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RESEARCH ARTICLE

Physicochemical and physiological changes of three soursop (*Annona muricata* L.) varieties during postharvest storage

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Abstract

This work aimed to characterize the physicochemical and physiological changes (respiration rate, ethylene production, weight loss, firmness, color, soluble solids, pH, and titratable acidity) of three soursop varieties (GUANAY-1, GUANAY-2, and GUANAY-3) stored at 28 °C ± 1 and 15 °C ± 1. Fruits stored at 28 °C ± 1 reached the highest respiration rate on day seven, while those at 15 °C ± 1 exhibited a delayed climacteric peak. GUANAY-3 showed the lowest weight loss and firmness at 28 °C ± 1 ($p<0.05$), whereas GUANAY-1 demonstrated an extended postharvest life of 11 days at 15 °C ± 1, maintaining minimal weight loss and firmness reduction. Across storage temperatures, fruit color progressively darkened as ripening advanced. Soluble solids, pH, and acidity peaked on day seven at 28°C ± 1, coinciding with the climacteric peak. At 15 °C ± 1, these parameters peaked on day nine for GUANAY-1, while GUANAY-2 and GUANAY-3 reached their highest values on day seven. Multivariate analysis revealed that GUANAY-2 and GUANAY-3 shared similar postharvest traits on day five at 28 °C ± 1, while all varieties presented comparable characteristics on days five and seven at 15 °C ± 1. Significant correlations were observed between pH and firmness, as well as weight loss and acidity at both temperatures. GUANAY-3 at 28 °C ± 1 and GUANAY-1 at 15 °C ± 1 exhibit promising potential for national and international markets, improving postharvest management strategies or enhancing marketability.

Keywords: cold storage; ethylene; physicochemical parameters; respiration; ripening

Introduction

Soursop (*Annona muricata* L.) belongs to the Annonaceae family and is cultivated worldwide in tropical and subtropical areas (1). Mexico is the leading global producer of soursop fruit, with 30121.20 t reported in 2023, 81 % of which were grown in Nayarit, resulting in an economic spillover for the region (2). The fruits are accepted in the market due to their edible and sweet-sour pulp, characterized by a soft and fibrous texture, presenting a high content of nutrients and bioactive compounds (3). However, one of the most significant and persistent problems during storage is quick softening, limiting their commercialization (4). This problem is further intensified by the climacteric behaviour of these fruits, which means they have a high rate of respiration and ethylene production, as well as high enzymatic activity (5). Despite these challenges, up to date, its postharvest handling is still deficient, impacting the quality of the fruit and limiting its distribution. Refrigeration usually extends the shelf life of fresh vegetables. Nonetheless, tropical fruits are vulnerable to low temperatures (≤ 10-14 °C), resulting in chilling injury (6). In this regard, studies have been carried out to characterize soursop fruits during postharvest storage using refrigeration, reporting that soursop fruits stored at 15 °C for 8 days showed no symptoms of cold damage (7, 8). In addition to these postharvest considerations, there is a diversity of soursop genotypes in Mexico because most of the established plantations correspond to trees propagated from seeds (9). In Nayarit, soursop plants are propagated sexually; hence, their fruits have different morphological characteristics

(10). In this context, three soursop varieties were identified based on the morphological and physicochemical characteristics of fruits at physiological maturity (11). These varieties were registered in the National Catalog of Plant Varieties of the National Seed Inspection and Certification Service of the Federal Government of Mexico (https://www.gob.mx/snics) and were named GUANAY-1 (registration number GUN-OO1-020719), GUANAY-2 (registration number GUN-OO2-020719) and GUANAY-3 (registration number GUN-OO3-020719). The importance of selecting these varieties lies in the fact that they are the first to be officially registered in Mexico, providing them legal recognition and enabling effective identification and traceability in both national and international markets. Understanding the fruit attributes and ripening behavior of these varieties is crucial because they influence customer perceptions, marketing decisions, shelf life, and potential applications. Nevertheless, up to date, there is a lack of research on the postharvest storage characteristics of these soursop varieties, which is essential for developing effective postharvest strategies and enhancing their market potential. Previous studies have focused on general postharvest storage conditions, but no research has specifically examined the physiological and physicochemical characteristics of these registered varieties. Therefore, this study aimed to assess the physiological and physicochemical characteristics of three soursop varieties (GUANAY-1, GUANAY-2, GUANAY-3) during postharvest storage at 28 °C ± 1 and 15 °C ± 1.

Materials and Methods

Plant material

Soursop fruits from each variety (GUANAY-1, GUANAY-2, and GUANAY-3) were collected at physiological maturity based on the criteria used by producers, including fruit shape, color, and size, from a 30 year old orchard located in Venustiano Carranza, Tepic, Nayarit (21° 32' 2.77" N and 104° 58' 39.73" W, with an altitude of 893 masl). The fruits were washed with commercial detergent and water, and disinfected with sodium hypochlorite at 1.0 % for 5 min. After, the fruits were allowed to air-dry at room temperature. Soursop fruits were stored at 28 ± 1 °C and 15 ± 1 °C in a controlled temperature chamber (Climacell® CLC-B2V-M/CLC404-TV, Angelbachtal, Germany) until senescence. Ten fruits of each variety and storage temperature were used to quantify the respiration rate and ethylene production from day 1 of storage until senescence. Six fruits of each variety and storage temperature were used for weight loss, firmness, and color analyses. Finally, 24 fruits per variety and storage temperature were used to analyze soluble solids, pH, and titratable acidity. These parameters were analyzed after 1, 3, 5, 7, 9 and 11 days of storage.

Respiration rate and ethylene production

Respiration rate and ethylene production were determined according to the method (12). The fruits were weighed and then placed in chambers with a septum, hermetically sealed for 60 min, allowing the extraction of 1 mL of the free headspace. Respiration rate and ethylene production quantification were carried out using a gas chromatograph (GC6890; Hewlett-Packard) equipped with an HP-PlotQ column (15 m x 0.53 mm and 40 μm film thickness) for gas separation. A thermal conductivity detector was used to detect CO_2 and a flame ionization detector was used to detect ethylene. The temperature of the injection port and both detectors was kept constant at 250 °C with a rate of change of 30 °C min^{-1}. The carrier gases were H_2 at a flow rate of 30 mL min^{-1}, N_2 at a flow rate of 7 mL min^{-1}, and air at 400 mL min^{-1}. The analysis was performed at 28 °C ± 1 and 15 °C ± 1 from the first to the 11th day of storage. The respiration rate was expressed in terms of mL of CO_2/kg·h, while the ethylene production was expressed in μL of ethylene/kg·h.

Weight loss

Fruits were weighed using a digital scale (Scout® Pro SP6001; Ohaus) to measure the weight loss of each fruit. Results were calculated as a percentage of weight loss (%) relative to the initial weight of the fruits.

Firmness

A digital penetrometer (GY-4; Yucheng-Tech) with a 1 cm diameter cylindrical strut was used to assess the firmness of the samples. Three random measurements were made at different points of the fruit exocarp, and the results were expressed in Newtons (N).

Color

Exocarp color components were evaluated by three random measurements in different parts of the fruit. Lightness (L*) was determined on a scale from 0 to 100 (where 0 represents pure black and 100 pure white), hue angle (°h) on a scale from 0 to 360, and chromaticity (C*) indicates the intensity from gray to pure chromatic color. These measurements were made using a colorimeter (CR-400; Konica Minolta®).

Physicochemical analysis

Sample preparation

1 g of soursop fruit pericarp was ground using an Ultra Turrax® (T25; IKA-Works) and dissolved in 10 mL of distilled water.

pH

The pH was measured by a digital potentiometer (HI2210; HANNA Instruments).

Soluble solids

Soluble solids were calculated using a digital refractometer (HI96801; HANNA Instruments), and results were expressed in ° Brix.

Titratable acidity

It was carried out by volumetric determination following the technique by the AOAC (13). The titration was performed with 0.1 N NaOH, using phenolphthalein as a marker. The results were calculated as a percentage of ascorbic acid (AA).

Statistical and multivariate analysis

The data sets were analyzed independently by storage temperature (28 °C ± 1 and 15 °C ± 1). A factorial design (day and variety) was used to analyze the respiration rate and ethylene production data. Further, a two-way analysis of variance (ANOVA) with a confidence level of 95 %, followed by a Tukey's HSD test for mean comparison ($P<0.05$), was used to analyze the results. On the other hand, a completely randomized block design (days of storage as blocks) using a one-way ANOVA ($P<0.05$) followed by Tukey's HSD test for mean comparison (P<0.05) was performed to analyze the other variables (weight loss, firmness, color, and physicochemical analysis). Shapiro-Wilk and Bartlett's tests were conducted on all datasets to assess normal distribution and variance homogeneity. Principal component analysis (PCA) was performed using a scaled correlation matrix (standardized to unit variance) to analyze the significance of each variable and examine the patterns across storage days and varieties. The graphics and statistical analysis were performed using the R language with the ggplot2, agricolae, FactoMineR and Factoextra packages.

Results and Discussion

Respiration rate and ethylene production

The fruits of the three varieties stored at 28 °C ± 1 presented significant differences in the respiration rate (P <0.05) showing a typical behavior of a climacteric fruit, reaching the climacteric peak on day seven for the three varieties, followed by a decrease on day nine that corresponds to the beginning of senescence (Fig. 1A). GUANAY-3 and GUANAY-2 showed the highest respiration rate values with 175.675 mL of CO_2 kg·h^{-1} and 170.141 mL of CO_2 kg·h^{-1}, respectively, followed by GUANAY -1 (101.477 mL of CO_2 kg·h^{-1}). These data coincide with those reported by other authors, since the respiratory rate of soursop ranges between values of 127.34 mL CO_2 kg·h^{-1} up to 283.42 mL CO_2 kg·h^{-1}, between four and six days of storage, depending on the genotype and temperature (14-16). In this study, the climacteric peak occurred until day seven at 28 °C ± 1, which could be attributed to the genotype, the state of maturity at the time of harvest, and/or the absence of stress in the fruits during the study, since no pests, diseases, or mechanical damage were detected.

Regarding ethylene production, the data showed no statistically significant differences among the varieties (P >0.05). GUANAY-3 presented the highest ethylene production on day four of storage with 15.34 µL of ethylene/kg·h compared to GUANAY-2 with 9.00 µL of ethylene/kg·h (Fig. 1B).

Alternatively, GUANAY-1 had the highest ethylene production until day five with 8.79 µL of ethylene/kg·h. Kou and Wu (17) indicated that this behavior could be attributed to the fact that climacteric fruits usually undergo an increase in ethylene production before or concurrently with respiration rate, which coincides with the results of this research.

On the other hand, fruits stored at 15 °C ± 1 showed significant differences in respiration rate between varieties (P <0.05). GUANAY-2 reached the climacteric peak on day eight of storage with an average value of 90.60 mL of CO_2 kg·h^{-1}. Conversely, GUANAY-1 and GUANAY-3 varieties reached the

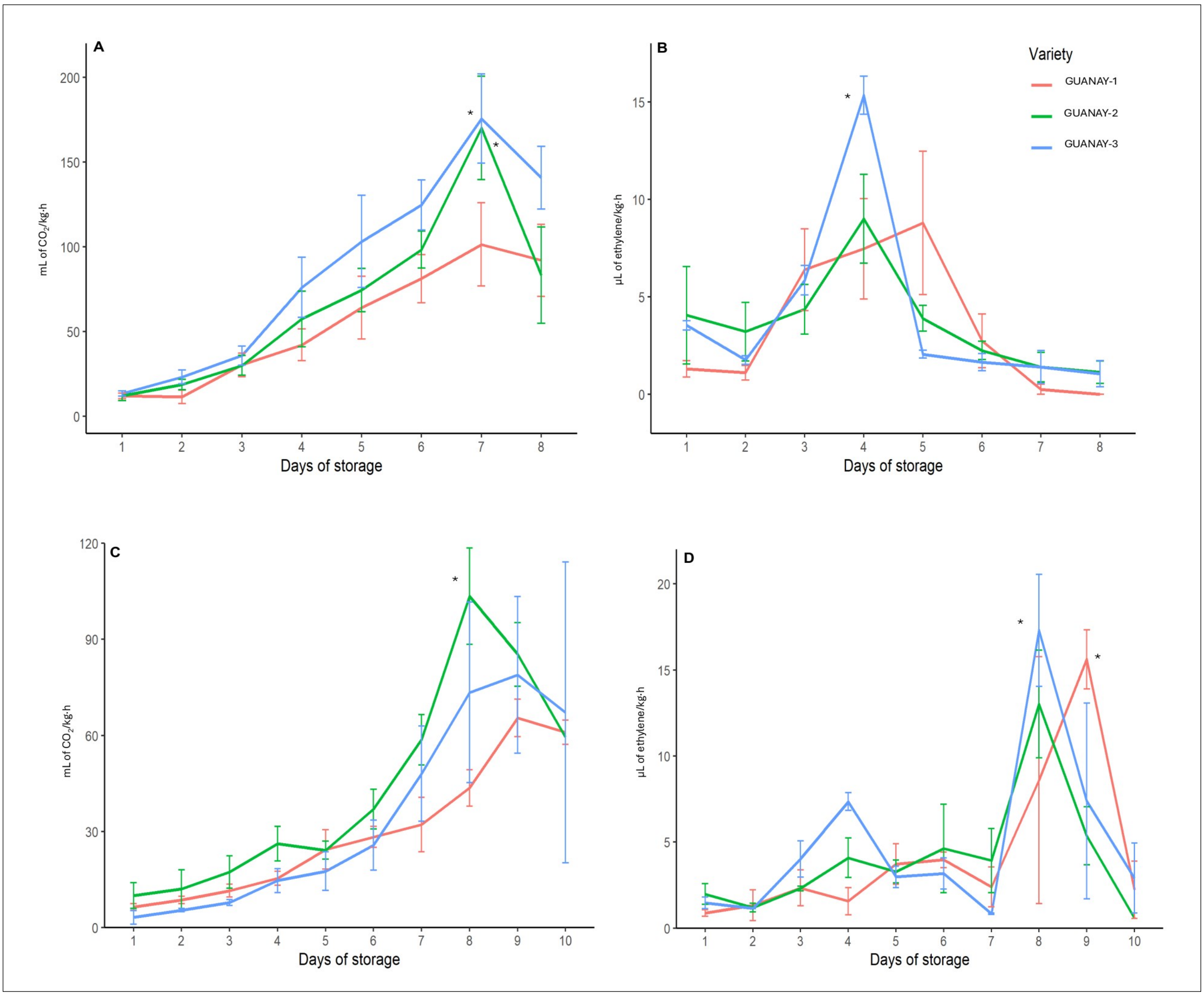

Fig. 1. Physiological analysis of soursop fruit varieties (GUANAY-1, GUANAY-2, and GUANAY-3) stored at 28 °C ± 1 and 15 °C ± 1. a) Respiration rate at 28 °C ± 1; b) Ethylene production at 28 °C ± 1; c) Respiration rate at 15 °C ± 1; d) Ethylene production at 15 °C ± 1 * Indicates significant differences between varieties on the day of storage according to Tukey's HSD test (P <0.05). Vertical lines represent standard error.

climacteric peak on day nine of storage with values of 65.46 and 78.91 mL of CO_2 kg·h^{-1}, respectively (Fig. 1C). The earlier climacteric peak of GUANAY-2 compared to GUANAY-1 and GUANAY-3 could be related to the fruits water content. A higher water content can make the cuticle more flexible but also increases susceptibility to microcrack formation when exposed to cold, which enhances gas exchange (18). The storage temperature of 15 °C ± 1 delayed the climacteric peak by one day in the GUANAY-3 variety and two days in the GUANAY-1 and GUANAY-3 varieties when compared to fruits stored at 28 °C ± 1. In the ethylene production, fruits stored at 15 °C ± 1 showed the same trend among varieties (P>0.05). On day eight of storage, the GUANAY-2 and GUANAY-3 varieties presented the highest ethylene production with an average of 15.73 and 17.30 µL of ethylene/kg·h, respectively. GUANAY-1 displayed the highest ethylene production on day nine with a value of 15.61 µL of ethylene/kg·h (Fig. 1D). Therefore, these results suggest that the temperature of 15 °C ± 1 delayed the postharvest life of the fruits by three days compared to those stored at 28 °C ± 1. The association between temperature and the climacteric peak stems from the fact that ethylene receptor binding diminishes at low temperatures, lowering biosynthesis. This leads to a lower ethylene concentration and, consequently, a proportional decrease in respiration rate (19). Furthermore, evidence indicates that the expression of genes encoding key enzymes in ethylene biosynthesis and signaling pathways, such as 1-aminocyclopropane-1-carboxylic acid synthase (ACS) and 1-aminocyclopropane-1-carboxylic acid oxidase (ACO), is regulated by temperature. Low temperature (below 18 ºC) can repress the transcription of these genes, limit ethylene production and delaying physiological processes associated with ripening, such as pectin degradation (20). Considering all this, low-temperature conditions alter ethylene signaling, impacting key physiological processes such as respiration rate and delayed fruit ripening.

Loss of weight and firmness

GUANAY-2 variety reached senescence after seven days of storage with a final weight loss of 12.2 %, while GUANAY-1 and GUANAY-3 varieties reached nine days of storage with a weight loss of 19.1 and 16.2 % (P<0.05), respectively (Fig. 2A). On the other hand, the firmness of the fruits decreased continuously in the three varieties as the fruit matured, showing significant differences between varieties (P<0.05). In this context, GUANAY -2 exhibited the lowest firmness with a decrease of 67 % on day seven of storage followed by GUANAY-1 with 65 % and GUANAY -3 with 43 % until day nine of storage, respectively (Fig. 2B). The results of this investigation coincide with those found by Ramos-Guerrero et al. (2019) (16) who reported a weight loss of 20.4 % and a decrease in firmness of 97.44 % in soursop fruits stored at 25 °C until day eight. Furthermore, Márquez-Cardoso et al. (2012) (14) recorded a weight loss of 14.71 % and a decrease in firmness of 94.1 % in soursop fruits stored at 25 °C until day 10. However, the loss of firmness was greater than the

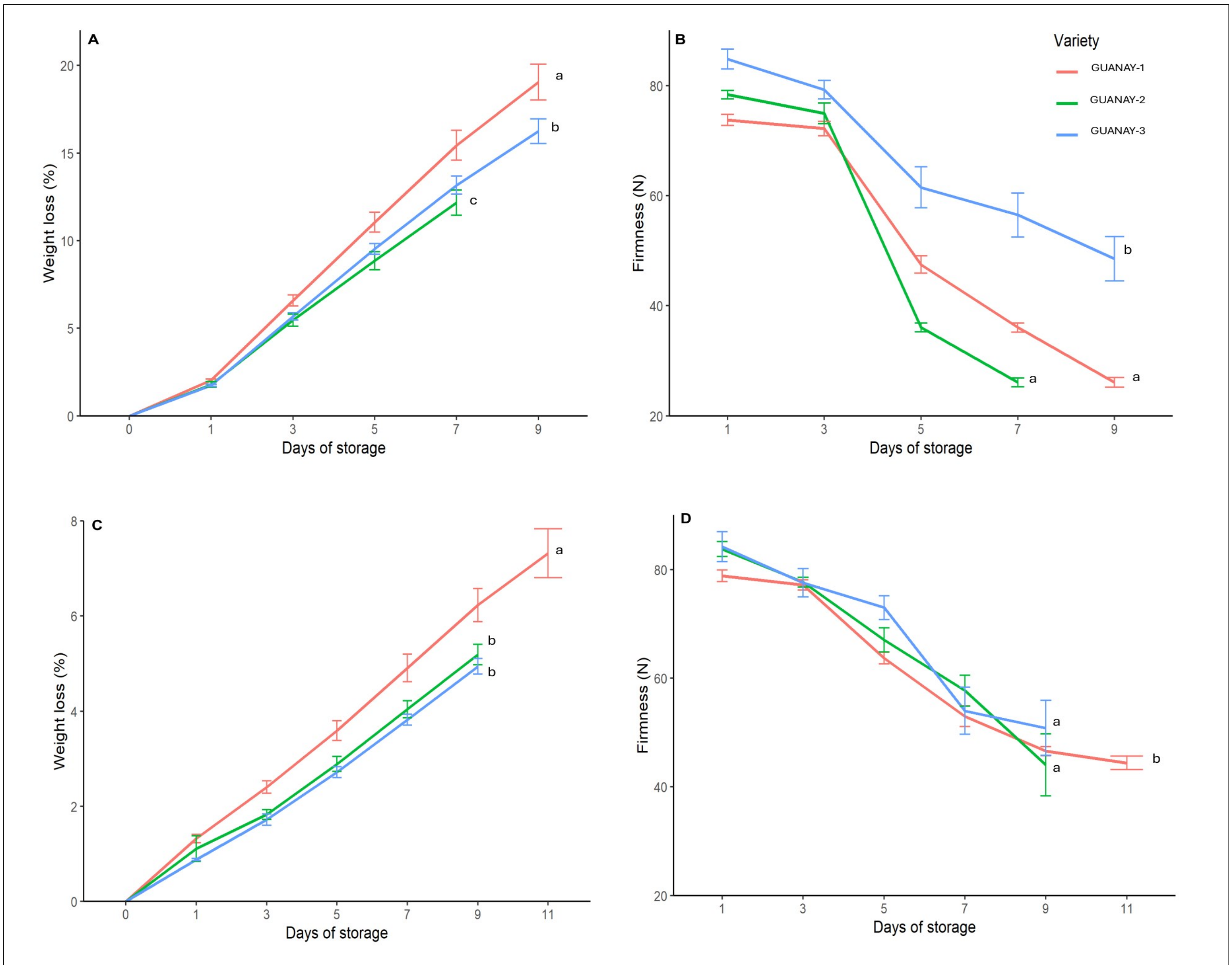

Fig. 2. Physiological analysis of soursop fruit varieties (GUANAY-1, GUANAY-2 and GUANAY-3) stored at 28 °C ± 1 and 15 °C ± 1. a) Weight loss at 28 °C ± 1; b) Firmness at 15 °C ± 1; c) Weight loss at 15 °C ± 1; d) Firmness at 15 °C ± 1. Different letters indicate significant differences between varieties according to Tukey's HSD test (P<0.05). Vertical bars represent standard error.

results of this research. This could be attributed to the composition of the fruit cuticle since its primary function is to minimize water loss (21). The cuticle's composition and properties differ between species, with wax (primarily alkanes) being responsible for reducing fruit transpiration (22). The amount of cuticle wax is perhaps different in each variety, conferring resistance to transpiration since morphologically the exocarp of the varieties is different from each other. On the other hand, the difference in firmness loss between varieties could also be related to the pectin and water content in the fruits (23). Indeed, each variety may have a distinct pectin content since the exocarp differs morphologically.

On the other hand, the fruits stored at 15 °C ± 1 showed significant differences between varieties (P<0.05). The temperature extended the postharvest life of the fruits, GUANAY-1 presented a weight loss of 7.32 % until 11 days of storage, while on the ninth day of storage, GUANAY-2 and GUANAY-3 lost 6.2 % and 5.2 % of weight, respectively (Fig. 2C). Likewise, in the loss of firmness, significant differences were also shown between varieties (P<0.05). GUANAY-1 presented a loss of firmness of 46 % until day 11 of storage. In contrast, GUANAY-2 lost 47 % and GUANAY-3 42 % on day nine (Fig. 2D). Low temperatures reduce the respiration rate, which slows down metabolic activities in the fruit and likely explains the decrease in weight loss. Furthermore, the activity of hydrolytic enzymes that degrade the cell wall is reduced, resulting in a smaller loss of firmness compared to fruits held at ambient temperature.

Color

The fruits stored at 28 °C ± 1 exhibit that the variables C* and L* showed significant differences between varieties (P<0.05). However, °h showed the same trend (P>0.05) (Table 1).

Regarding the fruits stored at 15 °C ± 1, the variables of C*, L*, and °h presented significant differences between varieties (P<0.05) (Table 2). Likewise, it was observed that GUANAY-2 and GUANAY-3 had similar behaviors based on the change in C* and °h.

These results indicate that, for both storage temperatures on day one, the fruits of the GUANAY-1 variety showed olive green hues, while GUANAY-2 and GUANAY-3 showed dark green hues. The C* and L* values remained constant at the beginning and the end of the storage period in the three varieties.

Nevertheless, significant variations in °h were noted, which may be related to the deterioration of chlorophyll as well as enzymatic activity during ripening, particularly oxidizing enzymes like polyphenoloxidase, and structural alterations in the cell that alter the absorption and reflection of light (24). These changes may also be influenced by the differential accumulation of pigments such as carotenoids and anthocyanins in the exocarp, which play an important role in the external coloration of the fruit during ripening, contributing to the development of greenish, yellowish, or brownish hues depending on the variety and storage conditions (25). Furthermore, regardless of storage temperature, all three varieties shifted toward darker, duller colors as they matured (Fig. 3).

Soluble solids, pH and titratable acidity

No statistically significant differences (P >0.05) were observed in the soluble solids and titratable acidity of fruits stored at 28 °C ± 1. Otherwise, pH variations were recorded between varieties (P<0.05). According to Fig. 4, a progressive increase in soluble solids and titratable acidity was observed, followed by decreased pH as the fruit ripened. On day seven, GUANAY-1 fruits presented a concentration of 14 °Brix, pH of 4.33, and 0.49 % ascorbic acid; GUANAY-2 fruits had a concentration of 13.8 °Brix, pH of 4.31, and 0.49 % acidity, while GUANAY-3 fruits exhibited values of 13 °Brix, pH of 4.8, and 0.49 % acidity.

The highest values in the three varieties were observed during the climacteric peak, which indicates the maximum ripening point of a fruit due to an increase in metabolic activity that triggers biochemical changes such as the accumulation of

Table 1. Color of soursop fruit varieties (GUANAY-1, GUANAY-2 and GUANAY-3) stored at 28 °C ± 1

Days	GUANAY-1 [a]	GUANAY-2 [b]	GUANAY-3 [c]
	Chromaticity (C*)		
1	20.72	19.38	16.67
3	23.72	16.78	13.83
5	23.29	18.53	14.98
7	25.52	14.47	14.25
9	21.91		12.80
	GUANAY-1 [a]	GUANAY-2 [b]	GUANAY-3 [c]
	Luminosity (L*)		
1	40.78	38.43	30.43
3	43.33	35.84	26.60
5	42.77	37.44	30.04
7	46.20	32.83	29.21
9	40.81		26.56
	GUANAY-1 [a]	GUANAY-2 [b]	GUANAY-3 [c]
	Hue angle (°h)		
1	117.35	120.56	117.32
3	118.70	120.28	121.15
5	116.03	114.86	115.21
7	111.31	102.27	113.21
9	102.89		110.98

Different letters indicate statistically significant differences between varieties according to Tukey's HSD test (P <0.05)

Table 2. Color of soursop fruit varieties (GUANAY-1, GUANAY-2 and GUANAY-3) stored at 15 °C ± 1

Days	GUANAY-1 [a]	GUANAY-2 [b]	GUANAY-3 [c]
	Chromaticity (C*)		
1	28.01	20.03	17.72
3	28.75	18.71	15.61
5	26.68	16.46	15.62
7	25.63	16.78	15.29
9	23.17	17.26	17.37
11	25.28		
	GUANAY-1 [a]	GUANAY-2 [b]	GUANAY-3 [c]
	Luminosity (L*)		
1	47.56	34.29	28.17
3	46.76	32.03	27.76
5	45.99	27.90	29.00
7	45.43	33.51	30.52
9	39.66	30.60	28.28
11	39.13		
	GUANAY-1 [a]	GUANAY-2 [b]	GUANAY-3 [c]
	Hue angle (°h)		
1	116.26	121.05	120.08
3	116.81	120.64	118.95
5	114.88	114.88	118.63
7	110.95	117.61	118.29
9	105.22	111.32	115.40
11	106.30		

Different letters indicate statistically significant differences

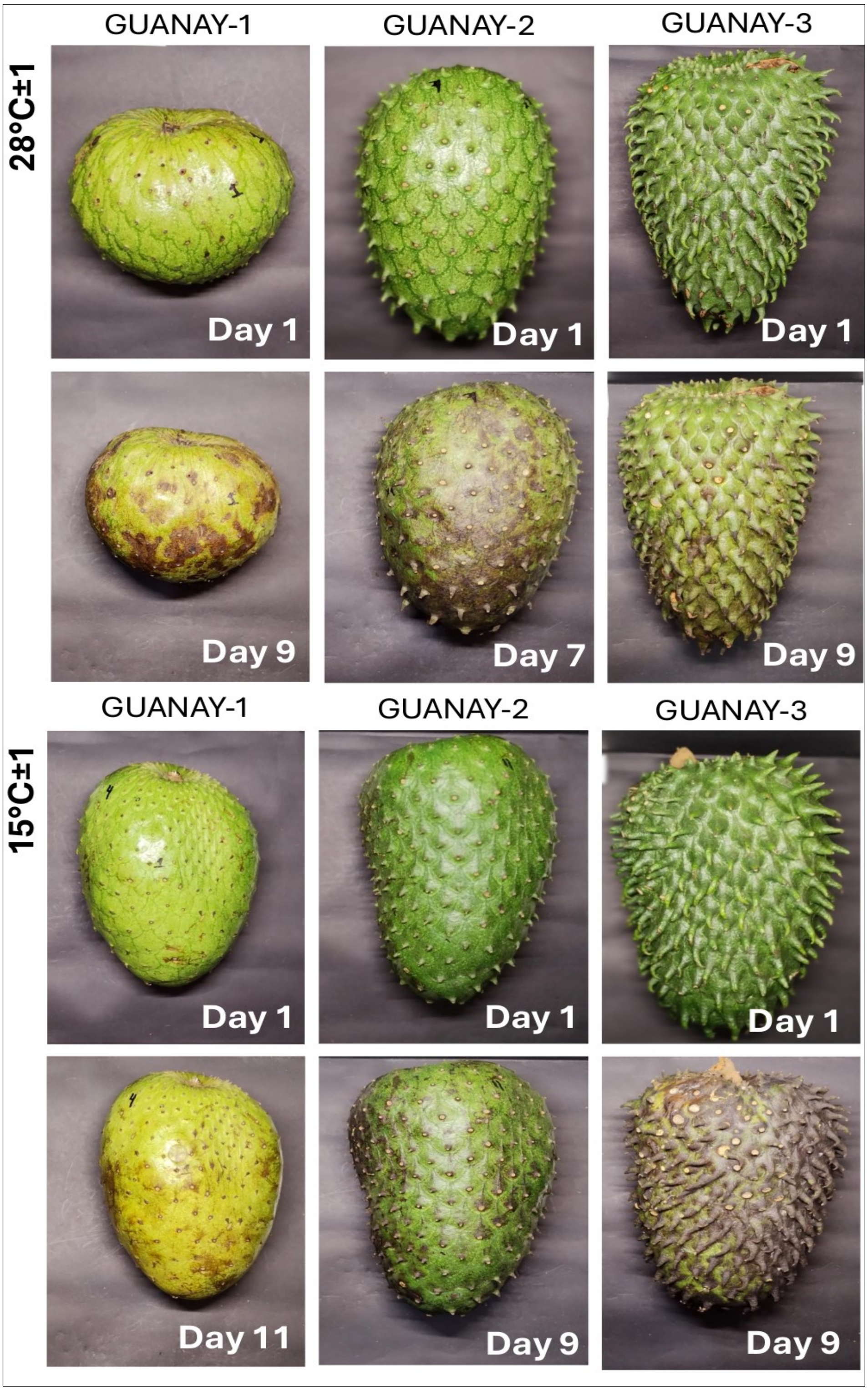

Fig. 3. The initial and final color of soursop fruits (GUANAY-1, GUANAY-2 and GUANAY-3) stored at 28 °C ± 1 and 15 °C ± 1.

sugars and organic acids, providing the physicochemical characteristics of a ripe fruit for consumption (26).

Alternatively, the fruits stored at 15 °C ± 1 showed significant differences between varieties in the content of soluble solids, pH, and acidity ($P < 0.05$). GUANAY-2 and GUANAY-3 had the highest values on day seven of storage. GUANAY-2 presented 11.8 °Brix, pH of 4.3, and 0.49 % acidity. GUANAY-3 showed 10.5 °Brix, pH of 4.6, and 0.49 % acidity on day seven. Conversely, the fruits of the GUANAY-1 variety showed a delay in ripening, occurring until the ninth day of storage, which coincides with its climacteric peak, with a soluble solid's concentration of 12.6 °Brix, pH of 4.11 and acidity of 0.67 % (Fig. 5).

On the other hand, the highest values in GUANAY-2 and GUANAY-3 were recorded before the climacteric peak, which could be related to a response to stress because they were susceptible to cold damage. The accumulation of sugars and organic acids before the climacteric peak is a defense mechanism of the fruits at low temperatures, since they function as osmoprotectors to prevent cell freezing, and dehydration (27). Therefore, the highest values before the climacteric peak may be related to a stress response due to their susceptibility to damage from storage temperature and a possible response to temperature in the initial days of storage, related to the regulation of gene expression of the fruits.

Principal component analysis

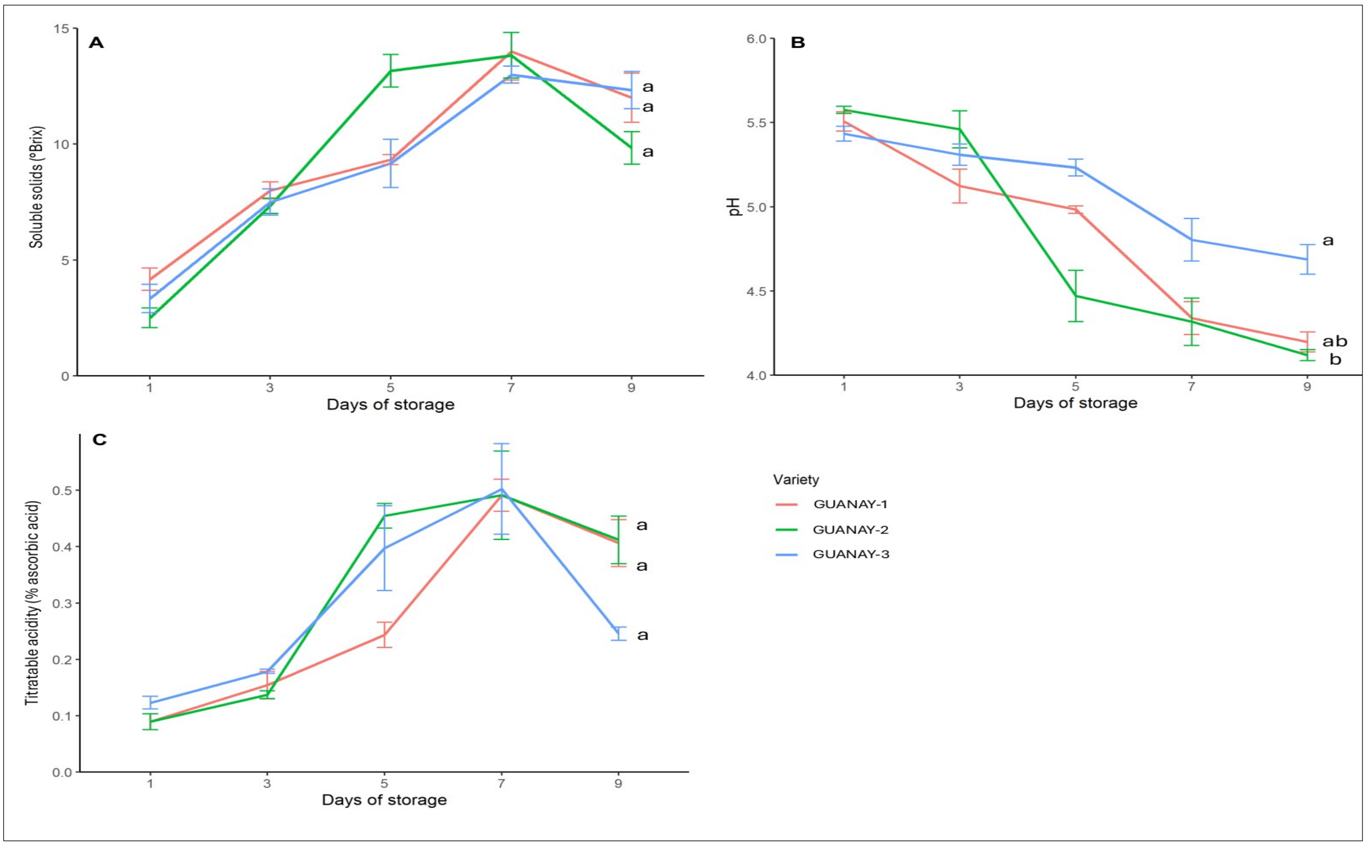

Fig. 4. Physicochemical analysis of soursop fruit varieties (GUANAY-1, GUANAY-2 and GUANAY-3) stored at 28 °C ± 1. a) Soluble solids; b) pH; c) Titratable acidity. Different letters indicate significant differences between varieties according to Tukey's HSD test (P<0.05). Vertical bars represent standard error.

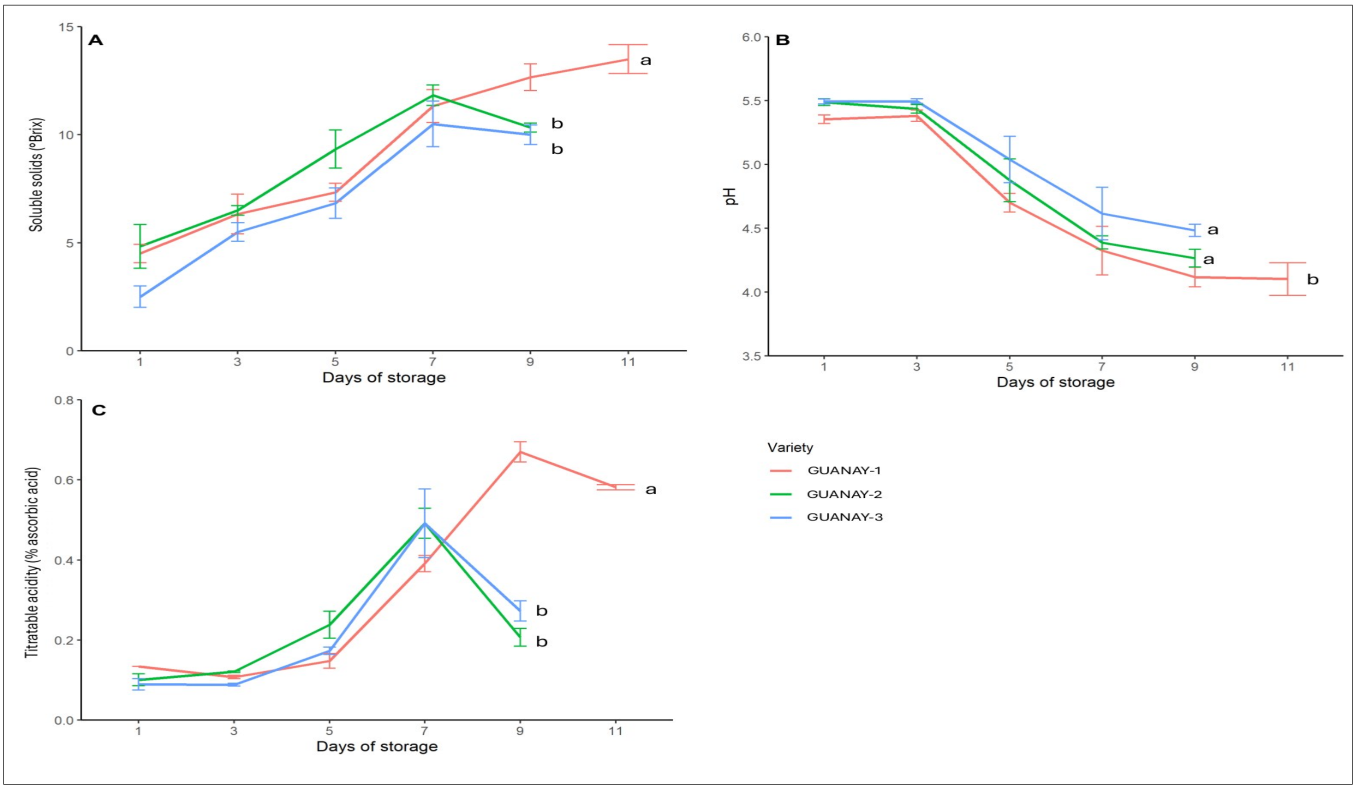

Fig. 5. Physicochemical analysis of soursop fruit varieties (GUANAY-1, GUANAY-2, and GUANAY-3) stored at 15 °C ± 1. a) Soluble solids; b) pH; c) Titratable acidity. Different letters indicate significant differences between varieties according to Tukey's HSD test (P<0.05). Vertical bars represent standard error.

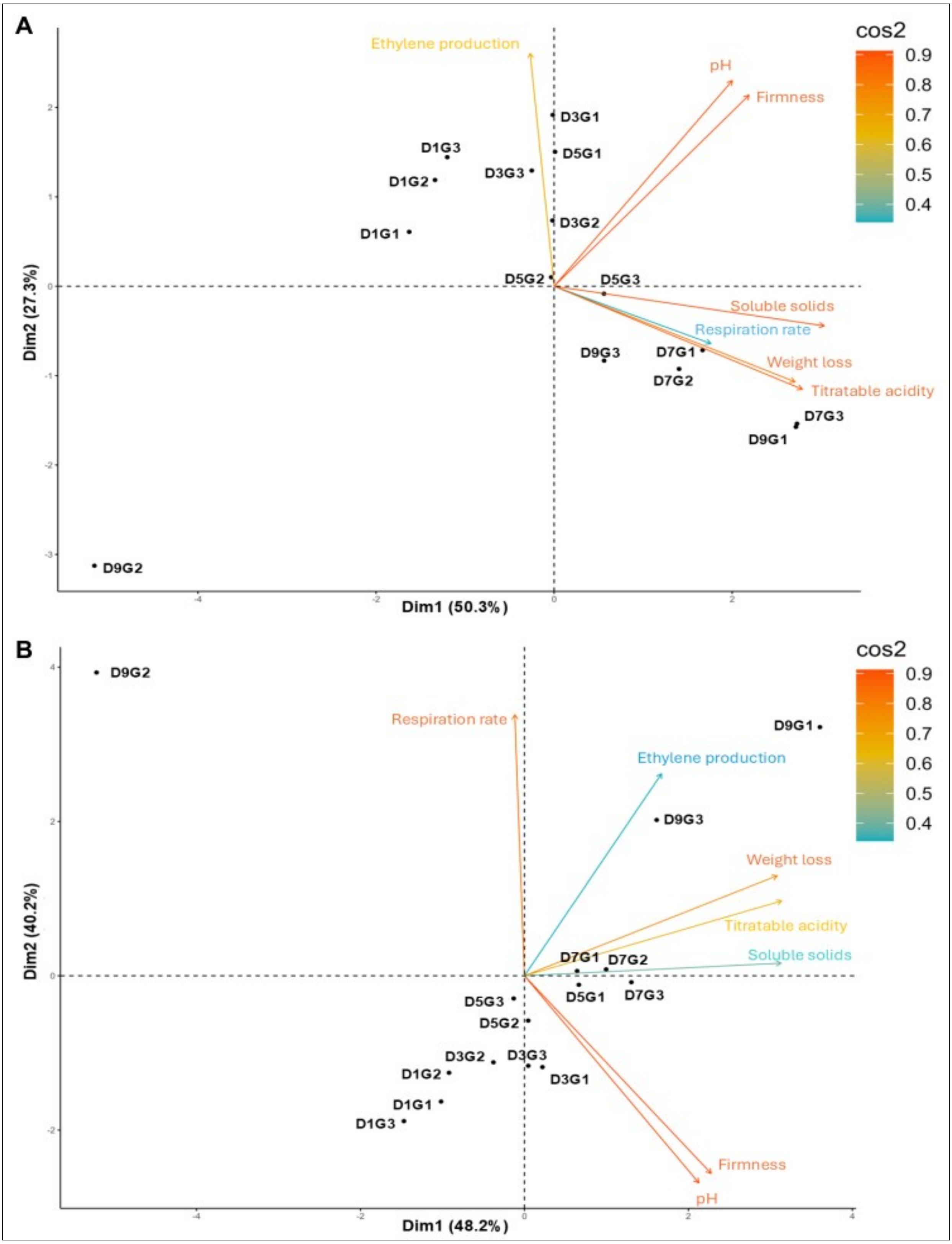

Fig. 6. PCA biplot of soursop fruits stored at 28 °C ± 1 and 15 °C ± 1. D: days of storage. GUANAY-1; G1, GUANAY-2; G2 and GUANAY-3; G3. Scale: cos2, the proportion of variance of each variable explained by each principal component in the PCA. Colors closer to red indicate a higher-quality representation of the variable. a) Fruits stored at 28 °C ± 1; b) Fruits stored at 15 °C ± 1.

A PCA was performed for the fruits stored at 28 °C ± 1 (Fig. 6A). The two components explain 77.6 % of the total variability. Principal component 1 (Dim1) explains 50.3 % of the data variability and is defined by the variables soluble solids, respiration rate, weight loss, and titratable acidity. In comparison, principal component 2 (Dim2) explains 27.3 % of the data variability, defined by the variables ethylene production, pH and firmness. On the other hand, the length of the arrows also indicates the level of impact they have on the variance of the data, and the color indicates the percentage of quality of the variable to the process. In this context, the variables pH, firmness, soluble solids, titratable acidity, and weight loss are the most important variables that impact this process. Furthermore, variables close to each other are positively correlated, while those negatively correlated are far from each other. In this regard, weight loss, titratable acidity, and respiration rate are positively correlated as well as pH with firmness. This information suggests that as the fruit ripens, sugars accumulate and respiratory activity increases, along with the accumulation of organic acids. GUANAY-2 and GUANAY-3 on day five of storage are grouped close to the center (origin), indicating they have similar characteristics (soluble solids, pH, firmness). These results suggest that GUANAY-1 has different characteristics as previously mentioned.

Meanwhile, in the PCA of the fruits stored at 15 °C ± 1, the two components explain 88 % of the total variability, as shown in Fig. 6B. Principal component 1 (Dim1) explains 48.2 % of the variability of the data and is defined by the variables pH and firmness. In comparison, principal component 2 (Dim2) explains 40.2 % of the variability of the data, defined by the variables of respiration rate, ethylene production, weight loss, titratable acidity, and soluble solids. Firmness and pH are correlated, being one of the most important variables of this process. Furthermore, titratable acidity and weight loss are also correlated. The decrease in acidity and firmness, and the increase in metabolic activity represented by respiration rate and ethylene production indicate an ongoing ripening process. GUANAY-1, GUANAY-2, and GUANAY-3 on day seven of storage are grouped together, indicating they have similar physicochemical characteristics (soluble solids, titratable acidity). Furthermore, the three varieties have identical properties on day five (firmness and pH). Indeed, the three varieties had different behaviors on day nine of storage, suggesting that each variety responds differently to this storage condition.

Conclusion

The climacteric peak for the three soursop varieties stored at 28 °C ± 1 was on day seven. In comparison, the temperature of 15 °C ± 1 delayed the climacteric peak by one day for the GUANAY-2 variety and by two days for the other two varieties. The physicochemical parameters TSS, pH, and acidity presented a similar behavior in the three varieties at both storage temperatures. GUANAY-3 showed the lowest weight loss and firmness at 28°C ±1 and GUANAY-1 at 15 °C ± 1. The most important variables that impact the ripening process at both temperatures were pH and firmness, showing that GUANAY-2 and GUANAY-3 have similar properties at 28 °C ± 1. In contrast, all varieties have identical properties on day seven of storage. Therefore, GUANAY-3 stored at 28 °C ± 1 and GUANAY-1 stored at 15 °C ± 1 are potential varieties to be marketed to national and international markets. Future research involving molecular and biochemical approaches must elucidate the mechanisms underlying soursop ripening in these varieties.

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Authors' contributions

LADR experimented and drafted the original manuscript. RBM and EMG reviewed and participated in editing the manuscript. PUBR helped in the statistical analysis of the study. JEBL was involved in the investigation and supervision. VAOJ and GBV conceptualized the idea of this investigation, designed the study, and reviewed and edited the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The Authors do not have any conflicts of interest to declare.

Ethical issues: None

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