Banana leaf as packaging of lulo for different storage temperatures and the effects on postharvest characteristics

Hoja de plátano como empaque de lulo para diferentes temperaturas de almacenamiento y los efectos en las características postcosecha

Nathalia M. Forero-Cabrera[1], Sebastián Gutiérrez-Pacheco[2], Javier Rivera-Acosta[3], Andrés F. Silva-Dimaté[1], and Carolina M. Sánchez-Sáenz[1]

ABSTRACT

In Colombia, the small and medium farmers are responsible for the production of nearly 45.000 t yr^{-1} of lulo (*Solanum quitoense*). However adequate and easy techniques for postharvest handling are not often available to be implemented by this sector of the producers. This research aimed to study banana (*Musa paradisiaca*) leaf as primary packaging to minimize the loss of quality of lulo stored at different temperatures. Chemical and physiological quality parameters were considered in the analysis of the maturation process. Loss weight, color changes in CIELAB coordinates, total titratable acidity (TTA), Young's modulus and firmness were measured to represent the fruit quality. Use of banana leaf as primary package show that weight losses and the color changes result of the ripening process were decreased. The color changes of lulo skin were significantly affected by storage temperature. To avoid changes in TTA, mechanical damage is not recommended. When the lulo fruits were packed with banana leaves, the Young's modulus and firmness values was higher. The results of this research allow the comparison of quality of lulo in the packaging proposal and the results of others researchers who use conventionally packaging like wood crates and carton packaging. The proposal packaging configuration (lulos packed with banana leaf in plastic crates of 80×60×20 cm) is an easy alternative to get and preserve the quality of lulo fruits for a longer storage time.

Key words: fruit preservation, primary packing, *Solanum quitoense*, *Musa paradisiaca*.

RESUMEN

En Colombia, los pequeños y medianos productores son responsables de la producción de cerca de 45.000 t $año^{-1}$ de lulo (*Solanum quitoense*). Sin embargo, técnicas de manejo poscosecha fáciles y adecuadas a menudo no están disponibles para ser implementadas por este sector de productores. Esta investigación tuvo como objetivo estudiar la hoja de plátano (*Musa paradisiaca*) como empaque primario para minimizar la pérdida de calidad del lulo almacenado a diferentes temperaturas. Se consideraron parámetros de calidad físicos y químicos en el análisis del proceso de maduración. Pérdida de peso, cambio de color en coordenadas CIELAB, acidez total titulable (ATT), módulo de Young y firmeza se midieron para determinar la calidad del fruto. El uso de hoja de plátano como empaque primario permitió que las pérdidas de peso y el cambio de color producto del proceso de maduración disminuyeran. Los cambios de color en la piel del lulo fueron afectados significativamente por la temperatura de almacenamiento. Para evitar cambios en la ATT, el daño mecánico no es recomendable. Cuando los frutos de lulo se empacaron con hoja de plátano, los valores de módulo de Young y firmeza fueron mayores. Los resultados de esta investigación permiten la comparación de la calidad de lulo bajo el empaque propuesto y los resultados de otros autores quienes usaron empaques convencionales como cajas de madera y cartón. La configuración de empaque propuesta (lulos empacados en hoja de plátano en cajas de plástico de 80×60×20 cm) es una alternativa fácil que permite obtener y preservar la calidad de frutos de lulo por un mayor periodo de almacenamiento.

Palabras clave: conservación de frutas, empaque primario, *Solanum quitoense*, *Musa paradisiaca*.

Introduction

In Colombia at 2013, the lulo culture (*Solanum quitoense*) reported an increase in its production of 1.87% (MADR, 2014). However, the production growth is accompanied by significant losses at harvest stage, caused by factors such as inadequate practices at harvesting, defective storage infrastructure, high perishability and problems of handling, transport and marketing.

Received for publication: 28 January, 2017 Accepted for publication: 15 March, 2017. Doi: 10.15446/agron.colomb.v35n1.64135

[1] Department of Civil and Agricultural Engineering, Faculty of Engineering, Universidad Nacional de Colombia, Bogota (Colombia). nmforeroc@unal.edu.co
[2] Faculty of Agriculture and Food Sciences, Université Laval, Quebec (Canada). sebastian.gutierrez-pacheco.1@ulaval.ca
[3] Independent researcher, Bogotá (Colombia).

Cooling and packaging are the common strategies deployed to preserve climacteric fruits like lulo. The temperature handling has been the dominant factor for extending the postharvest life of any collected product (Shao-Wei *et al.*, 2017). An increase of 10°C in storage temperature represents an increase in the respiratory activity by a factor of two or three (Silip *et al.,* 2015). Different researches (Nabati *et al.*, 2017; Olivares-Tenorio *et al.*, 2017; Rodoni *et al.*, 2016; Krarup, 1993) show that for some horticultural Solanaceae, temperature and relative humidity are the most important factors in their conservation, suggesting an appropriate storage temperature of 10°C and a relative humidity greater than 90% for eggplant (*Solanum melongena*), cucumber fruit (*Cucumis sativus*), red pepper (*Capsicum annuum*) and tomato (*Solanum lycopenicum*). In uchuva (*Physalis peruviana*), García *et al.* (2014) mention the positive effect of cooling reducing the maturation process. Other case reported by Rugkong *et al.* (2011), who stored tomato fruits, indicate that cooling reduced ethylene production, color change and firmness loss. According to Balaguera-López *et al.* (2014), less weight loss and lower color change were observed by dipping lulo (*Solanum quitoense* Lam.) for 10 min in a $CaCl_2$ solution before storage at 8°C.

Regarding the packing use, Rudra *et al.* (2013) used active packaging (with microbial and ethylene scrubbers) to store peach and plum at a temperature of 32±2°C. In their investigation an increased shelf life, marketability and retailer profitability through the use of this type of packaging was determined. Other reports involving the use of agro-industrial waste as raw material for packaging have presented satisfactory results: for example, Cavalcante *et al.* (2015) used waste of minimally processed carrots as edible films. They found that these films have beneficial properties to the consumer such as the antioxidant activity.

In Colombia, the use of different plant leaves as packaging is frequent due to its degradability and its ability to protect fresh or processed products (Díaz, 2012). The bijao leaf (*Heliconia bihai*) used to commercialize guava paste is an example of this kind of packaging. In addition, this package provides a pleasant flavor and odor characteristic (Prada *et al.,* 2006). "Envuelto de maiz" (a typical food of Colombian Caribbean coast and Panama), is a mass of ground corn/cob beans, cheese and sugar wrapped in corn leaves and cooked in water (Rodríguez *et al.,* 2008). "Casabe" is bread made from cassava starch, native of the Amazon. In the Department of Bolivar (Colombia), packages of this bread into banana leaves was reported aswell (Hoyos, 2002). The use of banana leaf as primary fruit packaging was explored (Forero *et al.,* 2014) due to its degradability, easy access, and its potential to preserve the fruit harvested quality. However, the effect on postharvest characteristics of this package for different storage temperatures has not been explored in depth.

Lulo is a tropical fruit characterized by its refreshing and intense aroma, attracting domestic and international markets (Forero *et al.,* 2015). Several studies interested in maintaining the qualities of lulo after harvest have been developed (Galvis and Herrera, 1999; Huyskens-Keil *et al.,* 2001; Franco *et al.,* 2002; Casierra-Posada *et al.,* 2004; Forero *et al.,* 2014) using parameters such as weight, color and texture to determine the effects of diverse procedures on the fruits. Some of them affect the pulp taste as titratable acidity, total soluble solids and pH. Monitoring these parameters allows quality control on fruits and vegetables and, as a whole, keeps the nutritional, culinary and commercial value of products reflected on the external appearance (Chacon, 2006).

Thus, this research was aimed to study banana leaf as primary packaging to minimize the loss of quality of lulo stored at different temperatures.

Materials and methods

Fruit material, acquisition and selection

The variety *quitoense* lulo fruit used in the experiment were grown in San Bernardo, Cundinamarca, Colombia, with geographical coordinates 4°10'44" N and 74°25'20" W. 500 kg of lulo were brought to the laboratory immediately after harvesting procedure. Color uniformity, size and absence of injuries and odors were the criterion considered to fruit selection. Banana leaves were harvested the same day of lulo fruit harvest. To choose the banana leaves, color uniformity and the absence of radiation damage and pest attack were considered. Data of initial characterization as follow: firmness: 18±7.07 N, total soluble solids: 7.14±0.68%, weight: 120±40 g, state at harvest (according with Corpoica, 2001): between 3 and 4 (25-50% of surface was yellow).

Packaging

The distribution of fruit and banana leaves as primary packaging inside the plastic containers was as follows: first, the banana leaves were pretreated by heating in an oven at 80°C during three minutes in order to avoid the spread of fungi of banana leaves. In plastics fruit crates of 80x60x20 cm a first layer of banana leaves was placed to protect lulos and avoid contact with the container surface. After this, a first layer of fruit was placed over the banana leaves. Later, interwoven layers of fruit and banana leaves were added until completing three layers of lulo. This packaging configuration led approximately 220 g of banana leaves used to pack 25 kg of lulo fruit. Then, two treatment groups were studied: lulo fruits packed with banana leaf (PBL) and lulo fruits without packaging (NPBL).

Storage conditions

Before the storage, samples were subjected to impacts to simulate the conditions that often make part of the postharvest process. Ordered fruit in baskets were submitted to mechanical damage for 5, 10, 15, 20 or 25 times (depending on treatment). The beatings were carried out by dropping the basket to a height of 80 cm from the ground. Then, the containers were stored at a temperature of 7°C (RH 90±5%), 10.25°C (RH 85±5%), 13.5°C (RH 60±5%), 16.75°C (RH 50±5%) and 20°C (RH 40±10%).

Experimental design

This study was based on a central composite rotational experimental design (CCRD) with two independent factors (or variables): temperature (between 7 and 20°C) and number of impacts suffered (NI) (between 5 and 25). This design helped to form a factorial planning 2^k (k = 2 independent variables) with three central points (level 0), four factorial points (levels ±1) and four axial points (levels ± α). In short, 11 experimental trials were packed with banana leaf (PBL) and 11 trials without packaging (NPBL) (Tab. 1). The α-value equal to 1.4142 was used according to $\alpha \approx (2^k)^{1/4}$.

A second-order model was generated from a CCRD experimental design, wherein the value of the dependent variables is the function of the independent variables, as described in Eq. (1).

$$Y = f(T, NI) = \beta_0 + \beta_1 T + \beta_2 NI + \beta_{11} T^2 + \beta_{22} NI^2 + \beta_{11} TNI \quad (1)$$

TABLE 1. Matrix treatments in the CCRD.

Treatments	X1 (Number of impacts)		X2 (Temperature, °C)	
	Code	Real	Code	Real
1	-1	10	-1	10.25
2	1	20	-1	10.25
3	-1	10	1	16.75
4	1	20	1	16.75
5	-1.414	5	0	13.5
6	1.414	25	0	13.5
7	0	15	-1.414	7
8	0	15	1.414	20
9	0	15	0	13.5
10	0	15	0	13.5
11	0	15	0	13.5

This design was chosen because is possible to obtain significant and predictive models and allowed to generate a response surface to optimize the process (Barros Neto *et al*., 2002).

Fruit quality measurements

The parameters of fruit quality were evaluated in the postharvest laboratory of Civil and Agricultural Engineering Department at Universidad Nacional de Colombia, immediately after harvest, until observe fruit overripe. Four lulos (repetitions) for each treatment were monitored, except for texture test, where twenty lulos at the beginning and twenty at the end of each treatment were evaluated.

The weight was determined by an electronic scale (Precisa Gravimetrics AG, model XT 220±0.0001 g, Dietikon, Switzerland). Weight loss was calculated as:

$$WL = \frac{W_0 - Wi}{W0} * 100 \quad (2)$$

Where *WL* was the weight loss expressed as a percentage, W_0 was the weight at initiation of treatment for each lulo, and *Wi* was the weight of lulo for *i*-day of treatment.

The skin color changes were registered by a digital colorimeter (Konica Minolta, CR-410, Ramsey, USA), using coordinates of CIELAB standard. The total difference between each coordinate obtained was modeled as:

$$\text{Delta } L^* = L^*_0 - L^*_f \quad (3)$$

$$\text{Delta } a^* = a^*_0 - a^*_f \quad (4)$$

$$\text{Delta } b^* = b^*_0 - b^*_f \quad (5)$$

Total titratable acidity (TTA) was obtained by titration with NaOH (1 N), in a sample of the fruit juice (between 0.9 and 1.7 g) and expressed as a percentage of citric acid.

$$\%\ Citric\ acid = \frac{(Vf - Vi) * 0.64}{Wm} \quad (6)$$

Where, *Vf* was the final volume of NaOH recorded, *Vi* meant the initial volume of NaOH recorded, *Wm* was the weight of the fruit juice sample and the constant 0.64 is the equivalence for citric acid. Change in TA was obtained as,

$$Change\ in\ TTA = |TA_i - TA_f| \quad (7)$$

Where *i* and *f* subscripts refer to the initial and final measure, respectively.

The textural properties, defined by Barreiro and Ruiz-Altisent (1996) as firmness and Young's modulus, were evaluated and determined by Magness Taylor test with the use of a texture analyzer (CT3 Brookfield, model CT3-4500, 0 to 4500 g, Middleboro, USA). A ratio to compare the change of Young's modulus from baseline was established. Young's modulus ratio between final and initial value was designated as equation 8.

$$\frac{Sf}{Si} \quad (8)$$

Where S_f was the final Young's modulus value and S_i was initial Young's modulus value.

Statistical analysis

Statistical package STATISTICA software 9.0 - 2001 (Statsoft, Tulsa, OK, USA) was used for ANOVA analysis (significance level α 0.05). ANOVA analysis allowed determinate the effect of the factors and their interactions on the response variables. Statistical models with its corresponding correlation coefficient (R^2), graphs of the response surfaces and contour curves were obtained. Models allowed estimate the optimum storage condition.

Results and discussion

Weight Loss

As shown in figure 1, to stored fruit at room temperature (20°C) and subjected to 15 strokes, average weight losses at 15 d were 8.7% for NPBL fruit and 6.6% to PBL fruit. Forero *et al.* (2014) reported weight losses of 7.3% for lulo fruits stored in plastic crates and 3.8% for fruits with the proposed packaging. Damage generated by impacts resulted in a higher percentage of weight loss for this assay. Balaguera-López *et al.* (2014) reported for lulo weight loss of 12.9% at the same storage time and storage temperature.

Reina *et al.* (1998) who worked with lulo stored at 12°C, reported weight losses of 7.7% at 18 d. In this research, similar temperature storage was used (at 13.5°C). To this condition, fruit subjected to 15 impacts and stored by 20 days, the weight losses were 10.9% for NPBL fruits and 9.4% for PBL fruits. The difference between Reina's results and the weight losses reported in this research may be caused by the storage temperature difference (difference by 1.5°C) and physical damage generated. This postharvest stress caused accelerated metabolism in fruit which resulted in greater weight and fruit quality losses.

As shown the figure 1, lower weight loss for fruits stored at temperatures above 13.5°C was found to PBL configuration compared to NPBL configuration. This may be a result of the characteristics of banana leaf to protect the lulo fruit to weight loss caused by fruit transpiration. In the first days of storage, the moisture content of the banana leaf decreased ("weight loss banana leaf") and then this leads to weight loss of lulo by transpiration (Forero *et al.,* 2014).

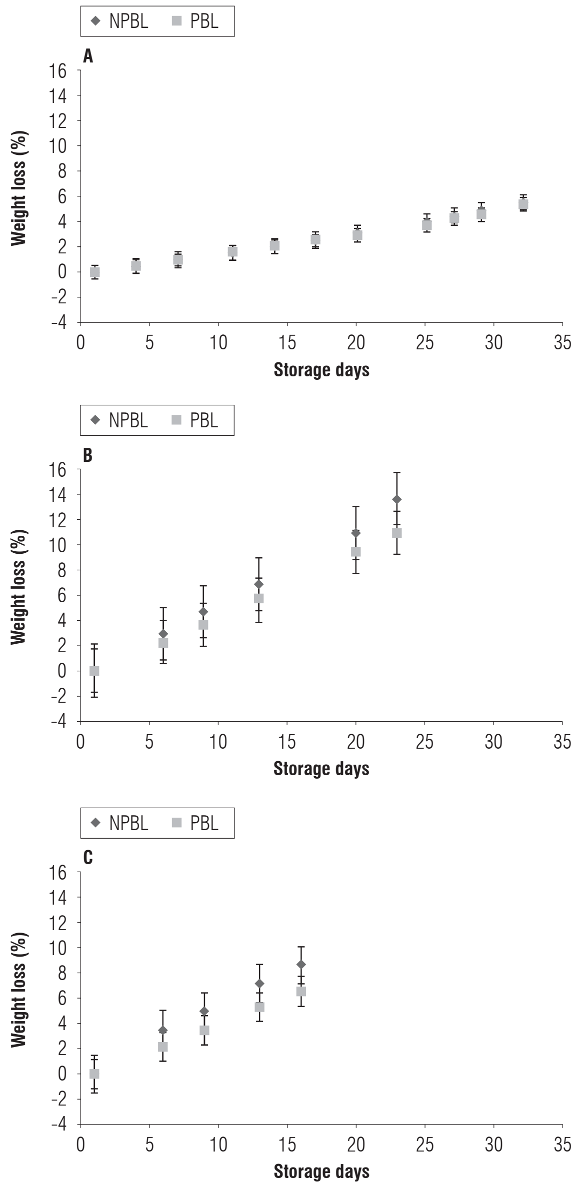

FIGURE 1. Monitoring of the weight loss in storage time for treatments with NI = 15 impacts. Storage temperature at: (A) 7°C; (B) 13.5°C, and (C) 20°C.

Moreover, for fruit stored at 7.5°C, Forero *et al.* (2014) reported weight losses of 5.8% at 18 d of storage. For this research, the lowest storage temperature was 7°C and this condition caused weight losses of 2.5% to NPBL fruit and

2.6% for PBL fruits at 17 d of storage. For this case, the temperature was the main factor in weight losses and there were not significant differences for the two packaging configurations studied (P>0.05).

Compared to fruit packaging used conventionally such as cardboard and wood crates, Bonilla (2010) reported weight losses of 6.8% with wood crates and 7.1% in cardboard packaging for lulos unrefrigerated (20±5°C) by 10 d. For this investigation, average weight losses of 7.2% for NPBL fruits and 5.3% for lulos PBL were recorded to day 13.

Similarly, Bonilla (2010) performed the same test for refrigerated (8±1°C) fruit and he reported weight losses of 1.9% for wood crates and 4.2% for carton packaging, both results for ten days of storage. For this study, the average weight loss for lulos stored at 7°C, at the 11th day was 1.6%.

The proposed packaging configuration yielded comparable results to conventional packaging reports for lulo. The banana leaf besides showing that fulfills its function of reducing weight losses by transpiration, also offers other advantages such as its low cost, its ability to be individually wrapped and especially its biodegradability, comparatives advantages over other materials used in food packaging (Bonilla, 2010).

Color change

A model to describe the change of the variables L* a* b* was not obtained for NPBL fruits (for all the factors P>0.05). However, for PBL fruits the models of equation 9, 10 and 11 were obtained:

$$\textit{Change in } L^* = 3.7515 + 2.1794(T)^2 \quad R^2\ 0.537 \qquad (9)$$

$$\textit{Change in } a^* = 6.2331 + 4.5848(T)^2 \quad R^2\ 0.520 \qquad (10)$$

$$\textit{Change in } b^* = 6.6819 + 3.9654(T)^2 \quad R^2\ 0.576 \qquad (11)$$

Where T is storage temperature. For all three models, the temperature factor (quadratic) was significantly different (P = 0.0103 for change of L*, P = 0.0122 for change of a* and P = 0.0068 for change of b*). The change in b* represents the blue-yellow changes and their model showed a better fit. Mejía *et al.* (2012) reported that this variable is the key to track the increase in the characteristic orange hue of lulo, and in the case of this fruit is postulated as a variable to summarize the changes in the external appearance of fruits harvested and stored.

The combination of storage temperature and packaging plays an important role in the degradation of pigments in the lulo. This combination can decelerate the changes of color as a result of the ripening process (Salinas *et al.*, 2010). The packaging besides protecting the fruit as we deduced in the analysis of weight loss, also reduces the amount of oxygen that available for the lulo, what it brings consequently the delay to manifest the characteristic yellow-orange hue of a mature lulo.

Total titratable acidity (TTA)

Initial TTA in all samples were similar (P>0.05). Temperature has an important effect on this variable. Significant differences were found between treatments stored at 7 and 20°C. Similar results were found by Díaz and Manzano (2002), who worked with lulo treated with sodium hypochlorite 2% for 5 min and stored at 5, 10 and 15°C for 21 d.

A model for change in TTA for NPBL fruits (Fig. 2) was obtained. This model responded to the number of impacts (P≤0.05) and an adjustment (R^2 0.483) was determined. The resulting model is described by equation 12, where NI is number of impacts.

$$\textit{Change in TA} = 0.965651 - 0.299860 * NI^2 \qquad (12)$$

When the impacts received by the fruit increased, the difference between the initial and final value of TTA increased. This is probably caused due to the increase in respiratory rate and then the degradation of organic acids reserves in the fruit as a result of respiration process, as Balaguera-López *et al.* (2016) found for uchuva (*Physalis peruviana*) storaged at 18°C throughout its ripening process. The greatest variation was found when the fruit receives fifteen impacts. For PBL fruits, an average value of 0.672% in the change in TTA of was obtained. A model was not obtained on the basis of the factors considered in this study and no statistical evidence of the significance of these factors on the change of TA value (P>0.05) was found.

Considering figures 2C and 2D during the first 10 d after the harvest of lulo, the reduction in TTA values was more evident in NPBL fruits than PBL fruits. Then, using banana leaves as packaging for lulo we can expect a steady performance of this variable to a storage period not more than 10 days.

Firmness

The average values for firmness in this research are observed in table 2. Firmness values between 13 and 23N were obtained for freshly harvested lulos, between 4.9 and 19 N, and between 5.4 and 11.6 N, for NPBL and PBL in ripe lulos, respectively. Galvis and Herrera (1999) reported values of 42.26 N for half-ripe fruits and 17.8 N for ripe fruits. Ospina *et al.* (2007) also found values of 15.7 N for unripe and 14.4 N for ripe fruits.

A decrease of the storage temperature and an increase of the CO_2 concentration (by use of packaging) result in a reduction of metabolic activity and a decrease in the rate of degradation of organic acids and hence, the evolution of physicochemical and quality properties such as color, firmness and shelf-life (Alam and Goyal, 2006; Gwanpua *et al.,* 2012).

Also, the variation on this parameter corresponds to the anisotropy of the material. Its value will depend of the physiological conditions of the fruit, postharvest time and load conditions. In addition, fracture strength values indicate that freshly harvested lulo resists greater burden

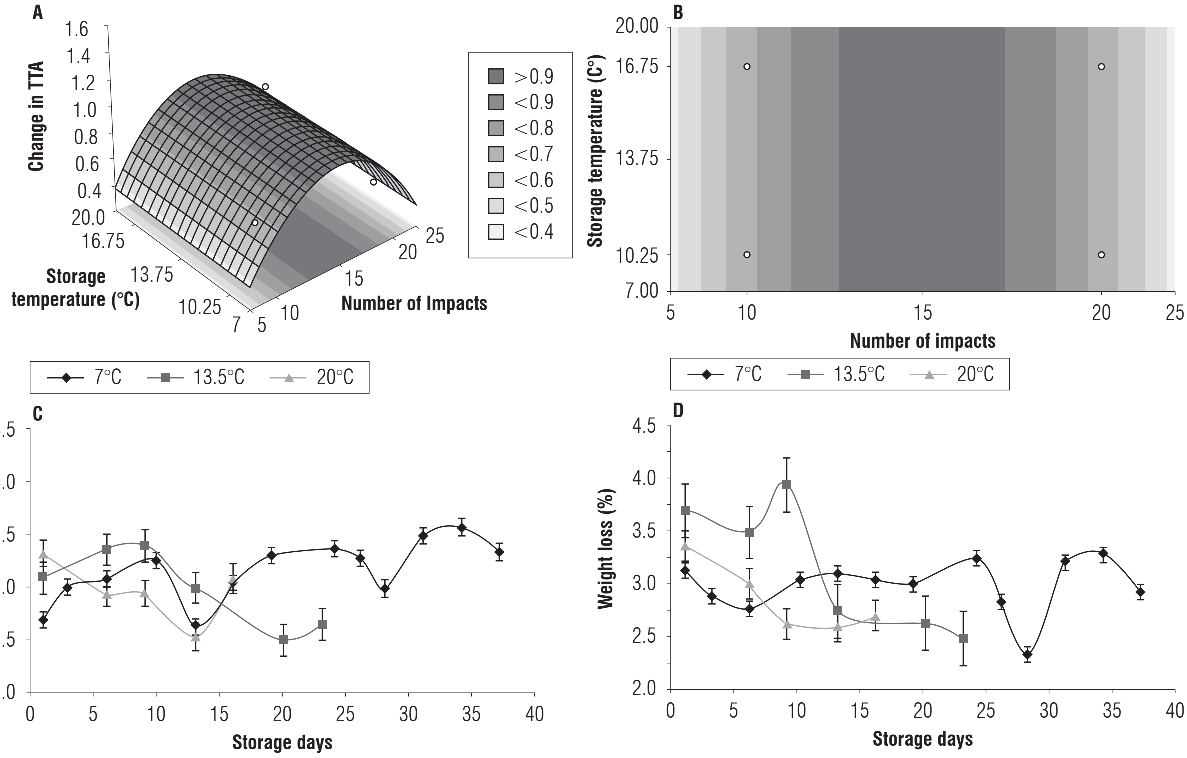

FIGURE 2. A. Response surface for the change of TTA; B. Contour curves for the change of TTA; C. Tracking of TTA values during the storage time for PBL fruits and D. NPBL fruits, at NI = 15 impacts (central NI value).

TABLE 2. Results of maximum strength (firmness) and modules of Young's modulus (stiffness) for fruit PBL and for fruit NPBL.

Treatments	PBL				NPBL			
	Firmness (N)	SD (N) - C.V (%)	Young's modulus (MPa)	SD (MPa) - C.V (%)	Firmness (N)	SD (N) -C.V (%)	Young's modulus (MPa)	SD (MPa) -C.V (%)
1	9.71	4.09-42.1	22.422	9.44-42.1	10.79	3.86-35.74	21.764	7.78-35.74
2	8.89	3.83-43.05	24.019	10.34-43.05	6.93	3.01-43.39	14.349	6.23-43.39
3	5.38	2.42-45	7.852	3.53-45	21.89	10.51-48	17.459	8.38-48
4	5.88	2.06-35.1	7.330	2.57-35.1	19.04	5.7-29.92	34.553	10.34-29.92
5	6.69	3.05-45.53	9.534	4.34-45.53	6.78	3.24-47.73	6.953	3.32-47.73
6	5.40	3.44-63.74	11.606	7.4-63.74	5.63	3.68-65.39	7.528	4.92-65.39
7	11.57	3.71-32.09	17.639	5.66-32.09	9.82	3.57-36.32	15.566	5.65-36.32
8	10.36	4.99-48.18	22.846	11.01-48.18	8.36	6.19-74.04	15.197	11.25-74.04
9	5.79	3.82-65.93	6.730	4.44-65.93	5.81	2.12-36.46	6.183	2.25-36.46
10	6.07	2.98-49.02	8.753	4.29-49.02	4.94	4.59-92.86	8.391	7.79-92.86
11	5.38	3.19-59.33	5.899	3.5-59.33	5.79	3.41-58.91	6.700	3.95-58.91

than lulos the end of each treatment, similar results are reported by Ospina *et al.* (2007) and SENA (1999).

A model of this response variable in function of temperature ($P \leq 0.05$) for lulos PBL was obtained with an adjustment of R^2 0.854. The NI variable did not have the incidence expected. Storage conditions are the factor affecting the degree of mechanical strength. Nevertheless, adequate storage technique must be ensured to protect them from damage during handling postharvest. To NPBL a significant model was not obtained.

$$Firmness = 5.64308 - 1.13106\,(T) + 2.38123\,(T)^2 \quad (13)$$

R^2 0.854

Young's modulus

The mean values of the modules of Young's modulus or deformability of the lulo epidermis can be seen in table 2. In general, for lulos PBL this value is higher, which mechanically represents that these fruits will be deformed unless than lulos NPBL under the same compressive stress. Water loss is one of the main causes of commercial and physiological deterioration of fresh produce, in the form of wilting, shriveling, and decrease of stiffness, turgidity and succulence (Rodov *et al.*, 2010). Then, PBL lulos allowed to loss less water and lower reduction on stiffness.

The model of Young's modulus ratio was only obtained for fruit PBL.

$$\frac{Sf}{Si} = 0.191808T + 0.125832\,T^2 \quad (14)$$

R^2 0.705

The results for NPBL have a greater dispersion because the blow was more random for this treatment. The banana leaf besides of cushion the blow, also keep the order among the layers of fruit.

Number of impacts (NI) did not have influence on final Young's modulus (Linear $P = 0.5029$ and quadratic $P = 0.3783$). However, as seen in figure 3, for lulos PBL, a model based on the Young's modulus mean and the temperature (linear $P = 0.0152$ and quadratic $P = 0.0145$) was obtained to predict this parameter. The proposed packaging configuration can cushion the blow that receives lulo.

Conclusions

In this research, the banana leaf as primary packaging reduces the damage caused by the impacts. As a result, less deformation and less mechanical damage to lulos packaged under this configuration were obtained. The packaging configuration consisting in lulos packed with banana leaf in plastic crates of 80×60×20 cm is an easy alternative to gets and preserves the quality of lulo fruits for a longer storage time. For PBL configuration of three layers of fruit, temperatures below 13.5°C and strokes not more than 15 are suggested. Analogously for NPBL fruits, strokes below 10 impacts are suggested.

However, to avoid color degradation and changes in the TA value mechanical damage is not recommended. The influence of impacts to the fruit on TA value and pigments was verified.

Regarding the temperature conditions, when a storage temperature of 7°C can be ensure, use of banana leaf is

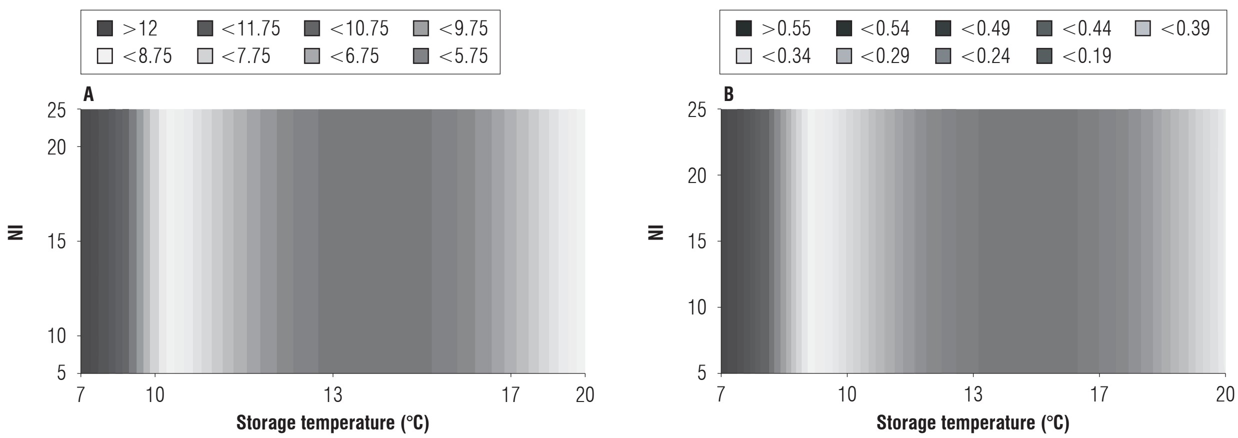

FIGURE 3. Contour curves for epidermis texture characterization for PBL lulos. A. Prediction of the final value of the maximum breaking force (firmness) of the epidermis of lulo; B. Prediction of the Young's modulus ratio (dimensionless).

not necessary to reduce weight losses. However, for future research, use of the proposal packaging configuration to protect the fruit of chilling injury caused by low cooling storage temperatures will be interesting.

For further tests, explore this kind of packaging with other tropical fruits is suggested. Also, analyze the fruit-packing-storage interaction by mathematical modeling will be necessary.

Acknowledgments

The authors acknowledge the support of the Department of Civil and Agricultural Engineering, Faculty of Engineering, Universidad Nacional de Colombia; the financial support of "Programa Nacional de Semilleros de Investigación, Creación e Innovación de la Universidad Nacional de Colombia" and the support of Mr. Jaime Cortés, farmer from San Bernardo, Cundinamarca, Colombia.

Literature cited

Alam, T. and G.K. Goyal. 2006. Colour and pigment changes during modified atmosphere packaging storage of fruits and vegetables. Stewart Postharvest Rev. 5, 1-9. Doi: 10.2212/spr.2006.5.16

Balaguera-López, H.E., C.A. Martínez-Cárdenas, and A. Herrera-Arévalo. 2016. Efecto del estado de madurez sobre el comportamiento poscosecha de frutos de uchuva (*Physalis peruviana* L.) almacenados a temperatura ambiente. Bioagro 28(1), 21-28.

Balaguera-López, H.E., D.A. Ramírez, and P.J. Almanza-Merchán. 2014. El tiempo de inmersión en $CaCl_2$ y la refrigeración modifican algunas características físicas del fruto de lulo (*Solanum quitoense Lam.*) durante la poscosecha. Acta Hortic. 1016, 147-150. Doi: 10.17660/ActaHortic.2014.1016.20

Barreiro, B. and M. Ruiz-Altisent. 1996. Propiedades mecánicas y calidad de frutos. Definiciones y medidas instrumentales. Frutic. Profesional 77, 48-51.

Barros Neto, B., I.S. Scarminio, and R.E. Bruns.2002. Como fazer experimentos: Pesquisa e desenvolvimento na ciência e na indústria, 2nd ed. Ed. UNICAMP, Campinas, Brazil.

Bonilla, D. 2010. Evaluación de dos índices de cosecha y tipos de empaque del fruto de naranjilla (*Solanum quitoense Lam.*) híbrido INIAP Palora, bajo dos condiciones de almacenamiento, en el Cantón Cevallos de la provincia de Tungurahua. Trabajo de grado. Facultad de Ingeniería Agronómica, Universidad Técnica de Ambato, Ceballos, Ecuador.

Casierra-Posada, F., E. García, and P. Lüdders. 2004. Determinación del punto óptimo de cosecha en el lulo (*Solanum quitoense Lam*. var. quitoense y septentrionale). Agron. Colomb. 22(1), 32-39.

Cavalcante, A.E., M.R. Alves de Souza, N. Vinhosa-Bruno, and E. Castello. 2015. Produção de revestimento comestível à base de resíduo de frutas e hortaliças: aplicação em cenoura (*Daucus carota* L.) minimamente processada. Scient. Agropecu. 6(1), 59-68. Doi: 10.17268/sci.agropecu.2015.01.06

Chacon, S. 2006. Manual de procesamiento de frutas tropicales a escala artesanal en El Salvador. Programa Nacional de Frutas del Salvador, Ministerio de Agricultura y Ganadería, La Libertad, El Salvador.

Corpoica. 2001. Manejo poscosecha del lulo 'La Selva'. Corpoica. Río Negro, Antioquia, Colombia.

Díaz, S. 2012. Las hojas de las plantas como envoltura de alimentos. Imprenta Nacional, Bogota, Colombia.

Díaz, J.G. and J.E. Manzano. 2002. Calidad en lulo (*Solanum quitoense* L.) almacenados a diferentes temperaturas. Proc. Interam. Soc. Trop. Hortic. 46, 27-28.

Forero, D., C. Orrego, D. Peterson, and C. Osorio. 2015. Chemical and sensory comparison of fresh and dried lulo (*Solanum quitoense Lam.*) fruit aroma. Food Chem. 169, 85-91. Doi: 10.1016/j.foodchem.2014.07.111

Forero, N.M., S. Gutierrez, R.L. Sandoval, J.H. Camacho, and M.A. Meneses. 2014. Evaluación poscosecha de las características del Lulo (*Solanum quitoense*) cubierto con hoja de plátano. Temas Agrar. 19(1), 73-85.

Franco, G., J. Bernal, M. Giraldo, P. Tamayo, O. Cataño, A. Tamayo, J. Gallego, M. Botero, J. Rodríguez, N. Guevara, J. Morales, M. Londoño, G. Ríos, J. Rodríguez, J. Cardona, J. Zuleta, J. Castaño, and M. Ramírez. 2002. El cultivo del lulo: manual técnico. Corpoica Reg. 9 y 4. Manizales, Colombia.

Galvis, J. and A. Herrera. 1999. El lulo (*Solanum quitoense* Lam.) - Manejo de poscosecha. Convenio SENA, Universidad Nacional de Colombia. Publicaciones SENA, Bogotá, Colombia.

García, M., A. Peña, and B. Brito. 2014. Desarrollo tecnológico para el fortalecimiento del manejo poscosecha de la uchuva (*Physalis peruviana* L.). In: Carvalho, C. and D. Moreno (eds.). *Physalis peruviana:* fruta andina para el mundo. Programa Iberoamericano de Ciencia y Tecnología para el Desarrollo-CYTED, Limencop SL, Alicante, España.

Gwanpua, S., B.E. Verlinden, M.L.A.M. Hertog, I. Bulens, B. Van de Poel, J. Van Impe, B.M. Nicolaï, and A.H. Geeraerd. 2012. Kinetic modeling of firmness breakdown in 'Braeburn' apples stored under different controlled atmosphere conditions. Postharvest Biol. Technol. 67, 68-74. Doi: 10.1016/j.postharvbio.2011.12.010

Hoyos, C. 2002. Tambucos, ceretas y cafongos: Recipientes, soportes y empaques del antiguo Departamento de Bolivar. Gamma S.A., Bogota, Colombia.

Huyskens-Keil, S., H. Prono-Widayat, and P. Peters. 2001. Effect of surface coating and film packing on the keeping quality of solanaceous crops (*Solanum muricatum Ait., Solanum quitoense* Lam.). Acta Hortic. 553. 621-625. Doi: 10.17660/ActaHortic.2001.553.150

Krarup, C. 1993. Tecnologías de pre y postcosecha de solanáceas relacionadas con su conservación y exportación. pp. 13.1-13.15. In: Curso internacional: Producción de hortalizas protegidas bajo plástico. Instituto de Investigaciones Agropecuarias de Chile (INIA), Santiago, Chile.

MADR. 2015. Anuario estadístico del sector agropecuario año 2013. Ministerio de Agricultura y Desarrollo Rural, Bogota, Colombia.

Mejía, C. M., D.A. Gaviria, A.L. Duque, R.M. Rengifo, E.F. Aguilar, and A.H. Alegría. 2012. Physicochemical characterization of the lulo (*Solanum quitoense* Lam.) Castilla variety in six ripening stages. Vitae 19(2), 157-165.

Nabati, J., F. Izadi, R. Abbasi, and F. Hassani. 2017. Effect of different storage methods on quantity and quality of potato. Iran. Food Sci. Technol. Res. J. 1396. Doi: 10.22067/ifstrj.v1396i0.57671

Olivares-Tenorio, M.L., M. Dekker, M.A.J.S. Van Boekel, and R. Verkerk. 2017. Evaluating the effect of storage conditions on the shelf life of cape gooseberry (*Physalis peruviana* L.). LWT-Food Sci. Technol. 80, 523-530. Doi: http://doi.org/10.1016/j.lwt.2017.03.027

Ospina, D.M., H.J. Ciro, and I.D. Aristizábal. 2007. Determinación de la fuerza de la fractura superficial y fuerza de firmeza en frutas de lulo (*Solanum quitoense x Solanum hirtum*). Rev. Fac. Nac. Agron. Medellín 60(2), 4163-4178. Doi: 10.15446/rfnam

Prada, L.E., J.J. Caceres, H.R. Garcia, and E. Kopp. 2006. Bijao: un empaque para la certificación de origen del bocadillo veleño. Produmedios, Bogota, Colombia.

Reina, C., C. Araujo, and I. Manrique. 1998. Manejo poscosecha y evaluación de la calidad del lulo que se comercializa en la ciudad de Neiva. Facultad de Ingeniería, Universidad Surcolombiana, Neiva, Colombia.

Rodoni, L.M., J.H. Hasperué. C.M. Ortiz, M.L. Lemoine, A. Concellón, and A.R. Vicente. 2016. Combined use of mild heat treatment and refrigeration to extend the postharvest life of organic pepper sticks, as affected by fruit maturity stage. Postharvest Biol. Technol. 117, 168-176. Doi: 10.1016/j.postharvbio.2015.11.016

Rodríguez, O., G. Salamanca, and J. Abril. 2008. Simulación y optimización de un proceso de transferencia de calor para la inactivación de *Clostridium botulinum* en alimentos colombianos. Memorias XLIII Congreso Nacional de Ciencias Biológicas. Yopal, Colombia. Facultad de Ciencias, Universidad del Tolima, Ibague, Colombia.

Rodov, V., S. Ben-Yehoshua, N. Aharoni, and S. Cohen. 2010. Modified humidity packaging of fresh produce. Hortic. Rev. 37, 281-329. Doi: 10.1002/9780470543672.ch5

Rudra, S., V. Singh, S. Jyoti, and U. Shivhare. 2013. Mechanical properties and antimicrobial efficacy of active wrapping paper for primary packaging of fruits. Food Biosci. 3, 49-58. Doi: 10.1016/j.fbio.2013.07.002

Rugkong, A., R. McQuinnc, J. Giovannonic, J. Rosee, and C. Watkins. 2011. Expression of ripening-related genes in cold-stored tomato fruit. Postharvest Biol. Technol. 61, 1-14. Doi: 10.1016/j.postharvbio.2011.02.009

Salinas, R., E. Liévano, F. Ulín-Montejo, J. Mercado, and D. Petit. 2010. Caracterización morfológica y cambios durante la vida postcosecha de cuatro tipos de chile amashito (*Capsicum annuum* L.) variedad glabriusculum (Dunal) Heiser & Pickersgill. Rev. Iberoam. Tecnol. Postcosecha 11(1), 92-100.

SENA. 1999. El Lulo *Solanum quitoense* Lam. - Manejo poscosecha Convenio SENA-ICTA, Universidad Nacional de Colombia, Bogota, Colombia.

Shao-Wei, C., H. Min-Chi, F. Hsin-Hsiu, T. Shang-Han, and L. Yu-Shen. 2017. Effect of harvest season, maturity and storage temperature on storability of carambola 'Honglong' fruit. Sci. Hortic. 220, 42-51. Doi: 10.1016/j.scienta.2017.03.047

Silip, J.J., R.R. Yung, K.S. Lim, M. Mohamad, and S.M. Hamdan. 2015. Postharvest life of guava fruit under selected postharvest handling practices. pp. 152-158. In: Proc. Int. Conf. Plant Physiology 2014. Malaysian Society of Plant Physiology, Kuala Lumpur, Malaysia.