Post-harvest quality of pineapple guava [*Acca sellowiana* (O. Berg) Burret] fruits produced in two locations at different altitudes in Cundinamarca, Colombia

Calidad poscosecha de frutos de feijoa [*Acca sellowiana* (O. Berg) Burret] producidos en dos localidades de Cundinamarca, Colombia, en diferentes altitudes

Alfonso Parra-Coronado[1]*, Gerhard Fischer[2], and Jesús Camacho-Tamayo[1]

ABSTRACT

The quality of pineapple guava fruits during post-harvest storage depends directly on their quality at harvest and is influenced by climatic conditions during growth. The aim of this study was to determine the influence of climatic conditions on certain parameters of fruit quality during post-harvest storage. Twenty trees were tagged in two locations within the department of Cundinamarca (Colombia), recording the climatic conditions during fruit growth until harvest. The fruits were differentiated by place of origin and stored at 18 ± 1ºC (76 ± 5% relative humidity, RH) for 11 d or 5 ± 1ºC (87 ± 5% RH) for 31 d, evaluating several quality attributes every two d. The places of origin were San Francisco de Sales (1,800 m a.s.l., 20.6ºC, 63-97% RH, with an average annual precipitation of 1,493 mm) and Tenjo (2,580 m a.s.l., 12.5ºC, 74-86% RH, with an average annual precipitation of 765 mm). The results indicated that the fruits stored at the highest temperature were sweeter and had reduced weight and firmness, lower acidity, and faster postharvest senescence (lower post-harvest durability). The postharvest fruit characteristics were determined by considering the fruit quality during growth and the influence of climatic conditions during cultivation in each location. At the higher altitudes, the total soluble solid content in the fruits was higher and firmness decreased, and the total titratable acidity and weight loss were lower. For fruit color, significant differences were not observed that would demonstrate the effect of climatic conditions during the post-harvest period.

Key words: feijoa, weight loss, firmness, total soluble solids, total titratable acidity, maturity ratio.

RESUMEN

La calidad de los frutos de feijoa durante el almacenamiento poscosecha depende directamente de la calidad que estos tengan en el momento de la recolección, la cual está influenciada por las condiciones climáticas de cultivo. El objetivo de este estudio fue determinar la influencia de las condiciones climáticas en algunos parámetros de calidad durante el almacenamiento en poscosecha. Se marcaron veinte árboles por finca en dos localidades del departamento de Cundinamarca (Colombia), donde se registraron las condiciones climáticas durante el crecimiento de los frutos hasta la cosecha. Los frutos diferenciados por el lugar de procedencia fueron almacenados a temperaturas de 18 ± 1ºC (humedad relativa: 76 ± 5%) durante 11 días y a 5 ± 1ºC (humedad relativa: 87 ± 5%) durante 31 días, con evaluación de los atributos de calidad cada 2 días. Los lugares de procedencia fueron San Francisco de Sales (1,800 msnm, 20,6 ºC, 63-97% humedad relativa (HR), precipitación media anual 1,493 mm) y Tenjo (2,580 msnm, 12.5ºC, 74-86% HR, precipitación media anual 765 mm). Los resultados obtenidos indican que los frutos almacenados a mayor temperatura son más dulces, con mayor pérdida de peso y de firmeza, así como con menor acidez y durabilidad en poscosecha, atributos que están determinados por la calidad de estos en la cosecha, la cual está influenciada a su vez por las condiciones climáticas registradas en el cultivo. Se observó que, a mayor altitud, también es mayor el contenido de sólidos solubles totales y la pérdida de firmeza, mientras que es menor la acidez total titulable y la pérdida de peso. En las mediciones de color no se evidenciaron diferencias significativas que permitan inferir que hubo alguna influencia de las condiciones climáticas en la variación de este parámetro durante la poscosecha.

Palabras clave: feijoa, pérdida de peso, firmeza, sólidos solubles totales, acidez total titulable, relación de madurez.

Introduction

Pineapple guava or feijoa (*Acca sellowiana* (O. Berg) Burret) is a perennial fruit species of the Mirtaceae family that is native to South America, particularly southern Brazil and Uruguay (Schotsmans *et al*., 2011), with high adaptability to different climatic zones (Parra and Fischer, 2013), and is cultivated commercially between 1,800 and

Received for publication: 30 October, 2017. Accepted for publication: 28 February, 2018

Doi: 10.15446/agron.colomb.v36n1.68577

[1] Departamento de Ingeniería Civil y Agrícola, Facultad de Ingeniería, Universidad Nacional de Colombia, Bogota (Colombia).
[2] Scientific consultant; Emeritus researcher of Colciencias, Bogota (Colombia).
* Corresponding author: aparrac@unal.edu.co

2,700 m a.s.l. in Colombia. In tropical areas, this crop can produce fruits continually throughout the year, whereas under seasonal temperature conditions, only one annual harvest occurs (Quintero, 2012). As reported by Parra and Fischer (2013), the principal commercial production of pineapple guava is found in New Zealand, Georgia, Azerbaijan, Colombia and California, with the recent addition of commercial production in Uruguay and Brazil. In Colombia, which has an estimated area of 650 ha for this crop (Quintero, 2012), different varieties of pineapple guava are cultivated, which facilitates cross pollination and yields of high-quality fruits.

After harvest, pineapple guava fruits, which are entirely green, ripen from the inside out; over-ripe fruits suffer a loss of taste and darkening of the seed and pulp (Yi *et al*., 2016). The external changes in quality that occur during post-harvest ripening are not excessive in this green fruit, which makes it difficult to determine the degree of fruit ripeness by visual, tactile, or non-destructive methods (Gaddam *et al*., 2005). According to Amarante *et al*. (2013), the physiological basis of fruit ripening is not well known, making it more difficult to determine strategies for preserving quality during the post-harvest stage.

During post-harvest, fruits undergo a series of changes that involve synthesis and degradation, which are genetically controlled and eventually lead to senescence. These changes generally include modifications of the texture and ultrastructure of cell walls, changes in turgidity, juice content, conversion of starches into sugars, increases in susceptibility to pathogens, and alterations in pigment biosynthesis and compounds that determine flavor (Kader and Yahia, 2011). The evolution of these properties determines the post-harvest quality of fruits.

Oxidative metabolism influences most of the physicochemical changes that occur in harvested fruits (Parra-Coronado and Hernández-Hernández, 2008), and respiration may have the greatest effect on fruit ripening during post-harvest through cell diffusion processes (Schouten *et al*., 2004). The respiration pattern of pineapple guava is the same as for other Mirtaceae species and is a climacteric fruit (Schotsmans *et al*., 2011). The inhibition of respiratory processes directly affects the maintenance of vegetable and fruit quality during storage and can be performed by using controlled or modified atmospheres and also by altering the temperature and relative air humidity (Yahia *et al*., 2011). General fruit quality depends directly on the stage of ripeness. Many parameters must be considered when determining quality, such as firmness, total titratable acidity, soluble solid content (Parra-Coronado *et al*., 2006; Parra-Coronado and Hernández-Hernández, 2008), and the ratio between soluble solids and titratable acidity (Parra-Coronado *et al*., 2015).

Quality parameters at the time of harvest depend upon prevailing weather conditions during growth and the levels of luminosity and temperature (Calvo, 2004). In pineapple guava fruits, these factors directly affect the soluble solid concentration and total titratable acidity but do not affect firmness and color (Parra-Coronado *et al*., 2015) or physiological and chemical changes that occur during post-harvest ripening (Mishra and Gamage, 2007). Notably, with increasing temperatures in the crop cycle and especially during maturation, the sugar content of the fruit decreases (Parra-Coronado and Miranda, 2016). Research performed on pineapple guava includes specific studies on post-harvest physiology and studies on fruit nutraceutical characteristics (Rodríguez *et al*., 2006; Velho *et al*., 2011; Amarante *et al*., 2013).

The aim of this study was to evaluate how weather conditions during the growth of pineapple guava fruits affect the quality characteristics of the produce stored under two different temperature conditions. The pineapple guava in this study was grown in two locations in the department of Cundinamarca, Colombia, with different altitudes and weather conditions.

Materials and methods

Pineapple guava fruits were collected at physiological maturity (considering the size, firmness, peduncle abscission, and color intensity described by Parra-Coronado and Fischer, 2013 and Schotsmans *et al*., 2011) from two farms located in the Andean region of the department of Cundinamarca, Colombia, where trees originating from clone 41 ('Quimba') were planted in 2006. The different crop management activities (e.g., pruning and fertilization) were performed equally on both farms following the recommendations of Quintero (2012) to eliminate the influence of cultivation variables. The soil characterization showed that the soils of the two farms had a sandy loam texture. The Ca/Mg, Mg/K, Ca/K and (Ca + Mg)/K ratios indicated that there were no K and Mg deficiencies and that Cu and Mn showed values below those considered optimal. The first farm was located in the municipality of Tenjo (4°51'23" N and 74°6'33" W) at an altitude of 2,580 m a.s.l., with a mean temperature of 12.5°C and relative humidity 74-86%. The farm had a bimodal rainfall pattern, with an average annual precipitation of 765 mm, concentrated within the periods

TABLE 1. Weather conditions in the study zones from anthesis to pineapple guava fruit harvest (Parra-Coronado *et al*., 2015).

Zone	Harvest	Days[a]	GDD[b] (ºC)	T[c] (ºC)	RH[d] (%)	P[e] (mm)	Rad[f] [W m^{-2}]
Tenjo	1	180	1,979	12.3	76.4	190	12,303
(2,580 m a.s.l.)	2	180	1,966	12.3	84.3	417	9,861
San Francisco	1	155	2,728	18.5	86.1	573	7,814
(1,800 m a.s.l.)	2	155	2,627	18.0	95.1	1,400	10,021

[a]Days: calendar days from anthesis to harvesting; [b]GDD: thermal time (growing degree-days accumulated from anthesis to harvesting); [c]T:average temperature during the study period; [d]RH: average relative humidity during the study period; [e]P: accumulated precipitation from anthesis to harvesting; [f]Rad: accumulated radiation from anthesis to harvesting.

March-May and September-November. The second farm was located in the municipality of San Francisco (4°57'57" N and 74°16'27" W) at 1,800 m a.s.l., with average temperature of 20.6°C and relative humidity between 63 and 97%. This farm had a bimodal rainfall pattern with an annual mean precipitation of 1,493 mm, concentrated within the periods February-May and September-November. For the choice of the two altitudinal sites, the authors found these sites were near the lowest and the highest elevation recommended for commercial pineapple guava cultivation in Colombia.

The climatic conditions of the locations were recorded from anthesis to harvest of the pineapple guava fruits (Tab. 1), between 2012 and 2014. The meteorological data were obtained from weather stations placed in each sampling site, which recorded hourly data on temperature, precipitation, relative air humidity, and total solar radiation.

Experimental design

Because pineapple guava is a perennial crop, 10 trees per element plot (Fernández *et al*., 2010) and two plots per farm were studied, for a total of 40 trees, planted at 4 × 4 m. The aim was to record fruit growth and development from anthesis to harvest along with the weather conditions. A total of 300 fruits free of defects and mechanical damage were collected during two harvests per plot and per farm. The fruits were transported to the laboratory for disinfection with a solution of 1 mL L^{-1} sodium hypochlorite. The fruits were differentiated per plot and site of origin for each harvest and stored at 18 ± 1°C (76 ± 5% RH, 90 fruits by 11 d) and 5 ± 1°C (87 ± 5% RH, 210 fruits by 31 d), taking into account that this fruit species can stand temperatures as low as 1.7°C (Valderrama *et al*., 2005).

Measured variables

The measured quality attributes included weight loss (WL), skin and pulp firmness, total soluble solids (TSS), total titratable acidity (TTA) and epidermal color (hue angle; °h). To determine WL, the weight variation during the storage of five samples from two fruits was determined based on a gravimetric method using an analytical precision balance, Precisa XT220A, with a capacity of 220 g and 0.0001 g precision (Precisa Instruments, Zurich, Switzerland). The skin and pulp firmness were quantified with a Brookfield CT3-4500 texturometer (Brookfield Engineering, Middleboro, MA, USA). Two readings per fruit were performed with a TA39 probe at a precision of ± 0.5%. The NTC 4624 Technical Standard (Icontec, 1999a) was used for the measurements of TSS with an Eclipse refractometer (Bellingham Stanley, Tunbridge Well, UK) using a scale from 0 to 32 and a precision of 0.2 °Brix. The TTA was determined following the NTC 4623 Technical Standard (Icontec, 1999b). The maturity ratio (MR), defined as the ratio between TSS and TTA (TSS/TTA), was determined. The epidermal color was measured using a Minolta CR-400 chroma meter (Konica Minolta, Ramsey, NJ, USA). The quality attributes of the fruits were evaluated after 1, 3, 5, 7, 9 and 11 d of fruit storage at 5 and 18°C. The quality attributes were also evaluated after 15, 19, 23 and 31 d of fruit storage at 5°C. The statistical design was entirely random, with five replicates per trial.

In order to analyze the behavior of each quality parameter and its variation over time, the statistical program IBM-SPSS v.20 (SPSS Inc., Chicago, IL, USA) was used to perform a correlation analysis between the fruit quality parameters. The data were analyzed with descriptive statistics, and the standard deviation (SD) was used as a measure of dispersion. An analysis of variance and comparison of means test (Tukey's tests) were performed for the fruit-quality characteristics during storage for each study location and harvest.

Results

Skin and pulp firmness

The pineapple guava fruit skin and pulp firmness had the same trends in behavior over time for both storage conditions and both locations, with initially high values that decreased during ripening (Tab. 2). The skin firmness was always higher than the pulp firmness for the same storage period.

At the beginning of storage, the skin firmness of the pineapple guava fruits showed mean values of 15.2 ± 1.6 N for San Francisco and 12.5 ± 3.1 N for Tenjo, with values decreasing over time. For the fruits stored at 5°C, the skin firmness at the end of the storage period reached average values of 13.8 ± 2.7 N for fruits coming from San Francisco and 7.8 ± 2.0 N for those coming from Tenjo, whereas the "San Francisco fruits" stored at 8°C showed average values of 9.3 ± 1.8 N and the "Tenjo fruits" showed mean values of 4.2 ± 0.9 N at the end of the storage period.

The pulp firmness had average values of 5.8 ± 2.0 N in fruits from San Francisco and 6.5 ± 3.1 N in fruits from Tenjo at the beginning of storage, at both temperatures. At the end of the storage period, the pulp firmness of the fruits stored at 5°C reached values of 1.7 ± 1.0 N in the fruits from San Francisco and 1.2 ± 0.5 N in the fruits from Tenjo, whereas the "San Francisco fruits" stored at 18°C had mean values of 0.8 ± 0.3 N and the "Tenjo fruits" showed average values of 0.5 ± 0.2 N.

The analysis of means (Tab. 2) indicated that, during storage, the differences were related to storage conditions and place of origin. However, differences were not observed in fruits from the same locations. The firmness behavior of the pineapple guava fruits during post-harvest depended on the storage temperature and fruit firmness at the time of harvest, which is influenced by the climatic conditions of the cultivation site. The weather conditions at the origin site influenced durability in postharvest and invariably affected the internal and external quality of the fruits and their storage capacity (Moretti *et al*., 2010).

The loss of firmness in fruit skin and pulp (Tab. 2) during storage was higher for fruits produced at the elevated altitude (Tenjo), with a lower average temperature and higher

TABLE 2. Analysis of means for skin and pulp firmness (N) of pineapple guava fruits during post-harvest under two storage conditions.

	Temperature: 5ºC; RH: 87%				Temperature: 18ºC; RH: 76%			
Day	**T-1**	**T-2**	**S.F.-1**	**S.F.-2**	**T-1**	**T-2**	**S.F.-1**	**S.F.-2**
				Skin firmness				
1	14.82 a	10.21 b	16.19 a	14.18 a	14.82 a	10.21 b	16.19 a	14.18 a
3	18.67 a	11.68 a	18.59 a	16.84 a	18.58 a	13.49 a	20.86 a	20.38 a
5	16.35 abc	11.12 bc	22.58 a	17.49 ab	17.32 ab	9.25 c	21.21 a	21.91 a
7	16.99 ab	10.79 cd	22.77 a	18.80 ab	15.59 bc	6.62 d	19.52 ab	18.39 ab
9	16.64 ab	10.99 bc	17.78 a	13.67 ab	10.88 bc	4.87 c	15.76 ab	14.75 ab
11	14.44 a	10.77 b	17.34 a	14.64 a	4.44 c	3.86 c	8.91 b	9.65 b
15	13.22 ab	10.07 c	18.59 a	16.50 ab				
19	12.45 b	8.32 c	16.86 a	14.87 ab				
23	10.42 b	7.87 b	16.09 a	16.54 a				
27	10.63 b	6.60 c	15.27 a	15.56 a				
31	9.03 bc	6.63 c	13.55 ab	14.03 a				
				Pulp firmness				
1	6.90 a	6.14 a	5.47 a	6.12 a	6.90 a	6.14 a	5.47 a	6.12 a
3	8.98 a	5.82 a	7.72 a	4.62 a	4.42 a	5.69 a	7.26 a	5.69 a
5	6.87 ab	6.49 ab	11.01 a	5.79 ab	4.15 a	2.27 a	5.88 ab	6.25 ab
7	5.56 abc	5.18 bc	10.96 a	6.75 ab	2.93 bc	1.03 c	2.81 bc	2.97 bc
9	5.29 ab	3.98 abc	5.88 a	4.05 abc	1.40 bc	0.60 c	1.87 abc	1.61 abc
11	4.43 b	3.36 bc	8.22 a	5.91 ab	0.40 c	0.60 c	0.91 dc	0.64 c
15	3.40 b	3.08 b	8.65 a	4.93 b				
19	3.18 bc	1.77 c	5.78 a	4.92 ab				
23	2.89 a	1.98 a	3.35 a	4.42 a				
27	1.75 a	1.18 a	2.95 a	2.89 a				
31	1.27 a	1.04 a	1.68 a	1.78 a				

T-1: Tenjo location, harvest 1; T-2: Tenjo location, harvest 2; S.F.-1: San Francisco location, harvest 1; S.F.-2: San Francisco location, harvest 2. Different lowercase letters in the rows show statistical differences according to the Tukey's test ($P \leq 0.05$).

Means followed by different letters for the same day indicate significant differences according to the Tukey's test ($P \leq 0.05$).

solar radiation; thus, a higher number of calendar d and lower thermal time (GDD) were required to proceed from anthesis to harvest (Tab. 1).

The average loss of skin firmness of the pineapple guava fruits from Tenjo and San Francisco was 37.1 and 8.2% for the fruits stored at 5°C, and 66.0 and 38.5% for the fruits stored at 18°C, respectively.

Contents of total soluble solids, total titratable acidity and maturity ratio

For the pineapple guava fruits stored at 18°C, the TSS (°Brix) and maturity ratio (MR) increased and TTA (% of citric acid) decreased with ripening, whereas the fruits stored at 5°C showed little variation of those parameters throughout the storage time (Tab. 3). The fruits stored at a higher temperature showed more changes because of the exponential increase in the speed of enzymatic reactions with increasing temperatures (Wills *et al*., 2007).

The TTS content showed average values of 10.8 ± 0.9 °Brix for San Francisco and 12.6 ± 1.1 °Brix for Tenjo at the beginning of storage for the two temperatures. Although the TSS in the fruits stored at 5°C showed an increasing trend, the variation was not significant, especially for the fruits from San Francisco, which was shown by comparing the values recorded at the beginning and end of the study (Tab. 3).

At the end of the storage period, the fruits reached mean values of 10.9 ± 0.7 °Brix for San Francisco and 14.2 ± 0.9 °Brix for Tenjo. The TSS of the fruits stored at 18°C increased as the fruits ripened, especially in the fruits from Tenjo. At the end of the storage period, mean TSS values of 12.0 ± 0.9 °Brix for San Francisco and 16.5 ± 0.7 °Brix for Tenjo fruits were observed.

TABLE 3. Analysis of means for total soluble solids (TSS) and total titratable acidity (TTA) in pineapple guava fruits under two storage conditions.

	Temperature: 5ºC; RH: 87%				Temperature: 18ºC; RH: 76%			
Day	T - 1	T - 2	S.F. - 1	S.F. - 2	T - 1	T - 2	S.F. - 1	S.F. - 2
				Total soluble solids (TSS, °Brix)				
1	13.35 a	11.73 ab	11.19 ab	10.25 b	13.35 a	11.73 ab	11.19 ab	10.25 b
3	12.67 abc	12.67 abc	11.32 bc	10.92 bc	14.42 a	13.21 ab	10.52 bc	10.25 c
5	13.48 ab	11.86 b	9.57 c	9.98 c	13.35 ab	14.02 a	10.11 c	10.11 c
7	14.56 a	12.13 b	9.30 c	9.30 c	14.02 a	14.15 a	11.59 b	11.05 bc
9	14.29 ab	12.54 bc	11.19 c	10.78 c	16.58 a	14.42 ab	11.46 c	11.32 c
11	15.77 b	13.48 cd	9.84 f	10.11 f	17.79 a	15.23 bc	12.67 cd	11.32 ef
15	14.83 a	12.67 b	10.92 c	11.59 bc				
19	16.04 a	13.88 b	9.71 c	10.38 c				
23	14.96 a	15.50 a	11.05 b	10.51 b				
27	14.96 a	13.88 a	11.32 b	11.19 b				
31	14.56 a	13.75 a	11.32 b	10.51 b				
				Total titratable acidity (TTA, % citric acid)				
1	1.91 a	1.68 a	1.58 a	1.80 a	1.91 a	1.68 a	1.58 a	1.91 a
3	1.77 ab	1.86 ab	1.61 b	1.81 ab	1.78 ab	2.20 a	1.65 ab	1.78 ab
5	1.86 a	2.12 a	1.66 a	1.86 a	1.82 a	1.86 a	1.88 a	1.85 a
7	1.95 a	1.81 a	1.50 a	1.90 a	1.58 a	1.49 a	1.77 a	1.80 a
9	1.87 ab	2.04 a	1.84 ab	1.97 b	1.30 b	1.49 ab	1.45 ab	1.50 ab
11	1.77 a	2.10 a	1.89 a	1.99 a	0.73 c	0.83 bc	1.20 b	1.25 b
15	1.93 a	2.10 a	1.88 a	2.16 a				
19	1.77 a	1.92 a	1.83 a	1.95 a				
23	1.45 b	2.28 a	1.92 ab	2.10 a				
27	1.50 b	1.74 ab	1.96 a	1.91 ab				
31	1.48 ab	1.57 ab	1.61 a	1.23 b				

T-1: Tenjo location, harvest 1; T-2: Tenjo location, harvest 2; S.F.-1: San Francisco location, harvest 1; S.F.-2: San Francisco location, harvest 2. Different lowercase letters in the rows show statistical differences according to the Tukey's test ($P \leq 0.05$).

Means followed by different letters for the same day indicate significant differences according to the Tukey's test ($P \leq 0.05$).

The TTA registered average values of 1.69 ± 0.18% for San Francisco and 1.80 ± 0.20% for Tenjo at the beginning of storage at both temperatures. Although the TTA in the fruits stored at 5°C showed low variation, the TTA tended to decrease during the last day of storage (Tab. 3) reaching final mean values of 1.42 ± 0.15% for San Francisco and 1.53 ± 0.19% for Tenjo. The TTA of the fruits stored at 18°C decreased as they ripened (Tab. 3), especially in fruits from Tenjo, with average values of 1.23 ± 0.25% for San Francisco and 0.78 ± 0.27% for Tenjo at the end of the storage period.

The MR increased for the two storage conditions (Fig. 1) and was elevated at the highest temperature. The MR showed average values of 6.6 ± 1.1 for San Francisco and 7.1 ± 1.2 for Tenjo at the beginning of storage for both temperatures. Although the MR at 5°C showed little variation, it generally tended to increase during the last 8 d of storage, reaching average values of 7.9 ± 0.9 for fruits from San Francisco and 9.6 ± 2.2 for fruits from Tenjo. The MR of the fruits stored at 18°C increased as the fruits ripened, presenting average values of 10.3 ± 2.6 for San Francisco and 23.9 ± 8.1 for Tenjo at the end of storage, with high dispersion for the latter location.

The analysis of means (Tab. 3) indicated that storage conditions and place of origin differed for TSS and TTA. The behavior of TSS, TTA, and MR in the pineapple guava fruits during post-harvest depended on the storage temperature and TSS and TTA values at the time of harvest, which were influenced by weather conditions during fruit growth. During storage, the fruits from the highest location (Tenjo) with an elevated accumulated solar radiation and lower mean temperature and relative air humidity (Tab. 1) had higher levels of TSS and MR, but lower TTA. These results indicate that pineapple guava fruits produced in cold climates have a better flavor than those from warm climates.

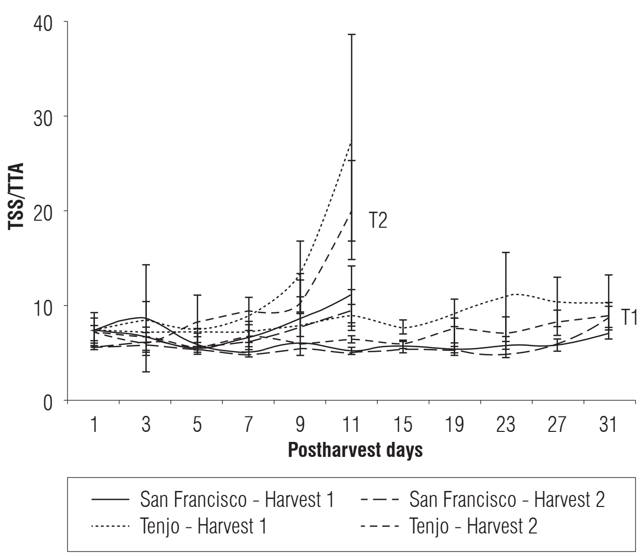

FIGURE 1. Variation of the maturity ratio (TSS/TTA) of pineapple guava fruits stored at T_1 (5ºC) and T_2 (18ºC).

The values listed in Table 3 indicate that the TTA in the pineapple guava fruits did not show differences at the time of harvest, which could help determine the influence of climatic conditions on this parameter, but differences were observed at the end of the storage period, especially for fruits stored at the highest temperature (18°C). The TTA was higher in the fruits produced at the lowest altitude (San Francisco), with less accumulated solar radiation and higher average temperatures and relative air humidity (Tab. 1).

Weight loss and color change

The weight loss (WL) in the pineapple guava fruits increased for both storage conditions (Fig. 2A). For fruits stored at 5°C, the WL at the end of the storage period showed a mean value of 8.48 ± 1.91% for San Francisco and 5.94 ± 0.75% for Tenjo, whereas those stored at 18°C presented a mean value of 20.37 ± 1.60% for fruits from San Francisco and 13.01 ± 1.98% for fruits from Tenjo. For the storage conditions (equal altitude), it was observed that, at a lower temperature, the relative humidity was lower (sensitive cooling of the air) and, therefore, the vapor pressure deficit was lower, which is the cause of the moisture loss of the product (weight loss). Transpiration and substrate consumption through respiration are the primary causes of WL of fruits during post-harvest ripening (Saladié *et al.,* 2007).

The analysis of means indicated that differences in WL occurred between storage conditions and cultivation location. The fruits stored at 5°C did not show significant differences for the site of origin or harvest when compared with fruits stored at 18°C. However, for the two storage conditions, the WL was lower in the fruits from the highest location (Tenjo), where the accumulated radiation is greater and mean temperature and relative humidity are lower (Tab. 1).

Color change occurred because of chlorophyll degradation and pigments synthesized such as anthocyanins and carotenoids (Mishra and Gamage, 2007). The color measured as the °h represented the color or tonality that varies from 0° in pure red to 180° in pure green (Hernández *et al*., 2007). The value of the °h of the pineapple guava fruits did not show a clear trend during the first d of storage, but decreased over time for the two storage conditions (Fig. 2B). The analysis of means indicated that statistically significant differences did not occur in the °h for the pineapple guava fruits during the last d of storage for the different sites and harvests.

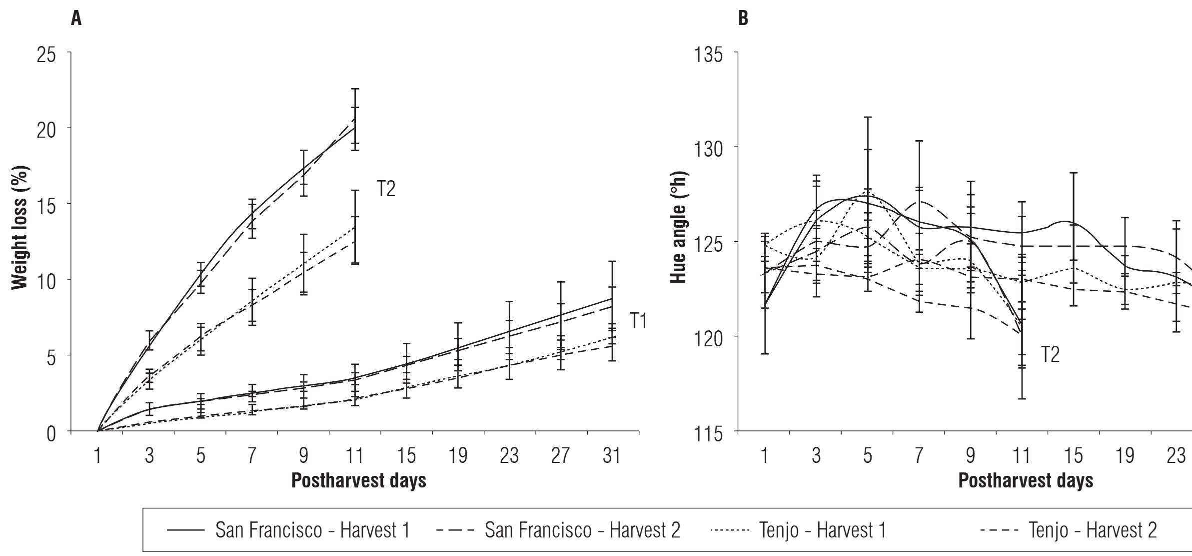

FIGURE 2. Variation in weight loss (A) and hue angle (B) of pineapple guava fruits stored at T_1 (5ºC) and T_2 (18ºC).

Discussion

Skin and pulp firmness

Different authors (Osterloh *et al*., 1996; Parra-Coronado *et al*., 2006) have indicated that decreased firmness values during fruit ripening are determined by propectin, the agglutinating substance within cells that gives turgidity to fruits and degrades along with pectin substances. This degradation process changes the texture and consistency of fruits, producing the characteristic softening during the ripening process. The decrease in firmness over the storage period has been reported by various authors for other fruits of the Mirtaceae family, such as guava (Solarte *et al*., 2010), champa (*Campomanesia lineatifolia*) (Álvarez *et al*., 2009), and araza (*Eugenia stipitata*) (Hernández *et al*., 2007). Firmness is an important fruit characteristic of consumption quality. When designing packaging and transport during the harvest and post-harvest periods (Parra and Fischer, 2013), the criteria set by Márquez *et al*. (2007) should be considered; these authors indicated that the load that a fruit can support is equivalent to 70% of its durability.

During pineapple guava fruit ripening, many enzymes are expressed, which modify the plasticity of cell walls, and one the main enzymes involved in this process is polygalacturonase (PG) (Öpik and Rolfe, 2005). The activity of PG in pineapple guava is higher inside the mesocarp, which suggests that softening progresses from the inside to the outside of the fruit (Parra and Fischer, 2013). This process is evidenced by the lower firmness value of the pulp as compared to that of the skin. For the storage conditions considered in this study, firmness decreased more rapidly for the pineapple guava fruits stored at the higher temperature (18°C). At day 11 of storage, the fruits with higher values of skin and pulp firmness were those stored at the lowest temperature (5°C) (Tab. 2). Similar results were reported by different authors for pineapple guava from clones 41 (‘Quimba’) and 8-4 (Rodríguez *et al*., 2006; Parra and Fischer, 2013) as well as for guava (Solarte *et al*., 2010) and pear (Parra-Coronado *et al*., 2006).

The post-harvest physiological behavior of fruits and vegetables depends on their storage conditions, with temperature being the main factor (Parra-Coronado and Hernández-Hernández, 2008). The decreasing intensity of respiration is the basis for extending the life of agricultural products through low temperatures, which reduces the speed of enzymatic activity (Wills *et al*., 2007). The speed of enzymatic reactions increases exponentially with increases of temperature, and, for every 10°C temperature increase, physiological and chemical changes increase 2 to 3 times (Q_{10}) (Mishra and Gamage, 2007). As the respiration rates increase, ethylene concentration is also increased, promoting the activation of enzymes that intervene in cell wall degradation, which causes loss of firmness and consequent softening of the fruit (Saladié *et al.*, 2007).

Although studies have not been performed to determine the influence of weather conditions on the post-harvest behavior of pineapple guava fruits, the results found in this study are consistent with observations by Minas *et al.* (2018), who found that peach fruits produced at higher crop temperatures were firmer, whereas their water content was lower. Limited studies have been performed to determine the influence of precipitation and relative humidity on fruit firmness. In this study on pineapple guava fruits, harvests with greater accumulated rain (Tenjo-2, with 417 mm; and San Francisco-2, with 1,400 mm) and average relative humidity produced fruits with lower skin firmness for the same location although the pulp firmness did not show differences (Tab. 2). This result is consistent with that of Gariglio *et al.* (2007), who reported that a high RH could severely affect fruit quality, as observed in mandarin, which quickly lost fruit consistency.

Contents of total soluble solids, total titratable acidity, and maturity ratio

The pineapple guava fruits stored at higher temperatures showed a higher and accelerated increase in TSS because the speed of enzymatic reactions increases exponentially with rises in temperature (Wills *et al.*, 2007). Although there is no consensus on variations of TSS in pineapple guava fruit during post-harvest, these results are within the range reported by certain authors, who indicated that TSS values increase up to the climacteric process and subsequently decrease (Rodríguez *et al.*, 2006; Parra and Fischer, 2013). Other authors have indicated that TSS decreases during post-harvest or remains constant when fruits are stored at a low temperature (Velho *et al.*, 2011), with values between 5 and 15 °Brix. According to Osterloh *et al.* (1996), these dissimilar behaviors were most likely influenced by varietal characteristics, plant age, and climatic and growing conditions to which the fruits were exposed. According to Rodríguez *et al.* (2006), the pineapple guava had high levels of starch at the time of harvest, which hydrolyzed during post-harvest ripening and caused the TSS to increase.

The TTA results in this study are similar to those observed by different authors. Rodríguez *et al.* (2006) observed that, in pineapple guava fruits, the TTA increases until the climacteric process and subsequently decreases, whereas other authors (Velho *et al.*, 2011) have reported that the TTA decreases during storage (4 to 23°C). Rodríguez *et al.* (2006) indicated that, in pineapple guava fruits (clones 8-4 and Quimba), acidity decreases during the ripening process because organic acids degrade during respiration. According to Wills *et al.* (2007), organic acids generally degrade during the ripening stage because they are utilized in respiration or transformed into sugars; such changes are shown in Table 3 for fruits produced in Tenjo, which presented increased TSS concentrations during storage at 18°C.

The maturity index increased for the two storage conditions (Fig. 1) and was increased at higher temperature, which is consistent with reports for the majority of fruits (Parra-Coronado *et al.*, 2006; Álvarez *et al.*, 2009). The MR was low and relatively constant when the product was stored at low temperatures and showed little dispersion because the starch hydrolysis was higher and more complete at low temperatures (Musacchi and Serra, 2018). The highest values for the MR occurred with the highest storage time, lowest relative air humidity and highest temperatures.

The behavior of TSS, TTA, and MR in pineapple guava fruits during post-harvest depends on the TSS and TTA values of fruits at the time of harvest, which are influenced by weather conditions at the origin site during fruit growth. The TSS content during post-harvest was higher in the fruits produced in Tenjo. These results are consistent with Kano (2015), who indicated that the TSS content in watermelon fruits would be lower at higher temperatures. Arah *et al.* (2015) also observed that, in tomatoes, the TSS content was lower at higher temperatures and relative humidity, and also at lower light intensity. Possibly, growing temperatures that are too high result in a loss of photoassimilates as a result of elevated respiration rates of carbohydrates (Wills *et al.*, 2007; Taiz *et al.*, 2014). However, when the higher temperature is still inside the optimum range of a fruit species, the warmer site can also promote the sugar translocation to the fruits, which was observed in Colombia in cape gooseberry (Fischer *et al.*, 2007) and banana passion fruits (Mayorga, 2016) at the lower and warmer site. For accumulated solar radiation, Martínez-Vega *et al.* (2008) found similar results for pineapple guava belonging to clone 41 and indicated that the fruits with the lowest TSS values were those located within the inner-middle area of the canopy, which has a low incidence of luminous radiation. The authors supposed that the higher accumulated solar radiation at the high elevation site (Tenjo) favored photosynthetic performance and thus the TSS content (Taiz *et al.*, 2014; Fischer *et al.*, 2016). On the other hand, the cooler nights in Tenjo (located at a higher elevation than San Francisco) decreased the maintenance respiration of the fruits and their energy costs, increasing the positive carbon balance (Gariglio *et al.*, 2007) and so, contributing to the higher TSS. Also, the lower TSS content in the fruits from San Francisco could have been influenced by the higher precipitation rates at this location (Tab. 1), especially because Osterloh *et al.* (1996) observed that high precipitation diminishes TSS production, possibly because of cloudy weather conditions and temperature decreases.

The results found in this study are consistent with those of Martínez-Vega *et al.* (2008), who observed that TTA increased slightly in pineapple guava fruits from less illuminated parts of the canopy.

Weight loss and color change

The weight loss (WL) in the pineapple guava fruits increased during both storage conditions (Fig. 2A), which is consistent with what Rodríguez *et al.* (2006) found for pineapple guava in clones 8-4 and Quimba and for champa fruits (Álvarez *et al.*, 2009). The WL was higher for the pineapple guava fruits stored at higher temperatures, a behavior also reported by Parra-Coronado *et al.* (2006) for pears. Rodríguez *et al.* (2006) found intermediate values compared with the results of this study for pineapple guava fruits of the 'Quimba' clone from the municipality of Vega (1,900 m a.s.l.) stored at ambient temperature (16.3°C, 65.1% RH); after 18 d in storage, the WL was 17.3%. Valderrama *et al.* (2005) indicated that pineapple guava fruits could be stored over long periods at low temperatures (1.7°C) with low WL and TSS.

The °h value of the green pineapple guava fruits did not show a clear trend during the first d of storage, but decreased over time for the two storage conditions (Fig. 2B). This undefined trend of °h of the pineapple guava fruit is consistent with reports by East *et al.* (2009), who indicated that significant variations might not be observed in skin color among certain cultivars as the fruit ripens. In other pineapple guava cultivars, the °h decreased, representing a loss in green color (Velho *et al.*, 2011). The results found in this study show that the pineapple guava fruit does not change color because of the genetics of the fruits and only varies in shades of green. This result should not be used to establish the influence of weather conditions during the growth stage of fruits over this parameter at post-harvest.

To date, studies reporting differences between pineapple guavas indicating the influence of weather conditions on the behavior of fruit quality parameters during the post-harvest stage have not been carried out. To our knowledge, this is the first study carried out on the subject. Further research covering a wide range of pineapple guava varieties and environments is recommended. Also, the application of research facilities such as FACE (Free-Air Carbon dioxide Enrichment), installed through weather measuring equipment in a circle around the studied trees (Jones *et al.*, 2014) could provide much more information on the direct influence of weather on the quality of fruits inside the FACE circle.

Conclusions

Storage temperature is a factor that affects the durability of pineapple guava fruits and shows a direct relationship with TSS, MR, and WL. Storage temperature has an inverse relationship with the TTA, firmness and shelf life of fruits. Therefore, stored fruits are sweeter and show a higher loss of weight and firmness and reduction in post-harvest durability.

The results obtained in this study clarify that the storage conditions and climatic conditions of origin (altitude) had a great influence on the behavior of the TSS, TTA, MR, firmness, and WL in the pineapple guava fruits during the post-harvest period. This behavior depends on the values of these parameters at the time of harvest and weather conditions during fruit growth. The conditions at the higher altitude (lower temperature but higher solar radiation) corresponded to a greater TSS content and firmness loss but lower TTA and WL. The color change (°h) of these nearly entirely green fruits did not show significant differences that might reveal the influence of weather conditions on the variation of this parameter during post-harvest.

Acknowledgments

We are grateful to the Agricultural Science Faculty of the Universidad Nacional de Colombia in Bogota for financial support, to Dr. Celsa Garcia for supplying two meteorological stations, and to biologist Omar Camilo Quintero for allowing access to his pineapple guava crops and for supplying the necessary resources for this study.

Literature cited

Álvarez, J.G., H.E. Balaguera, and J.F. Cárdenas. 2009. Caracterización fisiológica del fruto de champa (*Campomanesia lineatifolia* Ruiz and Pavón) durante la poscosecha. Rev. UDCA Act. Divul. Cient. 12(2), 125-133.

Amarante, C.V.T., C.A. Steffens, T.D.T. Benincá, C. Hackbarth, and K.L. dos Santos. 2013. Qualidade e potencial de conservação pós-colheita dos frutos em cultivares brasileiras de goiabeira-serrana. Rev. Bras. Frutic. 35(4), 990-999. Doi: 10.1590/S0100-29452013000400009

Arah, I.K., H. Amaglo, E.K. Kumah, and H. Ofori. 2015. Preharvest and postharvest factors affecting the quality and shelf life of harvested tomatoes: a mini review. Int. J. Agron. vol. 2015, Art. ID 478041, 6 p. Doi: 10.1155/2015/478041

Calvo, G. 2004. Efecto del 1-metilciclopropeno (1-MCP) en pera variedad Williams cosechadas con dos estados de madurez. Rev. Invest. Agropecu. 33(2), 3-26.

East, A.R., X.I.T. Araya, M.L.A.T.M. Hertog, S.E. Nicholson, and A.J. Mawson. 2009. The effect of controlled atmospheres on respiration and rate of quality change in 'Unique' feijoa fruit. Postharvest Biol. Technol. 53(1), 66-71. Doi: 10.1016/j.postharvbio.2009.02.002

Fernández, R., A. Trapero, and J. Domínguez. 2010. Experimentación en agricultura. Consejería de Agricultura y Pesca, Servicio de Publicaciones y Divulgación; Sevilla, Spain.

Fischer, G., G. Ebert, and P. Lüdders. 2007. Production, seeds and carbohydrate contents of cape gooseberry (*Physalis peruviana* L.) fruits grown at two contrasting Colombian altitudes. J. Appl. Bot. Food Qual. 81(1), 29-35.

Fischer, G., F. Ramírez, and F. Casierra-Posada. 2016. Ecophysiological aspects of fruit crops in the era of climate change. A review. Agron. Colomb. 34(2), 190-199.

Gaddam, U.S., A.J. Mawson, W.C. Schotsmans, and E.W. Hewett. 2005. Segregation of feijoa fruit using acoustic impulse response. Acta Hortic. 687, 365-367.

Gariglio, N.F., R.A. Pilatti, and M. Agustí. 2007. Requerimientos ecofisiológicos de los árboles frutales. pp. 41-82. In: Sozzi, G.O. (ed.). Árboles frutales – Ecofisiología, cultivo y aprovechamiento. Editorial Facultad de Agronomía, Universidad de Buenos Aires, Buenos Aires.

Hernández, M.S., O. Martínez, and J.P. Fernández-Trujillo. 2007. Behavior of Arazá (*Eugenia stipitata* Mc Vaugh) fruit quality traits during growth, development and ripening. Sci. Hortic. 111, 220-227. Doi: 10.1016/j.scienta.2006.10.029

Icontec, 1999a. Norma técnica colombiana NTC 4624. Jugos de frutas y hortalizas. Determinación del contenido de sólidos solubles. Instituto Colombiano de Normas Técnicas y Certificación, Bogota.

Icontec, 1999b. Norma técnica colombiana NTC 4623. Productos de frutas y verduras. Determinación de la acidez titulable. Instituto Colombiano de Normas Técnicas y Certificación, Bogota.

Kader, A.A. and E.M. Yahia. 2011. Postharvest biology of tropical and subtropical fruits. pp. 79-111. In: Yahia, E.M. (ed.). Postharvest biology and technology of tropical and subtropical fruits. Vol. 1. Fundamental issues. Woodhead Publishing, Cambridge, UK.

Kano, Y. 2015. Effects of summer day-time temperature on sugar content in several portions of watermelon fruit (*Citrullus lanatus*). J. Hortic. Sci. Biotech. 79(1), 142-145. Doi: 10.1080/14620316.2004.11511728

Márquez, C.C.J., C.M. Otero, and M. Cortés. 2007. Cambios fisiológicos, texturales, fisicoquímicos y microestructurales del tomate de árbol (*Cyphomandra betacea* S.) en poscosecha. Vitae 14(2), 9-16.

Martínez-Vega, R.R., G. Fischer, A. Herrera, B. Chaves, and O.C. Quintero. 2008. Características físico-químicas de frutos de feijoa influenciadas por la posición en el canopi. Rev. Colomb. Cienc. Hortic. 2(1), 21-32. Doi: 10.17584/rcch.2008v2i1.1170

Mayorga, M.J. 2016. Caracterización ecofisiológica de curuba (*Passiflora tripartita* var. *mollissima*) en dos condiciones ambientales. MSc thesis. Faculty of Agronomy, Universidad Nacional de Colombia, Bogota.

Minas, I.S., G. Tanou, and A. Molassiotis. 2018. Environmental and orchard bases of peach fruit quality. Sci. Hortic. 235, 307-322. Doi: 10.1016/j.scienta.2018.01.028

Mishra, V. K. and T.V. Gamage. 2007. Postharvest physiology of fruit and vegetables. pp. 19-48. In: Shafiur Rahman, M. (ed.). Handbook of food preservation. 2nd ed. Taylor & Francis Group, New York, USA.

Moretti, C.L., L.M. Mattos, A.G. Calbo, and S.A. Sargent. 2010. Climate changes and potential impacts on postharvest quality of fruit and vegetable crops: A review. Food Res. Int. 43, 1824-1832. Doi: 10.1016/j.foodres.2009.10.013

Musacchi, S. and S. Serra. 2018. Apple fruit quality: Overview on pre-harvest factors. Sci. Hortic. 234, 409-430. Doi: 10.1016/j.scienta.2017.12.057

Öpik, H. and S. Rolfe. 2005. The physiology of flowering plants. 4th ed. Cambridge University Press, Cambridge, UK.

Osterloh, A., G. Ebert, W.H. Held, H. Schulz, and E. Urban. 1996. Lagerung von Obst und Südfrüchten. Verlag Ulmer, Stuttgart, Germany.

Parra, A. and G. Fischer. 2013. Maduración y comportamiento poscosecha de la feijoa (*Acca sellowiana* (O. Berg) Burret). Una revisión. Rev. Colomb. Cienc. Hortic. 7(1), 98-11. Doi: 10.17584/rcch.2013v7i1.2039

Parra-Coronado, A., G. Fischer, and J.H. Camacho-Tamayo. 2015. Development and quality of pineapple guava fruit in two locations with different altitudes in Cundinamarca, Colombia. Bragantia 74(3), 359-366. Doi: 10.1590/1678-4499.0459

Parra-Coronado, A. and D. Miranda. 2016. La calidad poscosecha de los frutos en respuesta a los factores climáticos en el cultivo. Agron. Colomb. 34(1Supl.), S1415-S1418.

Parra-Coronado, A. and J.H. Hernández-Hernández. 2008. Fisiología postcosecha de frutas y hortalizas. 4th ed. Facultad de Ingeniería, Universidad Nacional de Colombia, Bogota.

Parra-Coronado, A., J.E. Hernández-Hernández, and J.H. Camacho-Tamayo. 2006. Comportamiento fisiológico de la pera variedad Triunfo de Viena (*Pyrus communis* L.) durante el período poscosecha. Rev. Bras. Frutic. 28(1), 46-50. Doi: 10.1590/S0100-29452006000100017

Quintero, O.C. 2012. Feijoa (*Acca sellowiana* Berg). pp. 443-473. In: Fischer, G. (ed.). Manual para el cultivo de frutales en el trópico. Produmedios, Bogota.

Rodríguez, M., H.E. Arjona, and J.A. Galvis. 2006. Maduración del fruto de feijoa (*Acca sellowiana* Berg) en los clones 41 (Quimba) y 8-4 a temperatura ambiente en condiciones de la Sabana de Bogotá. Agron. Colomb. 24(1), 68-76.

Saladié, M., A.J. Matas, T. Isaacson, M.A. Jenks, S.M. Goodwin, K.J. Niklas, R. Xiaolin, J.M. Labavitch, K.A. Shackel, A.R. Fernie, A. Lytovchenko, M.A. O'Neill, C.B. Watkins, and J.K.C. Rose. 2007. A reevaluation of the key factors that influence tomato fruit softening and integrity. Plant Physiol. 144, 1012-1028. Doi: 10.1104/pp.107.097477

Schotsmans, W.C., A. East, G. Thorp, and A. Woolf. 2011. Feijoa (*Acca sellowiana* [Berg] Burret). pp. 115-135. In: Yahia, E.M. (ed.). Postharvest biology and technology of tropical and subtropical fruits. Vol. 3. Cocona to mango. Postharvest biology and technology of tropical and subtropical fruits. Woodhead Publishing, Cambridge, UK. Doi: 10.1533/9780857092885.115

Schouten, R.E., R.H. Veltman, H.P.J. De Wild, T.J. Koopen, M.G. Staal, and L.M.M. Tijskens. 2004. Determination of O_2 y CO_2 permeance, internal respiration and fermentation for a batch of pears (cv. Conference). Postharvest Biol. Technol. 32, 289-298. Doi: 10.1016/j.postharvbio.2003.12.006

Solarte, M.E., M.D. Hernández, A.L. Morales, J.P. Fernández, and L.M. Melgarejo. 2010. Caracterización fisiológica y bioquímica del fruto de guayaba durante la maduración. pp. 85-119. In: Morales, A.L. and L.M. Melgarejo (eds.). Desarrollo de productos funcionales promisorios a partir de la guayaba (*Psidium guajava* L.) para el fortalecimiento de la cadena productiva. Facultad de Ciencias, Universidad Nacional de Colombia, Bogota.

Taiz, L., E. Zeiger, I.M. Møller, and A. Murphy. 2014. Plant physiology and development, 6th ed. Sinauer Associates, Sunderland, MA, USA.

Valderrama, J.K., G. Fischer, and M.S. Serrano. 2005. Fisiología poscosecha en frutos de dos cultivares de feijoa (*Acca sellowiana* [O. Berg] Burret) sometidos a un tratamiento cuarentenario de frío. Agron. Colomb. 23(2), 276-282.

Velho, A.C., C.V.T. do Amarante, L.C. Argenta, and C.A. Steffens. 2011. Influência da temperatura de armazenamento na qualidade pós-colheita de goiabas serranas. Rev. Bras. Frutic. 33(1), 14-20. Doi: 10.1590/S0100-29452011005000016

Wills, R., B. McGlasson, D. Graham, and D. Joyce. 2007. Postharvest: An introduction to the physiology and handling of fruit, vegetables and ornamentals. 5th ed. CAB International, Wallingford, UK.

Yahia, E.M., J. Ornelas-Paz, and A. de J. Elansari. 2011. Postharvest technologies to maintain the quality of tropical and subtropical fruits. pp. 142-193. In: Yahia, E.M. (ed.). Postharvest biology and technology of tropical and subtropical fruits. Vol. 1. Fundamental issues. Woodhead Publishing, Cambridge, UK.

Yi, J., B.T. Kebede, T. Grauwet, A. Van Loey, X. Hu, and M. Hendrickx. 2016. A multivariate approach into physicochemical, biochemical and aromatic quality changes of purée based on Hayward kiwifruit during the final phase of ripening. Postharvest Biol. Technol. 117, 206-216. Doi: 10.1016/j.postharvbio.2016.03.007