





## New insights into the *Butia capitata* accessions from Cerrado: Physicochemical characterization, antioxidant activity, and phenolic acids profile

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### Abstract

Analyzing the nutritional content of new fruit accessions is necessary to expand our knowledge of Brazilian biodiversity and benefit traditional communities. The aim of this study was to analyze the physicochemical composition of four *Butia capitata* accessions: yellow, orange, pink, and purple. This study examined physical parameters such as mass, length, width, color, and firmness. The physicochemical properties were also evaluated, and the profile of bioactive compounds, antioxidant activity, and phenolic acids was traced for each accession. The yellow accession presented the highest fruit and pulp mass (9.07 g and 5.98 g, respectively), with greater brightness ( $L^* = 66.51$ ) but lower total flavonoid content (2.75 mg QE/100 g). In contrast, the purple accession had a lower pulp mass (2.04 g) and less brightness ( $L^* = 35.83$ ). In return, it obtained a higher total flavonoid content (10.76 mg QE/100 g) and the highest levels of lipids, proteins, ash, and carbohydrates. Principal component analysis revealed that the pink accession exhibited the highest levels of syringic acid, whereas the purple accession was characterized by high levels of caffeic, vanillic, ferulic, and salicylic acids. The study revealed phenotypic diversity in *B. capitata* genotypes and identified characteristics of accessions that can be prioritized for future research programs.

**Keywords:** Arecaceae; Brazilian savanna; carotenoids; native fruit; vitamin C.

**Practical Application:** This study aids in identifying beneficial native fruits for conservation and nutrition.

## 1 INTRODUCTION

The Brazilian Cerrado is a biome with distinct edaphoclimatic characteristics compared to other vegetation domains. In response to environmental seasonality, Cerrado species have developed various natural protection mechanisms to ensure survival (Procópio & Barreto, 2021). According to Reis and Schmiele (2019), the defense mechanisms of these plants impart unique characteristics to the fruits of the region, distinguishing them from those of other areas of Brazil. However, in the Cerrado biome, there are still unexplored or poorly researched food species with limited information on their physical, chemical, and nutritional properties (Santos et al., 2024).

Among the various fruits restricted to the Cerrado, *Butia capitata*, locally known as “coquinho-azedo,” represents an important source of income for many agro-extractivist families, who sell the fruits in their natural state and as processed products (Faria et al., 2011; Fonseca et al., 2007). This species is at risk of extinction (Centro Nacional de Conservação da Flora, 2012) and is still in the early stages of being domesticated (Dias et al., 2022). Additionally, *B. capitata* has a promising composition, such as iron, manganese, copper, carotenoids, phenolic compounds, and unsaturated fatty acids (Faria et al., 2011; Lopes et al., 2012; Nascimento et al., 2020). In addition to

their functional potential, some of these bioactive compounds are natural pigments responsible for the color of fruits. Color differences may indicate varying chemical compositions that directly influence the bioactivity of the fruit (Sharma et al., 2021).

Studies have shown high phenotypic diversity in *B. capitata* fruits, influenced by environmental and genetic factors (Magalhães et al., 2017; Souza et al., 2023). This high variability is related to quantitative traits, such as the number of fruits in the bunch and fruit size, and some qualitative traits, such as rachis color and fruit color and shape (Souza et al., 2023). According to Schulz et al. (2020), as there are variations within the same species, identifying and characterizing fruits and their functional compounds is highly relevant and contributes to establishing diversity between species and determining their potential for use.

The literature on *Butia* spp. contains valuable information, but many aspects remain unexplored (Hoffmann et al., 2014). Researching and describing the nutritional composition of fruits from new accessions promotes the expansion of knowledge about Brazilian biodiversity and benefits traditional communities by valuing and expanding the potential for trade in products, contributing to food sovereignty. This study aimed to analyze the physicochemical composition of four *B. capitata* accessions.

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## 1.1 Relevance of the work

The Cerrado biome harbors diverse native plants that serve as vital food sources for wildlife and local communities. While these native fruits are traditionally harvested, many remain understudied or undiscovered. In this groundbreaking research, we present the first comprehensive analysis of phenolic acids in *Butia capitata* fruits with varying epicarp colors, examining four distinct accessions from the Cerrado biome. Our findings reveal significant variations in the physicochemical profiles among these *B. capitata* accessions, with the purple accession demonstrating particularly high levels of bioactive compounds. This novel investigation into the relationship between epicarp color and phenolic acid composition provides valuable insights into this understudied species.

## 2 MATERIAL AND METHODS

### 2.1 Fruit collection

Inflorescence (fruit bunch) of four accessions of the *Butia capitata* (Figure 1), with full physiological maturity, was collected from a native population in the municipality of Mirabela, Minas Gerais, Brazil (16° 17' 20" S, 44° 9' 2" W). These fruits were packed in polyethylene boxes and transported to the Federal University of Minas Gerais, in the city of Montes Claros, 65 km away. To obtain uniform batches, fruits with intact skin, without deformities or injuries, were selected. Subsequently, the fruits were sanitized by immersion in chlorine solutions at 100 ppm for 10 min, and after this step, they were used for physical-chemical and biometric analysis.

### 2.2 Biometric analysis

Fruit biometry was determined using four replicates of five fruits for each phenotype. The transversal and longitudinal diameter (TD and LD) measurements were taken with the aid of a digital caliper (Western, Brazil) and expressed in millimeters (mm). The fruits were manually cut using a stainless-steel knife to separate the epicarp, mesocarp, and pyrene (Figure 1 – Supplementary material). The pyrene was then placed in an oven at 40°C for 72 h. Afterward, it was fractionated with the help of a hammer to obtain the endocarp and almond (Figure 1 – Supplementary material). The weights of the whole fruit and its fractions were determined using a semi-analytical balance (Shimadzu, Brazil), and the results were expressed in grams (g).

### 2.3 Quality attributes measurement

The pH, titratable acidity (TA), and soluble solids (SS) were determined according to Association of Official Analytical Chemists (AOAC, 2016). For these analyses, the samples were ground and homogenized in a 1:10 ratio (5 g of fruit in 45 mL of deionized water) in a mixer, and the filtrates were used. The filtrate's pH was determined by direct reading in a digital potentiometer (Del Lab, DLA-pH). The TA was obtained by titrating 10 mL of the filtrate with 0.1 N sodium hydroxide solution, phenolphthalein solution was used as an indicator, and the results were expressed as % succinic acid. SS content

was determined in a portable refractometer (RT-30ATC), and results were expressed as °Brix. Firmness was determined by the flattening method described by Ventura et al. (2022), with the results expressed in N/cm<sup>2</sup>. The color coordinates (CIE L\*, a\*, b\*) were determined at four different points of the fruit using a Konica Minolta CR-400 Colorimeter. The hue and chroma parameters were calculated from a\* and b\* values, with hue as  $\tan^{-1}(b^*/a^*)$  and chroma as  $(a^* + b^*)^{1/2}$ .

### 2.4 Centesimal composition analysis

The proximate composition was determined according to AOAC (2016). Moisture and ash content were determined by the 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. Carbohydrate was calculated using the ratio: carbohydrates = 100 - (moisture + lipids + crude protein + ash).

### 2.5 Determination of total phenolics, flavonoids, and antioxidant activity

The extracts were obtained according to the method described by Souza et al. (2012), with slight modifications. Briefly, 5 g (3 g of pulp + 2 g of peel) of the macerated *B. capitata* were added to centrifuge tubes and extracted sequentially with 10 mL of methanol/water (50:50, v/v) at room temperature (25 °C) for 1 h. The tubes were centrifuged at 5,200 × g at room temperature for 10 min, and the supernatants were recovered. Then, 10 mL of acetone/water (70:30, v/v) was added to the pellet at room temperature. The samples were extracted for 1 h and centrifuged again under the same conditions as before. The methanol and acetone extracts were used to determine phenolic and flavonoid contents, and antioxidant activity as miniaturized methodologies proposed by Cacique et al. (2021), as follows.

#### 2.5.1 Total phenolic content determination

A sample or standard reference solution (40 µL) was homogenized by vortexing with 400 µL of 10% (v/v) Folin-Ciocalteu reagent, 400 µL 7% (w/v) Na<sub>2</sub>CO<sub>3</sub>, and 160 µL of ultrapure water for 1 min. The reaction mixture was incubated in the dark at room temperature for 90 min, and its absorbance was measured spectrophotometrically at 750 nm. A calibration curve was prepared using a gallic acid solution (1.0–8.0 mg/L). Results were expressed as mg of gallic acid equivalent per 100 g of sample (mg GAE/100 g).

#### 2.5.2 Total flavonoid content determination

Briefly, a reaction mixture of 100 µL of the sample extract or the standard reference solution, 50 µL of 5% (w/v) aluminum chloride solution, and 850 µL of methanol was prepared in an amber flask. The reaction mixture was homogenized, left undisturbed for 30 min, and then analyzed in an absorption spectrophotometer in the UV-vis region at 425 nm. Quercetin

dissolved in methanol was used as the reference standard in the concentration range of 1.0–12.0 mg/L to obtain the calibration curve. The results were expressed as mg quercetin equivalent per 100 g of the sample (mg QE/100 g).

### 2.5.3 Antioxidant activity determination

For 2,2-diphenyl-1-picrylhydrazyl (DPPH) determination, 25 mL of solution was first prepared by dissolving 4.0 mg of DPPH in methanol. The obtained solution was diluted twice with methanol:water (80:20, v/v) to get the working solution with an absorbance of  $1.1 \pm 0.02$  at 515 nm. Next, an aliquot of 830  $\mu\text{L}$  of the working solution was placed in tubes and mixed with 170  $\mu\text{L}$  of the extract or the standard reference solution. The reaction mixture was left undisturbed for 45 min and then analyzed in an absorption spectrophotometer in the UV–vis region at 515 nm. To obtain the calibration curve, Trolox dissolved in methanol was used as the reference standard in the concentration range of 1.0–7.0 mg/L. The results were expressed in mg Trolox equivalent per 100 g of sample (mg TE/100 g).

For ABTS determination, first, a stock solution containing ABTS was prepared by mixing 25 mL of 2.4 mmol/L potassium persulfate solution and 25 mL of 7 mmol/L ABTS solution in ultrapure water, and the resultant mixture was homogenized and left undisturbed in the dark for 16 h to allow the formation of  $\text{ABTS}^{\bullet+}$ . This solution with  $\text{ABTS}^{\bullet+}$  was diluted 50 times with methanol:water (80:20, v/v) mixture until a working solution with an absorbance of  $0.7 \pm 0.02$  at 734 nm was obtained. Next, an aliquot of 990  $\mu\text{L}$  of the working solution was placed in tubes and mixed with 10  $\mu\text{L}$  of the extract or the standard reference solution. The reaction mixture was analyzed in an absorption spectrophotometer in the UV–vis region at 734 nm. Trolox was used as the reference standard in the concentration range of 0.25–5.0 mg/L to obtain the calibration curve. The results were expressed in mg Trolox equivalent per 100 g of sample (mg TE/100 g).

For ferric chloride reduction power (FRAP) determination, first, a TPTZ stock solution with a concentration of 10 mmol/L in 40 mmol/L hydrochloric acid, a buffer solution of 300 mmol/L sodium acetate, and a 20 mmol/L solution of ferric chloride were prepared in ultrapure water. These three solutions were mixed in the ratio 1:10:1 (v/v/v), and the resultant mixture was homogenized and left undisturbed for 3 h in a water bath at 37°C, producing the working solution. Next, an aliquot of 900  $\mu\text{L}$  of the TPTZ working solution was placed in tubes and mixed with 30  $\mu\text{L}$  of the extract or the standard reference solution and 90  $\mu\text{L}$  of the ultrapure water. The reaction mixture was left undisturbed for 45 min at 37°C and then analyzed in an absorption spectrophotometer in the UV–vis region at 593 nm. Trolox was used as the reference standard in the concentration range of 1.0–7.0 mg/L to obtain the calibration curve. The results were expressed in mg Trolox equivalent per 100 g of sample (mg TE/100 g).

### 2.6 Total carotenoid content determination

The extraction of total carotenoids was carried out according to Carbonell-Capella et al. (2015), with slight modifications.

The sample (200 mg) was homogenized with 5 mL of extracting solvent (hexane/acetone/ethanol, 50:25:25, v/v/v) and centrifuged at  $4,500 \times g$  for 5 min at 4 °C. The top layer of hexane containing the color was recovered and transferred to a 25 mL volumetric flask. The volume recovered was then adjusted to 25 mL with hexane. The total carotenoid determination was carried out on an aliquot of the hexane extract by measuring the absorbance at 450 nm. The extinction coefficient used was of  $\beta$ -carotene,  $E^{1\%} = 2505$ . The results were expressed in mg  $\beta$ -carotene per 100 g of sample.

### 2.7 Determination of ascorbic acid content

The ascorbic acid content was quantified using Tillmans' titration method, which was described by Araújo et al. (2021). In short, 1 g of fruit was homogenized with 50 mL of 1% oxalic acid (v/v). The solution was quickly titrated using 2,6-dichlorophenolindophenol until the pink color was held for 15 s. The ascorbic acid concentrations were expressed as milligrams per 100 g of sample.

### 2.8 Determination of phenolic acids

The chemical composition of phenolic acids obtained from fruit extracts (obtained in item 2.5) was determined according to Cacique et al. (2020), with slight modifications. Before performing the main gas chromatography coupled to mass spectrometry (GC-MS) analysis, a derivatization step was required. The derivatization of the extracts involved mixing 600  $\mu\text{L}$  of the extract, 100  $\mu\text{L}$  of BSTFA, and 60  $\mu\text{L}$  of anhydrous pyridine in a conical flask, followed by shaking and heating to 50°C for 30 min. Subsequently, the reaction mixture was transferred to an injection vial with an insert and subjected to GC-MS analysis. Chromatographic analysis was performed on an Agilent Technologies gas chromatography system (GC 7890A) coupled to an Agilent Technologies (Australia) mass detector (MS5975C), using helium as a carrier gas at a rate of 1.0 mL  $\text{min}^{-1}$ . The sample (1.0  $\mu\text{L}$ ) was injected into the chromatography column using an auto-injector (CTC combiPaL) in splitless mode. The injector was maintained at 250°C. The capillary column used was DB-5MS (30 m  $\times$  0.25 mm  $\times$  0.25  $\mu\text{m}$ ; Agilent Technologies). Initially, the GC oven was at 100 °C, after which it was heated at the rate of 10°C/min, and then gradually heated up to 300 °C. The oven temperature was maintained at 300 °C for 2 min. The interface temperature was maintained at 280°C, and the electron impact ionization at 70 eV. The phenolic compounds in the extracts were identified by comparing the standard mass spectra with the apparatus library (NIST 2.0). The selected ions were:  $m/z$  135, 267, 268 (salicylic acid);  $m/z$  267, 297, 312 (vanillic acid);  $m/z$  312, 327, 342 (syringic acid);  $m/z$  281, 443, 458 (gallic acid);  $m/z$  338, 381, 396 (ferulic acid); and  $m/z$  219, 381, 396 (caffeic acid). The results of quantifying phenolic acids in the extracts using GC-MS were investigated with multivariate analysis.

### 2.9 Statistical analysis

Results are expressed as mean  $\pm$  standard error. This experiment was based on a completely randomized design with four independent replicates. The one-way analysis of variance (ANOVA) was performed to compare the variables, and the

Tukey test was used to calculate significant differences at  $p \leq .05$ . Standardized data of phenolic acids were subjected to principal component analysis (PCA). Data analysis was performed using Statistica software version 10.0 (StatSoft, USA).

### 3 RESULTS AND DISCUSSION

#### 3.1 Biometric characteristics

The accessions showed significant diversity in biometric attributes ( $p \leq .05$ ), except for epicarp weight (Table 1). The differences between the longitudinal diameters were smaller (8%,  $24.69 \times 22.75$  mm) than the differences in the transversal diameters because the yellow fruits were approximately 20% wider than the purple fruits ( $23.71 \times 18.95$  mm). The accession with the yellow color had the highest values for fruit and pulp masses, but it had lower values than the other accessions for the almond mass. The opposite behavior was observed in the purple accession, with higher almond and pyrene values. In all accessions, the mesocarp constituted the largest portion of the fruit, accounting for approximately 66% of the total fruit mass in the yellow accession. Thus, the yellow accession pulp yield was almost double that of the purple accession (34%). A high pulp yield is a physical attribute relevant to the commercial and agro-industrial use of the fruit, as the pulp is widely used for fresh and processed consumption (Souza et al., 2023).

In turn, larger pyrenes are linked to plants with higher germination rates, improved development, and greater vigor

(Silva & Scariot, 2013). Therefore, based on data shown in Table 1, we can characterize the fruits of *B. capitata* as oval and small, biometrically similar to those observed by Barbosa et al. (2021) and the congeneric species *B. purpurascens* (Rocha et al., 2022). In general, because the samples obtained come from the same region, it can be inferred that a significant portion of the observed phenotypic variability is due to the genetic factors of the species, which reduces the impact of the environment (Souza et al., 2023).

#### 3.2 Physicochemical evaluations

Physicochemical parameters (pH, SS, and firmness) in Table 2 were consistent among accessions ( $p > .05$ ), except for TA, in which there was a difference of over 39% between the purple and other accessions. Previous research has shown that variations in these parameters may be linked to the location of the sample (Magalhães et al., 2017; Souza et al., 2023). However, in our case, the discrepancies in some physicochemical results between the accessions were due to genetic factors (Souza et al., 2023), since both accessions were obtained from the same geographic region. Furthermore, we highlight that our TA results were expressed as a percentage of succinic acid rather than citric acid, as the former was reported as the predominant acid in *B. capitata* (Fonseca et al., 2021). The pH values obtained from the ripe fruits of *B. capitata* ranged from 3.31 to 3.55, classifying them as very acidic fruits, as well as *Psidium guineense* Swartz and *Spondias mombin* L. fruits (Schiassi et al., 2018). The observed SS content of *B. capitata* is in agreement

**Table 1.** Biometric characteristics of four accessions of *Butia capitata* fruits.

Parameter	Accessions			
	Yellow	Orange	Pink	Purple
Transversal diameter (mm)	23.71 ± 0.27 <sup>a</sup>	21.10 ± 0.45 <sup>b</sup>	21.00 ± 0.27 <sup>b</sup>	18.95 ± 0.28 <sup>c</sup>
Longitudinal diameter (mm)	24.69 ± 0.33 <sup>a</sup>	23.84 ± 0.26 <sup>ab</sup>	23.84 ± 0.36 <sup>ab</sup>	22.75 ± 0.23 <sup>b</sup>
Whole fruit (g)	9.07 ± 0.23 <sup>a</sup>	7.17 ± 0.23 <sup>b</sup>	6.51 ± 0.16 <sup>bc</sup>	6.02 ± 0.13 <sup>c</sup>
Pulp (g)	5.98 ± 0.19 <sup>a</sup>	3.27 ± 0.15 <sup>b</sup>	3.38 ± 0.09 <sup>b</sup>	2.04 ± 0.09 <sup>c</sup>
Epicarp (g)	0.92 ± 0.04 <sup>a</sup>	0.97 ± 0.09 <sup>a</sup>	0.92 ± 0.03 <sup>a</sup>	1.15 ± 0.07 <sup>a</sup>
Pyrene (g)	1.50 ± 0.05 <sup>b</sup>	1.67 ± 0.08 <sup>b</sup>	1.63 ± 0.06 <sup>b</sup>	2.09 ± 0.08 <sup>a</sup>
Almond (g)	0.27 ± 0.01 <sup>c</sup>	0.38 ± 0.02 <sup>bc</sup>	0.44 ± 0.03 <sup>b</sup>	0.64 ± 0.04 <sup>a</sup>

Means ± standard error in the same row followed by different lowercase letters indicate statistically significant differences at  $p \leq .05$ , according to the Tukey test ( $n = 4$ ).

**Table 2.** Physical–chemical characteristics of four accessions of *Butia capitata* fruits.

Parameter	Accessions			
	Yellow	Orange	Pink	Purple
pH	3.31 ± 0.03 <sup>b</sup>	3.31 ± 0.03 <sup>b</sup>	3.45 ± 0.05 <sup>ab</sup>	3.55 ± 0.04 <sup>a</sup>
TA (% succinic acid)	1.90 ± 0.12 <sup>a</sup>	1.92 ± 0.09 <sup>a</sup>	1.68 ± 0.04 <sup>a</sup>	1.02 ± 0.04 <sup>b</sup>
SS (°Brix)	9.50 ± 0.71 <sup>a</sup>	8.38 ± 0.24 <sup>a</sup>	9.13 ± 0.66 <sup>a</sup>	7.67 ± 0.17 <sup>a</sup>
Firmness (N/cm <sup>2</sup> )	13.60 ± 0.78 <sup>a</sup>	11.18 ± 0.65 <sup>a</sup>	11.35 ± 0.74 <sup>a</sup>	11.88 ± 0.70 <sup>a</sup>
L*	66.51 ± 0.60 <sup>a</sup>	64.06 ± 0.17 <sup>b</sup>	50.67 ± 0.53 <sup>c</sup>	35.83 ± 0.46 <sup>d</sup>
Chroma	48.65 ± 0.62 <sup>a</sup>	38.77 ± 0.39 <sup>b</sup>	39.02 ± 0.44 <sup>b</sup>	28.83 ± 0.33 <sup>c</sup>
Hue angle	79.08 ± 0.42 <sup>a</sup>	70.65 ± 0.35 <sup>b</sup>	51.24 ± 0.78 <sup>c</sup>	32.82 ± 0.86 <sup>d</sup>

Means ± standard error in the same row followed by different lowercase letters indicate statistically significant differences at  $p \leq .05$ , according to the Tukey test ( $n = 4$ ). TA: titratable acidity; SS: soluble solids.

with the study by Zaccari Veiga et al. (2021), who did not identify significant differences ( $p > .05$ ) between *Butia odorata* accessions. SS content is directly linked to the fruit maturation stage (Santos et al., 2024; Ventura et al., 2022) and may vary significantly among species of the same family (Souza et al., 2020).

The firmness of the pulp of *B. capitata* fruits varied between 11.18 and 13.59 N/cm<sup>2</sup>, with no significant difference between accessions ( $p > .05$ ) (Table 2). Ventura et al. (2022) reported lower firmness in *B. capitata* fruits obtained from another location, which makes the fruit accessions in the current study more resistant to postharvest handling and more advantageous for marketing. Firmness is an important quality parameter that can be used to assess fruit ripeness, storage potential, and consumer satisfaction (Echeverría et al., 2015), and it is related to the maturation stages of *B. capitata* fruits (Ventura et al., 2022).

The accessions showed significant differences ( $p < .05$ ) in the evaluated colorimetric parameters (Table 2). The yellow accession exhibited higher lightness ( $L^* = 66.51$ ) and greater saturation (chroma = 48.65), producing a purer and more defined color. Conversely, the values for the purple accession ( $L^* = 35.83$  and Chroma = 28.83) indicated a mixture of pigments of different and non-predominant colors. In addition to the observed differences between accessions, these color parameters are influenced by fruit ripeness (Martinel et al., 2022).

The color wheel's 79.08° and 70.65° hue angles correspond to colors between yellow and orange, with the first leaning more toward yellow and the second toward orange. The smallest angles, 51.24° and 32.82°, correspond to the colors orange and reddish-orange, respectively. When observing Figure 1, it is noted that there were differences between the color measured



**Figure 1.** Representative images of bunches of four *Butia capitata* accessions used in this study.

by the hue angle and the visual appearance. This contrast can be explained by the fact that the color is a three-dimensional measurement, and to obtain a more accurate representation of color, it is necessary to combine the hue angle with other attributes, such as the chroma parameter, to get closer to human perception (Pridmore & Melgosa, 2015). In addition, from a human point of view, color is a subjective perception mediated by neuronal responses to external stimuli (Cairone et al., 2020). All the hue angles were in the first quadrant, indicating a red-yellow hue on the fruit surface. According to Cömert et al. (2020), the coloration of the fruits in this range of hues can be attributed to carotenoids, ascorbic acid, and phenolic compounds in the fruit's structure. Fruit color is an important quality parameter for attracting consumers and indicating ripeness. It changes as the fruit ripens, and different colors can indicate genetic diversity. Carotenoids and anthocyanins are the main pigments responsible for fruit colors (Ranganath, 2022).

There were significant differences in the centesimal composition between the four accessions, except for the protein content (Table 3). The purple accession exhibited the highest levels of lipids, proteins, minerals, and carbohydrates, resulting in the lowest moisture content. In contrast, the orange accession showed the lowest levels of these components. Carbohydrates were the most abundant macronutrient (10.58–13.18%), whereas lipids were detected in amounts considered high (3.92–6.86%) for a food of plant origin. These carbohydrate and lipid concentrations were higher than those of other samples obtained in the region (Nascimento et al., 2020). The total lipid content in fruit is closely linked to the formation of odor-impacting volatile compounds, and samples with higher lipid content tend to have a stronger flavor (Ferrão et al., 2013), and, like other fruits of the *Arecaceae* family, *B. capitata* is recognized as a good source of polyunsaturated fatty acids (Souza et al., 2020). Similar values for ash and protein contents in *B. capitata* from Cerrado, below 1%, were reported in the literature by Barbosa et al. (2021) and Nascimento et al. (2020), who observed that the mineral composition of these fruits varies significantly depending on the region of cultivation. Furthermore, the fruits' mineral absorption and accumulation capacities may be considered a specific characteristic of each plant genotype (Alberto et al., 2023), which could justify the purple accession having the highest ash content (1.34%). Regarding protein content, the low amount is characteristic of some fruits from the Brazilian Cerrado region (Schiassi et al., 2018).

**Table 3.** Centesimal composition of four accessions of *Butia capitata* fruits.

Parameter (%)	Accessions			
	Yellow	Orange	Pink	Purple
Moisture	82.26 ± 0.03 <sup>b</sup>	84.04 ± 0.01 <sup>a</sup>	81.58 ± 0.04 <sup>c</sup>	77.64 ± 0.02 <sup>d</sup>
Lipids	4.86 ± 0.04 <sup>b</sup>	3.92 ± 0.06 <sup>d</sup>	4.41 ± 0.10 <sup>c</sup>	6.86 ± 0.03 <sup>a</sup>
Proteins	0.69 ± 0.01 <sup>b</sup>	0.64 ± 0.01 <sup>c</sup>	0.66 ± 0.01 <sup>bc</sup>	0.98 ± 0.01 <sup>a</sup>
Ashes	0.87 ± 0.01 <sup>c</sup>	0.82 ± 0.01 <sup>d</sup>	0.96 ± 0.01 <sup>b</sup>	1.34 ± 0.01 <sup>a</sup>
Carbohydrates*	11.33 ± 0.04 <sup>c</sup>	10.58 ± 0.06 <sup>d</sup>	12.39 ± 0.14 <sup>b</sup>	13.18 ± 0.03 <sup>a</sup>

Means ± standard error in the same row followed by different lowercase letters indicate statistically significant differences at  $p \leq .05$ , according to the Tukey test ( $n = 4$ ).

\*Calculated by difference.

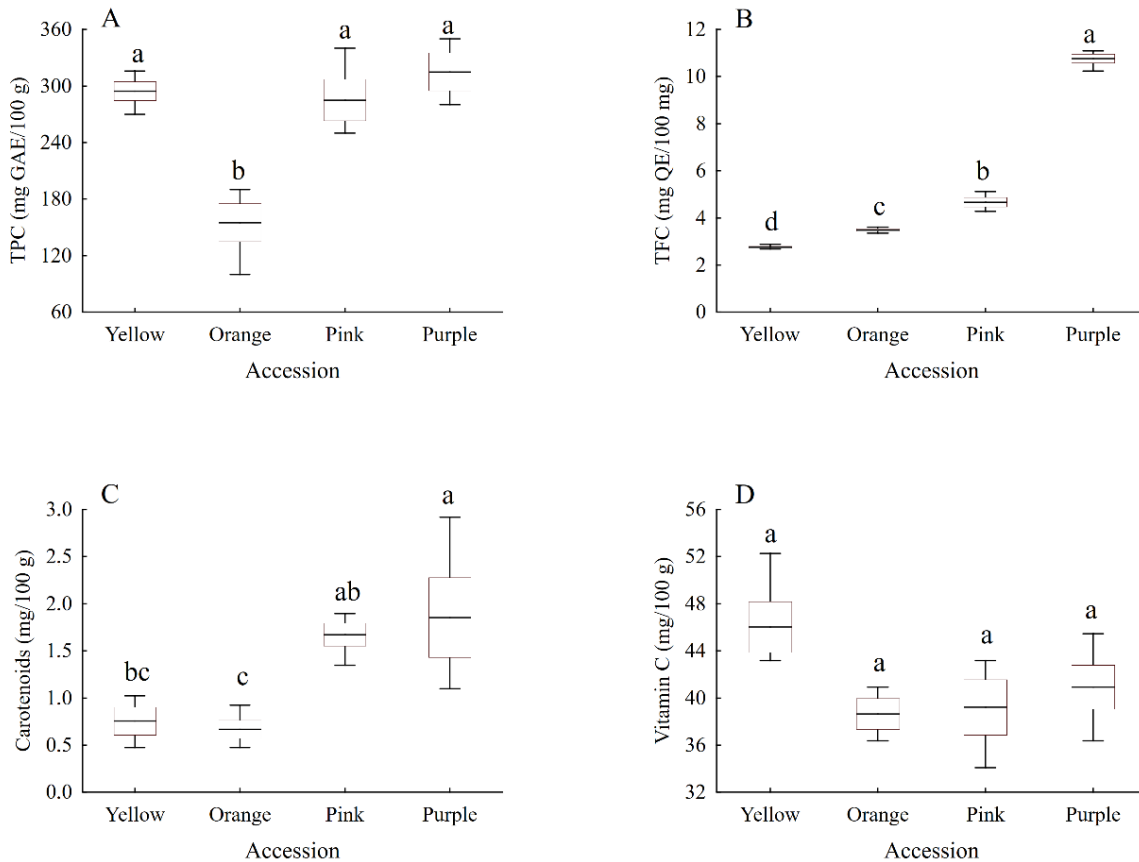
### 3.3 Bioactive compounds and antioxidant activity

The accessions presented significant differences in the contents of bioactive compounds, except for the vitamin C content ( $p > .05$ ), which obtained averages ranging from 38.6 mg/100 g for the orange accession to 46.0 mg/100 g for the yellow accession (Figure 2). The lowest Total phenolic content (TPC) and Total flavonoid content (TFC) contents were observed in the orange and yellow accessions, respectively (Figures 2A and 2B). These accessions also presented lower levels of carotenoids (Figure 2C). In contrast, the purple accession had TPC (315.00 mg GAE/100 g), TFC (10.76 mg QE/100 g), and carotenoid (1.85 mg/100 g) levels, at least twice as high as the orange accession.

As per the classification of TPC proposed by Souza et al. (2012): low ( $< 100$  mg GAE/100 g), medium (100–500 mg GAE/100 g), and high ( $> 500$  mg GAE/100 g), and according to the data in Figure 2A, the *B. capitata* accessions studied, in general, can be categorized as having a medium concentration of phenolic compounds. This medium TPC was related in literature to other fruits from the Cerrado region, such as araticum (433.75 mg GAE/100 g), murici (334.37 mg GAE/100 g), soursop (281.00 mg GAE/100 g), sweet passion fruit (245.36 mg GAE/100 g), and cagaita (143.81 mg GAE/100 g) (Nascimento et al., 2020; Souza et al., 2012). Phenolic compounds are

non-nutrient bioactive substances found in fruits, well-known for their antioxidant properties. They can be subdivided into two main groups: flavonoids and non-flavonoids (Durazzo et al., 2019). All of the accessions native to the Brazilian Cerrado used in this work presented lower TFC when compared to different species of *Butia* from southern Brazil (61.4–100.0 mg CE/100 g) (Hoffmann et al., 2017). On the other hand, the values were close to those reported by Ma et al. (2019) in *Butia odorata* harvested directly from palm trees cultivated in Australia (6.31 mg QE/100 g). From a nutritional point of view, regular consumption of fruits rich in these compounds has been linked to various health benefits and the prevention of diseases associated with oxidative stress (Haminiuk et al., 2012).

Carotenoids are lipid-soluble pigment compounds and one of the primary compounds responsible for the colors of fruits. The biosynthetic pathways of carotenoids may vary among genotypes, varieties, and tissues, whether within the same crop or across different crops (Ranganath, 2022). Although the purple and pink accessions present more than twice the concentration of total carotenoids than the orange and yellow accessions (Figure 2C), the four accessions showed levels of these compounds lower than those of other *B. capitata* fruits (Faria et al., 2011; Martineli et al., 2022). Along with the bioactive compounds mentioned above (phenolics and flavonoids), a higher dietary



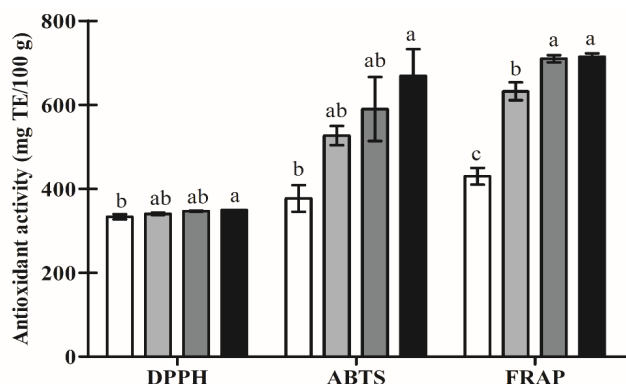
TPC: total phenolic content; GAE: gallic acid equivalent; TFC: total flavonoid content; QE: quercetin equivalent. Data are presented as box plots, where the boxes represent the standard error, the lines within the boxes denote the mean, and the whiskers contain min and max values. The box plots in each graph contain different letters if there is a significant difference ( $p < .05$ ) in the mean values of the bioactive compounds based on Turkey's test.

**Figure 2.** Total phenolic content, as mg gallic acid equivalent per 100 g (A); total flavonoid content, as quercetin's equivalent per 100 g (B); carotenoids, as mg per 100 g (C); and vitamin C content, as mg per 100 g (D).

intake of carotenoids is associated with a reduced risk of chronic diseases due to their biological actions. However, there is still no consensus on the daily intake of carotenoids to achieve beneficial effects, as several factors can influence the results (Eggersdorfer & Wyss, 2018). Regarding vitamin C, the recommended daily allowance (RDA) varies significantly worldwide, with recommendations ranging from 40 mg/day in the UK and India to 110 mg/day in several European countries (Carr & Lykkesfeldt, 2021). Our study estimates that a portion of 100 g of *B. capitata* pulp provides at least 35% of the RDA of vitamin C for middle-aged adults. According to the classification proposed by Ramful et al. (2011), the *B. capitata* pulps of this study can be considered to have intermediate contents (30–50 mg/100 g) of vitamin C (Figure 2D). Plants primarily produce vitamin C through the Smirnoff–Wheeler pathway, the main pathway in photosynthetic tissues. However, the D-galacturonate pathway might also be important in some fruits and during certain ripening stages (Fenech et al., 2019).

Arecaceae family fruits are recognized as rich in bioactive compounds (Morais et al., 2022). The discrepancies in the values of bioactive compounds observed in Figure 2 can be attributed to variations in fruit composition due to the mother plant, fruit maturation stage, and environmental factors (Guimarães et al., 2023).

In general, the results of antioxidant activity demonstrated consistent behavior across different assays (DPPH, ABTS, and FRAP). The DPPH assay showed the lowest activity in the analysis of the extracts of the four fruit samples (e.g., 333 mg TE/100 g in the yellow accession). The most potent assay in the study of the fruit extracts was the FRAP assay, which showed values up to 715 mg TE/100 g. Regardless of the test performed, the purple and pink accessions exhibited the highest antioxidant activity, while the yellow accession displayed the lowest (Figure 3). According to Thaipong et al. (2006) findings, a strong proportional correlation exists between the FRAP technique and TPC and vitamin C. However, the high levels of antioxidant activity shown by purple and pink accessions (715 and 709 mg

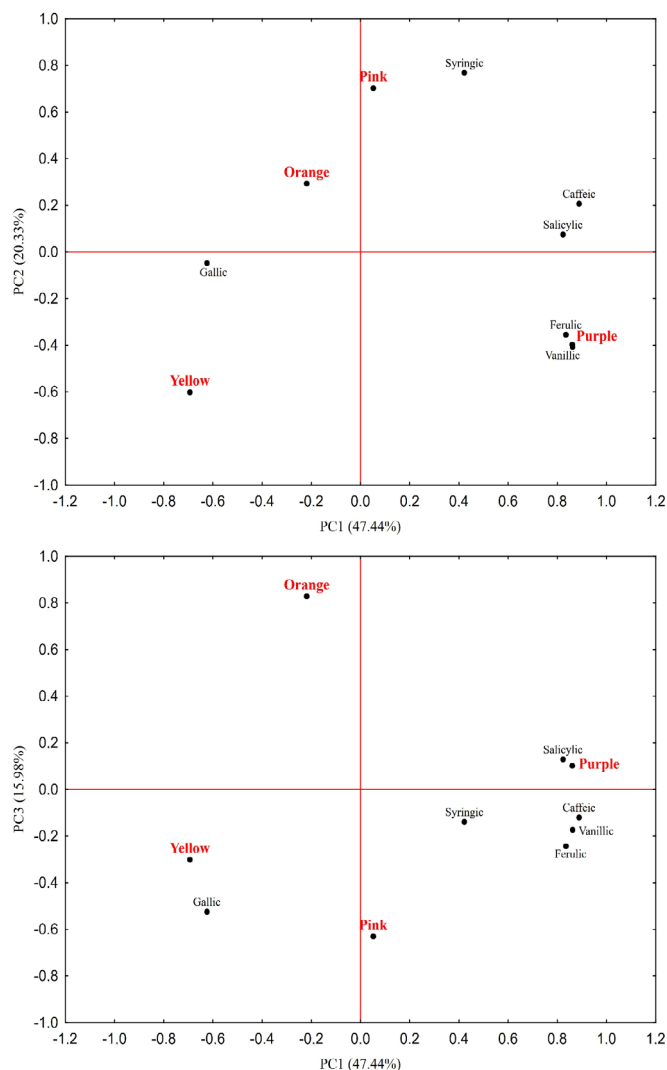


DPPH: 2,2-diphenyl-1-picrylhydrazyl; ABTS: 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid); FRAP: ferric reducing antioxidant power; TE: trolox equivalent. Bars indicate standard error of the mean of four independent experiments. Different letters above the bars of the same assay indicate significant differences between fruit accessions (Tukey,  $p < .05$ ). Yellow (□), orange (◊), pink (◊), and purple (■) accessions.

**Figure 3.** Antioxidant activity of *Butia capitata* accessions determined by 2,2-diphenyl-1-picrylhydrazyl, 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid), and ferric reducing antioxidant power assays, respectively.

TE/100 g, respectively, as determined by the FRAP assay) did not align with the levels of these compounds (Figures 2A and 2D). On the other hand, carotenoids may be related to antioxidant activity by the FRAP assay due to the ability of lycopene and hydroxy carotenoids to reduce ferric ions (Müller et al., 2011). The antioxidant capacity of fruits is usually associated with bioactive compounds, which play a crucial role in protecting the body from oxidative stress (Akbari et al., 2022). The chemical complexity of samples with various functional groups and polarities can lead to conflicting results in antioxidant activity. It's recommended to use multiple methods to assess the antioxidant activity of the samples (Guimarães et al., 2023).

The PCA was obtained using phenolic acid data from *B. capitata* accessions. The first three components had eigenvalues greater than 1 (4.74, 2.03, and 1.60), indicating that they should be interpreted (Kaiser Criterion). The first principal component (PC1) explained 47.44% of the variability contained in the original variables, whereas the second (PC2) and third (PC3) principal components explained 20.33% and 15.98%, respectively, accounting for 83.76% of the total variability (Figure 4).



**Figure 4.** Principal component analysis of phenolic acids of four *Butia capitata* accessions.

Accordingly, attributes displaying absolute loading values (> 0.700) for each feature were deemed to be significant. In PC1, caffeic, vanillic, ferulic, and salicylic acids were positively correlated with purple accession, while in PC2, syringic acid was positively correlated with pink accession. These results can be observed in Figure 4, where purple and pink accessions were on the positive side of PC1 and PC2, respectively. Finally, the remaining samples (yellow and orange accessions) had the lowest values of the analyzed phenolic acids. The use of PCA revealed variations existing in *B. capitata* genotypes. This phenotypic and genetic diversity among the *Butia* species is reported in the literature (Cidón et al., 2023).

#### 4 CONCLUSIONS

The samples presented in this research exhibited great diversity in most physicochemical parameters evaluated. This high variation can be mainly attributed to the genetic differences among the samples since they were collected from the same location. The best choice for processing *B. capitata* pulp is the yellow accession, while the purple accession is ideal for almond use. This result may aid in comprehending how fruit color adapts and evolves in response to adverse environments. High levels of macronutrients (ashes, lipids, proteins, and carbohydrates) were observed in fruits belonging to the “purple” accession. The phenolic acids proved to be relevant descriptors and may be given priority in future evaluations for the selection of *B. capitata* populations. Finally, our results may aid in comprehending how fruit color and biochemical mechanisms adapt and evolve in response to adverse environments.

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