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Research Article

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Physicochemical Properties of *Psidium guineense* (guava) as a Function of Temperature and Storage Time

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Abstract

Psidium guineense, a tropical fruit belonging to the Myrtaceae family, has high content of bioactive compounds with antioxidant properties. However, this fruit is perishable, and its postharvest shelf life is challenging for its commercialization and industrial processing, emphasizing the need for effective preservation strategies. Therefore, this study evaluates the impact of storing *P. guineense* for 15 days at different temperatures (2 ˚C, 4 ˚C, and ambient room temperature (RT) ≈ 21 ˚C) on its physicochemical properties. For this, 250 fruits were selected based on their size (ø ≈ 4 - 4.5 cm), color (yellowish green), and absence of damage, transported to the laboratory under refrigeration (10 ˚C), and stored under the designated conditions. Key parameters, including water activity, pH, soluble solids in degrees Brix (˚Brix), titratable acidity (TTA), phenolic content, and antioxidant activity, were analyzed from day 1 to day 15. Storage at 2 ˚C maintained stable pH and soluble solids, balancing sweetness and acidity while preserving antioxidant activity, though chilling injury compromised texture and color. At 4 ˚C, pH also remained stable, and phenolic compounds were partially retained, but antioxidant activity was lower than at 2 ˚C. In contrast, RT storage accelerated deterioration, resulting in damaging fruit. In conclusion, temperature control is essential for extending the postharvest life and commercial viability of *P. guineense*. Further studies on preservation methods are needed to optimize storage conditions, reduce physiological deterioration, and maintain physicochemical integrity for broader food industry applications.

Keywords

Psidium guineense, Quality, Storage, Postharvest, Climacteric fruits

Introduction

P. guineense, a member of the Myrtaceae family, is a tropical fruit from humid climates, requiring minimal agronomic input for successful cultivation [1]. This species grows on trees 2 - 6 meters in height, characterized by their ability to flower throughout the year [2]. The fruit is a globose to subglobose berry whose color transitions from greenish yellow to orange, featuring a juicy, edible pulp [3]. Its diameter varies between 4 and 7 cm, with thin skin and a fleshy, yellow interior, making it an ideal candidate for diverse food processing applications [2, 4].

P. guineense is distributed from northern Argentina and Peru to southern Mexico and in Caribbean Islands such as Trinidad, Martinique, Jamaica, and Cuba. Optimal growth is achieved in ecosystems with annual precipitation ranging from 1,000 - 2,400 mm, allowing them to adapt to varying humidity levels [3-8]. This resilience underscores its potential for cultivation across regions with diverse climatic conditions, promoting its agricultural and industrial importance. With its ability to thrive under variable environmental conditions, *P. guineense* emerges as an important resource for the food industry, given its versatility and nutritional value. This adaptability, combined with further exploration of its biological and functional properties, holds promise for expanding its applications in tropical agriculture.

From a sensory perspective, the flavor of *P. guineense* is characterized as subacidic and less musky than *Psidium guajava* [2]. Its nutritional composition underscores its significance for the food industry, as it is rich in soluble sugars, proteins, dietary fibers, and vitamins, particularly vitamin C. Moreover, it contains bioactive compounds such as tannins, flavonoids, and carotenoids, renowned for their antioxidant, anti-inflammatory, and anticancer properties [9-14]. Ethnobotanically, in Brazil, *P. guineense* fruits are traditionally employed for inflammation and pain management [5]. Recent research further highlights its potential as a functional food, reinforcing its value in the food industry [6, 12, 13, 15].

Despite its nutritional importance, guavas, including *P. guineense*, exhibit limited postharvest shelf life at ambient temperature due to their thin skin, which makes them prone to pathogen invasion, water loss, and rapid textural degradation [16]. As climacteric fruits, they experience a respiration peak shortly after harvest, accelerating deterioration [17, 18].

During storage, *P. guineense* maintains high metabolic activity, gradually deleting sugars, phenols, free amino acids, soluble proteins, flavonoids, and ascorbic acid. Ethylene production, transpiration, and pathogen susceptibility significantly compromise its commercial quality. Fruits of the *Psidium* genus are notably perishable and highly seasonal, posing substantial commercialization challenges with postharvest losses exceeding 90% of production [19]. Previous studies report a shelf life of approximately one week at ambient temperature or two weeks under controlled refrigeration (6 - 8 ˚C) [10]. However, under environmental conditions, quality may degrade within two to three days, emphasizing the critical need for effective conservation strategies [20].

Strategic approaches to enhance postharvest longevity are essential to mitigate losses and improve the commercial viability of this nutritionally and functionally valuable fruit. Cold storage is a critical approach to extending fruit shelf life; however, prolonged storage can result in chilling injuries [17]. A short shelf life, high sensitivity to mechanical damage, and significant postharvest losses pose a substantial barrier to large-scale commercialization. Varieties such as *P. guajava* and *Psidium cattleianum* have been extensively studied to optimize their storage conditions, identifying temperature and conservation time as key factors to mitigate deterioration [21, 22]. Research indicates that refrigeration at 5 ± 2 ˚C helps retain bioactive properties, including lipids and antioxidants [23]. Additionally, storage at temperatures near the freezing point has shown promise in extending guava's postharvest shelf life and reducing oxidative stress associated with cellular damage [17, 21]. In contrast, limited information exists on *P. guineense*. Few studies have evaluated critical parameters such as antioxidant activity, acidity, and soluble solids during its postharvest storage, hindering the development of tailored conservation strategies [24, 25]. This study, therefore, assessed *P. guineense* under varying storage conditions near freezing (2 ˚C, 4 ˚C, and RT ≈ 21 ˚C) for 15 days. Key physicochemical parameters and bioactive compounds, including antioxidant activity, water content, and maturity index (MI), were analyzed. The findings address the knowledge gap surrounding this undervalued species and contribute to improving tropical fruit conservation strategies, minimizing waste, and enhancing commercial potential.

Materials and Method

Sample preparation

P. guineense fruits were provided by a local producer in Magdalena, Chachapoyas, Amazonas, Peru (6˚22'22'' S; 77˚54'6" W; 1892 masl); they were manually harvested to prevent physical damage [26], those with black spots, cracks, or damaged were excluded from this study. Only 250 mature fruits measuring 4 - 4.5 cm in diameter and exhibiting a yellowish-green color [3] were selected and transported to the Food Engineering and Postharvest Research Laboratory from the Universidad Nacional Toribio Rodríguez de Mendoza. For transportation (45 min), two portable coolers (40 × 54 × 30 cm) with ice bags were used to maintain an inner temperature of 10 ˚C. Then, fruits were washed with distilled water to remove impurities and surface residues. At this stage, 25 fruits were discarded due to damage. The remaining 225 fruits were randomly assigned (75 units per condition) to three storage conditions: 2 ˚C, 4 ˚C, and ambient temperature (≈ 21 ˚C, 66.08% relative humidity). For the refrigeration conditions (2 ˚C and 4 ˚C), two refrigeration units of the same model (LG, Moist Balance Crisper™ system) were used. These units are designed to maintain an optimal humidity level in the storage compartment through a controlled condensation and evaporation mechanism, contributing to fruit preservation. Fruits stored at RT were kept in the dark to avoid photo degradation. A 15-day storage period was chosen for this study due to the short shelf life of the guava. The pH, TTA, water activity, antioxidant activity, weight loss, and color were analyzed for 15 days every 24 h in triplicate (Figure 1).

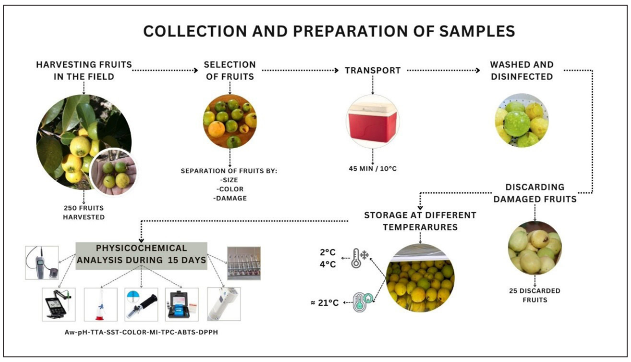

Figure 1: Graphic description of sample preparation.

Water activity (Aw)

Aw values were determined by the method described by Pesantes-Gallardo et al. [26], using a portable Aw instrument (Rotronic AG, HygroPalm, Bassersdorf, Switzerland). For the analysis, two fruits were used for each temperature and storage time. The fruits were crushed in a laboratory pestle and mortar until a homogeneous sample was obtained. Subsequently, 37.8 g of the crushed sample was taken and placed in the device reservoir until complete. After stabilization time (4 min), the Aw values were recorded in triplicate.

Measure of pH and TTA

The pH measurement (Hanna Instruments, HI2020, WoonsocketU, USA) was performed after the calibration of the instrument, following the procedure described by Nur et al. [27], with some modifications. For the analysis, samples were prepared by mixing approximately 10 g of pulp with 90 ml of ultrapure water in a beaker. Subsequently, the electrode was immersed in each sample, allowing the reading to stabilize before recording the values. The pH measurements were carried out in triplicate to ensure the accuracy of the results.

The TTA was determined using the official method AOAC 942.15A [26]. This process was carried out using a NaOH solution in the presence of a phenolphthalein indicator. Subsequently, the percentage acidity was calculated using equation 1.

$$\text{TTA (Acidity \%)} = \frac{\text{(ml de NaOH)} \times \text{(N)} \times \text{(weight (mEq) predominant acid)}}{\text{sample weight (g)}} \times 100 \quad (1)$$

Where: N is the normality of the titrant (NaOH) (0.01 N), and 0.064 g corresponds to the milliequivalent weight (mEq) of citric acid, which is the predominant acid in guava [28].

Total soluble solids (SST)

For the evaluation of SST, a homogeneous extract was obtained by grinding the pulp in a laboratory mortar. Subsequently, a few drops of the extract were placed in a portable refractometer (WZ-103, TOP Instrument Co., Zhejiang, China), and its concentration was measured following the methodology described by Balcázar-Zumaeta et al. [29]. The results of the measurements expressed in °Brix were recorded in triplicate to ensure the accuracy and reliability of the data.

Color coordinates

The color coordinates were determined with a trichromatic reflection colorimeter (Chroma Meter, CR-400, Japan). The color analysis was performed on the peel of the *P. guineense* fruit, and the equipment was placed at 10 different points on the fruit to obtain a representative measurement. The results were expressed according to the CIE Lab system. In this system, L^* represents lightness (from 0 - 100, from black to white), a^* indicates the intensity of the red-green component (positive for red, negative for green), and b^* the intensity of the yellow-blue component (positive for yellow, negative for blue) [30]. The hue angle (h°), which reflects the perceived h° of the color, was also calculated, with values such as red (0°), orange (45°), and yellow (90°). This angle, or h°, was obtained using equation 2.

$$h^\circ = \tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (2)$$

In addition, the Chora value (C^*), which indicates the purity or saturation of the color, was determined using equation 3.

$$C^* = \sqrt{(a^{*2} + b^{*2})} \quad (3)$$

The color index (CI) was also calculated using equation 4.

$$CI = \left(\frac{a^*}{b^*}\right) \quad (4)$$

Finally, the color difference (ΔE or ΔE* ab), which represents the Euclidean distance between two points in CIELAB space, was calculated by equation 5.

$$\Delta E^* = \sqrt{\left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]} \quad (5)$$

MI

This analysis was calculated according to Reyna-Gonzales et al. [31], following equation 6.

$$MI = \frac{SST}{TTA}$$

Total phenolic content (TPC)

For the determination of TPC in guava fruits, the Folin-Ciocalteu method [32] with some modifications. 1 mL of sample was extracted from guava fruits, which were mixed with 2.5 mL of 10% Folin-Ciocalteu reagent and 2 mL of 4% sodium carbonate solution. The mixture was stirred and left in the dark for 2 h at RT. Subsequently, the absorbance of each sample was measured at 750 nm against a blank using a GENESYSTM spectrophotometer (Thermo Scientific, Waltham, USA). The TPC was calculated using a gallic acid standard curve ($y = 0.0009x + 0.0825$; $R^2 = 0.9991$), and results were expressed as mg gallic acid equivalents (GAE) per gram of fresh weight (mg GAE/g).

Antioxidant activity

DPPH assay (2,2-Diphenyl-1-picrylhydrazyl)

It was performed following the procedure outlined by Medina-Mendoza et al. [33], with some modifications. The DPPH solution was prepared by dissolving DPPH in ethanol until an absorbance of 0.7 ± 0.02 units at 517 nm was obtained. To carry out the reaction, 0.1 mL of *P. guineense* extracts were mixed with 3.9 mL of this DPPH solution in a test tube. The mixture was kept under dark conditions for 30 min to avoid photodegradation of DPPH. After the reaction period, the resulting solution's absorbance reduction was evaluated using a spectrophotometer (GENESYSTM, Thermo Scientific, Waltham, MA, USA) at 517 nm. Three repetitions of the analysis were performed to ensure reproducibility and accuracy of the results. The results were expressed as μmol Trolox equivalent/mg of sample (μmol TE/mg), which facilitated the comparison of the antioxidant capacity of the guava extracts. A light purple color was observed in the solution, indicating the reaction between DPPH and the antioxidant compounds present in the guava extract.

ABTS assay (2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid))

It was performed according to the method proposed by Pesantes-Gallardo et al. [26], with some modifications. The radical cation ABTS was generated by reacting 5 mL of an aqueous solution of ABTS with 88 µM potassium persulphate, reaching a final concentration of 2.45 mM. The mixture was kept in the dark for 16 h before use. Subsequently, it was diluted with ethanol to an absorbance of 0.7 ± 0.02 units at 734 nm, measured using a spectrophotometer (GENESYS-TM, Thermo Scientific, Waltham, MA, USA). For the assays, 30 µM guava extracts were reacted with 3 mL of the product resulting from the ABTS radical solution, which showed a blue-green color in dark conditions. After 6 min of reaction, the absorbance was measured at 734 nm. The analyses were carried out in three replicates (R) to ensure the accuracy and reproducibility of the results. The results obtained were expressed in µmol TE/mg.

Statistical analysis and experimental design

The experimental design is shown in table 1. Results were presented as mean ± standard deviation (SD) based on three independent R. An analysis of variance (ANOVA) was performed to assess differences between experimental groups, and a one-way analysis was performed to study the impact on the sample of temperature and storage time. The normality of the data was verified by the parametric ANOVA test, followed by Tukey's post hoc multiple comparisons ($p \leq 0.05$). All statistical analyses were carried out using the R programming language, with the R statistical package (RStudio, version 4.3.3, Boston, MA, USA).

Results and Discussion

Physicochemical properties

Water activity

The analysis of Aw in *P. guineense* during storage (Figure 2a) reveals the influence of free water availability on its preservation [34]. Initially, the average Aw value under three storage conditions was between 0.93 - 0.94 after the first 24 h (day 1), reflecting a high free water availability, characteristic of fresh fruits [35]. During the first week (days 3 - 7), Aw remained stable at 0.93 at RT (21 °C) and at 2 °C, while at 4 °C it decreased slightly to 0.92. This indicates that, at this initial stage, the three storage conditions contributed to preserving the cell structure of the fruit for 7 days, with a low dehydration rate and minimal Aw variations.

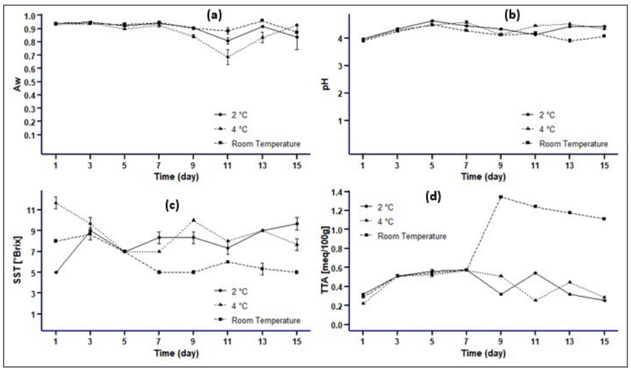

Figure 2: (a) Monitoring of Aw, **(b)** pH, **(c)** SST, and **(d)** TTA during different storage conditions of *P. guineense*. All values are expressed in mean ± SD (n = 3). Different letters on the bars indicate significant differences between days in each storage condition (Tukey's multiple range test, $p < 0.05$).

From day 9 onwards, more pronounced changes were observed. In guavas stored at 4 °C, Aw decreased significantly from 0.84 - 0.68 by day 11, due to increased water loss by dehydration caused by the thermal gradient between the fruit and its environment [36]. Guavas stored at 2 °C experienced a less marked reduction from 0.90 - 0.80, which could be associated with differences in the initial water content among the selected fruits. In contrast, Aw remained above 0.9 at RT over the same period (days 9 - 11), indicating better stability in free water content. However, this could increase the risk of microbial growth, compromising fruit quality in the long term [37].

When evaluating the Aw averages at day 15 of storage, it was observed that guavas stored at 4 °C showed the lowest water availability (0.87), a behavior characteristic of low temperatures that limits the development of microorganisms, spore germination, toxin production, and enzyme activity associated with spoilage [38]. However, this result was unexpected, as higher dehydration at 2 °C compared to 4 °C was observed. This behavior underlines the importance of considering chemical variability between fruits when analyzing the effects of storage. In this study, it became evident that fruits from the same tree do not have an identical chemical composition, which provides valuable information on their intrinsic heterogeneity. For future studies, it would be helpful to implement a more homogeneous protocol, such as pulping and stor-

Table 1: Experimental design.

Factor A: Storage temperature	Factor B: Days	Physicochemical properties	Repetitions (n)
≈21 °C (RT)	1, 3, 5, 7, 9, 11, 13, and 15	Aw, pH, TTA, SST, MI, TPC, DPPH, and ABTS	3
		Color coordinates	10
2 °C	1, 3, 5, 7, 9, 11, 13, and 15	Aw, pH, TTA, SST, MI, TPC, DPPH, and ABTS	3
		Color coordinates	10
4 °C	1, 3, 5, 7, 9, 11, 13, and 15	Aw, pH, TTA, SST, MI, TPC, DPPH, and ABTS	3
		Color coordinates	10

Note: The above shows two factors: **(A)** storage temperature (2 °C, 4 °C and ≈21 °C) and **(B)** storage time (days: 1, 3, 5, 7, 7, 9, 11, 13, and 15), totaling 24 treatments. Aw, pH, TTA, SST in °Brix, color coordinates, MI, TPC and antioxidant activity (DPPH and ABTS) were repeated in triplicate (3R) for all parameters except color, which had 10R, totaling 24 treatments.

age of fruits, to minimize this variability and allow for more consistent analysis.

Also, decreasing storage temperature to more extreme conditions could provide a more complete picture of how these variables affect guava preservations. Although low temperatures tend to reduce Aw [39], they can also cause chilling injuries, such as excessive dehydration and firmness loss, compromising fruit texture and quality [40, 41]. These results underline the importance of a proper storage temperature, considering the guavas variability and the effects of low temperatures on their preservation [42].

pH measurement

Guava is a climacteric fruit that continues to mature after harvest. This process increases ethylene production and reduces acidity, affecting its chemical composition, flavor, and quality [43, 44]. In this study (Figure 2b), the average pH of guava in the three storage conditions was 3.95 after 24 h (day 1), reflecting the presence of organic acids such as citric acid and malic acid, which are responsible for its characteristic acidity [45]. This acidity not only contributes to the freshness of the fruit but also inhibits microbial growth, as low pH limits bacterial growth [46].

According to the literature, the pH of fruits is generally between 4.5 [47], a behavior that coincides with the values obtained in this study, which range between 3.9 and 4.7, confirming the stability in its chemical composition. In addition, Sultana et al. [25] indicates that the pH of guava decreases as the fruit ripens, going from more neutral levels in the immature stage to more acidic values in over-maturation, a process related to metabolic and respiration changes that affect the sensory quality, flavor, and stability of the fruit.

However, in our study, an increase in the pH of guavas stored at RT (21 °C) was observed from day 5 onwards, from 4.2 - 4.7 at day 15. This increase could be due to the decomposition of organic acids and the accumulation of sugars, resulting in a sweeter and less acidic flavor profile while maintaining acceptable fruit characteristics [48]. This behavior differs from species such as *P. guineense*, whose acid pH (2.89 - 3) is preserved even at maturity [7]. However, as indicated by the same author, factors such as geographical origin and genetic variability influence fruit acidity, which may explain the variations observed under different storage conditions.

Guavas stored at lower temperatures (2 °C and 4 °C) maintained a more stable pH (4.1 - 4.2) throughout the 15-day period, suggesting that refrigeration effectively slows the processes that alter acidity, thereby prolonging the fruit's chemical and sensory stability. This behavior may be explained by the inhibitory effect of low temperatures on enzymatic activity, which reduces the degradation of organic acids and slows metabolic reactions that contribute to pH fluctuations [31, 49, 50]. Conversely, at 21 °C, enzymatic activity remains higher, potentially accelerating metabolic processes that lead to acid degradation and an increase in pH [51]. These findings align with previous reports indicating that temperature plays a crucial role in pH variation by modulating enzymatic reactions.

Although this study did not directly evaluate enzymatic activity, the results indicate that cold storage at 2 °C and 4 °C contributes to preserving the acidity and quality of *P. guineense*, which in turn may help extend its shelf life. These findings highlight the importance of storage conditions in the postharvest preservation of *P. guineense*.

SST

The values of SST, composed mainly of sugars and organic acids, are critical indicators of fruit maturation and quality [52]. In guava, SST (Figure 2c) reflects its sweetness, which is related to higher sensory acceptance by consumers, underlining its need to be evaluated [53]. At the beginning of storage (day 1, after 24 h), a variation in SST values of guavas was observed, which was 8.0 °Brix at RT, 5.0 °Brix at 2 °C and 11.67 °Brix at 4 °C. This variability may be attributed to differences in the degree of maturation at harvest and prior exposure to sunlight on the plant despite being from the same plant [54]. In addition, the difficulty in visually identifying the degree of fruit maturity may influence these differences, highlighting the need to carefully consider these factors during sorting, as they impact chemical composition and analytical results.

At RT, guava SST increased until day 3, reaching 8.67 °Brix, which reflects an initial ripening process due to the conversion of starch into simple sugars such as glucose and fructose [55]. However, between days 5 and 15, SST progressively decreased to 5.0 °Brix, suggesting the metabolism of sugars through cellular respiration and decomposition processes typical in climacteric fruits stored at RT [56]. This behavior coincides with an increase in pH, from 3.95 - 4.3, characteristic of ripe or decaying fruit due to a decrease in organic acids, which reduces acidity and raises pH [57].

At 2 °C, SST rapidly increased to 9.0 °Brix on day 3, indicating a ripening process with the conversion of starch into simple sugars [55]. In contrast to the ambient temperature, between days 5 and 15, SST remained relatively stable, with values above 6 °Brix and reaching 9.67 °Brix at the end of the period. This suggests that the low temperature slows down both sugar decomposition and metabolic activity, preserving a higher sugar content [58]. Furthermore, the relationship between SST and pH is evident since, as guava matures, organic acids are transformed into sugars, increasing SST and decreasing acidity, which raises pH [59]. This effect is particularly evident in guavas stored at RT, where SST decreases after an initial increase due to the decomposition of sugars, while pH increases to values of 4.3.

TTA

TTA is closely related to fruit pH and reflects the amount of acids present, citric acid being the main component in guava [60]. Its evolution during storage provides critical information on metabolic changes and fruit quality (Figure 2d). On day 1 of storage, TTA values show significant differences at RT (0.287%), 2 °C (0.319%), and 4 °C (0.223%). This initial variability could be related to the acid content of the selected fruits, influenced by factors such as harvest time and growing conditions [61].

During storage, guavas kept at RT exhibited a gradual increase in TTA until day 7 (0.573%), followed by a progressive decline from day 9 onwards, reaching 1.11% on day 15. This decrease is attributed to acid degradation and the higher respiration rate at RT, which accelerates metabolic reactions and promotes acid conversion into sugars [62].

In contrast, guavas stored at 2 °C showed a more stable TTA trend, with fewer fluctuations compared to those stored at RT. Similarly, at 4 °C, TTA remained relatively stable, indicating that cold storage effectively slows acid breakdown and preserves acidity. This aligns with previous studies reporting that lower temperatures reduce the rate of acid degradation, contributing to greater stability in TTA levels [63]. Additionally, the rate of lime degradation may be lower at refrigeration temperatures compared to fruits stored at RT, resulting in greater stability in acidity levels [31]. Previous studies have also shown that cold storage helps maintain acidity by slowing metabolic processes, thereby prolonging the fruit's shelf life [64].

In this study, we observed that storage at 2 °C and 4 °C contributed to maintaining guava's TTA over the 15-day period, highlighting refrigeration as a potential strategy to extend shelf life.

Color coordinates

The results of the color analysis of guava stored at different temperatures highlight the influence of maturity and storage conditions on its color properties (Figure 3). Fruit maturity is linked to the accumulation of pigments, sugars, and organic acids that determine its color [65]. Although the external color of guava generally reflects its maturity, it does not always coincide. According to Sultana et al. [25], in unripe fruits, the green color of the epidermis persists during the first three days of storage, regardless of temperature. In ripe fruits, the color gradually changes from green to yellow, being more uniform and better maintaining its sensory characteristics at 1.6 °C. At 0 °C. Also, the olive-green tone predominates towards the end of storage. In overripe fruits, the yellow color becomes dominant, accompanied by necrotic spots that indicate the beginning of deterioration, independent of storage temperature.

In our study, at RT (21 °C), the h° decreased progressively from 84.67 (day 1) to 55.95 (day 15), suggesting a transition towards more reddish tones, typical of greater maturation. C* initially increased from day 1 (41.22) to day 5 (52.71), indicating an intensification of color, and then decreased, possibly due to the degradation of pigments such as carotenoids. In parallel, the ΔE decreased significantly from 74.62 (day 1) to 51.73 (day 15), reflecting a loss of intensity and uniformity in the original color.

At 2 °C, the decrease in h° was more gradual, from 81.69 (day 1) to 73.95 (day 15), suggesting less chromatic variation associated with maturation. This is due to lower metabolic activity and reduced fruit transpiration [66]. This stability was also observed in SST and constant pH, which contributed to maintaining a yellow-green h. The Aw decreased progressively, helping to preserve the cell structure and slowing down decay. In addition, C* remained relatively constant, with values ranging from 41.22 (day 1) to 35.19 (day 15), indicating that color intensity was better preserved compared to storage at RT.

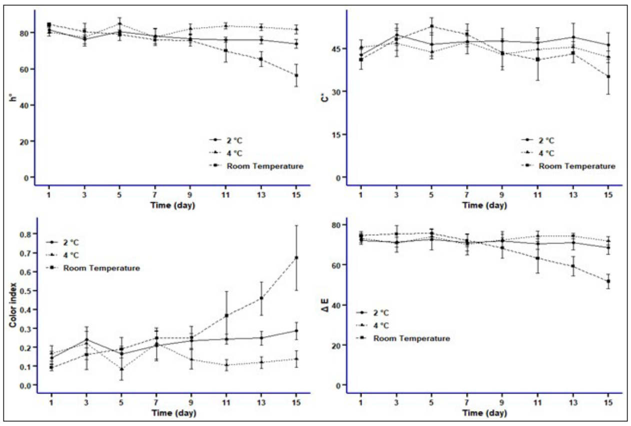

Figure 3: Monitoring of h°, C*, CI and ΔE value during different storage conditions of guava. All values are expressed in mean ± SD (n = 3). Different letters on the bars indicate significant differences between days in each storage condition (Tukey's multiple range test, $p < 0.05$).

At 4 °C, the variation in the h° was even more minor, ranging from 80.47 (day 1) to 82.02 (day 15), indicating a greater stability of the yellow-green h. This is due to less degradation of chlorophyll and other pigments at low temperatures and reduced pathogenic fungal activity [67]. Although this temperature preserves color better, it can also induce chromatic variations due to chilling damage caused by physiological stress generated by too-low temperatures [63]. Therefore, storage at low temperatures delays ripening and preserves the color of the guava better. However, it is essential to determine the optimal time and temperature to avoid damage to the visual quality of the fruit while preserving its attractive appearance.

MI

The MI of guava under different storage temperatures showed significant variations ($p < 0.05$) over 15 days (Table 2). It is important to note that, in this study, fruits were selected according to their color, as skin color is the best indicator of guava maturity at the time of collection and during the trial [61]. At RT (21 °C), the MI started at 27.842 ± 0.056 (day 1), decreasing rapidly to 9.798 ± 0.024 (day 3) and reaching its lowest value of 3.725 ± 0.005 (day 9). This indicates high

Table 2: MI at different storage conditions of guava.

Days	Storage temperature		
	RT (≈ 21 °C)	2 °C	4 °C
Day 1	27.842 ± 0.056^{a}	15.690 ± 0.028^{cd}	52.311 ± 2.394^{a}
Day 3	9.798 ± 0.024^{c}	17.671 ± 0.061^{c}	17.601 ± 0.020^{e}
Day 5	12.666 ± 0.381^{b}	12.403 ± 0.413^{d}	13.463 ± 0.504^{f}
Day 7	8.729 ± 0.027^{e}	14.845 ± 1.585^{cd}	12.031 ± 0.368^{f}
Day 9	3.725 ± 0.005^{g}	24.699 ± 3.641^{b}	19.570 ± 0.033^{de}
Day 11	4.830 ± 0.007^{f}	13.552 ± 1.062^{cd}	31.406 ± 0.031^{b}
Day 13	9.337 ± 0.024^{d}	28.284 ± 0.065^{b}	22.204 ± 2.299^{d}
Day 15	4.492 ± 0.012^{f}	38.011 ± 2.260^{a}	26.722 ± 1.925^{c}

Note: All values are expressed as mean ± SD (n = 3); and different superscripts indicate significant differences between days within each storage condition (Tukey's multiple range test, $p < 0.05$).

respiratory activity and rapid depletion of compounds available for maturation. This process is associated with increased enzyme activity favoring rapid conversion of sugars and other compounds, accelerating fruit senescence [68].

On the other hand, at 2 °C, the MI on day 1 was lower (15.690 ± 0.028) compared to 4 °C (52.311) and RT (27.843). This difference could be linked to the selection of fruits according to the day of analysis. However, the MI at 2 °C increased gradually, reaching a peak on day 15 (38.011 ± 2.260), which confirms that low temperatures help to preserve the quality of the fruit by reducing the metabolic activity, favoring a delaying the maturity in climacteric fruits such as guava [69, 70].

At 4 °C, the initial MI was 52.311 ± 2.394. This might indicate that guavas had already a degree of maturity at the beginning of fruit collection or that this temperature (4 °C) favors the early accumulation of maturity-related compounds. However, the index decreased to 17.601 ± 0.020 on day 3 and showed fluctuations until day 15, when it reached 26.722 ± 1.925. This behavior suggests that, although storage at 4 °C delays initial maturation, it is not optimal for maintaining a constant maturation process, as it favors irregular metabolic processes, possibly because the temperature is not low enough to continuously inhibit respiratory activity [71]. Statistical analyses confirm significant differences in the MI across the trial days and between temperatures. At RT, the rapid decline between days 1 and 3 is statistically significant, while at 2 °C, the differences between certain days are less marked, reflecting a greater stability in maturation.

Bioactive profile

Phenolic compounds include phenolic acids, flavonoids, and tannins [72]. These are secondary plant metabolites known for their antioxidant properties and defense against oxidative stress and pathogens. In the case of guava, the results of TPC under different storage conditions show significant variations ($p < 0.05$) over a period of 15 days (Figure 4a). At RT, the TPC content was 9.180 mg GAE/g on day 1 and slightly decreased to 8.628 mg GAE/g on day 3. However, by day 5, this value decreased to 5.524 mg GAE/g, followed by a steeper drop on the subsequent days. This decrease indicates a rapid depletion of the phenolic compounds due to the increased rate of respiration, a metabolic process in which oxygen is converted to carbon dioxide, water, and energy, which consumes reserves of nutrients and bioactive compounds as polyphenols [73]. These results suggest that polyphenols are best preserved at RT until day 3. In contrast, at 2 °C the TPC levels remained relatively stable (10.206 mg GAE/g) and reached a maximum level on day 3 (10.850 mg GAE/g) and dropped on day 5 (5.550 mg GAE/g). From day 9 onwards, values tend to stabilize, reaching 6.117 mg GAE/g on day 15. This behavior indicates that low temperatures help preserve phenolic compounds for a more extended period due to a reduced respiratory activity [74].

At 4 °C, although initial TPC levels were low (7.217 mg GAE/g), an increase was observed towards the end of the storage, reaching 8.917 mg GAE/g on day 15. Although this increase could be influenced by the selection of fruit for daily analysis, the results show that at 4 °C, the TPC levels remained relatively stable throughout the storage period. While low temperatures reduce the respiration rate and decrease the metabolic activity of the fruit, which generally prevents the deterioration of phenolic compounds [75], they do not always ensure their long-term stability [76]. Moreover, as observed in this study, cold conditions contribute to maintaining an adequate pH in guava, favoring the phenolic compounds' stability, solubility, and antioxidant activity [77]. Therefore, storage at 4 °C allows better preservation of polyphenols until day 15.

The antioxidant activity of guava measured by DPPH showed significant variations throughout the 15 days of storage, with a significant influence by temperature (Figure 4b). At RT, the antioxidant activity decreased between day 1 (136.467 µmol TE/mg) and day 3 (90.717 µmol TE/mg). However, a further increase was observed around day 5 (171.133 µmol TE/mg), and it remained constant until the last day of storage. This increase indicates that, as guava ripens, compensatory biochemical reactions occur that release additional antioxidant compounds, such as flavonoids and phenolic acids, in response to oxidative stress or ethylene production [78]. Therefore, this biosynthesis process remains constant the antioxidant activity, as observed until the end of storage.

At 2 °C, the antioxidant activity showed a more stable trend between days 1 (130.217 µmol TE/mg) and 3 (131.550 µmol TE/mg), with a noticeable increase towards day 7 (167.633 µmol TE/mg), indicating that the low temperature may delay the loss of initial antioxidants, favoring their preservation. However, from day 9 onwards (124.800 µmol TE/mg), a gradual reduction was observed, suggesting that prolonged storage time, even at low temperatures, eventually affects the stability of these compounds. At 4 °C, the initial antioxidant activity was lower (121.633 µmol TE/mg) compared to other temperatures but increased significantly by day 5 (169.300 µmol TE/mg). This may indicate that, although low temperatures help to preserve antioxidants initially, metabolic activity and prolonged storage time eventually affect their stability. From day 9 onwards (142.383 µmol TE/mg), the antioxidant activity decreased more drastically, suggesting that the effect of low temperature is maintained only during the first few days of storage. In addition, as guava matures, it is common for SST to increase, and for acidity to decrease, which influences the availability of antioxidant compounds [79].

The results of the antioxidant activity of guava using the ABTS compared to the DPPH method showed similar behavior, where the antioxidant activity initially (day 1 to 5) decreased at all storage temperatures (Figure 4c). This is related to the metabolic activity of the fruit and to the prolonged storage [80]. At RT (21 °C), the antioxidant activity decreased from day 1 (49.865 µmol TE/mg) to 5 (18.090 µmol TE/mg). However, an increase was observed on day 7 (47.565 µmol TE/mg). From day 9 onwards, the activity showed fluctuations but then stabilized (from day 13 to 15), reaching a value of 47.915 µmol TE/mg. At 2 °C, the antioxidant activity also decreased from 48.990 µmol TE/mg (day 1) to 27.740 µmol TE/mg (day 5). Day 7 showed a remarkable increase (50.340 µmol TE/mg). However, after day 9, the antioxidant activity tended to decrease, reaching 39.715 µmol TE/mg by day 15.

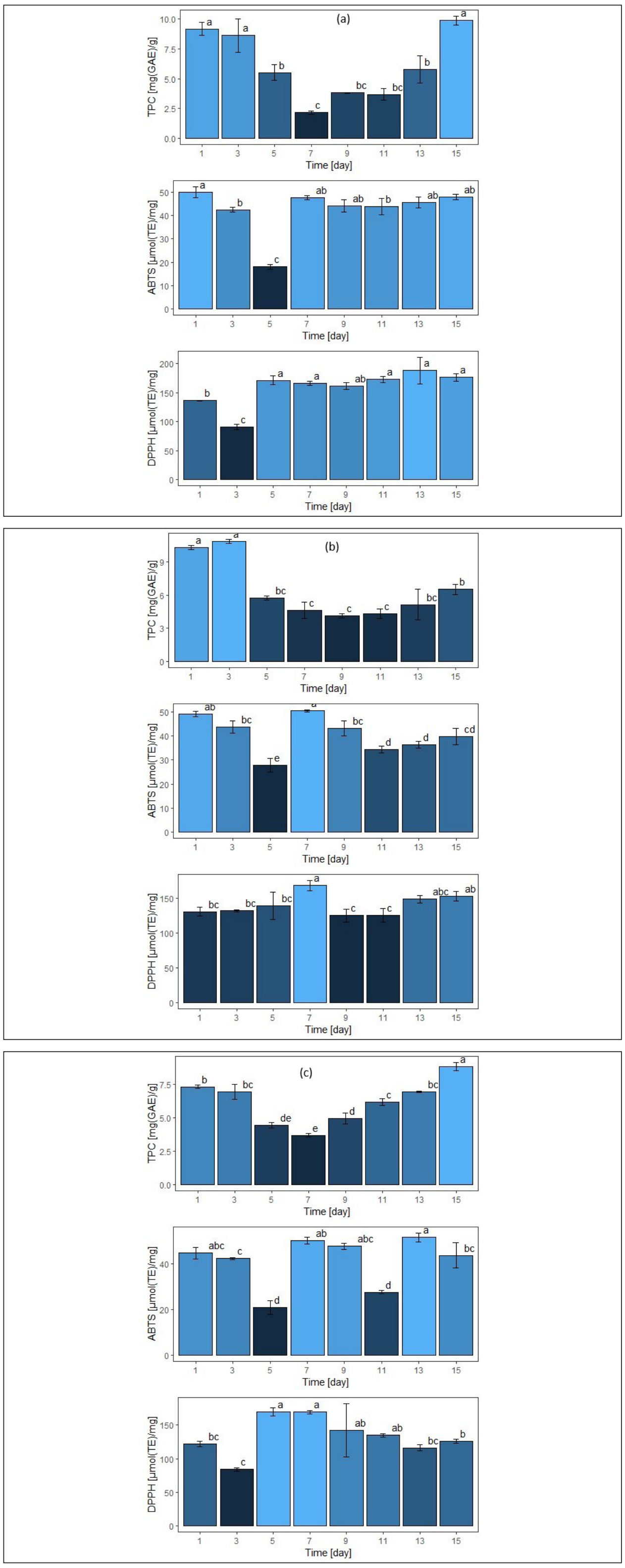

Figure 4: TPC and antioxidant activity (DPPH and ABTS) in guava under the three storage conditions. Storage conditions were **(a)** RT ≈ 21 ˚C, **(b)** 2 ˚C, and **(c)** 4 ˚C. All values are mean ± SD (n = 3). Different letters on the bars indicate significant differences between days under each storage condition (Tukey's multiple range test, $p < 0.05$).

At 4 ˚C, a similar pattern was observed, as the antioxidant activity decreased from 44.740 µmol TE/mg (day 1) to 20.890 µmol TE/mg (day 5). However, day 7 showed an increase of 50.215 µmol TE/mg. The antioxidant activity stabilized from day 11 (27.590 µmol TE/mg) to 15 (43.790 µmol TE/mg). The presence of phenolic compounds during ripening may explain the antioxidant activity observed during storage. In addition, factors such as MI, pH, soluble solids, and TTA also influence the stability of antioxidants, which may explain the variations recorded in temperatures and times. This suggests that, although low temperature helps to preserve antioxidants initially, prolonged storage eventually affects the stability of these compounds.

Although storage at low temperatures (2 ˚C and 4 ˚C) can decrease the chemical degradation of fruits [81-83], guava can suffer physiological disorders and alterations caused by cold due to its climacteric nature, manifesting as skin splitting and bract wilting [84], negatively affecting its commercial value and quality. Therefore, a suitable storage temperature for guava depends on several factors and should be set according to the required storage condition of each food [85].

Conclusions

P. guineense (guava) has a high nutritional and medicinal potential, standing out for its resistance and versatility in the food industry. However, information on its postharvest conservation needs to be improved, highlighting the need for further research on its optimal storage conditions to preserve its properties and improve its commercial use. The analysis of the physicochemical characteristics of guava stored at different temperatures reveals that 2 ˚C is the most effective temperature for preserving its integral quality for 15 days. This temperature maintains the stability of water activity, avoiding dehydration and preserving the freshness of the fruit. In addition, changes in pH, soluble solids (˚Brix), and TTA are adequately controlled, favoring a balance between sweetness and acidity. The MI develops progressively, maintaining an attractive color that improves the consumer's visual perception.

At 4 ˚C water availability is reduced, limiting enzymatic activity and toxin formation, affecting the texture and color of the fruit. Also, at this temperature a decrease in respiration slows the conversion of organic acids into sugars, favoring the preservation of acidity and stabilizing SST. However, the polyphenols content at 4 ˚C is insufficient to maintain an antioxidant activity high during storage. Antioxidant compounds decrease at both temperatures as storage progresses, but 2 ˚C is more effective in preserving them for the first 15 days. Although 4 ˚C may delay specific spoilage processes, it does not guarantee the physicochemical and antioxidant properties as is achieved at 2 ˚C. Statistical analyses show significant differences in MI and other parameters, highlighting the importance of a precise storage-temperature.

In general, 2 ˚C is the best option to preserve guava's quality and physicochemical properties. However, 4 ˚C helped to preserve a higher phenolic content for a longer storage time. Adequate management of temperature and storage time is crucial to avoid physiological damage and guarantee the fruit's overall quality.

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Conflict of Interest

None.

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