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Pre-harvest factors that influence the quality of passion fruit: A review

Factores precosecha que influyen en la calidad de las frutas pasifloráceas. Revisión

Gerhard Fischer[1]*, Luz M. Melgarejo[2], and Joseph Cutler[3]

ABSTRACT

Colombia is the country with the greatest genetic diversity in passion fruit species, some of which are cultivated on an area of approximately 13,673 ha. Each variety must be planted at a suitable altitude under optimal conditions to obtain the best quality. Regarding plant nutrition, potassium has the greatest influence due to the effect of its application on the yield increase, ascorbic acid content and lifecycle to harvest. Adequate water increases the percentage of the marketable quality and amount of fruit juice, and the use of rootstocks does not significantly change the fruit quality. Ensuring a pollination of the flowers in cultivation is decisive for the fruit formation and its juice content. The species differ greatly in their quality, as purple passion fruit (*Passiflora edulis* f. *edulis*) is a fruit that develops the highest content of ascorbic acid, while sweet calabash (*P. maliformis*) forms the maximum amount of phenols and total antioxidant activity. The maturation and ripening of passion fruit is determined by the skin coloration, during which the Brix grades and the maturity index increase and the titratable acidity diminishes. Fruits harvested early in physiological maturity and with unripe peel color can be treated with ethylene in post-harvest, matching fruits that ripened in the plant. More research is needed in the improvement of the quality of the *Passifloraceae*. Giant granadilla (*P. cuadrangularis*) and sweet calabash have been studied less than banana passion fruit (*P. tripartita* var. *mollissima*), purple passion fruit, yellow passion fruit and sweet granadilla (*P. ligularis*). The last three species are the most exported fruits in the country.

Key words: *Passiflora edulis* f. *flavicarpa*, *P. edulis* f. *edulis*, *P. ligularis*, *P. tripartita* var. *mollissima*, *P. maliformis*, *P. cuadrangularis*.

RESUMEN

Colombia es el país de mayor diversidad genética en especies de pasifloras, algunas de las cuales se cultivan abarcando aproximadamente 13,673 ha. Cada variedad debe ser sembrada en sitio y piso térmico apto para desarrollar su calidad óptima, igualmente debe ser cultivada con las mejores prácticas para aprovechar su potencial. En la nutrición, es el potasio el que muestra mayor influencia ya que aumenta el rendimiento y el contenido de ácido ascórbico y acorta el tiempo para cosechar. Suministro suficiente de agua aumenta el porcentaje de calidad de fruto mercadeable, así como el jugo del fruto, mientras que el uso de patrones no influye significativamente en la calidad de los frutos. Garantizar una polinización de las flores en cultivo es decisivo para la formación del fruto y el jugo. Las especies difieren mucho en su calidad, siendo la gulupa (*Passiflora edulis* f. *edulis*) la que desarrolla un contenido más alto en ácido ascórbico, mientras la cholupa (*P. maliformis*) se destaca por el máximo en fenoles y actividad antioxidante total. La maduración de los frutos de las pasifloráceas está bien determinada por la coloración de la cáscara, durante la cual los grados Brix y el índice de madurez aumentan, y la acidez titulable disminuye. Los frutos cosechados tempranamente en madurez fisiológica y con cáscara de poca coloración pueden ser tratados con etileno en poscosecha igualando a los frutos madurados en planta. Más investigación es necesaria para el mejoramiento de la calidad de las pasifloráceas, siendo la badea (*P. cuadrangulares*) y la cholupa las menos estudiadas, en comparación con la curuba (*P. tripartita* var. *mollissima*), la gulupa, el maracuyá y la granadilla (*P. ligularis*), de las cuales las últimas tres están dentro de las frutas más exportadas del País.

Palabras clave: *Passiflora edulis* f. *flavicarpa*, *P. edulis* f. *edulis*, *P. ligularis*, *P. tripartita* var. *mollissima*, *P. maliformis*, *P. cuadrangularis*.

Introduction

Colombia is a country with the highest diversity rates of *Passifloraceae* species (Ocampo *et al*., 2007), nine species are commercially cultivated to supply local and international markets (Ligarreto, 2012). Six of these species have been statistically assessed, and according to Agronet (2018) in 2016, a total of 195,942.2 t were produced on 13,673.45 ha. Provinces of Antioquia and Huila produce 119,388.87 t of yellow passion fruit (7,192.30 ha); Huila, Cundinamarca and Antioquia 42,950.51 t of sweet granadilla (3,793.55 ha); Antioquia, Tolima and Cundinamarca 15,945.67 t of purple

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passion fruit (1,001.55 ha); Boyaca, Norte de Santander and Tolima 13,741.8 t of banana passion fruit (1,319.1 ha); Huila, Santander and Choco 2,352.55 t of giant granadilla (156.05 ha); and finally, Huila produces 1,562.8 t of sweet calabash (211 ha).

The most exported passiflora from Colombia is purple passion fruit, which generated 25.8 million USD for the country in 2017 and is exported mainly to The Netherlands, Germany and the United Kingdom (La Nota Económica, 2018).

The physiological behavior, quality and perishability of the fruits depends on the characteristics of each fruit, environmental conditions and crop management, as well as postharvest care (Herrera, 2012). The word "quality" comes from the Latin "qualitas" which means attribute, property or basic nature of a product; however, nowadays it can be defined as the "level of excellence or superiority" (Kader, 1986), in terms of appearance, taste, nutritional value and safety, among others (López, 2004). Quality is a combination of the attributes, properties or characteristics that each product value confers in terms of its use (*e.g.* raw, cooked or processed) (Kader, 2002). The set of all the qualitative factors indicates the rate of deterioration, and the lack of control of these factors leads to post-harvest losses on a larger scale (Barmann *et al*., 2015). Kader (2002) estimates, in general, that a third of all fruits is lost before reaching the consumer.

Due to the fact that during the post-harvest of fruits, less importance has been given to the investigation of the influence of some pre-harvest factors, such as climate and crop management on physiology, quality and longevity (Barman *et al*., 2015), the objective of this review is to deal with these issues in the case of commercially cultivated passion fruits.

Development of the fruit quality during cultivation

Of the factors that influence the quality of the product in cultivation (pre-harvest), the most determining factors are the genetics of the variety, the environmental conditions, the further interaction between genotype and environment, and the crop management strategies (Herrera, 2012).

Environmental factors and quality

The environmental conditions of the site (climate and soil) are crucial for the process of crop quality formation, and are the basis for the development of commercial fruit growing in a country or region (Fischer and Miranda, 2012; Fischer and Orduz-Rodríguez, 2012). The environment influences processes such as photosynthesis, transpiration, respiration, translocation of photoassimilates and the metabolism of the plant, which are decisive for the internal and external quality of the fruit and its longevity in post-harvest (Ladaniya, 2008).

The effect of the physical, chemical and biotic environment on the physiological mechanisms of the plant is known as plant ecophysiology (Larcher, 2003; Lambers *et al*., 2008). Different cultivated passion fruit species are found in Brazil, Colombia and, in general, in tropical America and Central America (Miranda, 2012). The ecophysiological demands and climatic conditions of the different types of passion fruit are diverse, as shown in Table 1.

In Colombia, the altitude defines factors such as temperature. With an increase of 100 m the temperature decreases on average 0.6°C, while the UV radiation increases, and the atmospheric pressure and relative humidity decrease (Fischer and Orduz-Rodríguez, 2012). As shown in Table 1, different *Passifloraceae* can be grown commercially between 0 and 3,000 m a.s.l.

TABLE 1. Climatic factors of growth and production of passion fruits in Colombia.

Climatic factor	Yellow passion fruit (*P. edulis* f. *flavicarpa*)	Purple passion fruit (*P. edulis* f. *edulis*)	Sweet granadilla (*P. ligularis*)	Banana passion fruit (*P. tripartita* var. *mollissima*	Sweet calabash (*P. maliformis*)	Giant granadilla (*P. cuadrangularis*)
Temperature (°C)	24-28	15-18	16-20	13-16	26-32	20-24
Altitude (m a.s.l.)	0-1,300	1,700-2,200	2,000-2,500	1,800-3,000	600-1,000	0-1,000
Precipitation (mm)	800-1,500	1,300-1,800	2,000-2,500	1,000-1,500	1,200-1,450	1,000-1,800
Rel. humidity (%)	70	80-94	70-75	70-80	60-70	80
Light/solar radiation	<5 h/day direct sunshine	9-13 h light/day		7-8 h/day direct sunshine	8-11 h light/day	
Authors	Cleves *et al*., 2012	Ocampo and Wyckhuis, 2012	Miranda, 2012	Campos and Quintero, 2012; Ángulo and Fischer, 1999	Ocampo *et al*., 2015	Carrión and Pontón, 2002

Due to the increase in UV light with elevation, juicy fruits, as in the case of *Passifloraceae*, are more prone to sunburn (Fischer *et al*., 2016) and, in addition, a high and prolonged solar radiation increases both the temperature of the irradiated cells that can cause the splitting of the epidermis and a subsequent entry of pathogens to these unprotected tissues (Fischer, 2000). For this reason, the plants need leaves to cover fruits. However, it is important that part of the UV light reaches the fruits during ripening to stimulate the production of antioxidants that improve their nutritional value (Fischer *et al*., 2016).

At higher altitudes, due to the colder environment, production starts later and fruit development lasts longer than at lower sites, as Mayorga (2017) found in banana passion fruit. Outside their altitudinal range, crops can have a higher incidence of pests and diseases, and pollination processes are less effective (Fischer *et al*., 2009; Ocampo *et al*., 2015). In banana passion fruit at higher altitudes, the epidermis of the fruit is thicker and more resistant to anthracnose (Campos and Quintero, 2012). In sweet granadilla, at altitudes lower than 1,700 m a.s.l., fruit size is reduced producing 50% of second grade quality fruits (Castro, 2001).

After assessing *Passifloraceae* fruits in a high altitudinal zone (2,498 m, average 14.9°C), Mayorga (2017) found that in Pasca (Cundinamarca, Colombia) the banana passion fruits had a higher weight, size, citric and ascorbic acid contents; in contrast, the total soluble solids content (TSS) was lower in the high zone compared to fruits produced in lower areas (2,006 m a.s.l. and 17.9°C). It is possible that the organic acids in the higher area were not metabolized at the same rate due to the colder environment (Tellez *et al*., 2007) and the higher TSS at the lower elevation (2,006 m), leading to increase the transformation rate of starch in sugar by hydrolysis process. This was stated assuming that the TSS is basically a sugar dilution (80.95%) that does not depend directly on leaf photosynthesis rather than on the climatic conditions (Flórez *et al*., 2012), considering that in this research the photosynthetic rate increased proportionally to the elevation rate.

For banana passion fruit located in foggy areas, the espalier and the conduction of the canopy were exposed with an angle of 45° and an orientation towards the east, increasing the capture of light by the leaves and the production of fruits. These features produce 90 fruits per m^2 of canopy in low radiation sites and up to 100-150 fruits per m^2 in those of high radiation with productions as high as 40 t ha^{-1} $year^{-1}$, with 2.5 cycles annually for the cv. Momix (O.C. Quintero, personal communication, 2004).

Genetic material and quality

The highest genetic diversity of the passion fruit is found in Colombia, where Ocampo *et al*. (2007) observed 167 species, from which 165 were native, followed by Brazil with 127 and Ecuador with 90. According to Ligarreto (2012), in the National System of Germplasm Banks administered by Corpoica (Colombia), there are 170 accessions of passion fruits, with 52 molecularly characterized, including details about their biochemical and agro-industrial properties. The quality enhancement is the most important objective of genetic breeding, improving the flavor and acidity of the fruit for the industrialized beverages manufacture, increasing the content of TSS and the size of the fruit (Ligarreto, 2012). In the case of yellow passion fruit, the same author mentions that oval shaped fruits are preferred because they contain up to 10% more juice than the round ones.

Ocampo *et al*. (2015) collected and characterized sweet granadilla fruits in 35 municipalities of 11 provinces of the Andean region in Colombia to establish the degree of genetic variability as an important input for genetic improvement. Eleven physicochemical variables were characterized and seven elite accessions were identified through the quality parameters: fruit weight (>34 g), °Brix (>14.4) and pulp + seed (>52%).

Regarding the influence of the genetic material on the quality and production of the *Passifloraceae*, there are great differences between the species and the variety. In yellow passion fruit in Brazil, the kinetics of chlorophyll fluorescence allowed an accurate evaluation of the functional states of the photosynthetic apparatus in the different cultivars, which indicated that 'FB 300', 'BRS Sol do Cerrado' and 'BRS Ouro Vermelho' are photosynthetically more efficient and have better fruit quality (Gama *et al*., 2013).

Ramaiya *et al*. (2013) compared antioxidant contents (ascorbic acid, total phenols and total antioxidant activity) in four passion fruit species and found the highest content of ascorbic acid in purple passion fruit (0.32 g kg^{-1} FW) and the lowest in sweet calabash (0.15 g kg^{-1} FW). Regarding the total phenols, the highest content was found in sweet calabash (277.00 mg GAE/L FW) and the lowest in giant granadilla (272.96 mg GAE/L FW), while the highest total antioxidant activity was found in sweet calabash (1,685.00 μmol Trolox/L FW) and the lowest in purple passion fruit (547.70 μmol Trolox/L FW); yellow passion fruit obtained intermediate values of these antioxidants (Tab. 2).

TABLE 2. Some antioxidants, predominant organic acids and sugars contained in the pulp of passion fruits.

Fruit species	Antioxidants	Organic acids	Sugars
Yellow passion fruit	[1]Ascorbid acid 0.24 g kg^{-1} FW [1]Total phenols 361.73 mg GAE L^{-1} FW [1]TAA 524.00 μmol Trolox L^{-1} FW	[3]Citric acid 55.0 meq 100 g^{-1} [3]Malic acid 10.5 meq 100 g^{-1} [3]Lactic acid 0.5 meq 100 g^{-1} [3]Malonic acid 0.1 meq 100 g^{-1}	[1]Sucrose 28.6 g kg^{-1} FW [1]Glucose 14.1 g kg^{-1} FW [1]Fructose 14.6 g kg^{-1} FW
Purple passion fruit	[1]Ascorbic acid 0.32 g kg^{-1} FW [1]Total phenols 362.00 mg GAE L^{-1} FW [1]TAA 547.70 μmol μmol Trolox L^{-1} FW	[3]Citric acid 13.1 meq 100 g^{-1} [3]Malic acid 3.8 meq 100 g^{-1}, [3]Lactic acid 7.4 meq 100 g^{-1} [3]Malonic acid 4.9 meq 100 g^{-1}	[1]Sucrose 45.5 g kg^{-1} FW [1]Glucose 30.1 g kg^{-1} FW [1]Fructose 31.3 g kg^{-1} FW
Sweet granadilla	[2]Ascorbic acid 0.14 g kg^{-1} FW	[2]Citric acid 7.12 mg g^{-1} FW [2]Malic acid 2.86 mg g^{-1} FW [2]Oxalic acid 0.019 mg g^{-1} FW	[2]Sucrose 20.67 g kg^{-1} FW [2]Glucose 35.6 g kg^{-1} FW [2]Fructose 35.6 g kg^{-1} FW
Giant granadilla	[1]Ascorbic acid 0.22 g kg^{-1} FW [1]Total phenols 272.96 mg GAE L^{-1} FW [1]TAA 1,352.30 μmol Trolox L^{-1} FW	[4]Citric acid 15.2 mg g^{-1} FW	[1]Sucrose 28.1 g kg^{-1} FW [1]Glucose 43.7 g kg^{-1} FW [1]Fructose 39.0 g kg^{-1} FW
Sweet calabash	[1]Ascorbic acid 0.15 g g kg^{-1} FW [1]Total phenols 277.0 mg GAE L^{-1} FW [1]TAA 1,685.00 μmol μmol Trolox L^{-1} FW	[5]Acidity 3.0 %	[1]Sucrose 17.0 g kg^{-1} FW [1]Glucose 23.4 g kg^{-1} FW [1]Fructose 22.1 g kg^{-1} FW

[1]Ramaiya *et al.* (2013); [2]Espinosa *et al.* (2018); [3]Chan *et al.* (1972); [4]Sánchez *et al.* (2014); [5]Ocampo *et al.* (2015).

TAA - Total antioxidant activity

In a compilation by Casierra-Posada and Jarma-Orozco (2016) on the nutritive values of different passion fruits vary depending on the species. For example, according to the reports of Chan *et al.* (1972), the highest content of organic acids in yellow passion fruit are: citric acid (55.0 meq/100 g fruit juice), malic acid (10.5 meq), lactic acid (0.5 meq) and malonic acid (0.1 meq). In purple passion fruit, citric acid also presented the highest content, but only with 13.1 meq followed by lactic (7.4 meq), malonic (4.9 meq) and malic (3.8 meq) acids (Tab. 2).

Moreover, the different commercial passion fruit species differ in the content of sugars in the fruit juice. Ramaiya *et al.* (2013) analyzed the highest sucrose content in purple passion fruit (45.5 g kg^{-1} FW) and the lowest in sweet calabash (17.0 g), while the glucose content was the highest in giant granadilla (43.7 g) and the lowest in yellow passion fruit (14.1 g). Likewise, the lowest level of monosaccharide fructose was found in yellow passion fruit (14.6 g), and the highest one was reported in giant granadilla (39.0 g) (Tab. 2).

Some cultural practices and quality

Nutrition

Good crop management increases the potential of the variety. Plant nutrition is one of the key factors for the development of the typical fruit quality (Fischer and Álvarez, 2008), and due to its effect on the growth it highly influences the production and quality of the fruit (Aular *et al.*, 2014). Important practices can be lead to promote the development and quality of the fruit in purple passion fruit crop. For example, around 70 to 80 g of fertilizer 10-20-20 (NPK) should be applied seven times between 200 and 295 d after sowing (Jiménez *et al.*, 2012).

The absorption of nutrients increases at the beginning of the reproductive phase, for example in yellow passion fruit, the fertilizer demand increases at 250 to 280 d after transplanting, when the plants begin to grow exponentially. In this phenological stage, the absorption of nutrients such as nitrogen (N), potassium (K) and calcium (Ca) and the micronutrients rises, especially manganese (Mn) and iron (Fe) (Borges and Lima, 2007). In addition, the same authors reported that temperatures below 18°C decrease passion fruit growth which, consequently, reduces nutrient absorption and fruit production.

In order to understand the influence of N on yellow passion fruit, Borges *et al.* (2006) applied two sources, urea and calcium nitrate, in five doses (0 to 800 kg ha^{-1}) and found the maximum fruit yield (34.3 t ha^{-1}) with the application of 457 kg ha^{-1} of N in the form of urea, without influencing the characteristics of the fruit and the quality of the juice.

Freitas *et al.* (2006) studied the deficiencies of macronutrients and boron (B) in yellow passion fruit and found that the lack of Mg, N, phosphorus (P) and sulfur (S) in the nutrient solution caused the lowest number of fruits per plant (0, 2, 3 and 4, respectively), compared to the control (10 fruits). The authors also found that TSS were lower in fruits deficient in N, P and K, and the content of ascorbic acid decreased with the lack of N, K and S in the nutrient solution.

With different levels of K in the nutrient solution, Araújo *et al*. (2006) found that 6 mmol L^{-1} of K produced fruits of greater weight and yield/plant, while the thickness and relative water content of the pericarp as well as the concentration of vitamin C increased with the dose of K (from 0 to 8 mmol L^{-1}). Also, the increase in K concentration to 8 mmol L^{-1} shortened the time to fruit maturity by around 25 d (Araújo *et al*., 2005).

Passion fruits are notable for their high content of mineral nutrients. Martin and Nakasone (1970) reported higher contents of Ca and P (measured in 100 g of fresh weight) in purple passion fruit (14 g and 41 mg, respectively), while sweet granadilla excelled in Fe (0.8 mg), but yellow passion fruit and banana passion fruit presented low Ca contents (4 g).

Water and irrigation

In yellow passion fruit cultivated in the semi-arid region of Paraíba (Brazil) and irrigated with 133% of the crop evapotranspiration (Eto), gas exchange rates were higher in the 'BRS Sol do Cerrado' genotype, in addition to fruit production with a higher market classification, compared to 'BRS Gigante Amarelo' which was more prone to develop in conditions of low water availability due to its lower stomatal conductance (Melo *et al*., 2014). In the same semi-arid region, Suassuna *et al*. (2011) found in the yellow passion fruit hybrid IAC 273/277 that the irrigation level at 120% of ETo promoted a greater proportion of fruits with fresh weights higher than 150 g, an increase in juice yield and a higher percentage of skin compared to lower and higher levels of irrigation.

A symptom of severe deterioration is the cracking of the passion fruits due to possible effects such as higher water influx to organs, drastic change between night and daytime temperature and/or lack of B, Ca, K or Mg (Rivera *et al*., 2002; Fischer *et al*., 2009; Parra-Coronado and Miranda, 2016), which is observed especially in sweet granadilla and banana passion fruit.

Pruning

Regarding pruning, growing yellow passion fruits with a different number of reproductive branches (40, 30, 24, 20 and 14 branches/plant) evidenced that a smaller number of tertiary branches decreased production (number of fruits/plant) and productivity (kg ha^{-1} of fruits) and juice yield, but increased the average fruit weight without modifying the internal characteristics of organs (Hafle *et al*., 2009). According to Weber *et al.* (2017), fruit weight accumulation includes competition for compounds produced by photosynthesis, and a lower fruit number increases the available assimilates for fruit filling.

Grafting

In different combinations of yellow passion fruits in Viçosa-MG (Brazil) grafted on two wild species (*P. gibertti* and *P. mucronata*), Salazar *et al*. (2016) observed significant correlations in fruits for ascorbic acid, brightness values, chroma and angle Hue. However, the content of β-carotene in the fruit did not show significant differences, which indicates that the two rootstocks did not influence this compound; nevertheless, there was a decrease in the ascorbic acid content, compared to non-grafted plants. The results indicate the potential use of wild rootstocks due to their positive effects on grafted plants, while maintaining the commercial quality of the fruits.

Pollination

Akamine and Girolami (1959) reported that the fruit set, the number of seeds, the weight of the fruit and the fruit yield depend on the amount of pollen deposited on the stigma. Seed development is directly correlated to the juice content (Knight and Winters, 1962). The *Passifloraceae* species are commonly pollinated by bumblebees, especially by *Xylocopa* sp. (Miranda, 2012) and also by *Centris* sp., *Epicharis* sp., *Eulaema* sp., *Bombus* sp. and *Ptiloglossa* sp. (Schotsmans and Fischer, 2011). In the allogamous yellow passion fruit, artificial pollination is very common, achieving a fruit set of 80% (Cleves *et al*., 2012). Rodriguez-Amaya (2003) reports that manual pollination will produce larger and more succulent fruits**.**

Phytosanitary status

Bacteria affecting quality are: *Xanthomonas axonopodis* pv. *passiflorae* causing dark brownish green spot lesions (Castilho and Granada, 1995) and *Pseudomonas syringae* pv. *passiflorae* causing small green spots that develop into golden brown sticky necrotic lesions (Fischer and Rezende, 2008). The following fungi are causal agents affecting quality: *Fusarium oxyporum* f. sp. *passiflorae* causes a pale beige color in fruits (Fischer and Rezende, 2008), *Phytophtera* sp. causes gray spots (Varón de Agudelo, 1993), *Colletotrichum gloeosporioides* induces lesions on fruit skin that become corky and brown, *Alternaria passiflorae* causes browning, and *Septoria* sp. causes blotch. Of the viruses found in passion fruit, Cowpea-aphid borne mosaic virus (CaBMV) causes fruit deformation, East Asian Passiflora virus (EAPV) induces fading in fruit color, Passion fruit vein clearing virus (PVCV) reduces fruit size (Kitajima et al. 1986), Passion fruit green spot virus (PGSV) causes green spots on yellow passion fruit (Kitajima et al., 2003), and Passion fruit mottle virus (PaMV) induces fruit skin mottling (Fischer and Rezende, 2008).

Fruit ripening and quality

Ripening can be defined as the integration of external and internal changes, including the taste and texture that a fruit provides when it completes its growth (Agustí, 2004). The cultivated passion fruits are climacteric (Hernández and Fischer, 2009); it means that berries growth and development take place while attached to the plant or after the harvesting process, depending on the state of fruit development.

In two sweet granadilla plantations in the municipalities of Santa María and La Argentina in the province of Huila (Colombia), Espinosa *et al.* (2015) grouped the fruits into four stages of maturity, recording the change in color, the increase in TSS (Brix degrees) and maturity index (TSS/TTA), and the decrease in total titratable acidity (TTA) (Tab. 3). Since the color change of the epidermis during the maturation of the passion fruit is the most notable characteristic (Schotsmans and Fischer, 2011), the change of the passion fruit from green to yellow is due to the degradation of chlorophyll and the production of new pigments, mainly carotenoids, which generate the yellow to red coloration of the tissues (Valero and Serrano, 2010).

Similar results were obtained by Pinzón *et al.* (2007) for purple passion fruit, only differing in the purple skin color and the maturity index (MI). The purple passion fruit retains a higher content of TTA at the consumption ripeness, recording a MI of 4.14 (with a TTA of 3.92), regardless of the higher concentration of TSS (16.21), compared to 13.1 of the sweet granadilla (Tab. 2). After analyzing the stages immature (I), color change (breaker) (II) and mature (III) for purple passion fruits, Jiménez *et al.* (2011) found an increase of the TSS from 13.5 to 17.4, a decrease in the TTA from 4.68 to 2.51 and an increase in the concentration of anthocyanin, between stage II and III, from 0.45 to 1.73 g cy-3glu equiv./kg fruit.

The maturity index (TSS/TTA), which is the balance between sugars and acids giving the characteristic flavor to the fruit (Flórez *et al.*, 2012), is a parameter stated to identify the maturity of passion fruit. For example, in the case of purple passion fruit, the consumption quality improves mainly due to the decrease in acidity (Shiomi *et al.*, 1996a). In several sensory tests, it has been found that acidity masks the sensation of sweetness and as the acidity decreases due to the reduction of TTA during post-harvest, the sweetness is evident (Schotsmans and Fischer, 2011).

In relation to ascorbic acid, Patel *et al.* (2014) recorded the maturity of the purple and yellow passion fruits to contain the highest content (48.75 mg 100 mL^{-1}) of this antioxidant, produced in purple passion fruit (var. Megha Purple) at the end of maturation (90 d), while in yellow passion fruit (var. Kerala Yellow) the highest ascorbic acid concentration

TABLE 3. Development of sweet granadilla fruit quality grouped into four stages of maturity.

Maturity stage		Description	Color scale	TSS (°Brix)	TTA (%)	Maturity index (TSS/TTA)
1		Fruit with 100% growth, 100% green, 49-105 daa	L = 38.49 C = 15.08 h = 102.35	10.2	1.4	7.6
2		Fruit with 100% growth, 60% green - 40% yellow, 109-117 daa	L = 53.65 C = 40.41 h = 79.21	12.8	1.1	12.2
3		Fruit with 100% growth, 40% green - 60% yellow, 121-129 daa	L = 61.96 C = 57.86 h = 67.09	12.5	0.7	17.4
4		Fruit with 100% growth, 100% yellow, 133-141 daa	L = 61.77 C = 57.04 h = 64.53	13.1	0.7	18.5

daa - days after anthesis. Photos: D.D. Espinosa. Table and photos with permission from Espinosa *et al.* (2015) and Universidad Nacional de Colombia, Bogota.

(28.4 mg 100 mL^{-1}) is produced until 83 d and then decreases. The reduction of ascorbic acid in the final stage of fruit ripening was attributed by these authors to the oxidation of L-ascorbic acid to dehydro-ascorbic acid during the metabolic process.

Pongener *et al*. (2014) reported for purple passion fruit that the quality attributes of these fruits were better when they were harvested after the breaker state in which the fruits had developed 50% of their purple coloration (Tab. 4). The ethylene evolution rate increased almost 8.15 times the value with maximum levels of 505.35 μL kg^{-1} h^{-1} of C_2H_4 in fruits harvested in the color change (breaker) state. The changes in the color values L*, a* and b* indicated an optimal color development only in harvested fruits after 50% of its coloring. These authors concluded that the purple passion fruit should be harvested only after 50% of coloring on its fruit surface, for an optimal storage, appropriate ripening and development of flavor and quality.

In contrast, Shiomi *et al*. (1996b), in an experimental orchard of purple passion fruit in Kenya, observed that harvested fruits at 70 d after flowering (daf; "ripe" green stage), showed characteristics almost similar to the more developed fruits (80 and 90 daf). If the color can develop normally after the application of exogenous ethylene in post-harvest, it should be possible to harvest the purple passion fruit in a stage of "ripe" green or in the change from green to purple (breaker). This is much earlier than the usual maturity of the harvest and would give the product a good export quality, with a longer shelf life when marketed and transported abroad. Shiomi *et al.* (1996a) reported that the application of ethylene in post-harvest of the purple passion fruit should be at least 1 d after harvesting, given that the ethylene biosynthesis regulated mainly by the activity of the ACC synthase could change its sensitivity after the harvest when the fruit is ripening.

Flórez *et al*. (2012) harvested purple passion fruits in different ripening stages, from physiological (100% green) to mature (100% purple), registering in all of these a peak of ethylene production on day 18 of post-harvest. The fruits harvested in the states 70% (30% green, 70% purple) and 100% purple presented the highest ethylene production rate. In addition, these authors found that the climacteric peak (of respiration) preceded the ethylene production, which confirms the hypothesis that this hormone is not responsible for the respiratory increase in the purple passion fruits, which, in the 100% state, obtained the maximum CO_2 production.

Vianna-Silva *et al*. (2010) found a different behavior in yellow passion fruit, as fruits ripen differently depending on whether they are attached to the plant or have already been removed from it. Fruits delayed their coloration and decreased the thickness of the epidermis, compared with fruits of the same age already stored. The same authors stated that the optimum harvest time is 63 d after anthesis (daa), while when harvested at 54 daa fruits had 21% less juice yield.

Conclusions

In order to produce high quality passion fruit it is important to choose the suitable species and variety adapted to specific altitudinal and climatic conditions.

There are major differences between the species regarding quality, for example the purple passion fruit develops a very high content of ascorbic acid, while the sweet calabash contains the maximum amount of phenols and total antioxidant activity.

Regarding the crop management, an accurate plant nutrition strategy is decisive in the quality of yellow passion fruit, especially K supplement, which is the element with the highest effect on yield, content of ascorbic acid and the reduction of the fruit development time. Irrigation increases the percentage of the marketable qualities and the juice of the fruit, while the use of rootstocks does not

TABLE 4. Recommended harvest indices for different passion fruit crops.

Species	Maturity index[1]	Authors
Purple passion fruit	Skin with 50% purple color - 50% green	Pinzón *et al*., 2007; Pongener *et al*., 2014
Sweet granadilla	Skin with 40% green color - 60% yellow	Espinosa *et al*., 2015
Yellow passion fruit	Skin with 60% green color - 40% yellow	Hernández and Fischer, 2009
Banana passion fruit	Skin color $\leq$ 30% yellow	Campos and Quintero, 2012
Giant granadilla	Light yellowish or redness of the apical fruit part - opaque green fruit	Reina *et al*., 1996
Sweet calabash	Green or yellowish green fruit, before falling to the ground, with dry bracts	Ocampo *et al*., 2015

[1]The indices may vary according to the destination of the fruits.

significantly change the fruit quality. Guaranteeing a pollination of the flowers is decisive for the production of the fruit and its juice.

Fruit ripening is well determined by the change of color, an increment in sugar content (Brix degrees) and maturity index along to a decrease in the titratable acidity rate. Fruits harvested early in the physiological maturity and with a lower color expression in the peel can be treated with ethylene at post-harvest.

More research is needed on the improvement of the quality of the *Passifloraceae* in Colombia, as the purple passion fruit, yellow passion fruit and sweet granadilla are among the five most exported fruits in the country, and the giant granadilla and sweet calabash are the least studied so far.

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