with an average temperature of 14 °C. According to Colombian Technical Standard 4580, Cape gooseberries were selected at maturity stages (MS) 3 and 4, removing any fruit with quality defects such as cracks, cuts, bruises, microbiological damage, and dehydration [13].

2.2. Sodium hypochlorite and calcium chloride treatments

After removing the calyx, the selected cape gooseberries were immersed in a sodium chloride solution or calcium chloride 300 ppm solution for 2 min. The disinfected Cape gooseberries were stored in 100 g of polyethylene terephthalate (PET) boxes for 30 days at 5 °C and 10 °C. Cape gooseberries were stored in PET packages at 18 °C as a control (room temperature).

2.3. Physical analysis

The polar diameter (PD) and equatorial diameter (ED) of the fruit were measured with a digital caliper (Caliper, Bogotá, Colombia). Weight loss was monitored with an analytical balance (Pioneer, Bogotá, Colombia) to evaluate the weight of the fruit throughout storage. Firmness was determined whit a texturometer (Chatillon digital DFIS-50, Florida, United States) by counting ten fruits per replicate,performing compression tests with a 10.92 mm plunger plate, and descending at a speed of 60 mm/min.The outcome was given in kgf.

2.4. Physicochemical analysis

Ten fruits were taken for each replicate. They were macerated to extract the juice, and their volume was calculated and filtered. An aliquot was taken and placed in an ATAGO PAL1 digital refractometer to determine the soluble solids content (SSC) expressed in °Bx. The pH of the juice was determined using a potentiometer, and the acidity was determined using the titration method with NaOH 0.1N, 5 mL sample, expressing it as percent citric acid, using the following equation [14].

$$\%\ TA = \frac{V * N * F * 100}{Vs} \quad (1)$$

Where, TA = titratable acidity, V = volume of 0.1 N NaOH used in the titration, N = normality of NaOH (0.1 N), F = milliequivalent acid factor 0.064 per citric acid, and Vs = volume of the sample to be evaluated.

2.5. Statistical analysis

The statistical model corresponded to that of a completely randomized experimental design. The variation factors were two pre-treatments before storage (sodium hypochlorite and calcium chloride), storage temperature (5, 10, and 18 °C), and storage time (10, 20, and 30 days). The response variables were weight, polar and equatorial diameter, firmness, SSC, acidity, and pH. All samples were analyzed in triplicate.

The results of the completely randomized design with factorial arrangement were analyzed using tools such as ANOVA, with a confidence level of $p < 0.05$, mean values ($n = 3$), and standard deviation. This analysis was carried out using the statistical software StatGraphics Plus version 5.1.

3. Results and discussion

3.1. Physical change

During storage, fruits remained in good condition, with no rot damage. Statistical analysis (Table 1) showed significant differences in Cape gooseberry equatorial diameter ($p < 0.05$) due to temperature, time, and their interaction, but not pre-treatment, as shown in Figure 1.

Differences were most noticeable after 30 days of storage at 5 °C (Figure 1), where the fruit diameter was preserved, unlike at higher temperatures that changed the fruit diameter; this may be a consequence of water decrease due to processes related to transpiration [15].

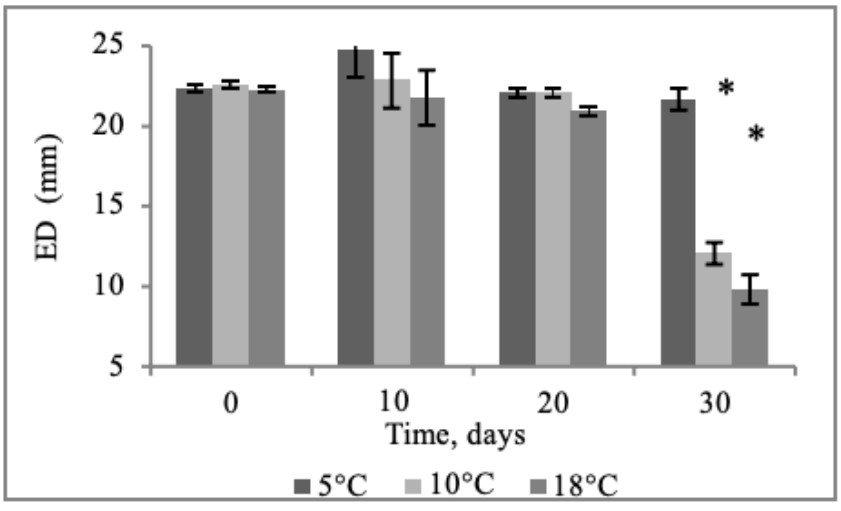

Figure 1. Effect of temperature and time on equatorial diameter.

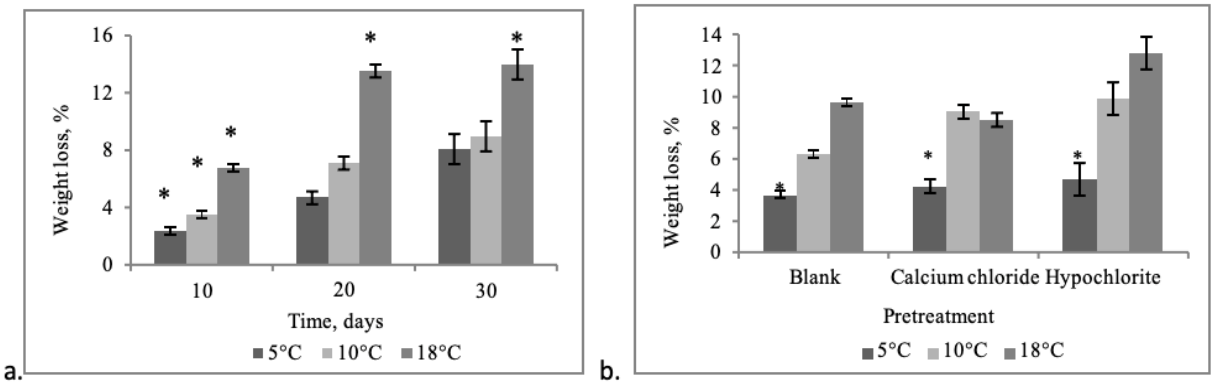

Figure 2. Weight loss of Cape gooseberry stored under three different temperatures. a) Dynamics over time of weight loss of Cape gooseberry. b) Weight loss of cape gooseberry after 30 days of storage subjected to different pre-treatments. Asterisks show significant differences between groups ($p < 0.05$).

Statistical analysis showed a statistically significant ($p < 0.05$) effect on Cape gooseberry weight loss: Low temperatures reduced weight loss, while storage time increased weight loss, as shown in Figure 2a. According to Figure 2b, pre-treatments of Cape gooseberry with hypochlorite and chloride resulted in a higher weight loss than the control. There was a size reduction, which can be correlated with the change in equatorial diameter explained by the respiration processes, where biological factors such as transpiration cause the evaporation of water from the fruit tissue, causing direct quantitative losses such as loss of saleable weight, loss in appearance such as wilting, and loss in texture such as softening.

As previously stated, the fruit consumes the carbohydrate and lipid reserves present in the cellular tissues, resulting in a size reduction [1]. The results revealed that the greatest change occurred between day 20 and possibly day 30 when the fruit had already progressed from the ripening stage to senescence, likely due to depleted food reserves.

On the other hand, fruit firmness was affected by all pre-treatments and time, their interaction, and the temperature–pre-treatment interaction ($p < 0.05$). Figure 3 represents the effect of pre-treatment and temperature on the firmness of Cape gooseberries during storage, demonstrating how a pre-treatment with sodium hypochlorite and storage at 18 °C preserved their firmness (0.424 kgf) after 30 days of storage, compared to cape gooseberries without pre-treatment and storage at 5 °C.

Concerning time, the fruits lost firmness after 20 days of storage (0.397 ± 0.004 kgf compared with 0.4220 ± 0.004 kgf at day 0). These results might be explained by the enzymatic activity: Storage at 18 °C with hypochlorite pre-treatment is most efficient in decreasing pectinolytic enzyme activities, which are responsible for degrading the cell wall, especially in the ripening process [16,17]; fruits stored at 5 °C reduced in size the least, which can be explained by the significant effect of temperature on respiration rate [18]. In terms of firmness, the treatment made a significant but somewhat perplexing difference; calcium treatment was expected to confer stabilization of the cell membrane and cell wall and increase rigidity due to the binding of calcium to free carboxyl groups of polygalacturonate polymer [19].

The concentration used may have been insufficient to reduce ethylene release, which triggers the vast majority of ripening processes. Among these are polygalacturonase activation and xyloglucosyltransferase/endohydrolase (XTH) activity, which is found in the epidermis and has been linked to fruit softening. As a result, the effect of calcium on ethylene release may have been greater

than on cell walls and cuticle binding to pectin, allowing the ripening process of Cape gooseberries to continue. On the other hand, studies on tomatoes have shown that proteins play a determinant role in fruit firmness and are dependent on the degree of maturity [20].

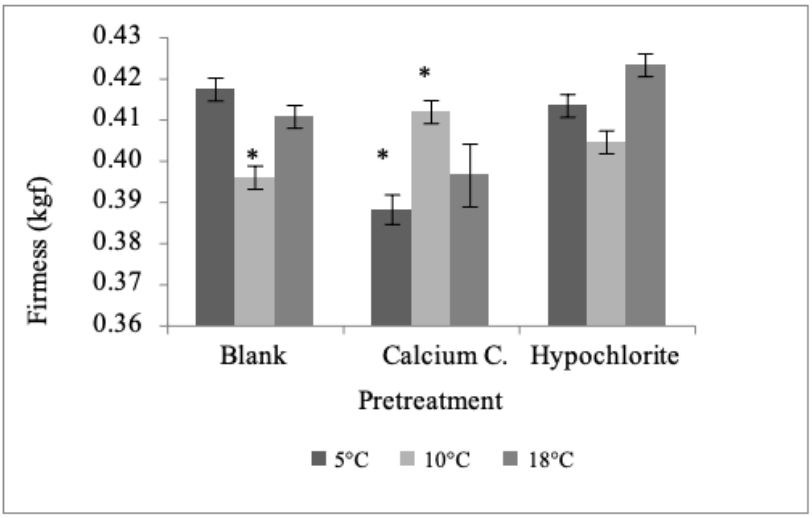

Figure 3. Effect of temperature on the firmness of Cape gooseberry subjected to different pre-treatments. Asterisks show significant differences between groups ($p < 0.05$).

The pre-treatment had the opposite effect on weight loss. Based on the results thus far, we can conclude that the treatments had no positive effect on the preservation of the fruits' quality. This could be due to the loss of the fruit's natural wax, which was removed during immersion in both the hypochlorite and calcium chloride solutions. This wax can exert a barrier effect on both moisture loss and gas exchange during respiration, reducing the respiration rate and thus reducing spoilage factors.

It is important to note that the cell wall degradation processes produce a variety of metabolites, primarily monosaccharides [21], which increase the total soluble solids content. Sugar accumulation typically occurs at the end of the growth stage and the start of ripening, coinciding with the loss of soluble acid invertase activity [22].

Sugars account for 70%–80% of total soluble solids in ripe fruit, and they are formed primarily before the fruit development process is complete. Throughout the ripening process, soluble solids content (SSC) increases in some fruits but not in others. However, in the case of Cape gooseberry, which is a climate-sensitive fruit, the process of starch splitting continues during storage. As a result, the sugars tend to increase, improving the fruit's organoleptic properties, but they are also used as a carbon source during respiration, alongside organic acids. As a result, the balance between generation and consumption determines its dynamic during storage [21,23].

3.2. Evaluation of physicochemical changes

Figure 4a shows that temperature was the most influential factor determining SSC, which increased for the first ten days and then decreased, except for Cape gooseberries stored at 5 °C, where SSC increased until day 30. The pre-treatments showed no significant differences. However, the temperature–pre-treatment interaction was significant, with calcium chloride pre-treatment and storage

at 5 °C producing the highest SSC (13.2 °Bx) after 30 days. SSC values for Cape gooseberry stored at 10 °C, regardless of treatment (Figure 4b), were similar (12–12.2 °Bx).

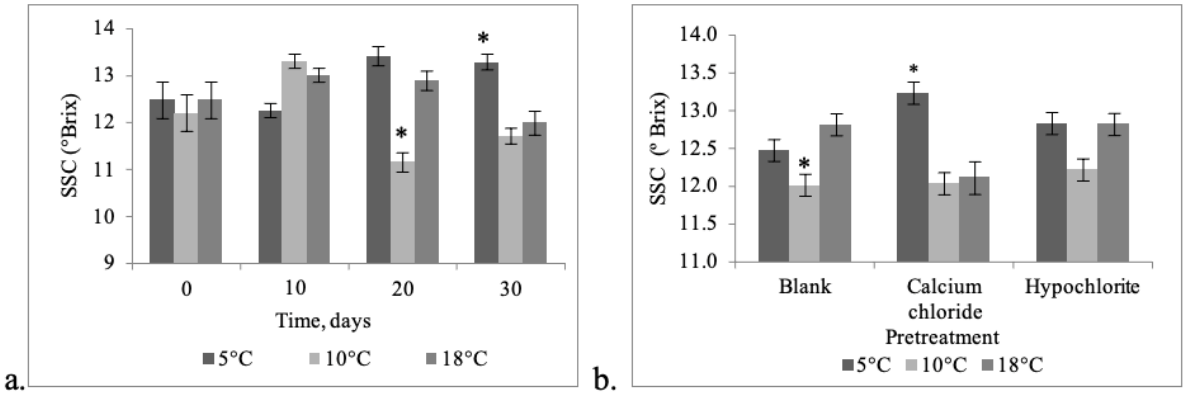

Figure 4. Change in soluble solids content (SSC) during storage of Cape gooseberry. Asterisks show significant differences between groups ($p < 0.05$).

Therefore, storage at 5 °C allowed a balance between starch breakdown and the consumption of sugars and lipids to maintain the biochemical processes involved in ripening. Pre-treatments revealed that Cape gooseberries treated with calcium chloride and stored at 5 °C had the highest SSC. Sugar's role in the activity of enzymes like invertase in the cell wall can affect both cell wall structure and cuticle [21].

At 5 °C, the metabolic activities related to respiration in the fruit might have been decelerated, leading to a slower breakdown of sugars to produce energy. This slower metabolic rate, combined with dehydration processes, as evidenced by changes in the equatorial diameter (ED) (Figure 1), could have contributed to the observed increase in SSC. Conversely, fruits stored at 18 °C exhibited the lowest ED, indicating greater moisture loss to the environment, which likely influenced the positive change in SSC.

Fruits stored at 18 °C tended to continue ripening, converting starches into sugars to utilize them as an energy source. Consequently, there was a near-equilibrium between the sugars released from starches and those consumed by respiration [24]. On the other hand, at a temperature of 10 °C, the degradation of sugars occurred more rapidly than the conversion of starches into sugars, resulting in a slight reduction in available sugars [25]. This behavior can have significant implications for the quality and flavor of fruit stored at different temperatures, as well as its shelf life and suitability for human consumption.

The data obtained in this study are similar to those obtained by Pinzón et al. [11] during an experiment regarding the behavior of the Cape gooseberry fruit, *Physalis peruviana* L., at different storage temperatures. Researchers found that the control treatment at 20 °C produced a maximum of 17.3 ± 0.96 °Bx, while the 2 and 4 °C treatments produced maximum values of 14.5 ± 0.40 °Bx and 15.8 ± 0.46 °Bx, respectively. As a result of the low temperature, the fruit's respiratory rate was reduced.

The data depicted in Figure 4b indicate that, in addition to the impact of low temperatures, the application of $CaCl_2$ treatments led to an increase in SSC. This effect aligns with previous research indicating that $CaCl_2$ can mitigate the respiration process, thereby slowing down fruit ripening [26]. Our study further elucidated that the combined effect of calcium chloride treatment and a temperature of 5 °C promoted an augmentation in SSC levels within the fruit. Understanding these interactions is pivotal for optimizing fruit preservation methods and enhancing overall fruit quality during storage.

Table 1. Statistical analysis of physicochemical parameter of cape gooseberry (var. Andina), subjected to different preservation methods.

	Equatorial diameter			Firmness			Polar diameter		
	DF	T	P	DF	T	P	DF	T	P
Preservation method	18	0.56	NS	14	10.41	0.0017	18	0.55	NS
Temperature	18	17.95	<0.0001	14	1.76	NS	18	15.97	0.0001
Time	63	100.06	<0.0001	36	5.1	0.0048	63	104.1	<0.0001
Pre-treatment vs. temperature	18	2.4	NS	14	16.66	<0.0001	18	1.02	NS
Pre-treatment vs. time	63	1.75	NS	36	0.46	NS	63	1.97	NS
Temperature vs. time	63	23.95	<0.0001	36	0.86	NS	63	25.88	<0.0001
	Weight loss			SSC			TA		
	DF	T	P	DF	T	P	DF	T	P
Preservation method	18	9.4	0.0016	18	1.18	NS	18	5.25	0.0159
Temperature	18	58.22	<0.0001	18	16.38	<0.0001	18	16.52	<0.0001
Time	44	152.06	<0.0001	63	4.61	0.0056	63	20.76	<0.0001
Pre-treatment vs. temperature	18	1.57	NS	18	6.8	0.0016	18	8.78	0.0004
Pre-treatment vs. time	44	6.03	0.0006	63	0.68	NS	63	0.8	NS
Temperature vs. time	44	11.94	<0.0001	63	17.12	<0.0001	63	5.8	<0.0001

NS: Not significant; SSC: soluble solids content; TA: titratable acidity; DF: degrees of freedom; T: a value that describes the relationship between a sample and its population; P: probability value. The value obtained statistically represents the significance of the variable analyzed ($p < 0.05$).

Table 1 shows the degrees of freedom, T value, which describes the relationship between a sample and its population, and the probability value for the parameters equatorial diameter, firmness, polar diameter, weight loss, soluble solids content, and total acidity for the different treatments regarding preservation method, temperature, time, and the interactions pre-treatment vs. temperature, pre-treatment vs. time, and temperature vs. time. As shown in Table 1, pre-treatment vs. temperature was significant for firmness, SSC, and AT (Table 2A, Table 2B). Pre-treatment vs. time was significant for weight loss (Table 3), and temperature vs. time was significant for polar diameter, equatorial diameter, soluble solids, acidity, and weight loss (Table 4A, 4B).

Table 2 A. Significant interaction for pre-treatment vs. temperature (firmness, SSC).

	°C	Media		E	DF	T	P	Lower	Upper
Firmness									
Blank	5	0.4173	A	0.002780	14	150.09	<0.0001	0.4113	0.4233
	10	0.3960	B	0.002801	14	141.39	<0.0001	0.3900	0.4020
	18	0.4107	A	0.002780	14	147.73	<0.0001	0.4048	0.4167
CC	5	0.3883	B	0.003608	14	107.62	<0.0001	0.3806	0.3960
	10	0.4120	A	0.002781	14	148.17	<0.0001	0.4061	0.4180
	18	0.3966	AB	0.007634	14	51.95	<0.0001	0.3802	0.4130
HC	5	0.4134	A	0.002780	14	148.70	<0.0001	0.4075	0.4194
	10	0.4045	AB	0.002801	14	144.42	<0.0001	0.3985	0.4105
	18	0.4234	A	0.002780	14	152.29	<0.0001	0.4175	0.4294
SSC									
Blank	5	12.473	BC	0.1459	18	85.49	<0.0001	12.1666	12.7797
	10	12.010	C	0.1459	18	82.32	<0.0001	11.7040	12.3171
	18	12.816	AB	0.1461	18	87.75	<0.0001	12.5094	13.1231
CC	5	13.240	A	0.1461	18	90.65	<0.0001	12.9332	13.5468
	10	12.041	C	0.1461	18	82.45	<0.0001	11.7350	12.3487
	18	12.116	BC	0.2148	18	56.40	<0.0001	11.6651	12.5679
HC	5	12.836	AB	0.1459	18	87.98	<0.0001	12.5303	13.1434
	10	12.222	BC	0.1459	18	83.77	<0.0001	11.9161	12.5291
	18	12.823	AB	0.1461	18	87.80	<0.0001	12.5170	13.1307

NS: Not significant; SSC: soluble solids content; DF: degrees of freedom; T: a value that describes the relationship between a sample and its population; P: probability value; SE: standard error; CC: calcium chloride; HC: hypochlorite. Means with the same letter are not significantly different. The value obtained statistically represents the significance of the variable analyzed ($p < 0.05$).

Table 2 B. Significant interaction for pre-treatment vs. temperature (acidity total).

	°C	Media		SE	DF	T	P	Lower	Upper
Blank	5	1.6448	CB	0.04901	18	33.56	<0.0001	1.5418	1.7477
	10	1.6988	B	0.04901	18	34.66	<0.0001	1.5958	1.8017
	18	1.6058	CB	0.04906	18	32.73	<0.0001	1.5027	1.7089
CC	5	1.6753	B	0.04906	18	34.15	<0.0001	1.5722	1.7784
	10	1.6576	B	0.04906	18	33.79	<0.0001	1.5545	1.7607
	18	1.3605	C	0.06579	18	20.68	<0.0001	1.2223	1.4987
HC	5	1.9599	A	0.04901	18	39.99	<0.0001	1.8570	2.0629
	10	1.6783	B	0.04901	18	34.25	<0.0001	1.5754	1.7813
	18	1.5137	CB	0.04906	18	30.85	<0.0001	1.4107	1.6168

NS: Not significant; DF: degrees of freedom; T: a value that describes the relationship between a sample and its population; P: probability value; SE: standard error. The value obtained statistically represents the significance of the variable analyzed ($p < 0.05$).

Table 3. Significant interaction for pre-treatment vs. time (weight loss).

	Time	Media		SE	DF	T	P	Lower	Upper
Blank	10	3.679	D	0.2479	44	14.84	<0.0001	3.1795	4.1785
	20	6.3255	BC	0.4512	44	14.02	<0.0001	5.4162	7.2348
	30	9.6319	AB	1.0497	44	9.18	<0.0001	7.5164	11.7474
CC	10	4.229	D	0.2479	44	17.06	<0.0001	3.7295	4.7286
	20	9.0614	AB	0.4512	44	20.08	<0.0001	8.1521	9.9707
	30	8.541	AB	1.0497	44	8.14	<0.0001	6.4255	10.6565
HC	10	4.6958	CD	0.2479	44	18.95	<0.0001	4.1962	5.1953
	20	9.8893	A	0.4512	44	21.92	<0.0001	8.9800	10.7986
	30	12.824	A	1.0497	44	12.22	<0.0001	10.708	14.9395

NS: Not significant; DF: degrees of freedom; T: a value that describes the relationship between a sample and its population; P: probability value; SE: standard error; CC: calcium chloride; HC: hypochlorite. Means with the same letter are not significantly different. The value obtained statistically represents the significance of the variable analyzed ($p < 0.05$).

Table 4 A. Significant interaction for temperature vs. time (PD, ED, SSC, AT).

°C	Time	Media		SE	DF	T	P	Lower	Upper
Equatorial diameter (ED)									
5	0	22.3569	A	0.1939	63	115.31	<0.0001	21.9694	22.7443
	10	24.7491	A	1.7081	63	14.49	<0.0001	21.3357	28.1624
	20	22.0741	A	0.2828	63	78.06	<0.0001	21.5090	22.6392
	30	21.6899	A	0.6795	63	31.92	<0.0001	20.3321	23.0477
10	0	22.5543	A	0.1939	63	116.33	<0.0001	22.1668	22.9417
	10	22.8585	A	1.7081	63	13.38	<0.0001	19.4451	26.2718
	20	22.0556	A	0.2828	63	78	<0.0001	21.4905	22.6206
	30	12.0927	B	0.6795	63	17.8	<0.0001	10.7349	13.4505
18	0	22.2729	A	0.1939	63	114.88	<0.0001	21.8855	22.6604
	10	21.7971	A	1.7081	63	12.76	<0.0001	18.3838	25.2105
	20	20.9573	A	0.2828	63	74.11	<0.0001	20.3923	21.5224
	30	9.8462	B	0.9054		10.87	<0.0001	8.0368	11.6556
Polar diameter (PD)									
5	0	20.7703	A	0.1651	63	125.8	<0.0001	20.4404	21.1002
	10	22.7198	A	1.7132	63	13.26	<0.0001	19.2963	26.1434
	20	20.3386	A	0.267	63	76.17	<0.0001	19.8049	20.8722
	30	20.2543	A	0.6218	63	32.57	<0.0001	19.0118	21.4969
10	0	20.8074	A	0.1651	63	126.03	<0.0001	20.4775	21.1373
	10	21.0042	A	1.7132	63	12.26	<0.0001	17.5806	24.4277
	20	20.2603	A	0.267	63	75.87	<0.0001	19.7267	20.7939
	30	11.2134	B	0.6218	63	18.03	<0.0001	9.9709	12.4560
18	0	20.6655	A	0.1651	63	125.17	<0.0001	20.3356	20.9954
	10	20.2023	A	1.7132	63	11.79	<0.0001	16.7787	23.6258
	20	19.2406	A	0.267	63	72.05	<0.0001	18.7069	19.7742
	30	8.9295	B	0.8247	63	10.83	<0.0001	7.2814	10.5776

Continued on the next page

°C	Time	Media		SE	DF	T	P	Lower	Upper
Soluble solids content (SSC)									
5	0	12.4667	ABC	0.3883	63	32.11	<0.0001	11.6908	13.2425
	10	12.2444	ABC	0.1503	63	81.49	<0.0001	11.9442	12.5447
	20	13.4111	A	0.2049	63	65.44	<0.0001	13.0016	13.8206
	30	13.2778	A	0.1675	63	79.26	<0.0001	12.9430	13.6125
10	0	12.2	ABC	0.3883	63	31.42	<0.0001	11.4241	12.9759
	10	13.3000	A	0.1503	63	88.51	<0.0001	12.9997	13.6003
	20	11.1556	C	0.2049	63	54.44	<0.0001	10.7460	11.5651
	30	11.7111	C	0.1675	63	69.91	<0.0001	11.3764	12.0459
18	0	12.4667	ABC	0.3883	63	32.11	<0.0001	11.6908	13.2425
	10	13	AB	0.1503	63	86.52	<0.0001	12.6997	13.3003
	20	12.8889	AB	0.2049	63	62.89	<0.0001	12.4794	13.2984
	30	11.9867	BC	0.2537	63	47.25	<0.0001	11.4798	12.4936
Total acidity (AT)									
5	0	1.9911	A	0.1073	63	18.55	<0.0001	1.7766	2.2056
	10	1.6782	A	0.0376	63	44.62	<0.0001	1.6031	1.7534
	20	1.6782	A	0.0844	63	19.87	<0.0001	1.5094	1.8470
	30	1.6924	A	0.0462	63	36.61	<0.0001	1.6001	1.7848
10	0	1.8702	A	0.1073	63	17.43	<0.0001	1.6558	2.0847
	10	1.7209	A	0.0376	63	45.76	<0.0001	1.6457	1.7960
	20	1.5431	AB	0.0844	63	18.27	<0.0001	1.3743	1.7119
	30	1.5787	A	0.0462	63	34.15	<0.0001	1.4863	1.6710
18	0	1.9911	A	0.1073	63	18.55	<0.0001	1.7766	2.2056
	10	1.6356	A	0.0376	63	43.49	<0.0001	1.5604	1.7107
	20	1.2302	BC	0.0844	63	14.56	<0.0001	1.0614	1.3990
	30	1.1165	C	0.0692	63	16.12	<0.0001	0.9781	1.2549

Table 4 B. Significant interaction for temperature vs. time (weight loss).

°C	Time	Media		SE	DF	T	P	Lower	Upper
Weight loss									
	10	2.3544	E	0.2479	44	9.5	<0.0001	1.8549	2.8539
5	20	4.6917	CD	0.4512	44	10.4	<0.0001	3.7825	5.6010
	30	8.0702	BC	1.0497	44	7.69	<0.0001	5.9547	10.1857
	10	3.5216	C	0.2479	44	14.21	<0.0001	1.8549	2.8539
10	20	7.0936	BC	0.4512	44	15.72	<0.0001	6.1843	8.0029
	30	8.9616	B	1.0497	44	8.54	<0.0001	6.8461	11.0771
	10	6.7278	BC	0.2479	44	27.14	<0.0001	6.2282	7.2273
18	20	13.4909	A	0.4512	44	29.9	<0.0001	12.5816	14.4002
	30	13.9652	A	1.0497	44	13.3	<0.0001	11.8497	16.0807

NS: Not significant; DF: degrees of freedom; T: a value that describes the relationship between a sample and its population; P: probability value; SE: standard error. Means with the same letter are not significantly different. The value obtained statistically represents the significance of the variable analyzed ($p < 0.05$).

3.3. Cape gooseberry pH

Temperature, time, and their interaction contributed significantly ($p < 0.05$) to the change in Cape gooseberry pH. According to Figure 5, the pH of cape gooseberries stored at 18 °C increased from 3.76 to 4.12 at the end of day 30, whereas Cape gooseberries maintained at 10 and 5 °C ended with a pH of 3.9 and 3.8, respectively.

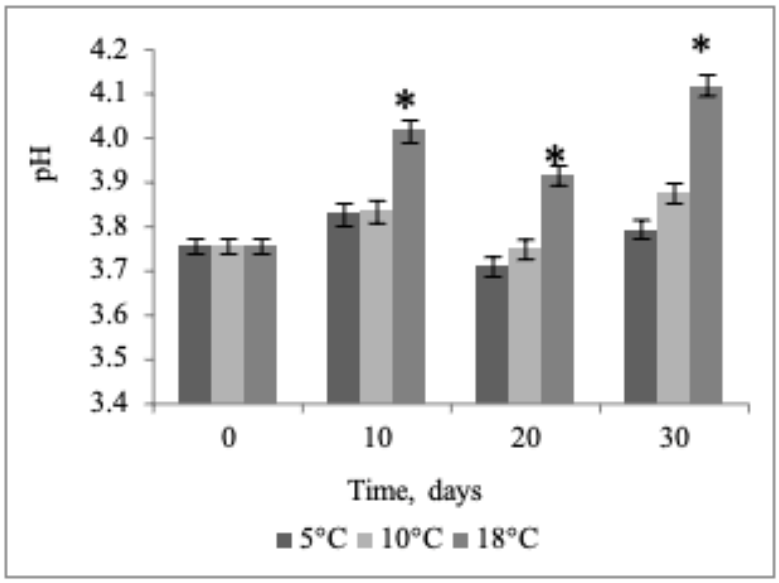

Figure 5. Change in pH of Cape gooseberry during storage at three temperatures. Asterisks show significant differences between groups ($p < 0.05$).

Cape gooseberry fruits, and all fruits in general, become less acidic over time as a result of the use of organic acids as a respiratory substrate and carbon skeletons for the synthesis of new compounds during ripening [27]. As we have seen in this paper, Cape gooseberry has the behavior of a climacteric fruit; hence, fruits stored at least at 10 °C do not show any change because the respiratory process stops.

The findings of this study are similar to those of Olivares-Tenorio et al. [28], who discovered an increase in pH in Cape gooseberry, obtaining maximum values of 4.7 after 76 d at 12 °C. The authors explained that the trend was caused by the Cape gooseberry having the behavior of climacteric fruits.

However, this paper shows that, although the increase in ascorbic acid could start at the first moment of post-harvest at 12 °C, such an increase only happened on day 44. After this, the compound started to decrease, which could be due to the oxidation process, which explains the behavior of the pH at 5 and 10 °C.

3.4. Titratable acidity

The fruits remained in good condition, with no rot damage. Statistical analysis (Table 1) showed significant differences in Cape gooseberry equatorial diameter ($p < 0.05$) due to temperature, time, and their interaction, but not pre-treatment. The differences were most noticeable after 30 days of storage at 5 °C, where the fruit diameter was preserved, unlike at higher temperatures that changed the fruit diameters; this may be a consequence of the decrease in water due to processes related to transpiration [15].

The findings revealed that the acidity of cape gooseberry was affected by time, temperature, and their interaction; therefore, significant differences ($p < 0.05$) were found in the fruit stored at 18 °C at 20 and 30 days of storage.

According to Figure 6a, acidity decreased with time, and the effect of temperature was observed after 20 days of storage. The lowest acidity values were found in fruits stored at 18 °C for 20 days (1.23%) and after 30 days (1.12%). On the other hand, Cape gooseberry pre-treated with hypochlorite was the only one whose acidity was affected by storage temperature (Figure 6b). The highest values were found in Cape gooseberries stored at 5 °C (1.96%), while the lowest value was observed in Cape gooseberries stored at 18 °C (1.21%).

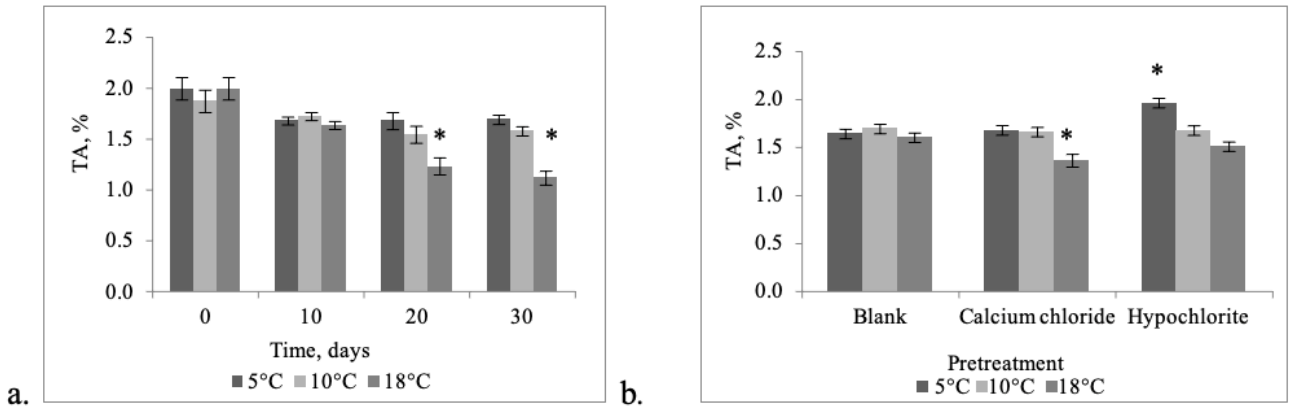

Figure 6. Changes in total acidity of Cape gooseberry during storage at various temperatures. a) Time. b) Pre-treatments. Asterisks show significant differences between groups ($p < 0.05$).

As already seen in pH changes, acidity decreases as the ripening process progresses because organic acids are used as substrates during respiration; another compound like ascorbic acid might degrade due to oxidation processes. Bravo et al. [29] investigated genotype effects at two different harvest times. Fruits were stored for 18 h at 4 °C; before analysis, the average TA was 1.88% ± 0.39%. A similar result is found in the findings of this paper; they concluded that ripening processes are one of the main factors in the change of this variable.

Previous works have also shown that the chemical agent does not play a very important role in the change of titratable acidity; instead, the factor that most affects acidity is high temperature, due to its utilization in the hydrolysis of polysaccharides and non-reducing sugars [30]. On the other hand, fruits were kept at a low temperature, causing the acidity to increase, possibly due to an adaptation of the metabolism at 5 °C and 10 °C [31]. The acidity was 1.36% ± 0.065% at 18 °C with the calcium chloride treatment, which was below the range due to a decrease in respiratory activity caused by an increase in calcium in the fruit cells, causing a blockage of the conversion of organic acids [32].

4. Conclusions

Temperature and time are the two factors that most influence the quality and physicochemical properties such as polar diameter, equatorial diameter, soluble solids content, acidity, and weight loss of the Andean variety of Cape gooseberries. The interaction between storage method and temperature

had a significant influence on firmness, soluble solids content, and total acidity. The interaction between storage method and time had a significant influence on firmness, soluble solids content, and total acidity. The interaction between storage method and time had a significant influence on Cape gooseberry weight loss.

The barrier method (calcium chloride in a solution of 300 ppm) was the best preservation method for the Andean variety Cape gooseberry in terms of physical and chemical properties. Calcium chloride assisted the fruit in retaining properties like polar and equatorial diameters, controlling weight loss, and strengthening the berry (penetration resistance). It also aids in the preservation of soluble solids, pH, and acidity under storage at 10 ºC, preserving the quality of the Cape gooseberry fruit for up to 20 days.

The treatment with the greatest impact was sodium hypochlorite pre-treatment at 18 °C. The fruit was significantly impacted by this disinfectant because its respiratory intensity increased, resulting in a tendency to ripen.

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Conflict of interest

All authors declare that they have no conflict of interest.

Author contributions

Conceptualization: M.C.G.; data curation: A.C.D.; formal analysis: M.C.G and M.P.T.; investigation: M.C.G. and M.P.T.; methodology: M.C.G; chemical analysis: A.C.D.; statistical analysis: M.C.G and M.P.T. writing original draft: M.C.G, M.P.T and A.C.D.; writing review and editing: M.P.T. All authors have read and agreed to the published version of the manuscript.

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