

Evaluation of postharvest properties in different passion fruit species during ripening

Evaluación de propiedades poscosecha de diferentes especies de fruta de la pasión durante la maduración



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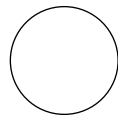
Fruits from a yellow passion fruit genotype (left), the commercial cultivar of yellow passion fruit 'FB 200' (right), and a sweet passion fruit genotype (down).

Photos: F.R. Gomes

ABSTRACT

During ripening, many transformations occur in passion fruits. The ripening stage affects fruit quality and post-harvest properties. Fruits with 65% yellow epidermis present chemical characteristics that meet industrial standards, facilitating harvest estimations and loss avoidance. Thus, this study aimed to evaluate the post-harvest properties of passion fruit species (genotypes of the yellow passion fruit and sweet passion fruit, and yellow passion fruit cultivar FB 200) during ripening. The fruits were evaluated by the color of the epidermis and the chemical characteristics of the pulp (titratable acidity, vitamin C, carotenoids, soluble solids content, and ratio). This experiment was conducted with a completely randomized design and a split-plot arrangement, where the plots were the species and the subplots were the evaluation periods (50, 58, 66, 74 and 82 days after anthesis), with four replications and 10 fruits per plot. The yellow passion fruit genotype and cultivar, harvested at 82 days after anthesis, presented desirable characteristics for the juice industry and for fresh consumption. The sweet passion fruit had a higher soluble solids content and titratable acidity ratio because of its high content of soluble solids and low acidity, which translate to a better fruit flavor.

Additional key words: ascorbic acid; carotenoids; *Passiflora alata*; *Passiflora edulis*.



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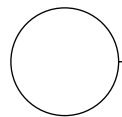
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RESUMEN

Durante la maduración del maracuyá, se producen muchas transformaciones. La etapa de maduración afecta a la calidad de la fruta y a las propiedades poscosecha. Se sabe que los frutos con un 65% de epidermis amarilla presentan características químicas dentro del estándar requerido por la industria, lo que permite anticipar la cosecha y evitar pérdidas. Así, este trabajo tuvo como objetivo evaluar las propiedades poscosecha de especies de fruta de la pasión (amarilla, dulce y el cv. FB 200) durante la maduración. Los frutos fueron evaluados por el color de la epidermis y las características químicas de la pulpa (acidez titulable, vitamina C, carotenoides, sólidos solubles y proporción). El experimento se realizó en un diseño completamente al azar con un arreglo de parcelas subdivididas, donde las parcelas constituyen las especies y las subparcelas constituyen los períodos de evaluación (50, 58, 66, 74 y 82 días después de la antesis), con cuatro repeticiones y 10 frutos por parcela. Los frutos del genotipo de maracuyá amarilla y el cultivar cosechados 82 días después de la antesis presentan características deseables ya sea para la industria del jugo o para consumo fresco. La fruta de la pasión dulce presenta una mayor proporción entre sólidos solubles y acidez titulable, debido a su alto contenido en sólidos solubles y bajo contenido de acidez, lo que implica un gran sabor a fruta.

Palabras clave adicionales: ácido ascórbico; carotenoides; *Passiflora alata*; *Passiflora edulis*.

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INTRODUCTION

The passion fruit belongs to the Passifloraceae Family and is grown in tropical and subtropical climate countries. The larger producers are located in South America, where Brazil, Colombia, Peru and Ecuador stand out (Coelho *et al.*, 2016). Brazil is the world's biggest producer of passion fruit with about 700,000 t of fruits per year, while Colombia produced about 228,000 t in a cultivated area of 10,000 ha in 2018. However, increasing productivity requires fruits that meet the standards required by markets for fresh consumption and industrial processing, i.e. big fruits with good peel appearance and color, a good ratio of soluble solids and titratable acidity and a good juice yield (Aires *et al.*, 2020; Hurtado-Salazar *et al.*, 2020; Martínez *et al.*, 2020; Medeiros *et al.*, 2020).

Commercial fruit production for the genus *Passiflora* is restricted to the species *Passiflora edulis* f. *edulis* Sims (yellow passion fruit) because of its high fruit quality and juice yield, which are connected to its economic potential and quick financial return (Braga *et al.*, 2017; Ribeiro *et al.*, 2019). However, the species *Passiflora alata* Curtis (sweet passion fruit) has great importance in the production of herbal medicines (Nascimento and Barbosa, 2014) and is highly regarded because of its taste and pleasant smell, which translate to higher market values (Alves *et al.*, 2012).

During ripening, carotenoids and other phenolic compounds are degraded by biochemical reactions that generate other volatile compounds, in addition, chemical transformations occur, such as sugar accumulation and reduction of acidity, with changes in peel color (Coelho *et al.*, 2010; Rotili *et al.*, 2018).

There are reports that, at the end of ripening, the sweet passion fruit pulp (*Passiflora alata* Curtis) presents about 18°Brix, with titratable acidity ranging from 1 to 2% citric acid (Alves *et al.*, 2012); the yellow passion fruit (*Passiflora edulis* Sims) presents about 16°Brix, with 4% citric acid (Vianna-Silva *et al.*, 2008); the orange cv. Valência fruit (*Citrus sinensis* (L.) Osbeck) when produced in the conventional system presents about 11°Brix, with titratable acidity ranging from 0.8 to 1.0% citric acid (Arruda *et al.*, 2011); and the mango 'Ubá' (*Mangifera indica*) presents pulp with about 18°Brix and 0.5% citric acid (Benevides *et al.*, 2008).

The ripening stage directly influences fruit quality and post-harvest shelf-life. Fruit harvest occurs after natural abscission and can lead to significant losses. Therefore, changes caused by ripening, especially color changes, aid harvest plans (Botelho *et al.*, 2019). Fruits with approximately 65% yellow colored epidermis have chemical characteristics in the pulp that

meet the required standards, aiding harvest plans and reducing risks of wrinkles, wilting, and deterioration (Silva *et al.*, 2005).

An ideal harvest point provides fruits with better quality and reduces losses. Therefore, this study aimed to evaluate the post-harvest properties in a yellow passion fruit genotype (*P. edulis* Sims), a sweet passion fruit genotype (*P. alata*), and the yellow passion fruit cultivar FB 200 (Flora Brasil 200 - *P. edulis* f. *flavicarpa*) at different ripening stages.

MATERIALS AND METHODS

This experiment was conducted in an orchard located at the Federal University of Jataí, in Goiás state - Brazil, where the annual average temperature is 23.3°C, and the annual rainfall index is 1,541 mm (Melo and Dias, 2019). The orchard had espaliers spaced at 3×4 m with two-wire threads, irrigated daily with a drip system (Gomes *et al.*, 2019).

A completely randomized design in a split-plot scheme was adopted, with the fruits (yellow passion fruit, sweet passion fruit, and yellow passion fruit cultivar FB 200) as the plots, and the days of evaluation as the subplots, with four replicates and 10 fruits per plot.

Fruits in the full physiological stage were harvested manually, based on the color change from green to yellow, when harvested fruits had an epidermis that was at least 20% yellow. The harvests were performed at five points: 50, 58, 66, 74 and 82 days after anthesis (DAA) because the literature indicates that fruits are physiologically mature at 50 DAA.

At each evaluation period, 40 fruits from each species were harvested: a yellow passion fruit genotype (*Passiflora edulis* Sims), a sweet passion fruit genotype (*Passiflora alata*), and yellow passion fruit commercial cultivar 'FB 200' (*Passiflora edulis* f. *flavicarpa*). After harvest, the fruits were sent to the laboratory in plastic boxes with one fruit layer, where they were washed in running water, dried at room temperature, and evaluated for epidermis color, titratable acidity, vitamin C content, carotenoids, soluble solids and ratio between the soluble solids and titratable acidity content.

The epidermis color was evaluated with the CIElab model using a colorimeter that measures the reflected light with a cartesian coordinate system (Konica Minolta, model CR-10), in which units or points of

approximate visual uniformity were obtained (Kong *et al.*, 2019). Two readings on opposite sides of the epidermis on each fruit were taken to obtain the Hue angle (h°), which represents the color of the samples.

The soluble solids content (SSC) was determined as recommended by AOAC (2016) method number 932.12, in which some drops of the juice samples were placed in a portable refractometer (Atago model Pal-1), and, after the reading, the results were expressed in °Brix.

The titratable acidity (TA) was evaluated following the procedure proposed by AOAC method number 942.15 (AOAC, 2016), with titration of 5 mL of pulp in a 0.1 N NaOH solution and phenolphthalein, in which the solution was stirred until the samples presented a persistent pink color. The results were given in % of citric acid/100 mL of pulp.

The ratio, which represents the flavor of the fruits, was obtained through the relationship between the soluble solids content and titratable acidity (SSC/TA).

The vitamin C content was determined by titration with Tillmanns reagent, using 2,6-dichloroindophenol sodium salt, following the procedure indicated by AOAC (2016) method number 967.21. The results were given in mg of ascorbic acid/100 mL of pulp.

For the carotenoid content, 1.5 mL of pure acetone were added to 150 mg of pulp, stirred for 24 h at a low temperature and in absence of light, followed by analysis with a spectrophotometer, in which the absorbances were determined at 470, 646.8 and 663.2 nm, and the carotenoid levels were determined with the equations described by Lichtenthaler (1987), expressed as µg per mL of extract.

The data were submitted to analysis of variance. Regression models physiologically explained the behavior of the fruits; these models were based on the coefficient of determination and the potential to explain the biological phenomenon. The averages of the analyzed characteristics were compared with the Tukey test ($P < 0.05$). The data were analyzed with SAS (SAS, 2004).

RESULTS AND DISCUSSION

The titratable acidity of the fruits presented a linear behavior, increasing over time and reaching the highest point at 82 DAA, especially for the FB 200 cultivar

and the yellow passion fruit genotype. The cultivar had the greatest citric acid accumulation at the end of the experiment. The sweet passion fruit presented a lower acidity content during ripening, probably because its main characteristic is sweeter pulp (Pereira *et al.*, 2018). The estimated citric acid percentage for each 100 mL of pulp for the FB 200 cultivar was 2.91% at 50 d and 6.04% at 82 d; for the yellow passion fruit genotype, it was 2.58% at 50 d and 4.33% at 82 d; and for the sweet passion fruit, it was estimated at 0.89% at 50 d and 1.22% citric acid at 81.99 d (Fig. 1).

A higher citric acid content in fruit juice is important because it allows greater flexibility in the addition of sugars for beverage preparations and reduces the deterioration processes caused by microorganisms (Flores *et al.*, 2011). Although a higher acidity content leads to a longer shelf-life, fruits with this characteristic do not have the sweet taste that is highly desirable for fresh consumption (Rotili *et al.*, 2018). However, for industrial uses, a high acidity content, usually between 2.9 and 5.0%, is desirable (Silva *et al.*, 2016a).

The vitamin C content presented a quadratic behavior during the evaluation days, which was higher at the beginning of the physiological development and lower at the highest maturity point for the different evaluated species (FB 200 cultivar, yellow passion fruit and sweet passion fruit). The yellow passion fruits had the highest vitamin C content at the end of the evaluated periods, while the sweet passion

fruits presented the lowest content at 82 DAA. The ascorbic acid estimated for each 100 mL of pulp for the yellow passion fruit genotype was 79.86 mg at 50 d and 62.43 mg at 81.74 d; for the FB 200 cultivar, it was estimated at 77.94 mg at 50 d and 48.58 mg at 82.09 d. In the sweet passion fruit, it was estimated that the fruits had a vitamin C content of 66.15 mg at 50 d and 31.54 mg at 81.84 d (Fig. 2).

The decrease in the vitamin C content during ripening occurs because of the degradation caused by the ascorbate oxidase enzyme, which intensifies in activity when fruits mature (Costa *et al.*, 2020). According to Coelho *et al.* (2010), the ascorbic acid content in fruit pulp is preserved throughout storage when fruits are harvested at an advanced ripening stage.

The carotenoid content in the yellow passion fruit and the FB 200 cultivar during ripening presented a quadratic behavior, and the content in the sweet passion fruits was adjusted to the linear model. There was an increase in carotenoids during the evaluated days, in which the commercial cultivar presented the highest content, and the sweet passion fruit presented the lowest carotenoid content, indicating that the cultivar has a predominance of pigments in its pulp, which is probably why its juice is yellower (Gomes *et al.*, 2019). The carotenoid accumulation estimate during ripening for the FB 200 cultivar was $1.82 \mu\text{g mL}^{-1}$ at 50 d and $2.88 \mu\text{g mL}^{-1}$ at 82.01 d; for the yellow passion fruit, it was estimated at $1.08 \mu\text{g mL}^{-1}$ of

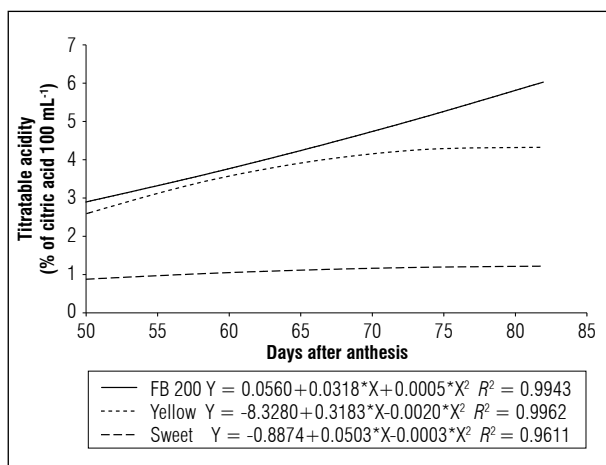


Figure 1. Titratable acidity of the pulp from different species: FB 200 cultivar (*Passiflora edulis* f. *flavicarpa*), yellow passion fruit (*Passiflora edulis* Sims) and sweet passion fruit (*Passiflora alata*) during the ripening.

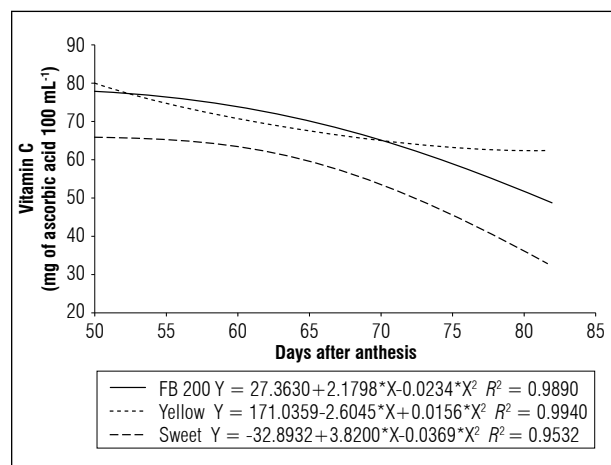


Figure 2. Vitamin C content in the pulp of different species: FB 200 cultivar (*Passiflora edulis* f. *flavicarpa*), yellow passion fruit (*Passiflora edulis* Sims) and sweet passion fruit (*Passiflora alata*) during ripening.

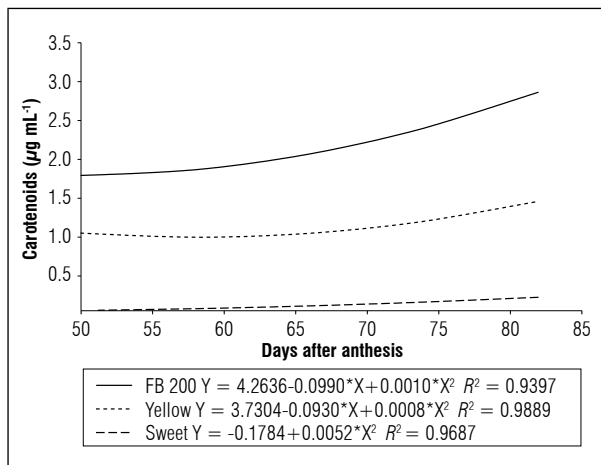


Figure 3. Total carotenoid content in the juice of different species: FB 200 cultivar (*Passiflora edulis* f. *flavicarpa*), yellow passion fruit (*Passiflora edulis* Sims) and sweet passion fruit (*Passiflora alata*) during ripening.

carotenoids at 50 d and $1.48 \mu\text{g mL}^{-1}$ at 81.74 d. The carotenoid content estimated for the sweet passion fruit during ripening was $0.10 \mu\text{g mL}^{-1}$ at 51.22 and $0.27 \mu\text{g mL}^{-1}$ at 82.11 d (Fig. 3).

Carotenoids are important precursors of vitamin A and have considerable antioxidant activity that is associated with a reduced risk of degenerative diseases. They are responsible for intensifying the yellow coloration of the pulp. Levels vary according to the fruit ripening stage and are synthesized during maturation by metabolic pathways to act as antioxidants (Rotili *et al.*, 2013).

The soluble solids content was adjusted to the quadratic model, increasing with ripening and reaching the highest level at 82 DAA. During the experiment, the sweet passion fruit presented the highest soluble solids content, which is one of its main characteristics, and the FB 200 cultivar presented a reduced soluble solids content, probably caused by the high titratable acidity content (Tab. 1) since a decrease in the soluble solids content leads to an increase in titratable acidity (Munaretto *et al.*, 2020). The soluble solids content estimated during the ripening of the sweet passion fruits was 13.93°Brix at 55.47 d and 22.49°Brix at 81.84 d; for the yellow passion fruits, it was 14.52°Brix at 50.04 d and 17.53°Brix at 81.79 d. For the FB 200 cultivar, the soluble solids content was estimated at 12.92°Brix at 50.04 d and 16.05°Brix at 82.04 d (Fig. 4).

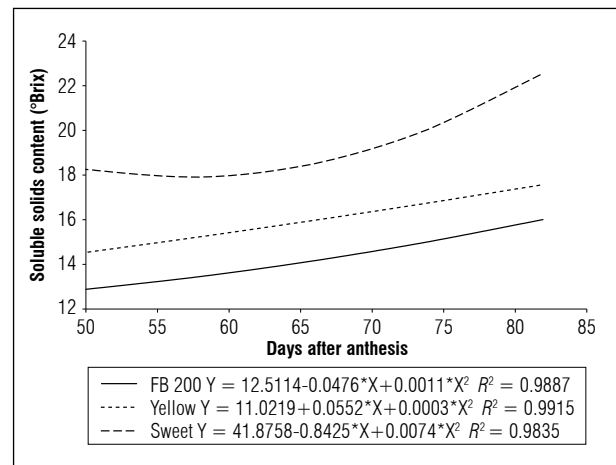


Figure 4. Soluble solids content in the fruit juice of different species: FB 200 cultivar (*Passiflora edulis* f. *flavicarpa*), yellow passion fruit (*Passiflora edulis* Sims) and sweet passion fruit (*Passiflora alata*) during ripening.

Soluble solids are water-soluble compounds that indicate the amount of sugars in fruit pulp, with other compounds at reduced proportions, such as acids, vitamins, amino acids, and some pectins. The highest point of soluble solid accumulation is reached at the end of maturation (Chitarra and Chitarra, 2005). Several factors affect the soluble solids content, especially weather conditions, harvest point, and harvest season (Moura *et al.*, 2016). The industry prefers fruits with a soluble solids content of about 14°Brix because it allows better technological productivity, which means a lower amount of sugar will be necessary for passion fruit juice production (Silva *et al.*, 2018).

The evaluation of soluble solids content is one of the most efficient ways to assay fruit quality because it has compounds that give the fruit flavor, which makes them more desirable in the consumer market and in the processing industry. In addition, fruits with higher soluble solids contents mean that a smaller number of fruits is used in juice production (Dias *et al.*, 2017).

The soluble solids content/titratable acidity (SSC/TA) ratio presented a quadratic behavior, increasing during ripening and reaching the highest content at 82 DAA. The yellow passion fruit and FB 200 cultivar presented lower values for the ratio, and the sweet passion fruit presented the highest ratio. The estimated ratio for the sweet passion fruit was 15.86 at

57.59 d and 27.13 at 81.87 d; for the yellow passion fruit, the ratio estimate was 3.52 at 53.08 d and 6.71 at 81.74 d. The estimated ratio for the FB 200 cultivar was 2.60 at 50.02 and 4.91 at 82.01 d (Fig. 5).

The ratio had a balance between sugars and acidity content; therefore, sweeter fruits lead to higher SSC/

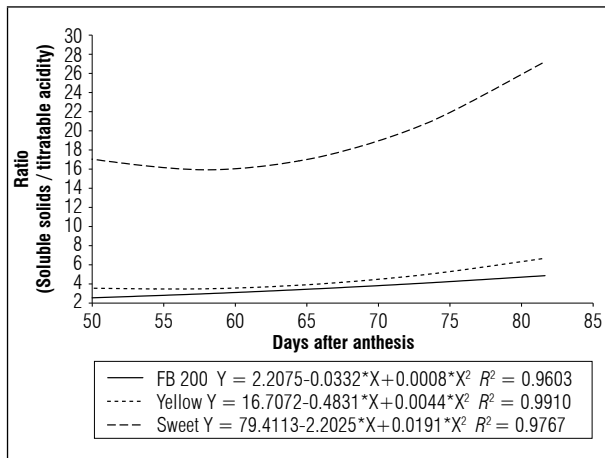


Figure 5. Soluble solids/titratable acidity ratio in the juice of different species: FB 200 cultivar (*Passiflora edulis f. flavicarpa*), yellow passion fruit (*Passiflora edulis* Sims) and sweet passion fruit (*Passiflora alata*) during ripening.

TA values (Silva *et al.*, 2016b). The ratio is a very important characteristic because a balance between the soluble solids content and acidity determines the fruit flavor (Rotili *et al.*, 2018).

At the end of the experiment (82 DAA), the epidermis of the yellow passion fruit and sweet passion fruit presented similar hue angle values (h°) without a significant difference. The FB 200 cultivar, however, differed statistically from the others, presenting

a hue angle of 95.10° (Tab. 1). These results indicate that the FB 200 cultivar presented fruits with a more intense epidermis color although all evaluated fruits were closer to the yellow color according to the $L^*C^*h^\circ$ (Ferreira and Spricigo, 2017).

Color is one of the main aspects used by consumers to evaluate fruit quality (Rotili *et al.*, 2018). Salazar *et al.* (2015) obtained a hue angle closer to 90° for yellow passion fruits, which, according to the authors, indicates a more intense yellow color, caused by the process of chlorophyll degradation in the pericarp and by the synthesis and/or manifestation of carotenoids. Similar hue angle values were obtained by Vianna-Silva *et al.* (2010) for yellow passion fruits at 63 DAA.

The titratable acidity had a significant difference between the evaluated species. The FB 200 cultivar fruits had the highest acidity content, and the sweet passion fruits presented the lowest values (Tab. 1), probably because of its main characteristics, which include a sweet taste and low acidity (Alves *et al.*, 2012). A minimum of 2.5% citric acid is demanded by the industry by default for passion fruit pulp used in juice processing (Viana *et al.*, 2016).

The acidity content obtained in the present study for the FB 200 cultivar and yellow passion fruit corroborates the values obtained by Gomes *et al.* (2019), who obtained 4.56 and 5.34% citric acid, respectively, for these fruits under the conditions of the Brazilian Savanna. Ferreira and Antunes (2019) observed yellow passion fruits in São Paulo state - Brazil with about 4% citric acid. Botelho *et al.* (2017) evaluated fruits from the FB 200 cultivar in Mato Grosso state - Brazil and obtained pulp with about 3% acidity. The acidity content in fruit pulp varies according to the ripening stage, where the ripest fruits present a lower acidity (Braga *et al.*, 2020).

Table 1. Fruit characterization of passion fruit from different species: FB 200 cultivar (*Passiflora edulis f. flavicarpa*), yellow passion fruit (*Passiflora edulis* Sims) and sweet passion fruit (*Passiflora alata*) at 82 DAA.

Passion fruit	Hue angle (h°)	Titratable acidity (% of citric acid/100 mL)	Vitamin C (mg of ascorbic acid/100 mL)	Carotenoids ($\mu\text{g mL}^{-1}$)	Soluble solids content ($^\circ\text{Brix}$)	SSC/TA ratio
FB 200	95.10 a	4.19 a	66.21 a	2.12 a	14.13 c	3.58 b
Yellow	80.54 b	3.59 b	69.15 a	1.19 b	15.83 b	4.63 b
Sweet	80.75 b	1.01 c	53.55 b	0.17 c	19.41 a	19.72 a
CV (%)	18.63	12.52	13.25	23.25	16.67	15.65

Means followed by the same letter are not different ($P < 0.05$) according to Tukey's test.

The soluble solids content differed among the species. The sweet passion fruit produced fruits with the highest soluble solids content, confirming the sweet flavor attributed to this species. The FB 200 cultivar presented the lowest solids content (Tab. 1). Gama *et al.* (2013) produced fruits from the FB 200 cultivar with a soluble solids content of 13.1 °Brix. Braga *et al.* (2017) evaluated the chemical characteristics of yellow passion fruit and reported fruits with a soluble solids content of 13° Brix. The values observed in the present study agree with the standard established by the Brazilian Ministry of Agriculture and Supplies for the quality standards of passion fruit, i.e. at least 11 °Brix (Mapa, 2018).

The ratio between the titratable acidity and soluble solids content was higher in the sweet passion fruit, which differed from the values observed for the yellow passion fruit and FB 200 cultivar (Tab. 1). Fruit flavor is represented by the titratable acidity and soluble solids ratio, in which a lower acidity content implies a higher ratio (Braga *et al.*, 2017). The SSC/TA ratio tends to increase during ripening because of a reduction in acidity levels. The bigger the ratio is, the better the fruit quality will be, leading to more acceptance by consumers (Silva *et al.*, 2019).

The SSC/TA ratio for yellow passion fruit, by default, ranges from 3.0 to 4.5 (Chitarra and Chitarra, 2005). Dias *et al.* (2017), who worked with different cultivars of the yellow passion fruit, obtained a ratio lower than 2, probably because the acidity content was higher than 8% in all evaluated cultivars. Borges *et al.* (2020) obtained an SSC/TA ratio for sweet passion fruit ranging from 8 to 17. Moura *et al.* (2020) evaluated fruits from the FB 200 cultivar and obtained an SSC/TA ratio of 3.0, similar to the results founded in the present study.

The vitamin C content in the FB 200 cultivar did not differ from the yellow passion fruit; however, both differed from the sweet passion fruit, which presented a lower vitamin C content (Tab. 1). The recommended daily intake according to the Brazilian Ministry of Health is 45 mg of vitamin C for adults (Anvisa, 2003); values equal to or greater than this recommendation confer benefits to human health, reducing the risk of developing chronic diseases.

Despite being very important to nutrition, there is no requirement for the vitamin C content of fruits in the processing industry (Moura *et al.*, 2016). The ripening stage and production location, along with other factors, influence the values of this content (Estevam *et al.*, 2018).

Salazar *et al.* (2015), who evaluated yellow passion fruits grafted on wild species of the *Passiflora* genus in a greenhouse, obtained a vitamin C content of 36.06 mg 100 g⁻¹ in yellow passion fruits. Alves *et al.* (2012) obtained approximately 20 mg 100 mL⁻¹ for sweet passion fruits produced in Viçosa-MG, Brazil. Conde *et al.* (2017) obtained about 25 mg of ascorbic acid in purple passion fruits produced in Colombia.

For the carotenoid content, the species differed from each other, with the FB 200 cultivar presenting the highest levels (Tab. 1). According to Zeraik *et al.* (2010), high levels of carotenoids are responsible for promoting a more intense juice color, and the synthesis of carotenoids is influenced by the season in which fruits are produced.

CONCLUSION

The post-harvest properties of fruits of different passion fruit species vary during ripening, which sees an adjustment of the characteristics responsible for good acceptance in the consumer market. At 82 DAA, the fruits of the yellow passion fruit and cultivar FB 200 presented desirable characteristics for industrial use and fresh consumption. During ripening, the sweet passion fruit presented a higher SSC/TA ratio because of its high content of soluble solids and low acidity content, resulting in a better fruit flavor.

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