

**Efeito do estágio de maturação na composição físico-química e compostos bioativos de
frutas de *Solanum granuloso-leprosum* Dunal**

**Effect of maturation stage on the physical-chemical composition and bioactive
compounds of *Solanum granosos-leprosum* Dunal fruits**

**Efecto de la etapa de maduración sobre la composición físico-química y los compuestos
bioactivos de frutas de *Solanum granosos-leprosum* Dunal**

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Resumo

O objetivo deste estudo foi caracterizar os frutos de capoeira-branca (*Solanum granuloso-leprosum* Dunal) cultivados em Lavras, Minas Gerais, Brasil. O crescimento do fruto foi avaliado, da inflorescência ao amadurecimento. Para isso, as medições foram realizadas semanalmente. Os frutos foram colhidos e separados em três estádios de maturação do desenvolvimento (1-imaturo; 2-verde esverdeado; 3-maduro), de acordo com a cor e tamanho. Os frutos foram avaliados quanto ao tamanho, peso, cor, respiração, firmeza, pH, acidez titulável, sólidos solúveis, pectina solúvel, composição centesimal, vitamina C e atividade antioxidante em três estádios. Durante a maturação, os frutos apresentaram aumento de massa (0,4076 a 0,9956 g), tamanho (7,9 a 12,2 mm), fração glicídica (15,95 a 27,23%) e cinza (0,94 a 1,60%) e redução de firmeza (4,23 a 1,50 kgf), teor de umidade (79,24 a 69,45%) e proteína (3,49 a 1,41%). Além disso, houve aumento no teor de sólidos solúveis (8,80 a 13,80%), atividade antioxidante (62,57 a 69,63 μM de trolox. g^{-1} e 1880,34 a 4602,40 $\text{mg}\cdot 100\text{g}^{-1}$) e vitamina C (46,81 a 236,02 $\text{mg}\cdot 100\text{g}^{-1}$) e uma diminuição nos fenólicos totais (257,58 a 171,00 $\text{mg}\cdot 100\text{g}^{-1}$) e pectina solúvel (0,92 a 0,69 $\text{mg}\cdot \text{g}^{-1}$). Os frutos, mesmo após o amadurecimento, mantiveram a cor esverdeada, embora menos intensa que a observada nos frutos verdes imaturos e maduros.

Palavras-chave: Frutas não convencionais; Desenvolvimento de frutas; Composição química; Atividade antioxidante.

Abstract

The aim of this study was to characterize the capoeira-branca (*Solanum granuloso-leprosum* Dunal) fruits cultivated in Lavras, Minas Gerais, Brazil. The fruit growth was evaluated, from inflorescence to ripening. For this, measurements were made weekly. The fruits were harvested and separated at three developmental maturation stages (1-immature; 2-green mature; 3-mature), according to the color and size. Then, the fruits were evaluated by size, weight, color, respiration, firmness, pH, titratable acidity, soluble solids, soluble pectin, centesimal composition, vitamin C and antioxidant activity at three stages. During maturation, the fruits showed increase in mass (0.4076 to 0.9956 g), size (7.9 to 12.2 mm), glycidic fraction (15.95 to 27.23%) and ash (0.94 to 1.60%) and reduction in firmness (4.23 to 1.50 kgf), moisture (79.24 to 69.45%) and protein (3.49 to 1.41%) contents. Furthermore, there was increase in soluble solids content (8.80 to 13.80%), antioxidant activity (62.57 to 69.63 μM de trolox. g^{-1} and 1880.34 to 4602.40 $\text{mg}\cdot 100\text{g}^{-1}$) and vitamin C (46.81 to 236.02 $\text{mg}\cdot 100\text{g}^{-1}$) and a decrease in the total phenolics (257.58 to 171.00 $\text{mg}\cdot 100\text{g}^{-1}$) and soluble pectin (0.92 to 0.69 $\text{mg}\cdot \text{g}^{-1}$).

The fruits, even after ripening, maintained their greenish color, although less intense than that observed in immature and mature green fruits.

Keywords: Unconventional fruits; Fruit development; Chemical composition; Antioxidant activity.

Resumen

El objetivo de este estudio fue caracterizar los frutos de capoeira-branca (*Solanum granuloso-leprosum* Dunal) cultivados en Lavras, Minas Gerais, Brasil. Se evaluó el crecimiento del fruto, desde la inflorescencia hasta la madurez. Para esto, las mediciones se realizaron semanalmente. Las frutas se cosecharon y se separaron en tres grados de madurez del desarrollo (1-inmadura; 2-verde madura; 3-madura), de acuerdo con el color y el tamaño de la fruta. Luego, los frutos fueron evaluados por tamaño, peso, color, respiración, firmeza, pH, acidez titulable, sólidos solubles, pectina soluble, composición centesimal, vitamina C y actividad antioxidante en tres estados de madurez. Durante la maduración, los frutos mostraron aumento en la masa (0.4076 a 0.9956 g), tamaño (7.9 a 12.2 mm), fracción glicídica (15.95 a 27.23%) y cenizas (0.94 a 1.60%); sin embargo, reducción en la firmeza (4.23 a 1.50 kgf), humedad (79.24 a 69.45%) y contenido de proteínas (3.49 a 1.41%). Además, hubo un aumento en el contenido de sólidos solubles (8.80 a 13.80%), actividad antioxidante (62.57 a 69.63 μM de trolox. g^{-1} y 1880.34 a 4602.40 $\text{mg}\cdot 100\text{g}^{-1}$) y vitamina C (46.81 a 236.02 $\text{mg}\cdot 100\text{g}^{-1}$) y una disminución en los fenólicos totales (257.58 a 171.00 $\text{mg}\cdot 100\text{g}^{-1}$) y pectina soluble (0.92 a 0.69 $\text{mg}\cdot \text{g}^{-1}$). Las frutas, incluso después de la madurez, mantuvieron su color verdoso, aunque menos intenso que el observado en frutas inmaduras, y verde maduro.

Palabras clave: Frutos no convencionales; Desarrollo de frutos; Composición química; Actividad antioxidante.

1. Introduction

The capoeira-branca (*Solanum granuloso-leprosum* Dunal) belongs to the Solanaceae family and is also known as “gravitinga”, “tomate selvagem” and “fumo bravo”. It is characterized as a small tree, with a height between 4 and 6 meters and occurs in the northwest region of Argentina, Uruguay, Paraguay and southern Brazil, mostly in secondary forests and degraded areas (Vallés et al., 2008, 2011).

The fruits characterization presents great importance in the elaboration and quality determination of industrialized products. Quality is influenced by several factors, such as

genetic and edaphoclimatic conditions, maturity stage and postharvest treatments (Ben Brahim & Bouaziz, 2019). Thus, the accompaniment of physical and chemical changes that occur during the fruit physiological development can be useful in culture management, assisting in determining the appropriate harvesting time, leading to increased productivity, loss reduction and quality maintenance (Lago et al., 2020; Magalhães et al., 2019).

Currently, several studies have evaluated the influence of different maturation stages on unconventional fruit characteristics, that is, those of little economic relevance and which are usually not part of human food, such as blueberry (Pérez & Mojica, 2018), besides several Brazilian native fruits (Gonçalves et al., 2017; Guedes et al., 2017; Henrique et al., 2017). According to Silva et al. (2011), consumer demand for exotic fruits and flavors and constant disclosures about the nutritional benefits of these products have contributed to increase the demand for scientific research on the subject.

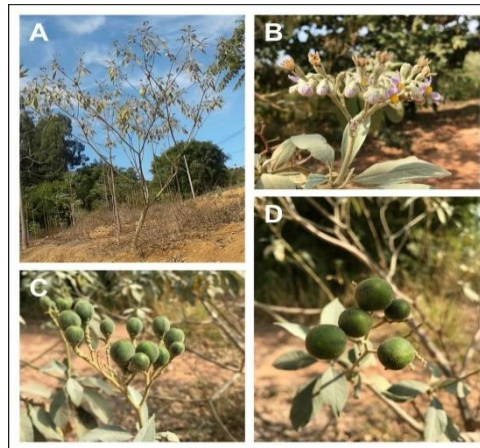
Studies with capoeira-branca fruits are rare. Petenatti et al. (1998) performed morpho-anatomical and micrographic studies of capoeira-branca. Vallés et al. (2008) extracted cysteine peptidase (Granulosa I) of ripe fruits. Jacomassa & Pizo (2010) identified the dispersal and germination performance of capoeira branca seeds by bats and birds. Considering the lack of studies on capoeira-branca fruits, the objective of this study was to evaluate the fruit growth curve and to characterize them as to the physical and chemical changes that occurred during their development and thus demonstrate the potential of this species as an unconventional source of nutrients and bioactive compounds.

2. Materials and Methods

2.1. Collection of fruits

The capoeira-branca tree, the flowers and fruits at different stages in the same cluster and ripe fruits are presented in Figure 1.

Figure 1 – Photos of the tree (A), flower (B) and fruits (C and D) of capoeira-branca (*Solanum granuloso-leprosum* Dunal) located on the campus of the Federal University of Lavras.

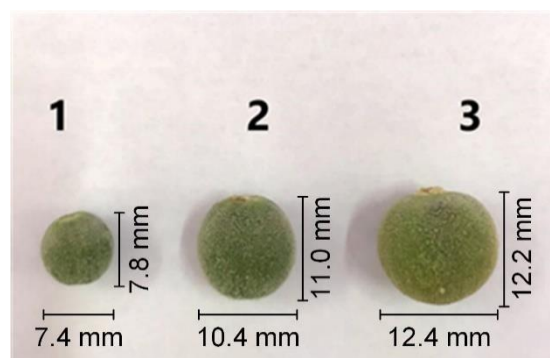


Source: Authors.

In this experiment, plants that had open and visually homogeneous flowers were marked on the same day at the Federal University of Lavras campus. From the marked flowers, fruits were collected at 10, 20, 30, 40, 50 and 60 days after anthesis.

Fruits of capoeira-branca (*Solanum granuloso-leprosum* Dunal) were harvested at three developmental stages (1-immature; 2: green-mature; 3: ripe); and packed in plastic bags in a freezer at -18°C until the proposed analyzes. Fruit classification was performed based on morphological parameters of size and color (Figure 2).

Figure 2 - Fruits and their measures at three different ripening stages used: 1 (immature), 2 (mature green), 3 (mature).



Source: Authors.

2.2. Analysis

The evolution of the polar diameter of the fruits was followed from the inflorescence

until the ripening, taking weekly measurements. Polar and equatorial diameters were also determined in immature, mature green and ripe fruits. The measurements were taken with the aid of a digital caliper and expressed in millimeters. Data dispersion as a function of days was elaborated and a four-parameter sigmoidal mathematical model (Equation 1) was chosen to represent the fruit diameter behavior over the days. The adjustment of the model parameters was done through minimizing the sum of squares of the deviations by nonlinear, regression with the aid of the SigmaPlot software.

$$L = y_0 + \frac{a}{1 + \exp\left(\frac{-(t-x_0)}{b}\right)} \quad (1)$$

Where L and t are, respectively, the length of the fruit in mm and the time in days; y_0 , a, x_0 and b are model parameters.

Mass, respiratory rate, color, firmness, pH, titratable acidity (TA) and soluble solids (SS) analyzes were performed on the day of fruit harvest.

Mass was determined using semi-analytical balance and the results expressed in grams.

The color parameters (L^* , $^{\circ}h$ and C^*) was determined at three different points of the fruit with the aid of a Konica Minolta CR-400 Colorimeter (D65 illuminant) (Lago et al., 2020).

Respiratory activity was evaluated by measuring carbon dioxide (CO_2) released by fruits. For this, the fruits at the three maturation stages were individually packed in a 100 mL glass container and kept tightly sealed for 1 hour. After this period, the reading of CO_2 gas in PBI Dansensor Model Checkpoint device was conducted. The results, obtained in % of CO_2 , were converted and expressed as $mL.CO_2.kg^{-1}.h^{-1}$, taking into account the container volume, the mass and the volume of the fruits and the elapsed time after closing of the container (Lago et al., 2020).

The firmness was determined in a texturometer (Stable Micro System model TATX2i), using a cylindrical probe (6 mm in diameter), with pre-test velocity 1.5 mm.s^{-1} ; test speed 1.0 mm.s^{-1} ; and post test speed 10 mm.s^{-1} . The penetration distance was 5 mm. An HDP/90 platform was used as a base and the firmness was expressed in Newton (N).

The pH, TA and SS were determined according to AOAC (2016). For these analyzes, the sample was ground and homogenized in a 1:5 ratio (10 g of fruit in 50 mL of deionized water) in a polytron and the filtrate was used. The pH was determined by direct reading in a digital pH meter. The TA was obtained by titrating 10 mL of the filtrate with 0.1N sodium hydroxide solution and use of a pH meter, up to pH 8.2. The results were expressed as %. SS content was determined in digital refractometer and results were expressed as %.

The analysis of centesimal composition, soluble pectin, vitamin C, total phenolics and total antioxidant activity (AAT) were performed on previously frozen material and stored at -18 °C.

The proximate composition was determined according to AOAC (2016). Moisture and ash content were determined by gravimetric method, in an oven at 105 °C and by incineration at 550 °C in a muffle, respectively. The crude protein content was estimated according to the “micro-Kjeldahl” method where protein concentration was estimated using a conversion factor of 6.25. The ether extract was measured by extraction in a Soxhlet apparatus using ethyl ether as the extracting agent and the crude fiber content was determined by vacuum filtration after acid hydrolysis. The glycidic fraction (FG) was calculated using the ratio: $FG = 100 - (\text{moisture} + \text{ether extract} + \text{crude protein} + \text{ash} + \text{crude fiber})$.

Soluble pectin extraction was performed according to the technique described by McCready & McComb (1952) and colorimetric determination by reaction with carbazole according to the Bitter & Muir (1962). Results were expressed as mg of galacturonic acid per g of sample.

Vitamin C content was determined by colorimetric method with 2,4-dinitrophenylhydrazine (2,4-DNPH) according to Strohecker & Henning (1967). The extraction was performed with 0.5% oxalic acid, under stirring and, after filtration, dosing was performed in the extract employing 2,4-dinitrophenylhydrazine. Ascorbic acid was used as standard. Quantitation was performed at 520 nm and results were expressed in mg ascorbic acid per 100 g sample.

Total phenolics were determined by the Fast Blue method, according to Medina (2011). The method uses the Fast Blue diazonium salt and is based on the reaction of the diazonium group (+ N = N-) with reactive hydroxyl groups of phenolic compounds (-OH), forming stable azo complexes, which can be measured spectrophotometrically at 420 nm. Results were expressed as mg of gallic acid per 100 g of sample.

The antioxidant activity (AA) was determined by the ABTS* method, according to the methodology described by Rufino et al. (2007), and the results were expressed in μM of trolox.g⁻¹ sample. A cationic solution of ABTS (2,2'-azinobis-3-ethyl-benzothiazoline-6-sulfonated) was prepared and reacted for 16 hours at room temperature and in the absence of light. After forming the ABTS radical, ethanol was added to the solution to an absorbance value of 0.700 (\pm 0.05) at 735 nm. The absorbance determination of the samples was performed at room temperature, after 6 minutes of reaction.

AA was also determined by the phosphomolybdenum complex method, according to

the methodology described by Prieto et al. (1999), which is based on the reduction of Mo^{6+} to Mo^{5+} , distinguished by its green coloration at acid pH, with maximum absorption at 695 nm. Results were expressed in mg ascorbic acid per 100 g sample.

2.3. Experimental design and statistical analysis

A completely randomized design was used, at developmental stages 1 (immature); 2 (mature green); 3 (mature), with five repetitions and the experimental plot consisted of 100 g of fruit.

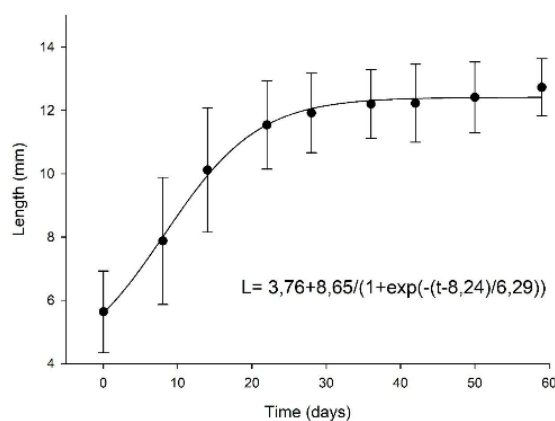
Data were statistically evaluated through analysis of variance (ANOVA) and Tukey mean tests, both at 5% significance level with the aid of Statistica v.10 software.

3. Results and Discussion

3.1. Maturity stages

The development of capoeira-branca fruits was marked by a high growth rate in the first 22 days, counted from the anthesis, followed by reduction, until the full ripening, which occurred at 59 days of development, when the fruits showed 12.5 mm of polar diameter (Figure 3).

Figure 3 - Evolution curve of the polar diameter of capoeira-branca fruits during 60 days of development.



Source: Authors.

The simple sigmoidal growth model (Equation 1) fit well with the data, with a determination coefficient of 0.9958 and a regression standard error of 0.9933, being significant

by regression variance analysis, at a 5% significance level. In addition, the model parameters (a, b, x_0 and y_0) were also significant by the t-test at 5% significance level.

A reduction in the standard deviation values was observed along the fruit growth curve. This is due to the variation in the development rate among fruits, especially between days 0-22, causing a larger discrepancy between the data at the same point of the curve. The estimated growth rate according to the adjusted sigmoidal model was 2.17, 1.82 and 0.21 mm.week⁻¹, between days 0-10; 10-20 and 20-59, respectively. Therefore, the growth occurred from fruit formation until approximately the 22nd day of development, followed by a stabilization trend.

The productivity of a crop, in biological terms, is affected by different factors such as genotype, environmental conditions and management conditions. As a result of these effects, changes occur in biomass accumulation between different parts of the tree (Körner, 2015). From the growth curve of capoeira-branca fruits, it is possible to verify the period of highest demand for nutrients, water, energy, which occurs between days 0-20, because the higher the growth rate, the higher the demand. These data can be used in irrigation and fertilization management, aiming at a better harvest.

Comparing the fruits in the three developmental stages, differences were noted regarding the mass and the polar (SD) and equatorial (DE) diameters ($p < 0.05$). The fruits in the stage 3 presented the highest values, followed by stages 2 and 1 (Table 1). The fruits presented SD and DE statistically equal to each other at the same maturity stage, which confirms the homogeneous growth in both longitudinal and transverse direction, giving the fruit a spherical shape.

Table 1 - Mean values of mass, polar (PD) and equatorial (ED) diameters of capoeira-branca fruits at three development stages: 1 (immature), 2 (mature green), 3 (mature).

| Analysis | Stages of development | | |
|----------|-----------------------|----------|----------|
| | 1 | 2 | 3 |
| Mass (g) | 0.4076 c | 0.7985 b | 0.9956 a |
| DP (mm) | 7.9 c | 10.1 b | 12.2 a |
| DE (mm) | 8.1 c | 10.3 b | 12.1 a |

Note: means followed by the same letters do not differ from each other by the Tukey test at 5% significance level.

Source: Authors.

Based on the mass and diameter data (Table 1), we can characterize the fruits of the capoeira-branca as small fruits, similar in size to blueberry (Shi et al., 2008).

3.2. Physicochemical fruit parameters

Color is one of the main factors defining fruit quality and is determined by four main groups of natural pigments: chlorophylls, carotenoids, flavonoids and betalains. The green color is dominant when the fruit has chlorophyll as the predominant pigment. In general, this pigment tends to degrade along the fruit maturation, at rates that vary among fruit species (Kidmose; Edelenbos; Nørbæk; Christensen, 2002). However, the predominantly green coloration of capoeira-branca fruits changed throughout the development, as already reported by Taiti et al. (2015), who did not detect significant changes in avocado peel coloration at different ripening stages, also corroborating the statement by Artés et al. (2002), that some fruits may retain chlorophyll after ripening.

The greenish color of the fruits is confirmed by the negative values of a^* (average of 7.79), which did not vary significantly in the three stages of development, and the h° values that varied from 120.94 in immature fruits to 118.20, in the mature. The L^* value increased from around 34 in immature fruits and green mature to 41.9, in ripe fruits, showing lighter in ripe fruits than in the other stages (Table 2). The fruits at different developmental stages did not differ in terms of b^* and C^* values.

Table 2 - Average color parameter values of capoeira-branca fruits at three different ripening stages: 1 (immature), 2 (mature green), 3 (mature).

| Analysis | Stages of development | | |
|----------|-----------------------|-----------|----------|
| | 1 | 2 | 3 |
| L^* | 34.57 b | 33.98 b | 41.96 a |
| a^* | -7.72 a | -7.71 a | -7.95 a |
| b^* | 12.89 a | 12.16 a | 12.55 a |
| Croma | 15.06 a | 14.64 a | 14.11 a |
| Hue | 120.94 a | 118.81 ab | 118.20 b |

Note: means followed by the same letters do not differ from each other on the horizontal by Tukey test at 5% significance level.

Source: Authors.

3.2.1. Respiratory Activity

Respiration is the most representative physiological process after fruit harvesting, since fruit no longer depends on the absorption of water and minerals by the roots, the nutrient conduction by the vascular system, or the photosynthetic activity of the leaves of the mother plant. Thus, the fruit acquires independent life and uses its own accumulated metabolic reserves in the growth and maturation phases (da Silva et al., 2009).

A decrease in respiratory activity was observed from stage 2 (Table 3).

Table 3 - Physicochemical characteristics of capoeira-branca fruits at three different ripening stages: 1 (immature); 2 (mature green); 3 (mature).

| Analysis | Stages of development | | |
|--|-----------------------|----------|----------|
| | 1 | 2 | 3 |
| CO ₂ (mL. kg ⁻¹ .h ⁻¹) | 160.21 a | 185.39 a | 119.49 b |
| Firmness (kgf) | 4.23 b | 7.00 a | 1.50 c |
| pH | 5.58 b | 5.68 b | 6.14 a |
| ATT (%) | 0.43 b | 0.48 a | 0.40 b |
| SST (%) | 8.80 b | 8.40 b | 13.80 a |
| Soluble Pectin (mg.g ⁻¹) | 0.92 a | 0.45 b | 0.69 ab |

Note: means followed by the same letters do not differ from each other on the horizontal by Tukey test at 5% significance level.

Source: Authors.

Respiratory activity reduction behavior with maturation advancement is commonly observed in fruits, as reported by Silva et al. (2009) in gabiobas. Immature and ripe green fruits have higher energy demand. The fruits use the energy released by respiration to continue the processes of biomass accumulation, pigment synthesis, enzymes, polysaccharide hydrolysis in simple sugars, oxidation of sugars in pyruvic acid, aerobic transformation of pyruvic acid into other organic acids. There is also degradation of cell wall constituents, that culminate in the fullness of the fruit, from the point of view of consumption (ripe fruits).

3.2.2. Firmness and soluble solids (SS)

Ripe green fruits were firmer than immature fruits, which may be associated with the cell wall construction observed during fruit growth (Tessmer et al., 2016). However, a reduction of approximately 65% in the firmness of the fruits was verified, between green and ripe fruits (Table 3). In fact, softening is one of the most egregious changes observed during fruit ripening, and different cultivars may have different firmness values at the same maturity stage (Tessmer et al., 2016). Firmness is directly associated with the degree of fruit maturity at harvest (Mo et al., 2015), moreover, due to its morphological and physiological characteristics, once separated from the mother plant, it loses turgor as result of the perspiration process (Jiménez León et al., 2013). The firmness reduction behavior of capoeira-branca fruits during ripening is similar to that presented by several other fruits, for example yellow pepper (Devgan et al., 2019).

Mature fruits of capoeira branca presented higher SS content than fruits at earlier stages of development (Table 3). The result obtained follows the tendency of SS increase during ripening, due to several modifications derived from hydrolysis of reserve polysaccharides (Chitarra & Chitarra, 2005). In capoeira-branca fruits there was an increase in the levels of glycidic fraction (Table 4) and SS along the stages of maturation, suggesting the presence of starch, in function of the difference between the levels of glycidic fraction and SS obtained. The SS content in the mature stage was close to those reported for ripe fruits by Seraglio et al. (2018) in jabuticaba and guabiju and higher than that of jamelão.

Table 4 - Average values of proximal composition of capoeira-branca fruits at three different ripening stages: 1 (immature); 2 (mature green); 3 (mature).

| Analysis | Stages of development | | |
|----------------------|-----------------------|---------|---------|
| | 1 | 2 | 3 |
| Moisture (%) | 79.24 a | 75.62 b | 69.45c |
| Ashes (%) | 0.94 c | 1.07 b | 1.60 a |
| Ethereal extract (%) | 0.381ab | 0.498 a | 0.309 b |
| Protein (%) | 3.49 a | 1.29 b | 1.41 b |
| Fibers (%) | 4.13 c | 5.43 b | 6.16 a |
| Glycid fraction (%) | 15.95 c | 21.52 b | 27.23 a |

Note: means followed by the same letters do not differ from each other on the horizontal by Tukey test at 5% significance level.

Source: Authors.

3.2.3. pH and titratable acidity (TA)

Capoeira-branca fruits in the immature and mature green stages did not differ statistically in relation to the pH, although the mature green fruits presented higher TA. Comparing the ripe green fruits with the ripe, there was a reduction of TA and consequent increase of pH (Table 3). Reducing acidity is a typical behavior observed during fruit ripening (Taiti et al., 2015), mainly due to the consumption of organic acids in the respiratory process (Paliyath et al., 2008).

3.2.4. Soluble pectin

As for soluble pectin, the only difference noted was its reduction, between fruits in the immature and mature green stages. However, the tendency towards increase in the soluble pectin content throughout the ripening was not observed in capoeira-branca fruits. The pectin solubilization process favors tissue softening due to the reduction of cohesion force between cells, since there is decomposition of macromolecules such as protopectins, cellulose and hemicellulose (Chylińska et al., 2017). Fruit softening is usually due to progressive solubilization, and depolymerization of pectic substances present in the cell wall resulting from

action of hydrolytic enzymes such as depolymerases and pectinesterase (Lamikanra, 2002).

A possible softening mechanism can be explained from the oxidation of ascorbic acid, catalyzed by ascorbate oxidase and ascorbate peroxidase. The enzyme ascorbate peroxidase uses ascorbate as an electron donor to remove hydroxyl radicals from the cell, preventing cell damage or other effects caused by reactive oxygen species. However, the degradation of ascorbate can lead to the production of free radicals, which can interact with cell wall polysaccharides, leading to fruit softening or allowing cell expansion (Gomez & Lajolo, 2008).

Another mechanism may be through activities of inducing enzymes such as lipid acylhydrolase and phospholipase D, that results in the production of free fatty acids from membrane lipids. These released fatty acids can disturb cellular function through the direct lysis of organelles, of the link to and subsequent inactivation of the protein, besides being subject to oxidation (Toivonen & Deell, 2002). Grape studies have suggested that changes in cell turgor and loss of transpirational water contribute to fruit softening (Gapper et al., 2013).

3.2.5. Proximal composition

When evaluating the centesimal composition (Table 4), reduction is observed in the humidity and increase in the fiber, ash and glycid contents during the development. Reduction of the ether extract was observed comparing ripe and ripe green fruits and also in protein content, comparing immature and the ripe green fruits.

The reduction in fruit moisture at the beginning of development may be associated with the accumulation of dry matter as a function of growth, while the fall observed during ripening may be associated with the exacerbated metabolism typical of this physiological stage. The capoeira-branca fruit has a high proportion of seeds and, according to Deepa et al. (2013), this characteristic is responsible for decline of moisture content. The reduction in ether extract contents and protein is a common feature during fruit ripening due to the oxidative processes that occur, such as lipid peroxidation and protein oxidation (Jimenez et al., 2002). Similar results in reducing these compounds were reported by El Arem et al. (2012) in tâmara cultivars during maturation. Regarding the changes observed in the ether extract and proteins, their contents were low, as in most fruits (Lago-Vanzela et al., 2011).

The increase in ash content during the fruit maturation process is associated with the absorption of minerals by the plant, translocated to the fruit during its development (Peñuelas et al., 2008). There was an increase in fiber content and glycidic fraction during ripening, as verified by Maieves et al. (2015) in Japanese grapes. Murrinie et al. (2017) also reported an

increase in apple glycidia content, related to the decomposition of more complex carbohydrates, such as cellulose and pectin, in sugars. The reduction, mainly of moisture, but also of ether extract and proteins, contributed to the increase of fiber, ash and glycidies.

3.2.6. Vitamin C and Phenolic content

Vitamin C content increased approximately fivefold during the development period of capoeira-branca, in particular during ripening. It reached a maximum level of 236.02 mg.100g⁻¹ (Table 5).

Table 5 - Average values of vitamin C (Vit.C), phenolics, antioxidant activity (AAT), in capoeira-branca fruits at three different ripening stages: 1 (immature); 2 (mature green); 3 (mature).

| Analysis | Stages of development | | |
|---|-----------------------|-----------|-----------|
| | 1 | 2 | 3 |
| Vit. C (mg.100g ⁻¹) | 46.81 b | 59.94 b | 236.02 a |
| Phenolic (mg. 100g ⁻¹) | 257.58 a | 235.95 a | 171.00 b |
| AAT (ABTS) (µM de trolox. g ⁻¹) | 62.57 b | 61.380b | 69.63 a |
| AAT (FOS) (mg. 100g ⁻¹) | 1880.34 b | 1921.36 b | 4602.40 a |

Note: means followed by the same letters do not differ from each other on the horizontal by Tukey test at 5% significance level.

Source: Authors.

Rufino et al. (2010) reported vitamin C levels of 290, 148, 1357, 87, 190 mg of ascorbic acid.100 g⁻¹ for mature mangaba, murici, acerola, acai and cashew, respectively. In general, vitamin C content decreases with maturity due to its consumption in order to maintain the fruit integrity. However, fruits such as guava have an increasing vitamin C content behavior with ripening, because in addition to efficient recycling by the glutathione ascorbate cycle, during ripening there occurs the synthesis of ascorbic acid by other metabolic routes. This suggests similar behavior for the fruit under study (Gomez & Lajolo, 2008).

With fruit maturation, there was a reduction of about 34% of the total phenolics concentration (Table 5), which did not differ between immature and ripe green fruits. The decline in total phenolic content with advancing maturity and ripening of the romã was reported by Fawole & Opara (2013) and by Kumar & Gill (2017), who attributed the decrease in total

phenolic content to oxidation of polyphenols by polyphenoloxidase during fruit maturation. In general, the composition of phenolics is quite variable, depending on the type of fruit and the environmental conditions to which they are subjected (Lado et al., 2018). The phenolic content of capoeira-branca fruit is low when compared to some fruits, such as strawberry (Gonçalves et al., 2017), buriti (Rudke et al., 2019) and blueberry (Zhang et al., 2016), since these fruits are rich sources of these compounds. However, capoeira-branca fruit presented phenolic compounds content close to wild cherry plum (Smanalieva et al., 2019).

3.2.7. Antioxidant activity (AAT)

The AAT of immature and mature green capoeira-branca fruits did not differ, although the increase was observed with fruit ripening, despite the analysis method (Table 5). The observed behavior is similar to that found in studies by Sabir & Rocha (2008), with *Solanum fastigiatum* (false jurubeba) and Russo et al. (2018), with pomegranate. Fruit AAT is usually associated with richness in terms of bioactive compounds such as vitamin C, carotenoids and phenolics. The increase in AAT may be mainly associated with increased vitamin C levels throughout ripening, which acts as an antioxidant to maintain fruit integrity (Gomez & Lajolo, 2008).

4. Final Considerations

The capoeira-branca fruit development was marked by the increase in mass, equatorial and polar diameters, pH, soluble solids, contents of glycodes, fiber, ash, vitamin C and antioxidant activity, and by the decrease in respiratory activity, firmness, acidity, contents of moisture, protein and total phenolics. Although the fruit is not usually consumed, the knowledge of its composition, rich in antioxidants, opens avenues of technological exploration for food and/or drug formulation purposes.

However, more studies are needed to broaden the knowledge about this fruit, such as the evaluation of the presence of antinutritional factors. Furthermore, before commercial exploitation, *in vivo* studies and clinical trials are requested to confirm their functional benefits and safety for consumers.

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