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Postharvest Characterization of *Passiflora cincinnata* Fruit Pulp at Different Ripening Stages

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HIGHLIGHTS

- Fruit ripening impacts pulp yield, shape, and firmness.
- Nutritional content changes with advancing ripening stages.
- Ascorbic acid increases with ripening, offering health benefits.
- Phenolic compounds decline with ripening, affecting antioxidants.

Abstract: Wild passion fruit (*Passiflora cincinnata*) has great adaptability to the semi-arid environment of the Caatinga biome, Brazil. However, information about the postharvest quality and the ideal ripening points of the fruits are still insufficient in the literature. Thus, the objective of this study was to analyze the physical, chemical characteristics and bioactive compounds of *P. cincinnata* fruit at different ripening stages, harvested in the Brazilian semi-arid region. Three ripening stages (stage I = 100% green peel color; stage II = green-yellow peel color; stage III = yellow-green peel color) were evaluated. Physical characteristics (pulp yield with seeds, pulp yield without seeds, pulp volume without seeds, fresh peel mass, rind thickness, longitudinal fruit diameter, transversal fruit diameter, fruit shape, longitudinal inner cavity diameter, transversal inner cavity diameter, and firmness) in the whole fruit and physicochemical (moisture, ashes, pH, H⁺ ion concentration, soluble solids, titratable acidity, SS/TA ratio, reducing sugars, non-reducing sugars, soluble sugars, and proteins) and bioactive compounds (ascorbic acid, total chlorophyll, carotenoids, flavonoids, anthocyanins,

and phenolic compounds) in the fruit pulp were evaluated. Based on the physical and physicochemical characteristics and bioactive compounds analyzed in the *P. cincinnata* pulp, the stage II of ripening stands out as the most promising for *in natura* consumption and elaboration of food products of this fruit. The results obtained allowed us to prove the nutritional potentiality of the fruit, providing technical subsidies for the use of *P. cincinnata* in agroindustry.

Keywords: Caatinga biome; bioactive compounds; wild passion fruit; fruit quality.

INTRODUCTION

The species *Passiflora cincinnata* Mast. (Passifloraceae) is popularly known in Brazil as *maracujá do mato*, *maracujá da Caatinga*, *maracujá selvagem* or *maracujá da casca verde*. This wild species of passion fruit has an opaque straw-green peel, and long-lived, aromatic, and acid-flavored fruits that are resistant to handling and transport [1]. Its fruit is extremely aromatic, presenting an exotic aroma and flavor, as well as good nutritional value, being a source of minerals (K, Fe, P, Ca) and vitamins A, C, and B complex [2].

This species is common in the semiarid region of northeastern Brazil, and shows greater tolerance to drought stress compared to other species such as the yellow passion fruit (*Passiflora edulis*) [3], with significant commercial and social potential, considering its good development and use as food in arid and semiarid areas subject to water restriction. Wild passion fruit produces fruits with smaller masses than other passion fruit species [4]. *P. cincinnata* has tolerance to drought, which makes its cultivation viable in water-restricted environments. In addition, this species produces a sour fruit, having resistance to drought and a number of diseases and/or pests that affect the common passion fruit [2].

From anthesis to ripening, fruits undergo several morphological, histochemical, and biochemical differentiations that are intrinsically related to the harvest point [5]. The fruits of *P. cincinnata* commence detaching from the plants at stage III, as determined in this study. Consequently, there is a necessity to establish an appropriate stage to prevent the harvesting of fruits prior to their detachment from the plant, as this may result in reduced fruit quality, as well as susceptibility to diseases and mechanical damage. This situation makes it difficult to identify the harvest point (physiological maturity), which can be perceived by applying pressure at the distal position of the fruit, which yields slightly to pressure when it is ripe [6]. Santos and coauthors [7] observed dehydration of the fruit of *P. cincinnata* and the possibility of contamination by microorganisms when harvested after its natural abscission, reducing the conservation and commercialization period, which can lead to significant losses in postharvest quality.

The postharvest quality of *P. cincinnata* fruits has already been investigated [1, 2, 3, 4]; however, studies on the optimal harvest time for these fruits are scarce. Because it is a fruit that presents a climacteric pattern of respiration, and thus can be harvested before ripening, there is a need to evaluate all its characteristics at different stages of maturity, to identify the composition and determine which stage of the fruit's development shows better characteristics for consumption and/or elaboration of food products. Furthermore, the cultivation of this fruit in semi-arid regions is an economically viable alternative for local farmers, considering its adaptation to the climate of these regions. Thus, the objective of this study was to analyze the physical, chemical characteristics and bioactive compounds of *P. cincinnata* fruit at different ripening stages, harvested in the Brazilian semi-arid region.

MATERIAL AND METHODS

Harvesting and locational aspects

Passiflora cincinnata fruit were harvested in the municipality of Cerro Corá, RN, Brazil (6° 02' 44" S and 36° 20' 45" W, altitude of 575 m), at different stages of physiological ripening. Homogeneous fruits, using criteria of peel coloration, uniformity of size, and good phytosanitary conditions, were harvested and packed in plastic boxes and transported to the Laboratory of Chemistry, Biochemistry, and Food Analysis, at the Universidade Federal de Campina Grande, Pombal Campus, Paraíba state, Brazil, where the physical and post-harvest fruit quality analyses were performed.

Experimental design and treatments

A completely randomized design with three treatments and five replications, with three fruits per experimental unit, was used, totaling 15 fruits per ripening stage. Three ripening stages (stage I = 100% green peel color; stage II = green-yellow peel color; stage III = yellow-green peel color) were evaluated (Figure 1).

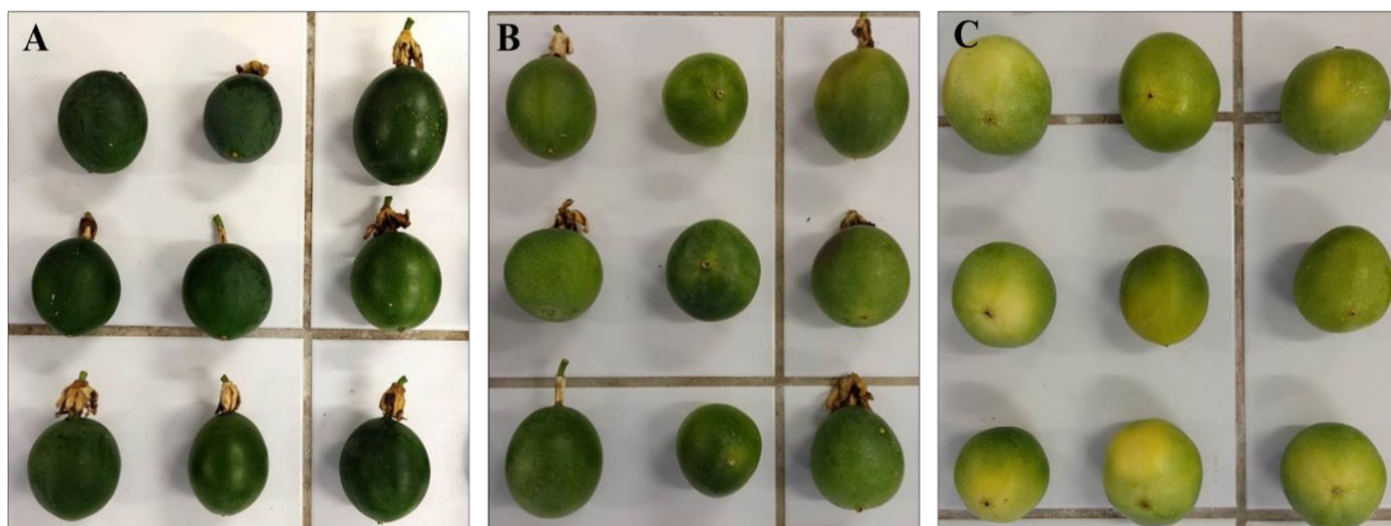


Figure 1. Ripening stages of *Passiflora cincinnata* fruit. Stage I (A), stage II (B), and stage III (C).

Experimental procedures

The fruits were washed in running water and sanitized in a sodium dichloroisocyanurate solution (2 g L^{-1} of water) for five min, and then dried at room temperature for 15 min. The fruits were then stored on sanitized and disinfected tables, with a temperature of $24 \text{ }^{\circ}\text{C} \pm 2 \text{ }^{\circ}\text{C}$ and a relative humidity of $55\% \pm 5\%$.

Physical analysis of the fruit

The pulp with seeds was extracted from the fruit and filtered through a 1 mm polyester sieve. The fresh masses of the fruit, pulp (with and without seeds), and peel, and the volume of the seedless pulp, were evaluated.

The transverse and longitudinal diameters of the intact fruit and the transversal and longitudinal inner cavity diameters were measured. Fruit shape was determined from the ratio of longitudinal to transversal outer diameter [8]. The firmness was measured on the opposite sides of the fruit, at the equatorial region with a penetrometer (PCE-PTR 200 - 3 mm tip), with results expressed in Newtons (N).

Physicochemical analysis of the pulp

Moisture and ash content

Pulp moisture was determined by the difference between fresh samples of 5 g and samples of the same weight dehydrated in a forced air circulation oven (Solab, SL-101) at $105 \text{ }^{\circ}\text{C}$ until constant mass was reached. A 5 g sample of the pulp was carbonized in a muffle furnace (LUCA-2000G/DI), gradually increasing the temperature to $550 \text{ }^{\circ}\text{C}$ to determine the ash content. The ashes were cooled in a desiccator to room temperature and then weighed on a digital precision balance [9].

pH and concentration of H^{+} ions

The pH was determined in a benchtop digital potentiometer (Digimed DM22), with direct reading of the fruit pulp samples. The pH results were also expressed as mM concentration of $[\text{H}^{+}]$ ions according to the equation: $[\text{H}^{+}] = 10^{-\text{pH}}$.

Soluble solids, titratable acidity, and SS/TA ratio

The pulps were ground and filtered through a layer of cotton cloth, and the soluble solids (SS) content was determined by direct reading in a digital refractometer (HI96801). Titratable acidity (TA) was determined by titrating 3.0 mL of macerated pulp diluted in 47 mL of 0.1 N sodium hydroxide, using 1% phenolphthalein as an indicator. The SS/TA ratio was expressed by the ratio between soluble solids and titratable acidity.

Soluble, reducing, and non-reducing sugars

The content of soluble sugars was determined according to the methodology of Yemm & Willis [10], and reducing sugars by the dinitrosalicylic acid method [11]. These variables were determined by

spectrophotometry (Spectrum SP1105) to be 620 and 540 for soluble and reducing sugars, respectively. Glucose was used as a reference to obtain the standard curve. Non-reducing sugars were the result of the difference between soluble and reducing sugars.

Proteins

Proteins were determined using the method described by Cecchi [12]. For the digestion procedure, 0.2 g of pulp, 1.5 g of catalyst, and 3 mL of H₂SO₄ were added in a test tube. The tube was inserted into a digester at 100 °C, increasing by 50 °C every 30 minutes, until 400 °C was reached. The samples remained in the hood until they reached room temperature. For the distillation procedure, 5 mL of water and two drops of phenolphthalein were added. Afterwards, the sample was transferred to a distiller, adding 63% NaOH until the medium was alkalized. In an Erlenmeyer flask, 10 mL of boric acid (2%), 4 drops of methyl orange, and 6 drops of bromocresol green were placed. Distillation was performed until 50 mL was reached in the Erlenmeyer flask. Titration of the distillate proceeded with a 0.1 M hydrochloric acid solution.

Bioactive compound analysis

Ascorbic acid

Ascorbic acid contents were determined by titrating 0.5 g of each sample diluted in 49.5 mL of oxalic acid (5%), followed by titration against 2,6 dichlorophenolindophenol solution (0.2%) [9].

Total chlorophyll and carotenoids

These variables were determined by the method proposed by Lichtenthal [13]. An extract was produced from the maceration and dilution of 0.2 g of pulp, 0.2 g of calcium carbonate, and 5 mL of 80% acetone, in a dark environment. The extract was placed in a refrigerated centrifuge (CT-500R) at 10 °C and 8.8 x 10³ g for 10 minutes. The supernatant was read in a spectrophotometer (Spectrum SP1105) at 663 and 646 nm (total chlorophylls) and 470 nm (total carotenoids).

Flavonoids and anthocyanins

The content of flavonoids and anthocyanins was determined according to the method described by Francis [14]. An extract was produced from maceration and dilution of 0.5 g of pulp in 10 mL of ethanol/HCl 1.5 N (85:15) in a dark environment, followed by refrigerated resting for 24 hours. The extract was centrifuged at 3500 rpm at 10 °C for 10 minutes. The supernatant was read in a spectrophotometer (Spectrum SP1105) at 374 nm for flavonoids and at 553 nm for anthocyanins.

Phenolic compounds

The phenolic compounds were determined from the Folin-Ciocalteu method [15], with modifications. Extract was prepared by maceration and dilution of 3 g of sample in 50 mL of distilled water, with subsequent resting for 30 minutes. A solution containing 500 µL of the pulp, 1,625 µL of distilled water, and 125 µL of Folin-Ciocalteu reagent was prepared in test tubes, which were shaken (NI 1107 shaker) and left to stand for five minutes. Then 250 µL of sodium carbonate (20%) was added, further shaking was performed, and the tubes were incubated in a thermostatic bath (HM 0128) at 40 °C for 30 minutes. The contents of phenolic compounds were quantified by reading the resulting solution in a spectrophotometer (Spectrum SP 1105) at 765 nm, using gallic acid as a reference.

Statistical analyses

The data was subjected to the analysis of variance (ANOVA) and, when significant effects were noted by the F test ($p < 0.05$), Tukey test ($p < 0.05$) was applied. Statistical procedures were performed using the R program [16].

RESULTS

The pulp yield with seeds, seedless pulp volume, transversal inner cavity diameter, fruit shape, and firmness of the fruit were different at different ripening stages. The peel fresh mass decreased (22.73%) with the advancing fruit ripening stage, as did the longitudinal fruit diameter (11.11%), shape (15.52%), and firmness (83.31%) of the fruit at stage III (Table 1).

Table 1. Physical analysis of the pulp of *Passiflora cincinnata* fruits harvested at different ripening stages

Variables	Stage I	Stage II	Stage III	CV (%)
Pulp yield with seeds, g	37.90 ± 2.15 b	46.60 ± 2.11 a	42.80 ± 2.20 ab	19.69
Pulp yield without seeds, g	17.10 ± 1.10 a	20.59 ± 1.47 a	19.82 ± 0.94 a	23.25
Pulp volume without seeds, mL	13.48 ± 0.98 b	16.33 ± 1.28 a	16.26 ± 0.82 a	15.89
Peel fresh mass, g	26.49 ± 1.87 a	23.37 ± 1.17 ab	20.47 ± 1.50 b	25.50
Peel thickness, mm	3.89 ± 0.29 a	3.69 ± 0.16 a	3.52 ± 0.20 a	23.92
Longitudinal fruit diameter, mm	57.81 ± 1.38 a	54.91 ± 0.92 ab	51.39 ± 1.19 b	8.34
Transversal fruit diameter, mm	49.91 ± 0.73 a	52.22 ± 0.61 a	52.25 ± 1.02 a	6.10
Fruit shape	1.16 ± 0.02 a	1.05 ± 0.02 b	0.98 ± 0.02 b	9.11
Longitudinal inner cavity diameter, mm	38.38 ± 1.05 a	39.46 ± 1.26 a	37.80 ± 1.39 a	12.50
Transversal inner cavity diameter, mm	37.78 ± 0.89 b	40.64 ± 0.68 a	39.33 ± 0.89 ab	8.20
Firmness, N	34.94 ± 0.36 a	17.60 ± 1.16 b	5.83 ± 0.48 c	15.09

Means ± standard deviation followed by the same letter, on the line, do not differ by Tukey test ($p < 0.05$). CV: coefficient of variation.

Seedless pulp yield, peel thickness, transversal fruit diameter, and longitudinal inner cavity diameter of the fruit were not affected by ripening stages (Table 1). However, in the pulp yield with seeds, there were differences between the stages of ripening, with the lowest value presented in stage I, while the pulp yield in stages II and III had increases of 22.95% and 12.92%, respectively. The pulp volume also increased by 17.09% in relation to stages I and III.

The pH, H^+ ion concentration, soluble solids, titratable acidity, SS/TA ratio, reducing sugars, non-reducing sugars, soluble sugars, and proteins had differences regarding the ripening stages. Pulp moisture and ash content were not affected by the stage of fruit ripening (Table 2).

Table 2. Physicochemical analysis of the pulp of *Passiflora cincinnata* fruits harvested at different ripening stages

Variables	Stage I	Stage II	Stage III	CV (%)
Moisture, %	87.85 ± 0.22 a	88.43 ± 0.40 a	87.79 ± 0.12 a	0.70
Ashes, %	0.30 ± 0.052 a	0.31 ± 0.006 a	0.31 ± 0.006 a	22.36
pH	3.09 ± 0.01 c	3.60 ± 0.03 b	3.74 ± 0.02 a	0.67
H^+ ion concentration, μM	817.90 ± 81.79 a	251.01 ± 25.10 b	180.54 ± 18.05 c	4.61
Soluble solids, %	12.80 ± 0.16 b	13.29 ± 0.13 ab	13.52 ± 0.58 a	2.68
Titratable acidity, %	6.07 ± 0.15 a	5.35 ± 0.22 b	5.04 ± 0.15 b	7.36
SS/TA ratio	2.11 ± 0.14 b	2.50 ± 0.22 a	2.69 ± 0.27 a	8.79
Reducing sugars, mg 100 g ⁻¹	1.73 ± 0.03 c	2.05 ± 0.02 b	2.45 ± 0.09 a	6.75
Non-reducing sugars, mg 100 g ⁻¹	5.13 ± 0.16 c	7.44 ± 0.27 b	9.35 ± 0.30 a	7.76
Soluble Sugars, mg 100 g ⁻¹	6.86 ± 0.14 c	9.49 ± 0.28 b	11.80 ± 0.27 a	5.85
Proteins, %	0.36 ± 0.006 a	0.29 ± 0.005 b	0.29 ± 0.013 b	6.50

Means ± standard deviation followed by the same letter, on the line, do not differ by Tukey test ($p < 0.05$). CV: coefficient of variation.

The pH increased by 17.38% with the increasing ripening from stage I to III of the fruit, while the concentration of H^+ ions decreased (73.93%) with advancing stages. Soluble solids content, SS/TA ratio, reducing, non-reducing, and total sugars increased with the advancing ripening stage (5.33, 21.56, 29.39, 45.13, and 41.86%, respectively), while titratable acidity and protein content decreased (16.97 and 19.44%, respectively) (Table 2).

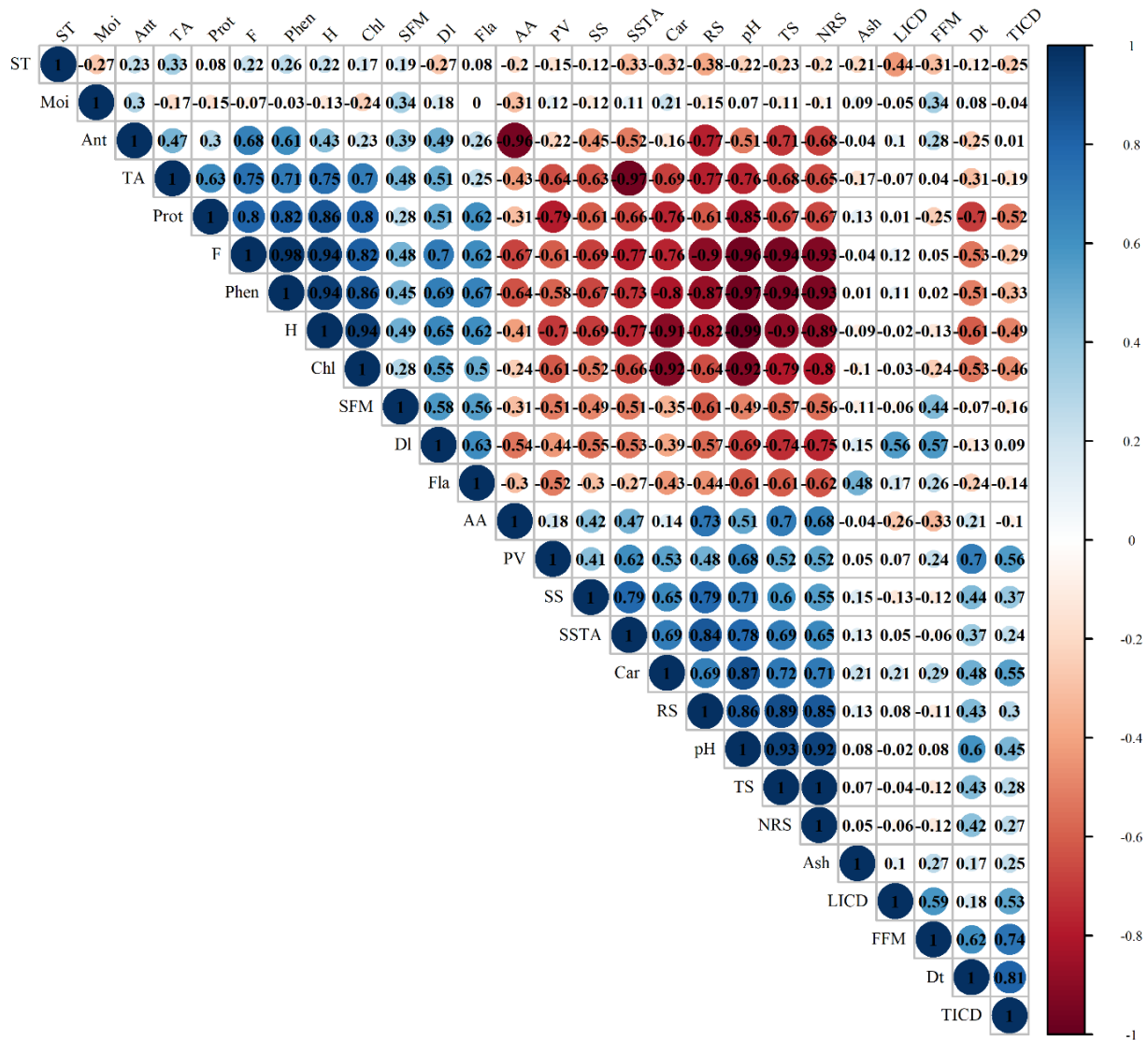
All bioactive components evaluated, except the flavonoid and carotenoid contents, were affected by the ripening stages of the fruit. The ascorbic acid content increased by 33.66% between ripening stages I and III. The content of chlorophylls, anthocyanins, and phenolic compounds decreased (47.52, 13.88, and 30.75%, respectively) (Table 3).

Table 3. Bioactive components of the pulp of *Passiflora cincinnata* fruits harvested at different ripening stages

Variables	Stage I	Stage II	Stage III	CV (%)
Ascorbic acid, mg 100 g ⁻¹	8.71 ± 0.24 b	7.60 ± 0.03 c	13.13 ± 0.07 a	3.35
Total chlorophyll, mg 100 g ⁻¹	1.01 ± 0.02 a	0.48 ± 0.04 b	0.53 ± 0.03 b	11.93
Carotenoids, mg 100 g ⁻¹	0.00 ± 0.004 a	0.06 ± 0.009 a	0.03 ± 0.007 a	17.81
Flavonoids, mg 100 g ⁻¹	10.08 ± 0.54 a	8.88 ± 0.30 a	8.68 ± 0.19 a	9.23
Anthocyanins, mg 100 g ⁻¹	0.72 ± 0.01 a	0.82 ± 0.03 a	0.10 ± 0.05 b	13.94
Phenolic compounds, mg 100 g ⁻¹	75.67 ± 1.08 a	60.78 ± 1.14 b	52.40 ± 0.55 c	3.42

Means ± standard deviation followed by the same letter, on the line, do not differ by Tukey test ($p < 0.05$). CV: coefficient of variation.

The variables of the first group, including anthocyanin content (Ant), titratable acidity (TA), protein (Prot), firmness (F), phenolic compounds (Phen), H⁺ ions (H), chlorophylls (Chl), and flavonoids had positive correlations with each other. The second group, formed by ascorbic acid (AA) content, pulp volume (PV), soluble solids (SS), SS/TA ratio (SS/TA), carotenoids (Car), pH, reducing sugars (RS), non-reducing sugars (NRS) and total sugars (TS) also correlated positively. The first group was negatively correlated with the second group (Figure 2). Transversal fruit diameter (Dt) and transversal inner cavity diameter (TICD) were negatively correlated with the first group and positively correlated with the second group.

**Figure 2.** Pearson's correlation for the analyzed variables of the pulp of *Passiflora cincinnata* fruits harvested at different ripening stages.

DISCUSSION

Advances in the fruit ripening stage influenced pulp yield with seeds, pulp volume, transversal inner cavity diameter, fruit shape, and firmness of *P. cincinnata* fruits (Table 1). In another study with two *P. cincinnata* genotypes, an increase in the yield of seeded pulp was also observed during advances in the fruit ripening stage [17].

The longitudinal fruit diameter diminished with increasing ripening stages, and this may be due to genetic factors and the soil and climate conditions of the region where the plants were grown. Reduction in fruit diameters with increasing ripening stages is common in passion fruit, as observed in *P. cincinnata* [1], mainly due to water loss and decreased peel firmness (Table 1). Fruit shape was highest in fruits harvested at stage I, decreasing with the advancing ripening stage, and this indicates that the fruits were more oval shaped at the first stage, and as ripening progressed, they approached a more rounded shape [1].

Fruit firmness decreased with increasing ripening stage. This reduction in firmness occurs mainly due to the degradation of polysaccharides in the cell wall, such as pectins, which promote consistency in the peel [18,19].

Pulp moisture was not affected by the stages of fruit ripening (Table 2), a trait which can be very useful in postharvest storage processes, since rapid water loss is one of the main factors responsible for decreasing the quality of passion fruit [20]. The ash content was also not altered by the stages of ripening. The moisture content ranged between 87.75 and 88.43%, values similar to those found by Carvalho and coauthors [21] (85.4-87.7%) and by Bomtempo and coauthors [22] (85.6-87.9%) in *P. setacea*.

The pH increased and the H^+ ion concentration decreased with advancing fruit ripening stages (Table 2). These results were consistent with the fruit pH data, because the lower the pH of a substance, the higher the concentration of H^+ ions. This behavior is typical of some acidic tropical fruits, due to the increased synthesis of organic acids during ripening [23]. In ripe fruits of *P. cincinnata*, pH similar to that of this work (between 3.09 and 3.74) was also observed [24].

The soluble solids content of the *P. cincinnata* fruits analyzed ranged between 12.80 and 13.52%. This characteristic indicates the amount of solids that are dissolved in the juice or fruit pulp, of which, between 65 and 85% correspond to sugars. This variable increased with the advance of the ripening stage, and normally it tends to increase with ripening [25]. According to Brazilian legislation, commercial yellow passion fruit should have pulp with a soluble solids content above 11% and a pH between 2.7 and 3.8 [26]. Based on these two quality parameters, the *P. cincinnata* fruits analyzed are within the Brazilian commercialization standards. The soluble solids behavior observed in this study was evidenced by the soluble sugars, which also increased with advancing ripening. These results indicate that most of the soluble solids present in the fruit of *P. cincinnata* are soluble sugars, and that the advancement of ripening promotes the accumulation of these compounds.

The titratable acidity decreased with the advancement of the ripening stages. These results are inverse to that of pH, which increased with the advancement of the ripening stage of *P. cincinnata* fruits. This is related to the fact that acidity decreases with advancing ripening and, consequently, pH increases [25]. Reduction of titratable acidity with the course of the ripening process was observed in *P. edulis* fruit [27].

The SS/TA ratio decreased with the advance of the fruit ripening stage (Table 2). This variable evaluates the sweet or acid nature of the pulp, which characterizes the taste of the fruits. This variable is one of the most practical ways to assess fruit flavor, so when acidity increases, the SS/TA ratio decreases, and when acidity decreases, the SS/TA ratio increases [28]. The results of this study indicate that with ripening, the relation between sugars and organic acids in the pulp was increased, thus increasing the sweet taste of *P. cincinnata* fruits. The SS/TA ratio values are quite variable in passion fruit due to the great genetic variability existing between species and varieties, which makes it difficult to establish an ideal value. In *P. cincinnata*, D'Abadia and coauthors [17] observed SS/TA values, in fruits in the final ripening stages (60 to 120 days after anthesis), ranging between 2.20 and 2.70, depending on the genotype used. In *P. alata*, Alexandre and coauthors [28] found SS/TA values ranging between 2.57 and 5.64, when evaluating 33 genotypes of this species.

Reducing sugars are monosaccharides, such as glucose and fructose, which have free carbonyl and ketone groups and can be oxidized by oxidizing agents in alkaline solutions [29]. In this study, the content of reducing sugars in the pulp of *P. cincinnata* increased with the advancement of the fruit ripening stage (Table 2). These results indicate that fruits harvested before maturity did not have total accumulation of reducing sugars, as was also reported in *P. edulis* [5].

Non-reducing sugars, in turn, are disaccharides that need to undergo hydrolysis of the glycosidic bond to oxidize, like sucrose [29]. In this research, the non-reducing sugars in the pulp of *P. cincinnata* were lower in the first ripening stage, increasing as the stages advanced (Table 2). This behavior is related to the

increase of sugars (glucose, fructose and sucrose) in the pulp occurring during the ripening of *P. cincinnata* fruits, simultaneously with the reduction of acidity, so that the sugars are used as substrates in the respiratory processes [5, 30].

The protein content was reduced with the advance of the fruit ripening stage (Table 2). This behavior is related to the maintenance of proteinase inhibitors in the initial stage of the fruit, as well as the increase in activity of proteinases with the advancement of the fruit development stage, since proteinase inhibitors inhibit the hydrolysis of proteins that accumulate during fruit development by endogenous enzymes [31].

The ascorbic acid content was higher in fruits harvested at the third ripening stage. This acid, which is the reduced form of vitamin C, is naturally present in several foods, especially fruits and vegetables, and is an antioxidant substance of great importance, which can prevent or delay the deleterious effects caused by reactive oxygen species, acting in the prevention of several diseases, such as heart disease, cancer, and diabetes, among others [32]. Silva and coauthors [33], evaluating *P. cincinnata* cv. 'BRS Sertão Forte', also observed an increase in ascorbic acid with fruit ripening. Ascorbic acid ranged from 7.60 to 13.13 mg 100 g⁻¹ (Table 3), having a higher ascorbic acid content than *P. quadrangularis* (7.0 mg 100 g⁻¹), similar to *P. maliformis* (15 mg 100 g⁻¹) [34] and *P. setacea* (10.1 - 17.3 mg 100 g⁻¹) [21].

The total chlorophyll content was highest in the first stage of ripening, diminishing in the subsequent stages (Table 3). The carotenoid content was not affected by the ripening stages. This fact may be due to the carotenoid content of *P. cincinnata* pulp depending on many factors, including the cultivation system, climatic factors, and fruit ripening [35]. In addition, light exposure and temperature also impact carotenoid production [36,37]. Thus, the content of carotenoids in fruits cannot be considered an absolute value. The flavonoid content was not affected by the stages of ripening (Table 3). However, Silva and coauthors [33] found that the total flavonoid content tended to increase with the ripening process.

The anthocyanins content was highest in the first and second stages of ripening, while in the third stage, it had reductions of more than 86% compared to the first two stages of ripening. The color of the fruit pulp is associated with the presence of components such as chlorophylls, carotenoids, yellow flavonoids, and anthocyanins, and as ripening proceeds, the degradation of these pigments results in a reduction of the green color [38].

The content of total phenolic compounds in *P. cincinnata* pulp was highest at stage I of ripening, with reductions in subsequent stages. This reduction in phenolic compounds during ripening can be attributed to the oxidative reactions caused by the enzyme polyphenoloxidase on phenolic compounds, which occur during the ripening process of most fruits [33]. These same authors also found that the content of phenolic compounds was higher in the pulp of *P. cincinnata* fruits at the intermediate stage of ripening and was reduced in fully ripe fruits. Therefore, the content of polyphenols found in passion fruit is an important variable, since phenolic compounds are the group of natural antioxidants and are associated with several benefits for human health, since they act in the protection against cancer, reduction of inflammation, and decrease of LDL cholesterol in the blood [27,38,39].

The correlation between the variables is related to the decrease in pH and the increase in soluble solids and reducing and non-reducing sugars (Figure 2) with increasing fruit ripening due to the hydrolysis of starch and pectin, the synthesis of secondary compounds (such as phenolic compounds and flavonoids), and the reduction of organic acids [2]. The positive correlation between ascorbic acid and sugar contents was due to the common and complex interactions between organic acids and sugars [40].

The results of the correlation analysis provide valuable insights into the postharvest physiology of fruits. The first group, composed of anthocyanin content (Ant), titratable acidity (TA), protein (Prot), firmness (F), phenolic compounds (Phen), H⁺ ions (H), chlorophylls (Chl), and flavonoids, demonstrates a series of positive correlations among these variables. This suggests a significant interdependence among these factors in terms of their effects on fruit post-harvest quality and ripening status. For instance, the positive relationship between anthocyanin concentration (Ant) and the amount of phenolic compounds (Phen) may indicate that these compounds are associated in the coloration and firmness of the fruits. The firmness (F) of the fruits may be directly linked to the presence of proteins (Prot) and the concentration of phenolic compounds (Phen), which play a crucial role in the structural integrity of the tissues. The presence of H⁺ ions (H) may be related to fruit acidity (TA), directly influencing taste and preservation. Additionally, the presence of chlorophyll (Chl) and flavonoids may be associated with fruit color, affecting its visual appeal and sensory quality. These positive correlations indicate that a change in any of these variables can trigger changes in other variables within the first group, which is crucial for understanding the postharvest physiology of fruits.

The second group of variables, including ascorbic acid (AA) content, pulp volume (PV), soluble solids (SS), SS/TA ratio (SS/TA), carotenoids (Car), pH, reducing sugars (RS), non-reducing sugars (NRS), and total sugars (TS), also exhibits positive correlations among themselves. This suggests an interconnectedness

among these variables with significant implications for taste, texture, and nutritional quality of fruits. For example, the concentration of ascorbic acid (AA) may affect pH and the soluble solids/titratable acidity ratio (SS/TA), influencing acidity and taste of the fruits. The presence of sugars, such as reducing (RS) and non-reducing (NRS) sugars, may affect the sweetness of the fruits, while carotenoids (Car) may be related to color. The negative relationship between the first and second groups of variables suggests that the variables in the first group, more related to the chemical composition and firmness of the fruits, tend to oppose the variables in the second group, which are more associated with taste and texture of the fruits. This may indicate a delicate balance in the postharvest physiology of fruits, where optimizing one characteristic may occur at the expense of another. Lastly, the variables related to fruit size, transversal fruit diameter (Dt), and transversal inner cavity diameter (TICD), display negative correlations with the first group and positive correlations with the second group. This may suggest that fruit size and its inner cavity are influenced by different sets of variables. Fruit size may affect the distribution of soluble solids and acids, while the inner cavity may be related to pulp quantity and volume available for components in the second group.

The pulp yield, firmness, soluble solids, SS/TA ratio, and levels of anthocyanins, flavonoids, and phenolic compounds were the main variables used to determine stage II as the ideal harvest stage for *P. cincinnata* fruits. Additionally, it is worth noting that the longer the fruits stay in the field, the higher the risk of pest and disease infestation, as well as increased costs for the producer. Therefore, stage II exhibits the ideal characteristics and is recommended as the optimal harvest stage.

CONCLUSION

Based on the physical and physicochemical characteristics and bioactive compounds analyzed in the *Passiflora cincinnata* pulp, the stage II of ripening stands out as the most promising for *in natura* consumption and elaboration of food products of this fruit.

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