Bioagro 28(2): 117-124. 2016

EFFECT OF THE MATURITY STAGE ON THE POSTHARVEST BEHAVIOR OF CAPE GOOSEBERRY (*Physalis peruviana* L.) FRUITS STORED AT ROOM TEMPERATURE

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ABSTRACT

Cape gooseberry (*Physalis peruviana* L.), a species belonging to the Solanaceae family, has fruits appreciated for their flavor and functional and medicinal properties. Fruit maturity at the time of harvest is one of the most important factors determining the behavior and postharvest quality. In order to determine the effect of maturity stage on postharvest behavior of cape gooseberry, fruits from ecotype Colombia were harvested at four maturity stages, S1 (25 % yellow and 75 % green fruit with green calyx), S2 (50 % yellow and 50 % orange with yellow-green calyx), S3 (100 % orange fruit and 100 % yellow calyx) and S4 (100 % orange dry fruit with brown calyx). Fruits were stored without calyx at room temperature (18 °C and 60 % RH) for 15 days. We found that as maturity increased, the values of ethylene production, weight loss, color index, total soluble solids and maturity ratio were higher, while firmness and titratable acidity were lower. However, fruits harvested at S1 had the lowest postharvest quality, since they showed the largest weight loss, lowest firmness and uneven coloration. Therefore, it is not beneficial to harvest fruits at this maturity state. It is advisable to harvest cape gooseberry fruits at S2 and S3 maturity stages because of the good postharvest behavior they show, while fruits at S4 stage should be harvested for immediate consumption only.

Additional key words: Shelf-life, skin color

RESUMEN

Efecto del estado de madurez sobre el comportamiento poscosecha de frutos de uchuva (*Physalis peruviana* L.) almacenados a temperatura ambiente

La uchuva (*Physalis peruviana* L.), especie perteneciente a la familia Solanaceae, posee frutos que son apetecidos por su sabor así como por sus propiedades funcionales y medicinales. La madurez del fruto en el momento de la cosecha es uno de los factores más importantes que determina el comportamiento y la calidad poscosecha. Con el objetivo de determinar el efecto del estado de madurez sobre el comportamiento poscosecha, se cosecharon frutos de uchuva ecotipo Colombia en cuatro grados de madurez, S1 (fruto 25 % amarillo, 75 % verde y cáliz verde), S2 (fruto 50 % amarillo, 50 % naranja y cáliz verde amarillento), S3 (fruto 100 % naranja y cáliz 100 % amarillo) y S4 (fruto 100 % naranja y cáliz seco de color café). Los frutos fueron almacenados sin cáliz a temperatura ambiente (18 °C y 60 % HR) durante 15 días. Se encontró que a medida que el estado de madurez fue más avanzado, los valores de producción de etileno, pérdida de peso, índice de color, sólidos solubles totales y relación de madurez fueron mayores, mientras que la firmeza y la acidez titulable fueron menores; sin embargo, los frutos S1 tuvieron menor calidad poscosecha porque presentaron la mayor pérdida de peso, menor firmeza y una coloración irregular, por lo que no es favorable cosechar los frutos en este estado de madurez. Es recomendable cosechar los frutos de uchuva en los estados S2 o S3 porque presentan un buen comportamiento poscosecha, mientras que los frutos S4 se deben cosechar sólo para consumo inmediato.

Palabras clave adicionales: Color de la epidermis, vida útil

INTRODUCTION

Cape gooseberry (*Physalis peruviana* L.) is a species belonging to the Solanaceae family; its fruits are appreciated because of their taste and functional and medicinal properties (Ramadan, 2011; Puente et al., 2011). This fruit stands out for its high content of antioxidants (ascorbic acid and A provitamin), phosphorus, iron, protein and fiber (Fischer et al., 2011). Recently it has been included on the list of “superfruits” because of its high vitamins, minerals and fiber content (Superfruit, 2011).

Fruit maturity at harvest is one of the key

Recibido: Junio 29, 2015 Aceptado: Febrero 1, 2016
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factors in harvesting that determines the postharvest behavior and quality, and it is related to the usage prerequisites of the traders and consumers (Delwiche, 1987; Santamaría et al., 2009). Fruits harvested at immature stage or at advanced maturity are more prone to suffer physiological damages during postharvest and have lower quality than fruits harvested at the proper maturity stage (Kader, 2002). The most appropriate fruit maturity stage for harvesting is the one that ensures a good flavor development but avoids the excessive softening associated to over-ripeness, which later on makes it difficult to manipulate the fruits (Proebsting et al., 1987). Immature fruits are more prone to physical damages and transpiration losses and develop poor flavor when they ripe. Overripe fruits become very soft with a floury texture and insipid flavor soon after harvest (Kader, 2002), situation that also occurs with cape gooseberry fruits, which leads to quality, sensory and nutritional losses in the fruits as well as profit losses to the production system.

Rincón et al. (2012) found that harvesting fruits previously to full maturity also helps in maintaining fruit quality, since they showed high firmness and acidity, with lower weight loss and maturity ratio in relation to fruits harvested at more advanced maturity stages. In agreement with this, Balaguera and Herrera (2012) indicate that the dynamic of the maturation process in champa fruits (*Campomanesia lineatifolia* R. & P.) is closely related to the maturity stage at the moment of harvest, being this slower in fruits harvested at an earlier maturity stage.

In many crops harvest is done by hand, which requires that the harvester has to be able to decide the moment at which a product has reached harvest maturity (Kader, 2002). There are different indexes that can help establish an objective criterion to carry out harvest (Kader, 2002; Kays, 2004). The color of the skin is one of the best suited (Kader, 2002) and correlates well with other physical, chemical and sensory indicators of the products quality (Mendoza et al., 2006); it is easy to use, non-destructive, and has a low cost, but it has to be used together with other indexes in order to make a more objective estimation (Balaguera and Herrera, 2012). In the case of cape gooseberry, the maturity index most used by growers and traders is the visual determination by calyx color that matches the fruit coloration. Normally, when fruits have yellow color and at the same time the color of calyx changes from green to yellow, it is the optimum harvest point for export fruits. This change is quite easy to identify and therefore it is mostly used by growers (Galvis et al., 2005).

Skin color is also used as maturity index in fruits of lulo (*Solanum quitoense*) (Casierra et al, 2004), pitahaya (*Selenicereus megalanthus* Haw.) (Rodríguez et al., 2005) and tomato (*Solanum lycopersicum* L.) (Casierra and Aguilar, 2008). Some studies on cape gooseberry have been done taking into account the maturity stage. For instance, Novoa et al. (2006) indicate that in fruits with a degree of maturity 5 (yellow) drying of the calyx at 24 ºC apparently turned out to be the best option for storage at 12°C; while the best minimum internal quality conditions were maintained in relation to acidity at degree of maturity 4 (green-yellow color). Balaguera et al. (2016) established the best doses of 1-methilcyclopropene (1-MCP, inhibitor of the action of ethylene) for preserving quality of cape gooseberry fruits during postharvest, and, previously, Gutiérrez et al. (2008) had evaluated this product at four degrees of maturity of the fruit (green, green-yellow, yellow and orange), and found that the degree of maturity is a determining factor for the efficiency of 1-MCP as a maturity retardant. Galvis et al. (2005) mention that one of the limiting factors occurring during postharvest of cape gooseberry is that the different changes involved in the ripening have not been studied enough. This knowledge could help develop viable recommendations from a technical point of view in order to apply proper management during the different postharvest operations and thus maintain quality and extend the fruit shell life.

Due to the above, the objective of this study was to determine the effect of the maturity stage at harvest on the postharvest behavior of cape gooseberry fruits (*Physalis peruviana* L.) stored at room temperature.

MATERIALS AND METHODS

Cape gooseberry fruits ecotype Colombia were harvested from a commercial plantation at the municipality of Ventaquemada, Boyaca Department, Colombia, located at 2630 meters above sea level with mean temperature of 12 °C. Analyses were done at the Faculty of Agricultural

Sciences of the Universidad Nacional de Colombia in Bogota.

A randomized experimental design was used, with four treatments corresponding to different stages of maturity based on skin color (Table 1); each treatment had four replications for a total of 16 experimental units (EU). Each one was composed of approximately 125 g of fruits without calyx. The fruits were collected directly from the plant using completely healthy units of homogeneous size (5.7-6.0 g). Table 1 shows the properties of the fruits in each treatment at harvest. Additionally, color difference between consecutive degrees of maturity was calculated following the methodology applied by Mendoza et al. (2006) in order to ensure that the color of the fruits of each treatment was different. Fruits were taken to the laboratory and left at ambient temperature (18±2 °C and 60±8 % RH).

Table 1. Description of cape gooseberry fruits harvested at different consecutive maturity stages, based on skin color

Maturity stage	Description	Skin color	Δ color[b]
S1	[a]Fruit: 25% yellow 75% green Calyx: Green	L*: 62.34 a*: -8.22 b*: 45.51 CI: -2.90	-
S2	[a]Fruit: 50% yellow 50% orange Calyx: Green-yellow	L*: 64.05 a*: 1.83 b*: 52.23 CI: 0.55	12.2
S3	[a]Fruit: 100% orange Calyx: 100% yellow	L*: 67.12 a*: 9.33 b*: 52.67 CI: 2.64	8.1
S4	Fruit: 100% orange Calyx: Dry and brown	L*: 65.67 a*: 12.47 b*: 48.99 CI: 3.88	5.1

[a] The stages S1, S2, S3 correspond to stages 2, 4 and 6 of the Icontec NTC 4580 regulation (Icontec, 1999)
[b] Corresponds to the color difference with the previous treatment; if the difference is >4 the color is sensed as different

At days 1, 8 and 15 after harvest color index (CI) was recorded [CI= (1000 x a*)/(L* x b*)], being this variable calculated based on the parameters of the CIELab system L*, a*, and b*. Three readings were taken at the equatorial diameter of each fruit using a Minolta digital colorimeter. Fruit firmness was measured using a Lloyd LS1 texture analyzer with a 1 KN load cell, 3 mm cylindrical die and Nexygen Plus software. Weight loss was calculated by relating weight loss to the initial fruit weight, using a 0.01 g precision scale. Total soluble solids (TSS) were recorded by measuring degrees Brix using a Hanna digital refractometer 0.1 °Brix precision. Total titratable acidity (TTA) was determined using a 916 Food Ti-Touch 120 automatic titrator. Maturity ratio was calculated using the TSS/TTA ratio.

In order to quantify ethylene production approximately 120 g of cape gooseberry fruits were placed in hermetical 500 cm^3 glass chambers for 1 hour, after which a gas sample of 0.3 mL was extracted from the chamber using a 1 mL syringe that was then injected into a Agilent Technologies 7890A gas chromatograph (CG) equipped with a flame ionization detector (FID). A HP-PLOT column (30 m x 0.55 mm x 40 μm) was used. The chromatographic conditions were as follows: injector temperature of 70 °C, oven temperature of 50 °C and FID detector temperature of 250 °C. Helium was used as carrier gas at a flow rate of 7.0 $mL{\cdot}min^{-1}$, and the combustion gases from the FID detector where dry air and hydrogen with a flow rate of 300 and 40 $mL{\cdot}min^{-1}$, respectively. Quantification was done using an ethylene pattern (AGA, Colombia) with a concentration of 99 $mg{\cdot}L^{-1}$ in nitrogen.

The data obtained was used to generate an analysis of variance (Anova), then Tukey's multiple comparison test was performed using SAS software v. 9.2 (Cary, N.C).

RESULTS AND DISCUSSION

A representative increase in ethylene production was observed at all maturity stages at 5 days after harvest, after which ethylene emission decreased progressively. In general, ethylene production increased as the maturity stage advanced. Significant statistical differences were found at all sampling points (Figure 1). Similar results were reported by Gutiérrez et al. (2008), who state that during ripening of cape gooseberry ethylene is autocatalytic and depends on the maturity stage at harvest being ethylene production higher in more mature harvested fruits. Valdenegro et al. (2012) also observed a higher ethylene production in cape gooseberry fruits at a more advanced maturity stage.

The ethylene levels encountered in cape

gooseberry fruits are quite high. Trinchero et al. (1999) indicate that ethylene production in this species is extremely high compared to other fruits. These same authors found that ethylene may increase 45 times its initial concentration during ripening and up to 70 times when fruit is overripe. Different studies indicate that ethylene can be associated to different processes during ripening of cape gooseberry fruits such as softening, antioxidant activity, and color change (Gutiérrez et al., 2008; Valdenegro et al., 2012). For this reason, fruits harvested with a more advanced degree of maturity and with a higher ethylene production can show a faster ripening process than fruits harvested at a lower maturity stage.

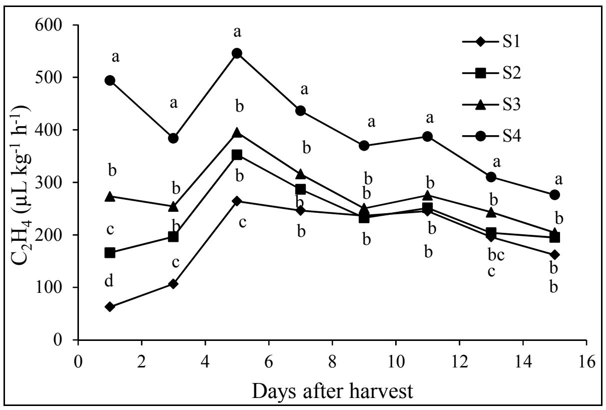

Figure 1. Ethylene production during postharvest of cape gooseberry fruits harvested at different maturity stages. Description of S1, S2, S3, S4 according to Table 1. Means of each sampling followed by different letters show significant differences according to Tukey's test ($P \leq 0.05$)

Weight loss increased linearly at all stages. The fruits at S3 showed a significantly lower weight loss, while the highest weight loss was encountered in fruits at S4 and S1, where these last ones showed skin crumpling due to high water loss (Figure 2A). Cape gooseberry fruits are characterized by having a waxy film with low impermeability on the skin that mainly consists of therpenic resins with characteristic complex microstructures (Puente et al., 2011), which turn into a key barrier to the gas exchange between the fruit and the external environment. Apparently the fruits at S1 and S4 have a lower content of these waxes. At S1 this could possibly occur, because these waxes have not been synthesized completely, and at S4 because they are already being degraded with simultaneous cell disintegration, and thus these fruits have a higher water loss by transpiration. Kader (2002) explains that water loss is the main cause of fruit deterioration, because it leads to a direct reduction in fresh weight and quality and shortens shelf life due to acceleration of ripening and senescence. For this reason, it would not be advisable to harvest cape gooseberry fruits at the maturity stages S1 or S4. In agreement with this, Dick et al. (2009) reported higher weight losses in mango fruits, which were harvested at less advanced maturity stages.

Firmness decreased during storage, being this decrease higher from the day 1 to 8 after harvest. Statistical differences ($P \leq 0.05$) were found in the two first samplings. At day 1 the fruits at S1 showed the highest firmness and as the maturity stage progressed firmness was lower. At day 8 firmness was lower in the more mature fruits, and the other stages had statistically shown the same firmness (Figure 2B).

Gutiérrez et al. (2008) also observed lower firmness in cape gooseberry fruits at a more advanced maturity stage. It is important to note that the fruits at S1 had the highest loss of firmness: At day 1 firmness was 12.98 N and at day 15 it was 4.85 N. This value was similar to those encountered in the rest of treatments at the same day, and apparently, it had no relation with ethylene production. This atypical behavior, which also was found by Gutiérrez et al. (2008), does not agree with the information reported in other species such as lulo (Casierra et al., 2004), guava (Azzolini et al., 2004) and champa (Balaguera and Herrera, 2012), where the fruits harvested at a lower maturity stage showed higher firmness during storage. This is because fruits at a lower maturity stage can have a higher protopectin concentration (Hernández et al., 2007), which makes tissues more consistent. The behavior observed at S3 can be associated to the higher weight loss, a process that can indicate a higher cell and tissue degradation that accelerates the aging process, including loss of firmness. The relation between weight loss and loss of firmness has been reported by various authors (Shackel et al., 1991; Vicente et al., 2007; Balaguera and Herrera, 2012).

At the other stages it is possible to observe that the higher ethylene production can be responsible for the lower firmness values. Apparently, ethylene is regulating the activity of enzymes involved in softening such as polygalacturonase (Majumder and Mazumdar, 2002). Hydrolysis of the middle lamella and cell wall is the main process responsible for the loss of firmness in fruits (Morais et al., 2008). In this way, cape gooseberry fruits at S2 show the best behavior in terms of firmness which can facilitate postharvest operations.

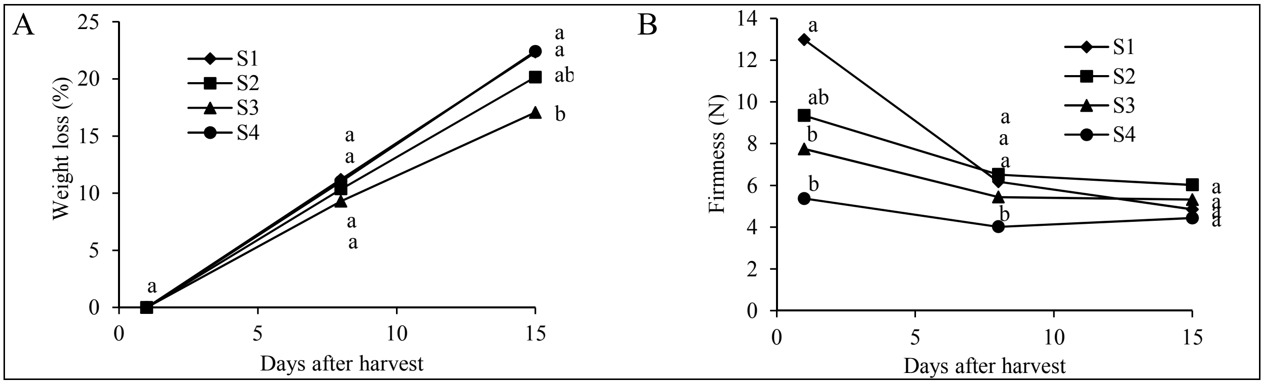

Figure 2. Behavior of A. Weight loss, and B. Firmness, during postharvest of cape gooseberry fruits harvested at different maturity stages. Description of S1, S2, S3, S4 according to Table 1. Means of each sampling followed by different letters show significant differences according to Tukey's test ($P \leq 0.05$)

There was a marked increase in skin color from day 1 to day 8, which then remained stable at all the stages, except for S1, at which it increased. Statistical differences ($P \leq 0.05$) were found in all the samplings. A direct relationship between maturity stage and color index was found. The fruits at S1 showed the lowest values, while the fruits at S4 and S3 showed a similar behaviour between them (Figure 3A).

Similar results were observed by Balaguera and Herrera (2012), who worked with champa fruits and found that fruits harvested at a more advanced maturity stage had a better color development than fruits harvested at a lower maturity stage. These authors place emphasis on the possibility of considering that the action of chlorophylases in the first maturity stages is lower, and thus the loss of green color is not as evident as in those fruits harvested at more advanced maturity stages, possibly because the synthesis and action of ethylene is lower in fruits harvested at early maturity stages. This might also explain the behavior observed in cape gooseberry fruits. In relation to this, Trinchero et al. (1999) claim that the color changes in cape gooseberry fruits are caused by the degradation of chlorophyll and the accumulation of carotenoids in plastids, being β-carotene the predominant pigment (Fischer et al., 2000). As a consequence, it is also possible that the β-carotene accumulation in fruits of S1 may be considerably lower, and those fruits, with poor color development (irregular coloration) would have a lower visual and nutritional quality in relation to the more mature harvested fruits.

The fruits at stage S1 tended to increase in total soluble solids until day 8, after which they decreased (figure 3B). The other stages showed a continuous increase during the whole experiment, being this increase more notorious in the fruits at S4. There were statistical differences ($P \leq 0.05$) in all the samplings and a direct relationship was found between maturity stage and TSS, so the fruits at S4 had a highest TSS. The increase in TSS during the ripening process is a marked characteristic in cape gooseberry fruits of ecotype Colombia (Fischer and Lüdders, 1997), and it is attributed to the hydrolysis of starch and polysaccharides of the cell wall that give rise to soluble sugars (Kays, 2004; Menéndez et al., 2006). The fruits with higher degree of maturity have the ability to accumulate a higher amount of TSS that is associated with better sensory and nutritional quality. In turn, the fruits at S1 apparently have lower enzymatic activity related to metabolism and soluble sugar accumulation that can be explained by the lower ethylene production. Anzzolini et al. (2004) observed similar results in guava and Gutiérrez et al. (2008) in cape gooseberry, where ripe fruits showed a higher increase in TSS than the fruits at a lower maturity stage.

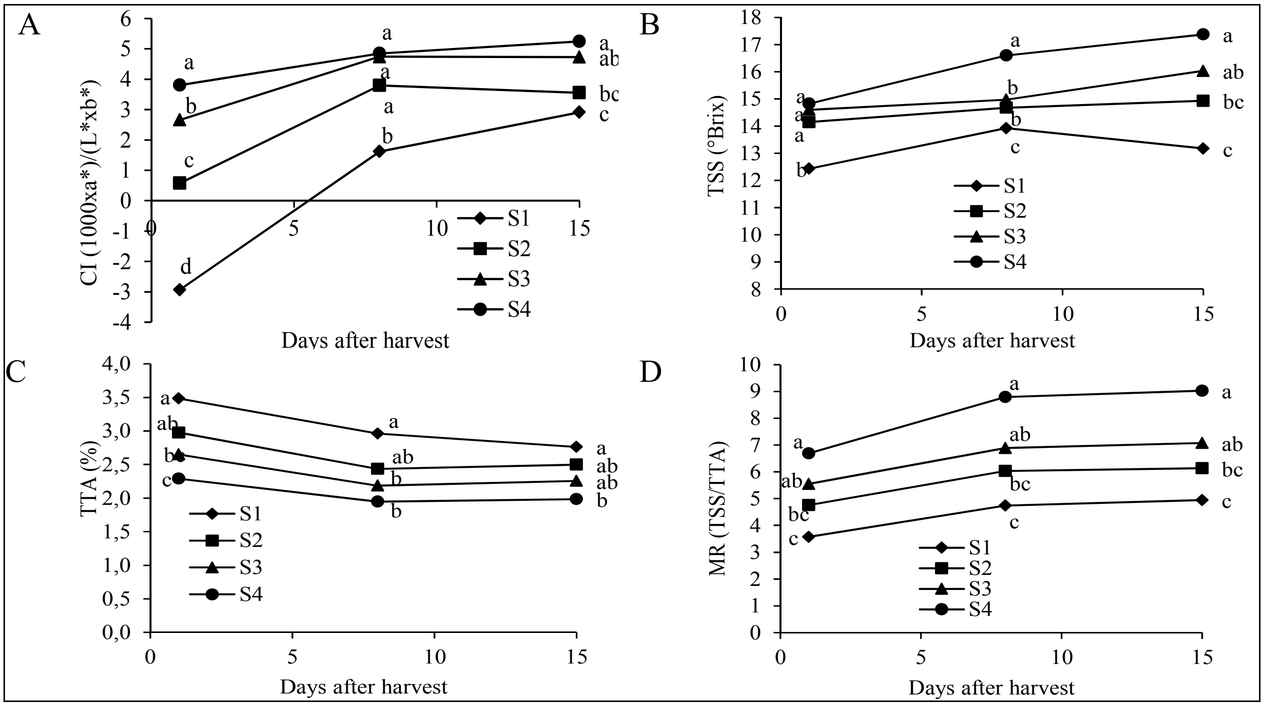

Figure 3. Behavior of A. Color index (CI), B. Total soluble solids (TSS), C. Total titratable acidity (TTA) and D. Maturity ratio (MR) during postharvest of cape gooseberry fruits harvested at different maturity stages. Description of S1, S2, S3, S4 according to Table 1. Means of each sampling followed by different letters show significant differences according to Tukey's test ($P \leq 0.05$)

In relation to total titratable acidity, significant statistical differences ($P \leq 0.05$) were found in the three samplings. There was a decrease from day 1 to day 8, after which it remained stable. The fruits at S1 showed a higher TTA value, and as the degree of maturity at harvest increased, the TTA value decreased (Figure 3C). Novoa et al. (2006) determined that cape gooseberry fruits harvested at a lower maturity stage (green yellow) showed higher TTA during storage compared with those that were harvested at more advanced maturity stages (yellow), the same as observed in this study. Fruits with a lower degree of maturity can behave better during the postharvest, because they show a higher amount of organic acids to be used as respiratory substrate, which coincides with a higher shelf life expectation. However, although the fruits harvested at S1 stage showed a higher TTA value, they did not have a better postharvest quality. These fruits did not express a typical maturation, and apparently the organic acid metabolism (Krebs cycle, gluconeogenesis) did not occur normally as it did in the fruits harvested at the other maturity stages, which could have caused the higher TTA value (2,76 %).

With a continuous increase during storage cape gooseberry fruits showed significant differences ($P \leq 0,05$) in maturity ratio at all the sampling dates. At day 15, maturity ratio was higher in fruits with higher degree of maturity (S4; 9,03), while fruits at S1 showed the lowest MR with 4,95 (Figure 3D). The increase in maturity ratio at all stages occurs because TSS increased and TTA decreased. An increase in maturity ratio as a function of the degree of maturity of cape gooseberry was also reported by Valdenegro et al. (2012). These same authors also found that ethylene increases maturity ratio, thus the fruits with a highest maturity (which produced higher ethylene levels) showed the highest MR values.

This does not only shows that the maturity ratio is an indicator of the degree of maturity of cape gooseberry fruits, but it is also an indicator of the fruit taste, if we take into consideration that when the fruit has a high sugar content, it is important that the acid level is high enough in order to satisfy the consumer (Osterloh et al., 1996). Therefore, possibly, cape gooseberry fruits with higher degree of maturity will be preferred by the consumer.

The maturity ratio in fruits harvested at S1 at the end of storage indicates that the ripening process was retarded but also that they are very acid fruits in terms of sugar content, since the value at day 15 (4,95) is very low compared with the fruits at the other maturity stages, which could lead to rejection by the consumer.

CONCLUSIONS

The postharvest behavior of cape gooseberry fruits is closely related to the maturity stage at the moment of harvest. The fruits harvested at S4 degree of maturity (100% orange fruit and dry brown calyx) show higher values in terms of ethylene production, weight loss, color index, soluble solids and maturity ratio. These same fruits showed the lower values in terms of firmness and total titratable acidity. The fruits harvested at S1 (25% yellow, 75% green fruit and green calyx) showed lower values in terms of ethylene production, color index, total soluble solids and maturity ratio and higher total titratable acidity, but weight loss and firmness were similar to the fruits of S4. These fruits had a large weight loss with poor color and internal ripeness development. It is not recommendable to harvest fruits with this degree of maturity and subsequently store them at ambient temperature. It is recommendable to harvest the fruits at S2 (50% yellow, 50% orange fruit and green-yellow calyx), because they have a better postharvest behavior and are able to maintain quality for a longer time. It is recommendable to harvest at S3 and S4 when consumption shall occur immediately or in a short time.

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