Article

Evaluation of the postharvest behavior of cape gooseberry from conventional and agroecological production systems

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Abstract

The production of cape gooseberry (*Physalis peruviana* L.) in Colombia has a high socioeconomic interest due to its commercial potential and the large number of small-scale producers that make up the production system. The growing areas in Colombia are located on the cold thermal floors of the departments of Boyaca, Cundinamarca and Antioquia. Recently, in order to seek sustainability in agricultural production, agroecological production has had a growing increase in areas where this type of crop is established. Therefore, the objective of this research was to evaluate and compare the postharvest behaviors of cape gooseberry fruit, obtained under two agricultural production systems (conventional and agroecological) established under climatic conditions of the savanna of Bogota. The methodology consisted of the measurement and quantification of the main physicochemical variables: weight, equatorial diameter, firmness, pH, total soluble solids, acidity, respiration and weight loss during the different stages of maturity. These values were compared in reference to the provisions of NTC 4580. The results obtained for each property showed significant differences between each productive system and each state of maturity evaluated, finding a higher sensitivity to postharvest deterioration in fruits obtained through agroecological production.

Keywords: *Physalis peruviana* L., acidity, firmness, maturity index.

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Introduction

The fruits of cape gooseberry (*Physalis peruviana* L.) belong to the solanaceae family, this type of fruit is botanically classified in the group of berries, its shape is spherical or ovoid and they have a particular yellowish orange color and another characteristic is that it is wrapped in a calyx or cape, this fruit is native to the South American Andes (Almanza and Espinosa, 1995). Its nutritional composition shows high content of antioxidants, iron, phosphorus, fiber and proteins (Fischer *et al*., 2011), which provide functional and medicinal food properties (Puente *et al*., 2011).

Currently, Colombia is the largest exporter of fresh cape gooseberry fruit (SENA, 2014). In the national territory there are approximately 1 023 hectares established in cape gooseberry crops with a total production of 15 711 t. The total area is distributed in the departments of Boyaca, Cundinamarca and Antioquia with percentages of participation in the national production of 40.47, 22.88 and 22.7% respectively. On the other hand, in the departments of Santander, North of Santander, Nariño, Cauca and Tolima the participation percentages are below 5% in each of them (Agronet, 2016).

The predominant productive system in a high percentage of these crops is conventional agricultural production, although it should be noted that in recent years the area dedicated to organic and agroecological production of this product and others of economic importance nationwide has increased (Sánchez, 2017).

The agroecological production approach is framed by ecological principles for the design and management of sustainable agroecosystems (Gliessman, 2000). These systems are usually characterized by not using products of synthetic origin, or by relying on external inputs, organic fertilization is promoted and comprehensive preventive management of the crop, this type of strategies was driven by the rise of cleaner production and demand for green markets.

The cultivation of cape gooseberry is considered a productive system of economic interest due to its export potential, the Colombian ecotype, it is desired in international markets due to its adequate organoleptic characteristics (color, flavor and aroma), obtained from agro conditions predominant climatic conditions of the temperate and cold thermal floors of the Colombian Andes, a factor that allowed the expansion of the crop to the different zones that present this type of conditions (Ligarreto *et al*., 2005). Additionally, the production of cape gooseberry generates a high social impact since it is a productive system for small producers (Balaguera, 2015).

The fruit of cape gooseberry belongs to the group of climacteric fruits (Avila *et al*., 2006), additionally it is classified as a highly perishable food (Balaguera *et al*., 2016). These types of products have a reduced useful life mainly due to an accelerated maturity process associated with high respiration rates, high production and sensitivity to ethylene and high water content, these factors generate losses in product quality and quantity, which a priori they become a productive constraint (Kader, 2002), affecting the sustainability of agricultural production systems, especially in developing countries (DNP, 2016).

In Colombia for the year 2010, according to statistics presented by FAO in (2011), a total of 1 426 932 t of fruit and vegetables were lost in the post-harvest stage, of which 81% corresponded specifically to fruits.

In order to determine the appropriate conditioning and infrastructure operations to be used in the post-harvest period, in order to extend the shelf life and maintain the quality of agricultural products, it is necessary to know the physical changes that occur in the fruit, changes generated by the ripening process and mainly by physiological and biochemical factors of each type of fruit, in the case of cape gooseberry grown in conventional agricultural systems, there are several studies that characterize postharvest behavior (Lanchero *et al.*, 2007; Fischer *et al*., 2011; Balaguera, 2015; Pinzon *et al*., 2015).

On the other hand, information on postharvest behavior in agroecological production systems is scarce, some advanced research has found significant differences in the postharvest stage associated with the production system. Castelo *et al*. (2014) reported better quality parameters in organic fruits and similar yields in all production systems for tomato cultivation (*Solanum lycopersicum*). Also, Campuzano *et al*. (2010) found that there is no significant difference between organic and conventional production systems for the cultivation of Cavendish bananas (*Musa acuminata* AAA). Although the fruits obtained organically exhibited a longer shelf life influenced by a lower respiration rate.

The objective of this research was to evaluate and compare the physicochemical and physiological properties of the ripening processes of cape gooseberry (*Physalis peruviana* L.) grown in conventional and agroecological forms. In order to generate base information that can be used in the future to design management strategies for the harvest and post-harvest of agroecological products, since the production of cape gooseberry under this productive system is recent and requires this type of study.

Materials and methods

Experimental sites

The samples were obtained in two production systems, a conventional agricultural production system (SC) located in the municipality of Subachoque department of Cundinamarca (4° 56’ 59.12” north latitude, 74° 11’ 35.78” west longitude and an altitude of 2 710 m), where semi-humid cold weather predominates, with average temperature conditions of 13 °C and rainfall between 600 and 1 200 mm year^{-1} (Climate-Data, 2016). The agroecological production system (SA) is located in the municipality of Guasca department of Cundinamarca (4° 53’ 22.33” north latitude, 73° 53’ 16.35” west longitude and a latitude of 2 620 m), where cold weather predominates and humid, with average temperature conditions of 13 °C and rainfall between 800 and 2 000 mm year^{-1} (Ideam, 2010).

Vegetal material

For the experimental development, fresh cape gooseberry fruits (*Physalis peruviana* L.) from ecotype Colombia plants, collected for SC and SA production system, fruits were collected in stages of maturity (Em) between 0 and 6, according to the scale of the Colombian Technical

Standard NTC 4580, Colombian Institute of Technical Standards and Certification ICONTEC (1999). The fruits were transported to the chemistry and agroecology laboratory of the University Minuto de Dios (max. temperature 19 °C and min. 11 °C, HR: 88%), where the fruits were disinfected by the immersion method in a solution of chlorine at 50 ppm.

Measurements

The data reported in the measurements correspond to the average of six fruits per Em, where they made 3 replicates for each measurement, except for the determination of weight loss.

Fresh weight and equatorial diameter

The fresh weight of fruit in each MS was performed with an analytical balance accurate brand OHAUS model EX225D (0.0001 g). The dimensions of the diameter of the fruit were made with a Mitutoyo brand calibrator model HL128.

Firmness

The deformation resistance of the fruits was measured with the use of a GY-3 fruit penetrometer (range 0.5-12 kg cm^{-2} and 1-24 kg cm^{-2} accuracy ±0.1).

Total titratable pH and acidity (ATT)

The juice was extracted by maceration of the fruits. To determine the pH of the juice a potentiometer Hanna Instruments model PH211 was used. The ATT expressed as (%) of citric acid was calculated by titration with NaOH and the (%) of acid was calculated by equation 1 taken from NTC 4580 (ICONTEC, 1999).

$$\text{Citric acid } (\%)=\frac{V_a * N}{V_b} * K * 100 \qquad 1)$$

Where: V_a is volume of NaOH consumed (mL); V_b is weight in grams of sample used (6 g); K is equivalent weight of the predominant acid of the fruit (citric acid 0.064 g meq^{-1}); and N is normal for NaOH (0.1 meq ml^{-1}).

Total soluble solids (SST) and maturity index (Im)

The SST expressed as degrees (°) Brix were determined using a Hanna Instruments digital refractometer model HL96801. Im is obtained by equation 2.

$$Im= \frac{SST}{ATT} \qquad 2)$$

Breathing

In order to determine the CO_2 production of cape gooseberry fruits in each Em and each production system, the procedure described in the work developed by Trinchero *et al*. (1999). Which raises the use of a closed static system and an analysis by chromatography.

Weight loss

To determine the weight loss of cape gooseberry fruits; through time to environmental conditions of the post-harvest laboratory, the samples were classified by type of production system (SC, SA) and Em. The weight change was followed for 19 days. Weight loss (PP in %) per day is obtained from equation 3.

$$PP= \frac{Pi-Pd}{Pi} * 100 \quad 3)$$

Where: PP is weight loss (%), Pi is initial weight, Pd is daily weight.

Experimental design and data analysis

For the evaluation of the two production systems (SC and SA) in seven stages of maturity (Em: 0-6) a completely randomized experimental design was implemented with a factorial arrangement of 2 x 7 for a total of 14 treatments. The results of the quantified variables were analyzed and compared using simple one-way Anova, once the fundamental assumptions of normality and homocedasticity were verified. The comparison of the means was carried out by Fischer's minimum significant differences (LSD) method at a 95% confidence level ($p \leq 0.05$). The Anova was developed with the statistical software package R (R Development Core Team, 2017).

Results and discussion

Fresh weight and fruit diameter

These physical parameters are relevant to define the appropriate conditioning operations that must be performed in the post-harvest period. Significant differences were found ($p \leq 0.05$), for each Em and between SC and SA (Table 1). The maximum average fresh weight values obtained were 6.27 ±1.21 g and 4.8 ±0.48 g, for Em 6 and Em 4 in SA and SC respectively. The minimum fresh weight values were obtained in the Em 0 in SA and SC showing a value of 1.31 ±0.19 g and 2.83 ±0.3 g respectively.

Table 1. Mean values of the variables weight (g) and equatorial diameter (cm) determined in cape gooseberry fruits (*Physalis peruviana* L.) Ecotype Colombia.

Production system	Maturity status	Weight (g)	Equatorial diameter (cm)	Firmness (kg cm^{-2})
SA	Em 0	1.31 ±0.19 a	1.34 ±0.09 a	5.35 ±0.76 a
SA	Em 1	2.68 ±0.3 bcd	1.61 ±0.08 b	4.05 ±0.72 bc
SA	Em 2	2.98 ±0.21 b	1.65 ±0.07 bc	4.46 ±0.57 b
SA	Em 3	3.86 ±0.48 efg	1.78 ±0.08 de	3.37 ±0.3 de
SA	Em 4	3.19 ±0.32 bcde	1.64 ±0.07 b	3.21 ±0.41 de
SA	Em 5	4.23 ±0.67 gh	1.80 ±0.09 e	2.47 ±0.47 fg
SA	Em 6	6.27 ±1.21 def	2.04 ±0.14 g	2.25 ±0.26 g

Production system	Maturity status	Weight (g)	Equatorial diameter (cm)	Firmness (kg cm^{-2})
SC	Em 0	2.57 ±0.47 b	1.67 ±0.06 bcd	4.53 ±0.46 b
SC	Em 1	2.83 ±0.3 bcd	1.68 ±0.11 bcd	4.48 ±0.22 b
SC	Em 2	3.93 ±0.83 fg	1.86 ±0.14 ef	3.70 ±0.37 cd
SC	Em 3	3.32 ±0.62 cdef	1.76 ±0.1 cde	3.28 ±0.27 de
SC	Em 4	4.8 ±0.48 h	1.96 ±0.09 fg	2.91 ±0.46 ef
SC	Em 5	3.78 ±0.66 efg	1.78 ±0.12 de	2.88 ±0.44 ef
SC	Em 6	3.37 ±0.52 i	1.67 ±0.09 bcd	2.16 ±0.23 g

SC= conventional production system. SA= agroecological production system. Em= state of maturity. Means with different letters in each column have significant differences ($p \leq 0.05$).

The values of the equatorial diameter of the fruits show significant differences ($p < 0.05$), for each Em and between productive systems (Table 1). The trend of the data shown by this parameter is similar to that obtained for fresh weight. Maximum diameter values ranged from 2.04 ±0.14 cm and 1.96 ±0.09 cm for Em 6 and Em 4 in SA and SC respectively, while the minimum values were 1.34 ±0.09 cm and 1.67 ±0.06 cm for Em 0 in SA and SC. The differences found for fresh weight and diameter may be strongly influenced by the different cultural and agronomic practices that are used for each productive system, such as irrigation, training pruning and fertilization plans (Martínez *et al*., 2008).

According to these results, it is concluded that the fruits of SC and SA are found in a high percentage within the B and C sizes referenced in the NTC 4580 (ICONTEC, 1999), with the exception of the Em 0 of SA that is rated A caliber, although this is not a limiting factor for its commercialization, since the norm establishes that you can have fruits of the different categories regardless of their size.

Firmness

The value of the deformation generated from a force applied to a fruit is usually associated with structural changes at the cellular level and some biochemical changes that occur in the pericarp during the ripening process (Chitarra *et al*., 2005). In addition, the loss of firmness is a quality parameter in cape gooseberry fruits in its post-harvest stage. This variable showed statistically significant differences ($p \leq 0.05$), in a large percentage of the Em evaluated and the production systems SC and SA (Table 1). In Em0 for SA and SC, the maximum mean firmness values were found (5.35 ± 0.76 kg cm^{-2} and 4.53 ±0.46 kg cm^{-2}, respectively).

However, this variable as a function of time shows a decreasing behavior for the remaining Em to reach minimum values of 2.25 ±0.26 and 2.16 ±0.23 kgcm^{-2} for Em6 in SA and SC respectively.

The loss of firmness is an indication that during the ripening process a deterioration of the cape gooseberry fruits is generated, this study revealed that this loss is gradually more accentuated in SA, this may be influenced by the fertilization practices used under this production system, especially the management of elements such as calcium (Ca) and potassium (K) (Sanders, 2002). Loss of firmness in cape gooseberry is associated with the hydrolysis of structural and reserve polysaccharides due to the activity of enzymes such as pectinmethylesterase, polygalacturonase and glycosylated (Trinchero *et al*., 1999), these enzymes generate a degradation of the cell wall that they cause the loss of resistance of the fruit (Morais *et al*., 2008).

The presence of ethylene hormone and its level of concentration have also been related to loss of firmness in cape gooseberry (Balaguera *et al*., 2011).

pH

Table 2 shows the change in pH according to the state of maturity by productive system. In general, there were significant differences ($p\leq 0.05$), between Em and productive systems. Lower pH values are presented in SA (3.85 ± 0.07 and 3.48 ± 0.01). However, there is a similar behavior between SA and SC regarding the decrease in the pH value in the first stages of maturity and a subsequent increase in this. These changes may be associated with the increase in organic acids (Marschner, 1995).

The pH takes relevance in fruits mainly because it is a regulator of metabolism, in most fruits approximately 90% of the cell volume is occupied by a cellular organ called vacuole, which has a pH below 5 (Nanos *et al*., 1993; Novoa *et al*., 2006), results that support and validate those obtained in this research.

Table 2. Mean values of the variables pH, SST (°Brix), ATT (% citric acid) and Im, determined in cape gooseberry fruits (*Physalis peruviana* L.) Ecotype Colombia.

Production system	Maturity status	pH	SST (°Brix)	ATT (%) citric acid	Im (SST/ATT)
SA	Em 0	3.85 ±0.07 a	6.46 ±0.23 a	2.62 ±0,03 a	2.46 ±0.05 a
SA	Em 1	3.54 ±0.04 f	7.1 ±0.27 b	2.45 ±0.05 c	2.89 ±0.11 b
SA	Em 2	3.49 ±0.01 fg	9.58 ±0.18 d	2.29 ±0.02 e	4.18 ±0.03 d
SA	Em 3	3.48 ±0.01 g	118 ±0.33 f	2.07 ±0.01 g	5.70 ±0.09 f
SA	Em 4	3.66 ±0.03 e	12.75 ±0.29 h	1.91 ±0.02 i	6.65 ±0.09 h
SA	Em 5	3.69 ±0.05 de	13.41 ±0.22 ij	1.78 ±0.01 j	7.47 ±0.15 i
SA	Em 6	3.64 ±0.04 e	14.53 ±0.2 l	1.66 ±0.08 k	8.74 ±0.02 j
SC	Em 0	3.77 ±0.1 bc	8.03 ±0.2 c	2.51 ±0.05 b	3.20 ±0.13 c
SC	Em 1	3.73 +0.08 cd	9.48 ±0.38 d	2.36 ±0.03 d	4.01 ±0.11 d
SC	Em 2	3.69 ±0.05 de	11.43 ±0.18 e	2.25 ±0.02 f	5.07 ±0.02 e
SC	Em 3	3.75 ±0.06 cd	12.36 ±0.15 g	2.02 ±0.03 h	6.11 ±0.05 g
SC	Em 4	3.69 ±0.01de	13.21 ±0.08 i	1.78 ±0.05 j	7.43 ±0.07 i
SC	Em 5	3.74 ±0.01 cd	13.58 ±0.17 j	1.52 ±0.09 l	8.95 ±0.03 k
SC	Em 6	3.82 ±0.05 ab	14.18 ±0.21 k	1.24 ±0.13 m	11.44 ±0.13 l

SC= conventional production system. SA= agroecological production system. Em= state of maturity. Means with different letters in each column have significant differences ($p\leq 0.05$).

Total soluble solids (SST)

In the juice of the cape gooseberry fruit, the percentage of sugars present in the SST content is in the range of 80 to 95% (Fischer and Martínez, 1999). The SST exhibited a behavior that presented statistically significant differences ($p \leq 0.05$) for each Em and for each productive system. The behavior of SST presents an increasing trend during the maturation process, which is associated with the processes of cell wall hydrolysis, where polysaccharides are degraded to monosaccharides (Menendez *et al*., 2006).

For this study, minimum values of 6.46 ±0.23 and 8.03 ±0.2 °Brix were obtained, for Em 0 in SA and SC respectively, the maximum values were obtained in Em 6 with 14.18 ±0.21 for SA and 14.53 ±0.2 in SC, it should be mentioned that none of the Em met the minimum requirement of °Brix recommended by NTC 4580. The above may be correlated with the location of the production systems. Since these are above 2 300 meters above sea level, studies by (Fischer *et al*., 2007) have shown that these height levels generate a reduction in SST and sucrose concentration.

Total titratable acidity (ATT)

The value of ATT is directly related to the presence of acids in the fruit of cape gooseberry, the characteristic acids for this fruit are citric, tartaric, malic and oxalic (Pinzón *et al*., 2015). The behavior observed in SA and SC showed a decrease in the acidity percentage for each Em (Table 2). This is a typical behavior during the ripening process of the cape gooseberry fruit (Balaguera *et al*., 2011). The decrease in ATT is associated with the use of organic acids as breathing substrates (Kader, 2002) or their transformation by glucogenesis to sugars.

The values obtained showed significant differences ($p \leq 0.05$) between Em and the production systems evaluated, the maximum average value obtained was 2.62 ±0.23 and 2.51 ±0.23% for Em 0 in SA and SC respectively, the average minimum value was 1.66 ±0.23 and 1.24 ±0.23%, for Em 6 in SA and SC (Table 2), the values obtained in Em 0-6 for the two production systems were below the value recommended by NTC 4580 (ICONTEC, 1999).

Maturity index (SST/ATT)

This value is an indication of the taste of the fruit and its state of maturity (Balaguera, 2015) therefore it is a commercial acceptance parameter. Increasing behavior was observed, for the two productive systems, behavior associated with the general increase in SST for each Em and the reduction of acidity for these same states (Table 2). Significant differences ($p \leq 0.05$) were found for SA and SC, and similarly among Em.

For the SA, it can be mentioned that the values of maturity indexes for all Em, were below the minimum value recommended in NTC 4580; this means that these fruits in terms of organoleptic quality for the flavor component have disadvantages compared to those produced in SC, since the values obtained from the maturity index for Em 3-6 in SC are above the recommended minimum.

Respiratory pattern

The fruits of cape gooseberry are considered as climacteric, mainly because they increase their respiratory pattern after obtaining their physiological maturity (Balaguera, 2015). The values obtained for SA and SC showed a similar trend under the environmental conditions present in the laboratory (Figure 1). Significant differences were found between Em and the production systems, for SA there is a respiratory pattern that has an initial maximum value per unit weight of 7.05 ±0.33 mg CO_2 g^{-1} d^{-1} for Em 1, then this value decays to a value of 2.89 ±0.03 mg CO_2 g^{-1} d^{-1} in Em 5, to subsequently increase to a value of 7.3 ±0.1 mg CO_2 g^{-1} d^{-1} (Table 2).

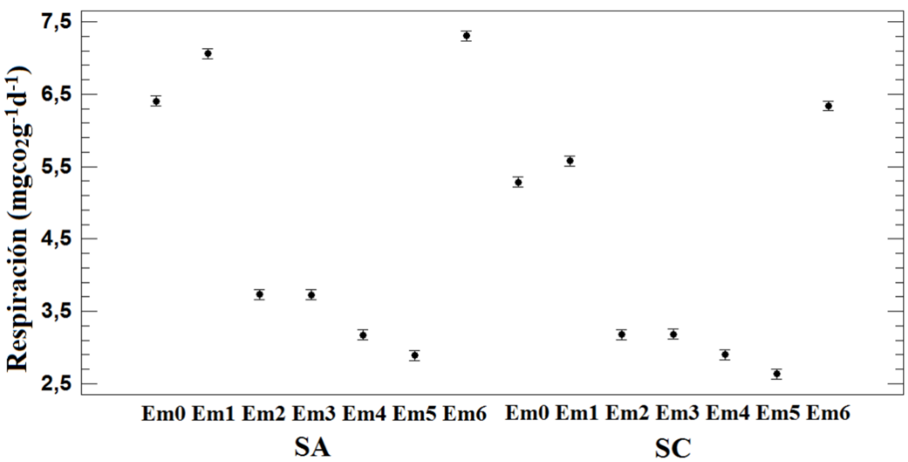

Figure 1. Behavior of respiration rates for ca Em in SA and SC.

For the SC an initial maximum of 5.58 ± 0.08 mg CO_2 g^{-1} d^{-1} was obtained, this value decreased to 2.9 ±0.04 mg CO_2 g^{-1} d^{-1} in Em 4 and then increased to 6.33 ±0.03 mgCO_2 g^{-1} d^{-1} in Em 6. This behavior is mainly explained because the cape gooseberry has its own characteristic of this type of fruit and is the increase in size and weight while it is linked to the plant during its ripening phase, something previously demonstrated by Trinchero *et al*. (1999), these results allow us to conclude that the respiration rate of cape gooseberry produced in SA is higher, therefore its deterioration process is more accelerated, which translates into a shorter postharvest life compared to SC.

Weight loss

The loss of weight in perishable fruit products presents an increasing trend over time, this loss is associated with the ripening process and more directly with the processes of respiration and perspiration of the fruit, additionally it can be accelerated by factors such as mechanical damage or attack of pathogens. Figure 2, shows the percentage behavior of weight loss for SC and SA, it was found that by day 5 the loss value for SA was 21.08, 10.31, 11.09, 12.04, 10.51, 16.72 and 8.02% for the Em of the 0 to 6 respectively, while for the SC they were 14.73, 9.93, 6.87, 5.59, 6.54 and 9.78.

For Em from 0 to 6, values that are below those obtained in SA, this trend continued for day 10 and was reaffirmed on day 15 where values for SA of 42.08, 38.02, 56.93, 49.11, were obtained. 58.74, 89.12 and 43.54 for the Em from 0 to 6, while for the SC values of 33.46, 24.88, 22.19, 17.57, 43.44, 35.09 and 56.46% were obtained for the Em from 0 to 6. For subsequent days you can observe how the Em 0-3 of the SC are the ones that accumulate the least percentage weight loss (Figure 2A).

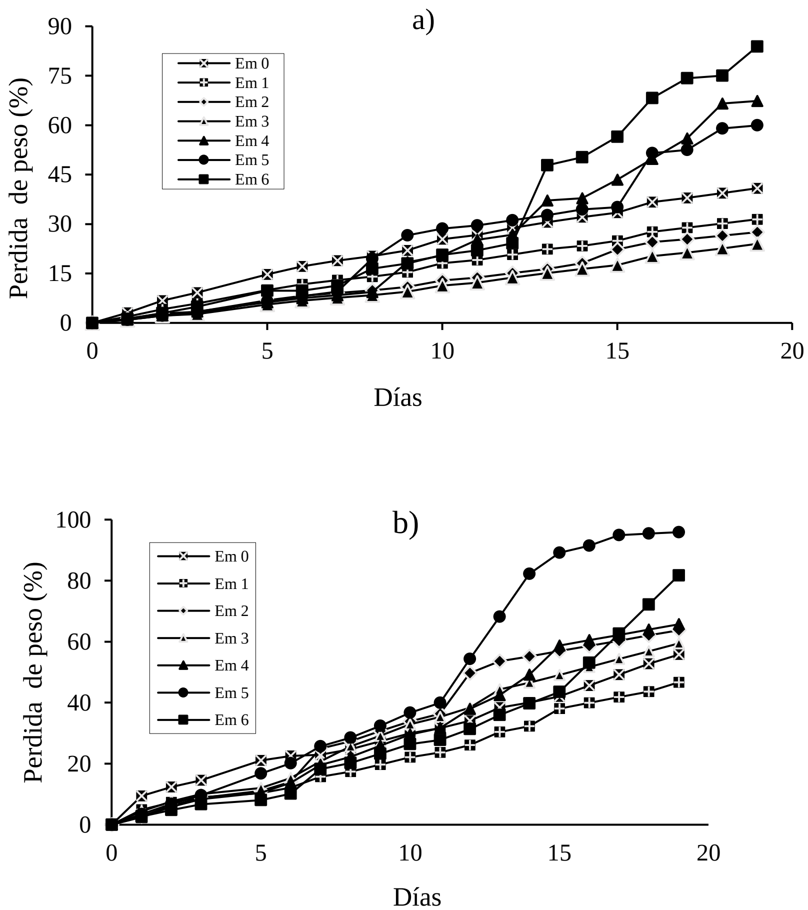

Figure 2. Weight loss (%) in cape gooseberry fruits (*Physalis peruviana* L.) Ecotype Colombia, A) conventional agricultural production system (SC); and B) agroecological production system (SA).

Conclusions

For the SA and SC production systems, the physicochemical characteristics such as, SST, ATT, firmness and pH, presented significant differences in a high percentage of Em, mainly due to the physiological and biochemical processes that originate in the maturation process of climacteric fruits In general terms, it was observed how the fruits produced in SA have a higher respiration rate, a more pronounced loss of firmness during the maturity process, a higher percentage rate of weight loss, which leads to a more restricted postharvest life compared to the fruits obtained in SC, which demonstrates that the shelf life of a cape goose obtained under a conventional production system is longer.

It is recommended that future studies evaluate a greater number of farms under these same production systems in different climatic conditions, identifying the minimum characteristics of the cape gooseberry under agroecological production and its behavior under different storage scenarios that allow comparing the variables obtained with those established by NTC 4580, since the fruits obtained in SA from this research did not reach the minimum maturity index levels reported in the standard, this maturity index relates the flavor component of the fruit and is a factor that can be commercially punished, to it is also a parameter that does not depend on the postharvest stage directly, but rather on pre-harvest factors that can be climatic, agronomic or physiological.

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