

Quality of *Butia capitata* fruits harvested at different maturity stages

Calidad de frutos de *Butia capitata* cosechados en diferentes estados de madurez

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ABSTRACT

Butia capitata (Mart.) Becc. or “coquinho azedo” is a native palm species of the Brazilian savannah, bears fruits which are sold fresh or as frozen pulp. This study examined postharvest changes in “coquinho azedo” harvested at a commercially immature stage and later evaluated the quality of these fruits by comparing them with those harvested fully ripe. Fruits purchased in the 2020 harvest in Santo Antônio do Retiro, MG (Brazil), were harvested at different degrees of maturity, namely, commercially immature and ripe, according to the point of harvest adopted in the region. For 7 d, weight loss, skin color and respiratory activity were evaluated in the commercially immature-harvested fruits. At 7 d postharvest, physical and chemical evaluations of the pulp were performed. The ripe-harvested fruits were subjected to the same evaluations, but only at 1 d postharvest. The skin color of commercially immature-harvested fruits tended to yellow over the days. Respiration postharvest increased in the immature-harvested fruits. Fresh weight loss exceeded 10% but without compromising appearance. The commercially immature-harvested fruits had 55% more total phenols, whereas the ripe-harvested fruits had higher soluble solids and ascorbic acid contents. Pulp color, soluble solids/titratable acidity ratio and total carotenoid contents were similar regardless of the degree of maturity at harvest. During the days after the harvest of the commercially immature “coquinho azedo”, changes take place which cause them to resemble the fruit harvested ripe. Based on the evaluated traits, the early harvest did not compromise the ripening of the fruits.

Key words: coquinho azedo, postharvest, quality, ripening.

RESUMEN

Butia capitata (Mart.) Becc. o “coquinho azedo” es una especie de palma nativa de la flora brasileña, produce frutos que se venden frescos o como pulpa congelada. Este estudio examinó los cambios poscosecha en los frutos de “coquinho azedo” recolectados en su etapa comercialmente inmaduros y evaluó su calidad comparándola con los cosechados completamente maduros. Los frutos adquiridos en la cosecha de 2020 en Santo Antônio do Retiro, MG (Brasil), fueron cosechados en diferentes grados de madurez: inmaduros o maduros según el punto de cosecha adoptado en la región. Durante 7 d, se evaluó la pérdida de peso, el color de la epidermis y la actividad respiratoria en los frutos inmaduros recolectados. A los 7 d poscosecha, se realizaron evaluaciones físicas y químicas de la pulpa. Los frutos cosechados maduros fueron sometidos a las mismas evaluaciones, pero 1 d después de recolectados. El color de la epidermis de los frutos inmaduros tendió a amarillarse con el paso de los días. La respiración poscosecha aumentó en los frutos inmaduros. La pérdida de peso fresco superó el 10%, pero sin comprometer la apariencia. Los frutos cosechados inmaduros tuvieron un 55% más de fenoles totales, mientras que los maduros tuvieron mayores niveles de sólidos solubles y ácido ascórbico. El color de la pulpa, la relación sólidos solubles/acidez titulable y el contenido de carotenoides totales fueron similares independiente del estado de madurez en la cosecha. Durante los días posteriores a la cosecha del “coquinho azedo” comercialmente inmaduro, ocurren cambios que los hacen similares a los cosechados maduros. Con base en las características evaluadas, la anticipación de la cosecha no comprometió la maduración de los frutos.

Palabras clave: coquinho azedo, poscosecha, calidad, maduración.

Introduction

Butia capitata, commonly known as “coquinho azedo” in Portuguese, is a Brazilian endemic palm tree that grows in the Cerrado regions of the states of Bahia, Minas Gerais, and Goiás (CNCFlora, 2020). The “coquinho azedo” fruits constitute an important source of income for producers

during the harvest period, which runs from October to January (Lima *et al.*, 2010). The fruit is sold fresh and as frozen pulp for use also during the off-season. According to Castricini *et al.* (2020), “coquinho azedo” pulp frozen for eight months exhibited variations in instrumental color (lightness, chroma and *hue*), pH, titratable acidity (TA), contents of soluble solids (SS), and ascorbic acid content,

Received for publication: November 23, 2021. Accepted for publication: April 15, 2022.

Doi: 10.15446/agron.colomb.v40n1.99651

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without prejudice to the minimum standards of identity and quality.

The “coquinho azedo” pulp is a source of vitamin C, β -carotene and phenolic compounds (Barbosa *et al.*, 2021). According to these authors, the consumption of the fruit should be encouraged due to the antioxidant action of these compounds on growth, development, and protection against diseases.

Optimum postharvest fruit quality is influenced by the maturity stage at the time of harvest, with fruits harvested immature or overripe having inferior quality and a shorter shelf life (Braman *et al.*, 2015). In addition, Chitarra and Chitarra (2005) stated that early harvested (immature) fruits will have poor sensory attributes, even if they reach maturity some time later. This was demonstrated in fruits of *Ziziphus jujube*, cv. Dongzao harvested with a light green color (80 d after full flowering), which showed lower sensory acceptance up to the sixth day of shelf life, compared with fruits harvested with 50% of the skin red (110 d after full flowering) (Zhao *et al.*, 2021). Finally, Lobos *et al.* (2018) mentioned that *Vaccinium corymbosum* L. fruits harvested at a higher degree of maturity exhibited higher soluble solids contents and soluble solids/titratable acidity ratio at 30 and 40 d of cold storage.

Lima *et al.* (2010) suggested that the best time for harvesting “coquinho azedo” is when most of the fruits in the bunch are yellowish-green (color-turning stage), since, if harvested green, not all of them will ripen and become good for consumption. However, if they are harvested ripe, the percentage of fruit losses due to decay can be high, reducing marketing time.

Therefore, this study was undertaken to examine the post-harvest changes (physical, chemical, and physiological) of “coquinho-azedo” harvested at a commercially immature stage of maturity and evaluate the characteristics of these fruits by comparing them with those harvested fully ripe.

Material and methods

Fruit collection

The “coquinho azedo” fruits were acquired from the 2020 harvest period in the municipality of Santo Antônio do Retiro - MG, Brazil. The fruits were harvested by the producer at different degrees of maturity, namely, ripe and commercially unripe, according to the point of harvest adopted in the region.

B. capitata is a native species of the Brazilian flora and, for this reason, the fruit collection activity was registered in the National System for the Management of Genetic Heritage and Associated Traditional Knowledge (SisGen) under no. A8E6425.

Experimental design

The study was divided into two stages, according to the degree of maturity at harvest: ripe and commercially immature. A completely randomized experimental design with six replicates was used, with each replicate consisting of three fruits.

The ripe-harvested fruits had completely yellow skin (lightness=64.07, chroma=63.33, and $^{\circ}hue=72.02$), whereas the skin of those harvested when commercially immature was green with yellow spots (lightness=57.39, chroma=37.19, and $^{\circ}hue=103.99$).

Evaluations of fruits picked ripe and commercially immature

After harvesting, the fruits were sent to the laboratory, and on the following day (1 d postharvest), respiratory activity was evaluated for 1 d in the ripe and for 7 d in the commercially immature-harvested fruits. The average temperature and relative humidity of the environment in the experimental period were 26.66°C and 79.43%, respectively. Respiratory activity was measured simultaneously by two methods, to confirm the respiratory trends of the commercially immature fruits.

The evaluation by titrimetry followed the methodology of Crispim *et al.* (1994), adapted by Deliza *et al.* (2008), with results expressed in $\text{mg CO}_2 \text{ kg h}^{-1}$ on each evaluation day. Instrumental evaluation consisted of measuring the percentage of carbon dioxide (CO_2) accumulated inside the container holding the fruits, which was determined by direct measurement with a CO_2 Analyzer (MOCON, Ametek®) throughout the experimental period. In both methodologies, each replicate was placed in a covered 5.2-L PET bottle protected by a PVC film to ensure better sealing, preventing and/or reducing gas exchange with the external environment.

Parallel to measurement of respiratory activity, the fruits harvested at the commercially immature stage were weighed daily on a digital scale to determine weight loss. Losses were calculated each day relative to the initial weight of the fruits, with the result expressed in percentage terms.

Skin color in the immature fruits was also measured daily (before packaging), using a colorimeter (CR 400 Chroma meter, Minolta®) operating in the LCH system (lightness, chroma and °hue). Three readings were performed in the mid-region of each fruit.

On the last day of evaluation (7 d postharvest), these fruits were crushed without the skin and the pulp subjected to the following assessments:

- instrumental color, following the methodology described for whole fruits;
- pH, by potentiometry;
- titratable acidity, by titration with 0.1 M NaOH, with results expressed in g citric acid 100 g⁻¹;
- soluble solids (°Brix), determined by digital refractometry, according to the Adolfo Lutz Institute – IAL (2008);
- ascorbic acid (mg 100 g⁻¹), measured by the reduction of the indicator 2,6-dichloroindophenol (DCIP) by ascorbic acid (Brasil, 2013);
- total carotenoid contents (mg 100 g⁻¹), by spectrophotometry, as proposed by Lichtenthaler (1987); extraction took place in ethyl alcohol (95% ethanol), in a dark and refrigerated environment, for 24 h. The filtered extract was read in a spectrophotometer, with the absorbance (A) of chlorophyll “a” determined at 664 nm, chlorophyll “b” at 648 nm, and total carotenoids at 470 nm;
- total contents of phenolic compounds, determined according to Singleton and Rossi (1965) and Georgé *et al.* (2005) with modifications. The extraction took place in 70% acetone for 20 min in an ultrasound device and centrifuging at 4,000 rpm for 20 min. The mixture was filtered through rapid-filtration filter paper and the extraction (successive extraction) was repeated. The 10% Folin-Ciocalteu and 7.5% calcium carbonate reagents were added to the extract. Total phenolic compounds were quantified using a gallic acid calibration curve, with values expressed in mg gallic acid 100 g⁻¹.

The ripe-harvested fruits were subjected to these same assessments, 1 d post-harvest, following the methodology described for immature fruits.

Data analysis

The data were subjected to the Shapiro-Wilk and Bartlett tests to check for the normality of errors and homogeneity of variances, respectively. Because they did not meet the

assumptions, the skin color data of “coquinho azedo” collected at the commercially immature stage were subjected to non-parametric statistics, with the color change over the days of storage analyzed by the Kruskal-Wallis test and, subsequently, Dunn’s test.

The other characteristics met the assumptions. The fresh weight loss data of the immature-harvested fruits were subjected to analysis of variance, in which losses over the storage days were analyzed by regression.

Data on the physical and chemical characteristics of the pulp (destructive evaluations) of fruits harvested at the ripe stage (1 d postharvest) and commercially immature (7 d postharvest) were compared by the t-test, to observe whether the commercially immature-harvested fruits would complete their ripening and resemble the ripe produce.

The respiratory activity of commercially immature-harvested fruits (by both methods used) during ripening was evaluated by descriptive statistics. All analyses were performed at the 5% significance level, using Sisvar statistical software (Ferreira, 2007).

Results and discussion

Skin color, weight loss, and respiratory activity of fruits picked commercially immature

The skin color of the immature-harvested fruits (Tab. 1) changed over the days. Between the first and fifth days postharvest, there was a 27.51% decrease in °hue, with the fruit skin shifting from green (°hue values between 90 and 180) to a color tending to yellow (°hue values between 0 and 90), which remained until the end of the experimental period. Chroma was 56.71% higher at 5 d postharvest, indicating that the skin was a more intense (or “purer”) yellow. Because of yellowing or degreening, the skin was lighter, with higher lightness values (closer to 100) seen after the 4 d postharvest. The change in the color of the commercially immature-harvested “coquinho azedo” fruits was due to their ripening over the 7 d of study. This was mentioned by Lima *et al.* (2010), who stated that the yellow color is an indication of ripeness in “coquinho azedo”. Additionally, according to Spoto *et al.* (2020), changes in color allow the consumer to identify the maturity of fruits.

Fruit ripening results in color changes due to biosynthesis, degradation and appearance of pigments, events catalyzed by enzymes activated at this stage of fruit development (Kapoor *et al.*, 2022).

Carotenoids are pigments present in green leaves and fruits, red, yellow and orange flowers, roots, and seeds, whose biosynthesis begins with the production of phytoene by the condensation of two molecules of geranylgeranyl diphosphate by the enzyme phytoene synthase (PSY) (Gonzalez-Jorge *et al.*, 2013). Saini *et al.* (2015) mentioned that, after their biosynthesis, the main carotenoids accumulate in specialized plastids, chromoplasts, chloroplasts or leucoplasts, and the main carotenoids present in yellow-orange fruits are β -carotene and α -carotene. Additionally, Gonzalez-Jorge *et al.* (2013) argued that the concentration of carotenoids can also be regulated by enzymatic degradation (carotenoid cleavage dioxygenases) in plastids.

Fresh weight loss was significantly influenced by the days postharvest, fitting a quadratic model and reaching a maximum value of 13.42% at 7 d postharvest (Fig. 1). Although most fruits have their quality compromised when they lose 5 to 10% of moisture (Chitarra & Chitarra, 2005), our results suggest that the final percentage of fresh weight loss in the fruits did not cause them to wilt.

TABLE 1. Instrumental color of “coquinho azedo” (*B. capitata*) fruits harvested at a “commercially immature” stage and stored at an average temperature of 26.55°C and 79.43% relative humidity.

Days after harvest	Lightness	Chroma	$^{\circ}$ hue
1	57.64 b	37.09 e	103.98 a
2	59.28 b	39.43 de	99.96 ab
3	60.05 b	42.31 edc	92.48 abc
4	64.83 a	51.71 cdb	81.54 bcd
5	65.03 a	55.97 cba	75.97 cde
6	65.31 a	58.25 ba	73.05 ed
7	64.88 a	58.91 a	71.94 e

Medians followed by the same lowercase letter do not differ from each other by Dunn’s non-parametric test at 5% significance.

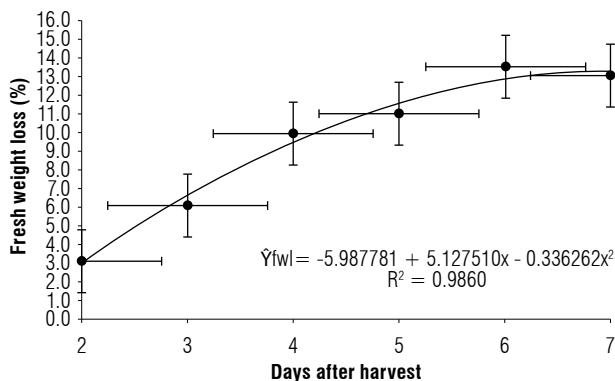


FIGURE 1. Fresh weight loss (%) in “coquinho azedo” (*B. capitata*) fruits harvested at the “commercially immature” stage and stored at an average temperature of 26.55°C and 79.43% relative humidity. Significance of the quadratic model at $P < 0.05$.

The transpiration caused by the difference in vapor pressure between the plant tissue and the surrounding atmosphere compromises fruit quality, inducing loss of fresh weight (Khaliq *et al.*, 2015). Coatings on the fruit surface can reduce transpiration and the consequent fresh weight losses, as observed by the authors in mango. Similarly, fruits of *Physalis peruviana* L. (cape gooseberry) packed in a PET tray with cast PP film showed reduced weight loss (Garavito *et al.*, 2022).

Respiratory rate decreased between the 1 and 2 d of storage, with a subsequent increase until the 5 d, followed by a decline until the last day, in both analyzed methods (Figs. 2A-B). This behavior suggests a climacteric pattern, since, after harvest, climacteric fruits exhibit a significant increase in respiratory activity and rapid ripening, with color changes, increases in sugar concentration and texture changes (Chitarra & Chitarra, 2005). In non-climacteric fruits, after harvest, there is a decrease in respiratory activity, regardless of the stage of development at which they were harvested (Spoto *et al.* 2020).

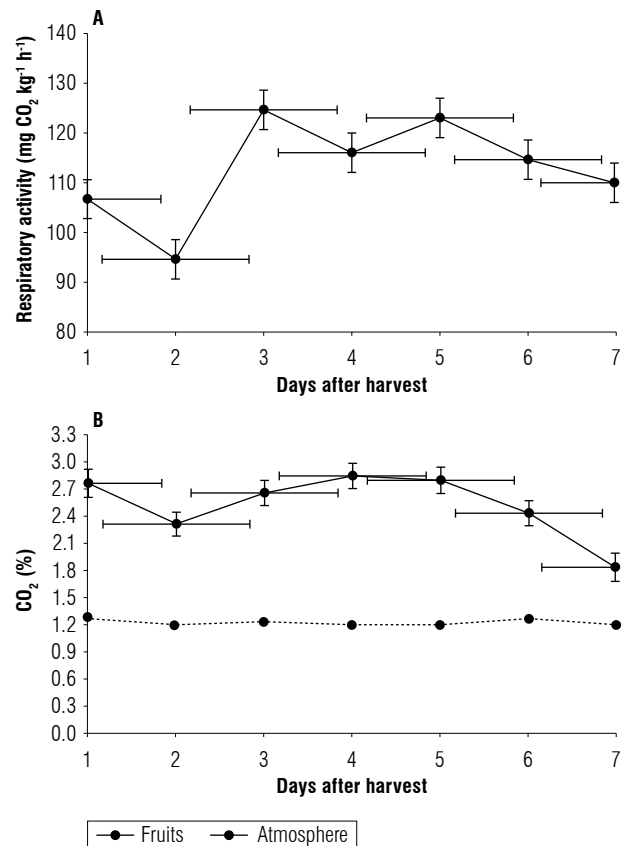


FIGURE 2. A) Respiratory activity and B) CO_2 production of “coquinho azedo” (*B. capitata*) fruits harvested at the “commercially immature” stage of maturity, during 7 d of storage at average temperature of 26.55°C and 79.43% relative humidity.

Respiratory activity and percentage CO₂ of fruits picked commercially immature (7 d postharvest) and ripe (1 d postharvest)

There was no significant difference in respiratory activity and percentage CO₂ of the commercially immature-harvested fruits at 7 d postharvest and ripe-harvested fruits 1 d postharvest (Tab. 2). Considering that as the fruit ripens its respiratory rate generally decreases (Saltveit, 2016), it can be assumed that, in terms of these evaluations, the immature-harvested “coquinho azedo” is able to complete its ripening in a similar way to the fruits that ripened on the plant. Therefore, anticipating the harvest is not detrimental from the maturation standpoint.

TABLE 2. Respiratory activity (mg CO₂ kg⁻¹ h⁻¹) and CO₂ production (%) of “coquinho azedo” (*B. capitata*) harvested “ripe” (1 d postharvest) and 7 d after harvesting the fruits “commercially immature”.

Characteristics	Degrees of maturity at harvest		
	Commercially immature*	Ripe	CV (%)
Respiratory activity	110.18 ± 7.65 a	123.64 ± 3.49 a	10.40
CO ₂ production	1.89 ± 0.10 a	2.52 ± 0.28 a	22.86

Means of six replicates ± standard error. Means followed by the same letter in the rows do not differ by the t-test at 5% significance. *Evaluation performed at 7 d postharvest.

Physical and chemical characteristics of pulp from fruits picked at different degrees of maturity

As for pulp color (Tab. 3), at 7 d postharvest, the commercially immature-harvested fruits had a higher lightness value than those that were harvested ripe. The chroma in the pulp of ripe-harvested fruits was higher, whereas the pulp color *hue* was similar between the fruits of both groups. The yellowish color of the fruit pulp indicates that both fruit groups were ripe, corroborating Lima *et al.* (2010). Nonetheless, due to the higher lightness (although this difference was not visually observable) and chroma values in the ripe-harvested “coquinho azedo”, their pulp color was a lighter and more intense yellow shade.

During the ripening of “coquinho azedo” fruits, the change from greenish to yellowish color is due to the unmasking of preexisting pigments by the degradation of chlorophylls and synthesis of carotenoids (Maduwanthi & Marapana, 2019). In addition, according to Li and Yuan (2013), the yellowish color of the fruits is due to the synthesis and deposit of carotenoids in the chromoplasts, with β-carotene being the predominant carotenoid in “coquinho-azedo” (Faria *et al.*, 2011).

The pH of the immature-harvested fruits was significantly higher, with a value inversely proportional to titratable

TABLE 3. Lightness, chroma and *hue* of “coquinho azedo” (*B. capitata*) fruits harvested “ripe” (1 d postharvest) and harvested “commercially immature” (7 d postharvest).

Characteristics	Degrees of maturity at harvest		
	Commercially immature**	Ripe	CV (%)
Lightness	65.10 a	64.06 b	1.18
Chroma	58.59 b	63.33 a	4.22
<i>hue</i>	72.07 a	72.02 a	2.53

Means followed by the same letter in the rows do not differ by the t-test at 5% significance.

**Evaluation performed at 7 d postharvest.

acidity. At 7 d postharvest, this fruit category exhibited a lower citric acid content. Following the same response, the ripe-harvested “coquinho azedo” had a higher soluble solids content. Soluble solids are mostly composed of sugars, which makes the sweetness of a fruit dependent on this trait (Cao *et al.*, 2015). During the ripening of fruits in a non-refrigerated environment, there is an increasing accumulation of organic acids and sugars within the vacuole (Ventura *et al.*, 2022), which will be used in respiration or in the conversion to sugars (Tosun *et al.*, 2008). In addition, during ripening, the partial degradation of the cell wall contributes to the increase in sugar levels in the fruits (Canton *et al.*, 2020).

In the commercially immature-harvested “coquinho azedo”, the fruits, possibly, continued the expected respiratory process after harvest, with the use of organic acids and sugars, which possibly explains the lower acidity and soluble solids contents in the commercially immature-harvested fruits at 7 d postharvest.

The higher soluble solids content in the ripe-harvested “coquinho azedo” can be explained by the longer time the fruit remained on the plant, which favors a greater accumulation of sugars. This phenomenon was demonstrated in papaya, where the soluble solids content in the fruits remained practically constant after harvest despite the change in skin color, loss of firmness, among others (Gutierrez & Watanabe, 2017). The soluble solids content determines the degree of sweetness of fruits (Spoto *et al.*, 2020) due to the higher proportion of soluble sugars in their composition (Fernandes *et al.*, 2017). In the literature, average soluble solids levels of 7.70 and 9.60 °Brix were reported in mature coconuts (Souza, 2016; Souza *et al.*, 2018).

The SS/TA ratio was significantly the same in fruits harvested at different ripening degrees. According to Spoto *et al.* (2020), the SS/TA ratio is a criterion for the evaluation of flavor, which can express the degree of fruit ripeness.

Chitarra and Chitarra (2005) stated that the SS/TA ratio provides a good idea of the balance between the soluble solids content and titratable acidity, constituting a more representative measure than the evaluation of these traits in isolation. Therefore, it is likely that the “coquinho azedo” did not have their flavor altered 7 d after being harvested commercially immature.

Ascorbic acid, also known as vitamin C, is an important compound that has antioxidant and metabolic functions (Cruz-Rus *et al.*, 2011), and its content was higher in the ripe-harvested fruits. In contrast, the total carotenoid content did not differ between the fruits harvested ripe or commercially immature.

After harvest, the concentration of organic acids in the fruits commonly declines due to their use as a respiratory substrate (Chitarra & Chitarra, 2005), which may explain the lower ascorbic acid content in the immature-harvested “coquinho-azedo”. Greater synthesis of ascorbic acid in papaya fruit occurred in parallel with higher respiratory activity in the fruits, with a subsequent decrease during storage (Maringgal *et al.*, 2021). This is because, as stated by Mellidou and Kanellis (2017), ascorbic acid participates in the synthesis of ethylene as a cofactor of 1-aminocyclopropane-1-carboxylate oxidase (ACC oxidase).

The similar total carotenoids contents in both studied fruit groups may be due to the continued biosynthesis of this phytochemical 7 d after the fruits were harvested commercially immature. This agrees with the findings of Rodriguez-Amaya (2001) that the carotenoids content intensifies with fruit ripening.

Phenolic contents were higher in the immature-harvested fruits, which showed approximately 55% more of these compounds. With respect to phenolic compounds, the literature reports that in citrus fruits, the concentration of flavonoids (a specific class of phenols in vegetables) decreases with increasing fruit size and maturity. This statement corroborates Mcharek and Hanchi (2017), who observed a reduction in the concentration of phenols throughout the ripening of lime. Kosar *et al.* (2004) did not observe significant differences in the flavonoid content of green and ripe strawberries. In the present study, the total phenolic content in the “coquinho azedo” was higher than that reported by Nascimento *et al.* (2020) in fully ripe fruits. The higher total phenolic content in this study may have been due to the two successive extraction steps used, which resulted in more compounds being extracted.

Phenolic compounds are aromatic organic compounds including secondary metabolites, which determine the color and flavor of fruits, in addition to actively participating in the mechanism of resistance to insects and diseases (Milind, 2010). In a study with guava, papaya and mango, Oliveira *et al.* (2011) stated that these metabolites are the antioxidant compounds that most contribute to antioxidant activity in these fruits. Therefore, the “coquinho azedo” can be a good source of natural oxidants for human consumption, especially if the fruits are harvested commercially immature and consumed 7 d postharvest.

TABLE 4. Means of pH, titratable acidity (TA-g citric acid 100 g⁻¹), soluble solids (SS-°Brix), SS/TA ratio, ascorbic acid (mg 100 g⁻¹), total carotenoids (mg 100 g⁻¹) and total phenols in the pulp of “coquinho azedo” (*B. capitata*) fruits harvested at different degrees of maturity and evaluated at different times after harvest.

Characteristics	Degrees of maturity at harvest		
	Commercially immature**	Ripe	CV (%)
Respiratory activity	110.18 a	123.64 a	10.40
pH	3.80 a	3.25 b	0.94
Titratable acidity (TA)	1.39 b	2.32 a	7.00
Soluble solids (SS)	4.45 b	6.53 a	9.19
SS/TA ratio	3.21 a	2.84 a	10.36
Ascorbic acid	7.51 b	52.91 a	10.31
Total carotenoids	15.42 a	19.12 a	19.90
Total phenolic compounds	729.99 a	408.26 b	18.20

Means followed by the same letter in the rows do not differ by the t-test at 5% significance.

**Evaluation performed at 7 d postharvest.

Conclusions

“Coquinho-azedo” fruits harvested commercially immature had an increase in respiratory activity after harvest, with changes in skin color and fresh weight losses of over 10% throughout storage. At the end of the ripening period after harvest, the color (*°hue*), respiratory activity, SS/TA ratio and total carotenoids in “coquinho azedo” resembled those of fruits that ripened on the plant. “Coquinho-azedo” fruits harvested fully ripe had higher titratable acidity, soluble solids and ascorbic acid contents than the fruits harvested commercially immature, when ripe. The total phenolic content of “coquinho-azedo” fruits harvested at the commercially immature stage, when ripe, was 55% higher than that of the ripe-harvested fruits.

Acknowledgments

The authors thank the National Council for Scientific and Technological Development (CNPq) of Brazil, the Research

Support Foundation of Minas Gerais (FAPEMIG) and the Coordination for the Improvement of Higher Education Personnel - Brazil (CAPES) - (Finance code 001).

Conflict of interest statement

The authors declare that there is no conflict of interest regarding the publication of this article.

Author's contributions

MM designed the experiments, carried out the laboratory experiments, performed the statistical analyses, and wrote this manuscript. AC contributed to the design of the experiments and the writing and review of this manuscript. JLS and LPS carried out the laboratory experiments and reviewed the manuscript. CMAM contributed to the data analysis and reviewed the manuscript. All authors have reviewed the manuscript.

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