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# Chemistry Composition and Bioaccessibility Study of Phenolic Compounds and Carotenoids of New Brazilian Biofortified Sweet Potato “CIP BRS Nuti”

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## ABSTRACT

Sweet potatoes biofortified in carotenoids have been an alternative to combat malnutrition in vulnerable populations. This work is the first comprehensive study of the bioactive potential of the new Brazilian biofortified sweet potato cultivar “CIP BRS Nuti.” In two harvests, the chemical composition and profiles of organic acids, phenolic compounds, and carotenoids were analyzed using high-performance liquid chromatography. The bioaccessibility of phenolics and carotenes was also studied. The main simple sugars and organic acids found were glucose, fructose, citric, malic, succinic, and lactic acids. “CIP BRS Nuti” showed high concentrations of chlorogenic acid (228.3–330.4 mg/kg) and hesperidin (385.2–530.9 mg/kg), with the presence of other phenolics such as catechin, epicatechin, and procyanidin B1, with high levels of bioaccessibility (> 104%). The main carotenoid quantified was 9-*cis*- $\beta$ -carotene (294.9–503.8 mg/kg), with low bioaccessibility, but  $\beta$ -carotene and lycopene were also present. Our results show the nutritional and bioactive potential of the “CIP BRS Nuti” potato, providing essential information for its use in food and industrialization, with an applied view to nutrition and food science.

## 1 | Introduction

Sweet potatoes (*Ipomoea batatas* L.) are a globally consumed food grown in more than 115 countries (FAO 2021; Qin et al. 2022). Due to their high productivity, they have been an alternative for food security (Alam et al. 2020). They are also considered a nutraceutical food because they serve as a source of bioactive compounds, such as carotenoids and phenolic compounds, depending on the cultivar (Gabilondo et al. 2022).

The sweet potato cv. “CIP BRS Nuti” (RNC 46899) is a new Brazilian cultivar developed by the Brazilian Agricultural

Research Corporation (EMBRAPA), biofortified with carotenoids, which has pink skin and orange flesh (Mello et al. 2022a). “CIP BRS Nuti” was developed in 2006 using a controlled cross between the elite OFSP clone SR01.018 (CIP101048.1) and the advanced OFSP clone PJ05.172 (CIP194583.2). It is characterized by high productivity and was created to meet the demands of fresh consumption (Mello et al. 2022b). Potatoes biofortified in terms of carotenoids have been proposed as an alternative for nutritional supplementation (Rosero et al. 2022). In the study by Infante et al. (2017), the flour was obtained from the orange-fleshed sweet potato cv. “Beauregard” was used to increase the carotene content in cookies, and it was shown that its

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incorporation increased the nutritional quality of the product. This suggests that biofortified potatoes can serve as an enrichment alternative for various processed foods.

Vitamin A deficiency remains a global health problem that has not yet been eradicated. The biofortification of crops, such as potatoes with carotenes, has been widely advocated (Rosero et al. 2022; Drapal and Fraser 2019). Orange-fleshed sweet potatoes serve as a source of provitamin A due to the bioavailability of carotenes, which can be influenced by variety, environment, and crop management conditions (Rosero et al. 2022).

Regarding the bioactivity of carotenes, a study by Zhou et al. (2020) demonstrated that higher plasma levels of this compound were associated with lower cholesterol levels and a reduced impact of atherosclerosis. However, Tao et al. (2021) state that all *trans*- $\beta$ -carotene undergoes high degradation during gastrointestinal digestion. The beneficial effects of bioactive compounds present in food are directly related to their bioaccessibility, which is their ability to be absorbed after the digestion stages (Dantas et al. 2023), and no previous studies were found that evaluated the bioaccessibility of the “CIP BRS Nuti” sweet potato.

About bioactive compounds characterization, this is the first study to evaluate the “CIP BRS Nuti” sweet potato. The studies by Mello et al. (2022a) and Mello et al. (2022b) measured their centesimal composition. However, comprehensive studies of its chemical composition have not been conducted, particularly with regard to bioactive phenolic compounds and their bioaccessibility.

This study evaluated the HPLC profiles of antioxidant phenolic compounds, carotenoids, sugars, and organic acids in the Brazilian cultivar “CIP BRS Nuti” sweet potato. Furthermore, the bioaccessibility of phenolics and carotenes in sweet potatoes subjected to simulated *in vitro* digestion was evaluated for the first time. This provides essential information to establish the bioactive potential of this cultivar, integrating aspects of food composition and nutrition.

## 2 | Materials and Methods

### 2.1 | Reactants and HPLC External Standards

Trolox (6-hydroxy-2,5,7,8-tetramethylchromate-2-carboxylic acid), 2,2-diphenyl-1-picrylhydrazyl (DPPH), TPTZ (2,3,5-triphenyltetrazolium chloride), gallic acid, *p*-coumaric acid, chlorogenic acid, syringic acid, *t*-caftaric acid, caffeic acid, hesperidin, malvidin 3,5-diglucoside, pelargonidin 3,5-diglucoside, cyanidin 3,5-diglucoside, naringenin, and procyanidin B2, 9-*cis*- $\beta$ -carotene,  $\beta$ -carotene, lycopene, lutein, and violaxanthin were purchased from Sigma-Aldrich (St. Louis, MO, USA). Procyanidin A2, epigallocatechin gallate, epicatechin gallate, kaempferol 3-glucoside, quercetin 3-rutinoside (rutin), quercetin 3-glucoside, myricetin, delphinidin-3-glucoside, cyanidin 3-glucoside, peonidin-3-glucoside, pelargonidin 3-glucoside, malvidin-3-glucoside, and petunidin-3-glucoside were obtained from Extrasynthese (Genay, France).

*Cis*- and *trans*-resveratrol were obtained from Cayman Chemical (Michigan, USA). Fructose, glucose, tartaric acid, citric acid, malic acid, lactic acid, acetic acid, succinic acid, and propionic acid were obtained from Química Vetec (Rio de Janeiro, Brazil). Acetonitrile, methanol, acetone, potassium persulfate, and ethyl alcohol were obtained from Merck (Darmstadt, Germany). Ultrapure water was obtained from a Marte Científica purification system (São Paulo, SP, Brazil).

### 2.2 | Sweet Potato “CIP BRS Nuti” Samples

The potatoes were grown on the experimental farm of the Instituto Federal do Sertão Pernambucano, Campus Petrolina Zona Rural, in Petrolina, PE, Brazil (90°20' South and 40°41' West), at an average altitude of 418 m. The region's climate is classified as BSwH according to the Köppen classification, and the soil in the experimental area is a yellow latosol. The chemical analysis of the soil is shown in Table S1. The planting spacing was 0.40 m between plants. The crop was harvested 123 days after planting, in November of the 2023 and 2024 harvests, and roots with an average weight of approximately 300 g were selected.

Twenty-five tubers/harvest were randomly collected from the experimental area, washed under running water, and manually cut into cubes (1 × 1 cm). Three cubes of each tuber were collected and ground in a blade mill to homogenize them for chemical composition analysis and bioaccessibility study, with the analytical results expressed in fresh weight (FW).

### 2.3 | Classic and Nutritional Analysis

Classical pH and titratable acidity analyses were determined by potentiometry and titration with 0.01 mol/L NaOH. The Soxhlet method was used to determine the fat content using hexane as the extraction solvent. The ash content (fixed mineral residue) was determined by incineration in a muffle furnace at 550°C. Protein was determined using the Micro-Kjeldahl nitrogen distillation method. Total carbohydrates were determined using the Fehling reduction method after acid hydrolysis of the sample. Soluble and insoluble fibers were determined using the enzymatic-gravimetric method. All the methods followed the recommendations of AOAC (2005).

### 2.4 | Determination of Phenolic Compounds, Sugars, Organic Acids, and Carotenoids by HPLC

All extractions for chromatographic analysis were performed using potato puree obtained as described in Section 2. To determine phenolic compounds, the sample was diluted 1:10 m/v in methanol 70% and macerated by sonication at 40 kHz for 30 min at 45 ± 1°C. This was followed by centrifugation and filtration of the supernatant through a 0.45-micron membrane for injection. The same procedure used for phenolics was used to extract sugars and acids, except that methanol was replaced with ultrapure water.

All liquid chromatography analyses were carried out using an LC Agilent 1260 Infinity chromatograph (Agilent Technologies, SC, USA) coupled to a refractive index detector (RID, model G1362A) and a diode array detector (DAD, model G1315D). The data was processed using the OpenLAB CDS ChemStation Edition software (Agilent Technologies, SC, USA).

Individual phenolics were determined following the methodology validated by da Silva Padilha et al. (2017). The column used was Zorbax Eclipse Plus RP-C<sub>18</sub> (100 × 4.6 mm, 3.5 μm particle size). The injection was 20 μL of the sample. The solvent flow was 0.8 mL/min. The gradient used in the separation was 0 at 5 min: 5% B; 5 at 14 min: 23% B; 14 at 30 min: 50% B; 30 at 33 min: 80% B, where solvent A is a solution of phosphoric acid (pH 2.0) and solvent B is methanol acidified with 0.5% H<sub>3</sub>PO<sub>4</sub>. The phenolics quantified had calibration curves with  $R^2 > 0.995$ . The detection limits for all the compounds were < 0.15 mg/L (limit of detection, LOD) and < 1.1 mg/L (limit of quantification, LOQ).

Sugars and organic acids were determined simultaneously using the methodology validated by Coelho et al. (2018). An Agilent Hi-Plex H column (300 × 7.7 mm, 8.0 μm particle size) protected by a PL Hi-Plex H pre-column (5 × 3 mm), was used (Agilent Technologies, SC, USA). The column temperature was at 70°C. The injected sample volume was 10 μL, and the solvent flow rate was 0.8 mL/min. The mobile phase was a solution of H<sub>2</sub>SO<sub>4</sub> 4 mmol/L. The organic acids citric, tartaric, malic, lactic, succinic, acetic, propionic, butyric, and formic were determined at 210 nm, while the sugars glucose, fructose, and rhamnose were determined at RID. All the compounds quantified had calibration curves with  $R^2 > 0.997$ , LOD < 0.04 g/L, and LOQ < 0.11 g/L.

Carotenoids were determined by the methodology of Barros-Santos et al. (2023). Carotenoids were extracted using the liquid-liquid extraction (LLE) with a 1:1 (v/v) hexane:acetone mixture. The collected colored fraction was evaporated under vacuum using a rotavaporator at 120 rpm (≤ 40°C), and the pigments were resuspended in 2 mL of an ethanol:hexane (1:1 v/v) mixture. The sample was filtered through a 0.45 μm PTFE hydrophobic membrane and injected. The detection was at 450 nm. An Eclipse Plus C18 (50 × 4.6 mm, 1.8 μm particle size) column by Zorbax (USA) was used for separation. The injection was 20 μL, and the solvent flow was 1.0 mL/min. The gradient was 0 at 5 min: 80 at 88% B; 5 at 9 min: 95% B (isocratic); 9 at 10 min: 80% B (isocratic), where solvent A was ultrapure water and solvent B was acetone. The linearity was  $R^2 \geq 0.999$ , precision CV ≤ 4.31%, recovery > 87%, and quantification limits < 0.29 mg/L.

Typical chromatograms of the phenolics and carotenoids analysis in the “CIP BRS Nuti” sweet potato are shown in Figures S1 and S2.

## 2.5 | Antioxidant Capacity

According to Singleton and Rossi (1965), the total bioactive content was assessed using the Folin-Ciocalteu method. The

samples' absorbance (765 nm) was compared to an analytical curve using gallic acid, and the results were expressed in mg gallic acid equivalent (GAE) per kilogram.

The antioxidant capacity of sweet potatoes was determined using the DPPH (2,2-diphenyl-1-picrylhydrazyl) and FRAP (Ferric Reducing Antioxidant Power) methods, following the methodologies proposed by Y. K. Kim et al. (2002) and Rufino et al. (2006), respectively. After the reactions were completed, absorbances were measured using a UV-Vis spectrophotometer (Instrutherm, PR, Brazil), and the calibrations were compared with those of Trolox and ferrous sulfate standards.

For the DPPH analysis, a hydroalcoholic solution of DPPH at 1.0 mmol was prepared and adjusted to an absorbance of  $0.950 \pm 0.050$ . Subsequently, 2.9 mL of this solution was added to 0.1 mL of the sample. The mixture was kept in the dark for 30 min, after which the absorbance was analyzed (517 nm). The results were presented in millimoles of Trolox equivalents per kilogram of fresh sample (mmol TE/kg).

The FRAP method was performed by preparing a reagent containing 300 mmol/L acetate buffer (pH 3.6), a 20 mmol/L solution of ferric chloride, and 10 mmol/L TPTZ (2,4,6-tris(2-pyridyl)-s-triazine). Thus, 90 μL of the sample was added to 270 μL of ultrapure water and 2.7 mL of the FRAP reagent. This mixture was incubated at 37°C for 30 min. Ultimately, absorbance was measured at 595 nm, and antioxidant capacity was expressed as millimoles of Fe<sup>2+</sup> per kilogram of sample.

## 2.6 | Simulation of Sweet Potato Digestion and Bioaccessibility

In vitro gastrointestinal digestion of CIP BRS Nuti sweet potato was simulated according to the INFOGEST protocol (Minekus et al. 2014). For the simulation of the oral phase, 5 g of sweet potato puree (as described in Section 2), 3.5 mL of simulated salivary fluid-SSF, 25 μL of 0.3 mol/L CaCl<sub>2</sub>, 0.5 mL of α-amylase (1500 U/mL), and 975 μL of ultrapure water were used. The pH of the solution was adjusted to pH = 7.0, and the mixture was incubated for 2 min (37 ± 1°C at 90 rpm). For the solution simulating the gastric phase, 7.5 mL of simulated gastric fluid (SGF), containing 5 μL of 0.3 mol/L CaCl<sub>2</sub>, 1.6 mL of pepsin (25,000 U/mL), 200 μL of 1 mol/L HCl and 0.695 μL of ultrapure water; the pH was adjusted to 3.0, and the material was incubated (37 ± 1°C for 2 h at 90 rpm).

The intestinal phase simulation solution was made by mixing 20 mL of gastric chyme with 11 mL of simulated intestinal fluid-SIF, containing 1 mL of bile salts (25 mg of bile/g of sample), 5 mL of pancreatin (800 U/mL), 40 μL of 0.3 mol/L CaCl<sub>2</sub>, 150 μL of 1 mol/L NaOH and 1.31 mL of ultrapure water; The pH was then adjusted to 7.0 with NaOH 1 mol/L and the solution kept stirring (90 rpm for 2 h at 37 ± 1°C). The bioaccessibility of phenolics was expressed as a percentage using Equation (1) as described in de Assis et al. (2025).

Bioaccessibility (%)

$$= \frac{\text{Phenolic concentration in the intestinal phase}}{\text{Phenolic concentration in the undigested potato}} \times 100. \quad (1)$$

## 2.7 | Statistical Analysis

The results were analyzed using analysis of variance (ANOVA) and compared using the *F* test at a 5% probability of error (SPSS 20.0 statistical package for Windows, SPSS, Chicago, USA). Pearson's correlation analysis was performed using Past 4.03.

## 3 | Results and Discussion

### 3.1 | Nutritional Composition, Sugars, and Organic Acids

The Brazilian cultivar “CIP BRS Nuti” is a new biofortified sweet potato genotype regarding carotenoid content. Its phenotype is characterized by the orange color of its flesh, as evident from the chromaticity coordinates  $+a^*$  ( $36.57 \pm 0.74$ ) and  $+b^*$  ( $46.19 \pm 1.15$ ), which indicates a tendency towards red and yellow chromaticity (Figure 1). The values for physico-chemical analysis, centesimal composition, free sugars, and organic acids are shown in Table 1.

Carbohydrates were the main macronutrient in potatoes, ranging from 20.3% to 22.0%, with a significant difference ( $p < 0.05$ ) between the 2023 and 2024 harvests. Carbohydrates play a crucial role in human metabolism, making sweet potatoes a staple food crop with high nutritional value (Dung et al. 2024).

Sweet potatoes are already widely known for their high carbohydrate content. For example, Mello et al. (2022a) previously



**FIGURE 1** | Visual appearance and flesh color of Brazilian sweet potato cv. “CIP BRS Nuti.”

analyzed the cv. “CIP BRS Nuti” and identified a carbohydrate content of 18.03%. In the work by He et al. (2025), the carbohydrate content was found to be for the cv. “Yantian” was 24.3%. Dung et al. (2024) found that the total carbohydrate values of orange-fleshed potatoes grown in Vietnam ranged from 24.58% to 24.94%. These results underscore the significance of potatoes as a primary source of carbohydrates in the human diet.

Carbohydrates can be classified into simple sugars and complex sugars. Complex sugars are mostly present in sweet potatoes, mainly in starch (Trancoso-Reyes et al. 2016). In this study, the average starch content of the “CIP BRS Nuti” cultivar was 20.25%, with the 2023 harvest standing out as having the highest values ( $21.3\% \pm 0.20$ ), representing 95.74% of the total carbohydrate content.

The study by Yao et al. (2023) assessed the significance of starch in determining the sensory properties of sweet potatoes. These authors found 18.15% starch in the “Guangshu 79” variety, which decreased to 7.10% and 7.84% during cooking. In the research conducted by Dung et al. (2024), it was noted that most of the starch in potatoes is present in the form of resistant starch, accounting for 10.2% of the total starch in potatoes. The

**TABLE 1** | Nutritional components, free sugars, and organic acids quantified by HPLC in sweet potato cv. “CIP BRS Nuti.”

Physico-chemistry analysis	Harvests	
	2023	2024
pH	$6.16 \pm 0.05^a$	$6.20 \pm 0.1^a$
Titrate acidity %	$0.12 \pm 0.04^a$	$0.09 \pm 0.03^a$
Ash %	$0.48 \pm 0.04^a$	$0.44 \pm 0.05^a$
Soluble fibers %	$1.0 \pm 0.10^a$	$0.9 \pm 0.08^a$
Insoluble fibers %	$4.1 \pm 0.30^a$	$4.0 \pm 0.50^a$
Lipids %	$0.45 \pm 0.04^a$	$0.4 \pm 0.03^a$
Carbohydrates %	$22.0 \pm 0.80^a$	$20.3 \pm 0.50^b$
Total starch %	$21.3 \pm 0.20^a$	$19.2 \pm 0.30^b$
Proteins %	$2.1 \pm 0.20^a$	$2.0 \pm 0.10^a$
Sugars g/kg		
Glucose	$2.40 \pm 0.26^a$	$2.75 \pm 0.40^a$
Fructose	$0.98 \pm 0.28^a$	$2.48 \pm 1.37^a$
$\Sigma$ sugars	$3.38 \pm 0.52^a$	$5.23 \pm 1.70^a$
Organic acids g/kg		
Citric acid	$0.31 \pm 0.09^a$	$0.09 \pm 0.02^b$
Malic acid	$0.22 \pm 0.08^a$	$0.05 \pm 0.02^b$
Succinic acid	$0.27 \pm 0.11^a$	$0.24 \pm 0.12^a$
Lactic acid	$0.28 \pm 0.10^a$	$0.27 \pm 0.08^a$
Formic acid	$0.01 \pm 0.29^a$	$0.08 \pm 0.02^a$
$\Sigma$ organic acids	$1.18 \pm 0.27^a$	$0.73 \pm 0.19^a$

Note: The results are expressed as mean  $\pm$  standard deviation ( $n = 4$ ). Means followed by the same letter in lines are not different among themselves by the *F* test at 5% of error probability.

Abbreviation: ND, not detected or  $< LOD$ .

results of the starch content in the “CIP BRS Nuti” potato in this work corroborate other potatoes in the literature.

The sweetness of potatoes is one of the main parameters influencing their acceptance by consumers and is represented by the simple sugars in their composition (Mello et al. 2022b). In this study, the amount of simple sugars identified in the raw material ranged from 3.38 to 5.23 g/kg, which did not differ significantly between harvests ( $p < 0.05$ ). Glucose values ranged from 2.75 to 2.40 g/kg, while fructose varied from 0.98 to 2.48 g/kg. Other studies have also observed the presence of these monosaccharides in different potato genotypes, highlighting their sensory and processing importance (He et al. 2025; Ibrahim et al. 2025).

Organic acids significantly impact the taste of food. They also act as preservatives or natural antioxidants (Ibrahim et al. 2025). No studies evaluated the individual organic acids in the CIP BRS Nuti sweet potato. The quantified acids ranged from 0.73 to 1.18 g/kg. The main acids quantified in the potatoes were citric

acid (0.09–0.31 g/kg), lactic acid (0.27–0.28 g/kg), succinic acid (0.24–0.27 g/kg), and malic acid (0.05–0.22 g/kg). Some studies using metabolomic analysis to investigate sweet potato cultivars have observed the presence of succinic acid, citric acid, and lactic acid as the main acids in potato genotypes, with orange-fleshed cultivars having the highest values compared to white-fleshed ones (Wan et al. 2024; Ibrahim et al. 2025). These results corroborate those obtained in this study.

## 3.2 | Bioactive Compounds in Sweet Potato cv. “CIP BRS Nuti”

### 3.2.1 | Phenolic Compounds Profile

Table 2 shows the bioactive compound profile of the “CIP BRS Nuti” cv, including individual phenolic compounds, a carotenoid profile, and antioxidant capacity.

**TABLE 2** | Bioactive phenolic compounds profile and antioxidant capacity of the sweet potato “CIP BRS Nuti.”

Phenolic compounds mg/kg	Harvests	
	2023	2024
Flavanols		
Catechin	3.96 ± 0.17	ND
Epicatechin	1.90 ± 0.31 <sup>a</sup>	1.66 ± 0.20 <sup>a</sup>
Epigallocatechin gallate	0.23 ± 0.21	ND
Procyanidin B1	1.54 ± 0.20 <sup>a</sup>	1.50 ± 0.26 <sup>a</sup>
Flavonols		
Quercetin-3-glucoside	3.21 ± 0.29 <sup>a</sup>	2.86 ± 0.38 <sup>a</sup>
Rutin	7.14 ± 2.02 <sup>a</sup>	5.07 ± 0.64 <sup>a</sup>
Myricetin	1.15 ± 0.20 <sup>a</sup>	7.32 ± 1.38 <sup>b</sup>
Kaempferol-3-glucoside	1.60 ± 0.23 <sup>a</sup>	1.24 ± 0.28 <sup>a</sup>
Isorhamnetin	2.93 ± 1.75 <sup>a</sup>	0.59 ± 0.09 <sup>a</sup>
Phenolic acid		
Chlorogenic acid	330.42 ± 19.64 <sup>a</sup>	228.32 ± 30.66 <sup>b</sup>
Isoflavone		
Hesperidin	530.94 ± 51.39 <sup>a</sup>	385.22 ± 141.96 <sup>a</sup>
∑ phenolics quantified	885.03 ± 70.53 <sup>a</sup>	633.78 ± 174.89 <sup>a</sup>
Carotenoids mg/kg		
β-carotene	3.79 ± 1.77 <sup>a</sup>	2.20 ± 0.49 <sup>a</sup>
9-cis-β-carotene	503.77 ± 189.27 <sup>a</sup>	294.93 ± 37.07 <sup>a</sup>
Lycopene	11.77 ± 4.46 <sup>a</sup>	5.69 ± 0.84 <sup>a</sup>
∑ carotenoids quantified	526.59 ± 191.56 <sup>a</sup>	302.84 ± 38.30 <sup>a</sup>
Antioxidant capacity		
DPPH mmol TE/kg	5.80 ± 0.41 <sup>a</sup>	4.60 ± 0.66 <sup>a</sup>
FRAP mmol Fe <sup>2+</sup> /kg	17.52 ± 1.21 <sup>a</sup>	13.82 ± 1.96 <sup>b</sup>
Folin mg GAE/kg	1228.08 ± 93.43 <sup>a</sup>	946.05 ± 182.74 <sup>a</sup>

Note: The results are expressed as mean ± deviation ( $n = 4$ ). Means followed by the same letter in lines are not different among themselves by the  $F$  test at 5% of error probability.

Abbreviation: ND, not detected or < LOD.

In this study, 30 phenolic compounds were analyzed, of which 11 were quantified: five flavonols, four flavanols, one phenolic acid, and one isoflavone. The total amount of phenolics quantified by HPLC in the potatoes ranged from 633.8 to 885 mg/kg and did not differ ( $p < 0.05$ ) between the harvests evaluated. Of this quantity, the main components were hesperidin (385.2–530.9 mg/kg) and chlorogenic acid (228.3–330.4 mg/kg), which represented 60.3% and 36.7% of the total quantified, respectively.

The predominance of chlorogenic acid in other sweet potato genotypes is reported in several studies, and in general, this compound represents between 49% and 90% of the total phenolic content (Orsák et al. 2019; Gutiérrez-Quequezana et al. 2020). Structurally, chlorogenic acid consists of a molecule of caffeic acid esterified with quinic acid and is found in various food matrices, including vegetables, fruits, and coffee (Li et al. 2022). The consumption of chlorogenic acid is associated with neuroprotective, anti-inflammatory, antioxidant, and cardioprotective effects (Nguyen et al. 2024). The study by Pazos et al. (2022) determined the phytochemical composition of the cultivars “Beauregard,” “Boni INTA,” and “Arapey.” In all samples, the main compound identified was chlorogenic acid. Similarly, Orsák et al. (2019) reported average chlorogenic acid values ranging from 148 mg/kg for cv. “Agrida” (yellow flesh) to 769.5 mg/kg for cv. “Vitelotte” (purple flesh). Furthermore, Musilová et al. (2024), when investigating the chemical composition of the cultivars “Beauregard” and “Japonesa,” also characterized chlorogenic acid as the most representative phenolic. These findings corroborate those in this study regarding the importance of chlorogenic acid as the primary bioactive phenolic compound in CIP BRS Nuti sweet potatoes.

Various intrinsic and extrinsic factors significantly influence the concentration of bioactive compounds in the raw material, including genotype, climatic conditions, and environmental factors (Musilová et al. 2024). For example, the study by Orsák et al. (2019) aimed to investigate the impact of pulp color and growing locations on different sweet potato cultivars, and it was found that the content of phenolic acids was higher in all colored pulp samples.

The hesperidin values found in the “CIP BRS Nuti” cv. in this study are a distinctive characteristic, as in other sweet potato cultivars previously characterized, this phenolic is not representative. For example, in the study by Suo et al. (2022), phenolic extracts from 19 potato cultivars with purple, red, and yellow flesh were analyzed, and hesperidin was detected only in the “Heijingang” cultivar (213.4 mg/kg DW). Other antioxidant phenolics such as rutin (5.07–7.14 mg/kg), quercetin 3-glucoside (2.86–3.21 mg/kg), myricetin (1.15–7.32 mg/kg), epicatechin (1.66–1.9 mg/kg) and procyanidin B1 (1.5–1.54 mg/kg) were also found in the “CIP BRS Nuti” variety.

Hesperidin is a typical isoflavone found in citrus fruits, including oranges, lemons, and pomelos (Coelho et al. 2021). However, its interaction with  $\beta$ -carotene can increase the expression of transport proteins, such as the scavenger receptor class B type 1 (SR-BI), resulting in greater cellular uptake of this pigment (Nie et al. 2019). This reinforces the role of the CIP BRS Nuti potato as a functional food.

### 3.2.2 | Carotenoids

The carotenoid profile of the sweet potato cv. “CIP BRS Nuti” are shown in Table 2. The quantified carotenoid content ranged from 302.8 to 526.6 mg/kg and did not differ ( $p < 0.05$ ) between the harvests analyzed. Among the carotenoids, the lowest concentrations were for  $\beta$ -carotene (2.2–3.79 mg/kg) and lycopene (5.69–11.77 mg/kg). The compound 9-*cis*- $\beta$ -carotene was the main carotenoid quantified, with values of 294.9 mg/kg for the 2024 harvest and 503.8 mg/kg for the 2023 harvest. In this study, 9-*cis*- $\beta$ -carotene accounted for around 96% of the total carotenoid content quantified.

In the study by Liu et al. (2009), the “Tainung 66” and “Tainung 57” cultivars showed 2.2–5.7 mg/kg values for 9-*cis*- $\beta$ -carotene. These differences are primarily attributed to the genotype factor, which significantly influences the phytochemical composition of this vegetable (Pazos et al. 2022; Mello et al. 2022a). Although  $\beta$ -carotene is the main carotene found in orange vegetables, studies characterizing the isomers of this substance have shown that 9-*cis*- $\beta$ -carotene is one of the primary forms of carotene (Amotz and Fishier 1998).

Some carotenoids play a pro-vitamin A role due to enzymatic mechanisms during digestion (Drupal and Fraser 2019). Due to this, biofortification of sweet potatoes with carotenoids is an important strategy adopted by various organizations to mitigate vitamin A deficiency in developing countries (Infante et al. 2017; Rosero et al. 2022). These approaches highlight the nutraceutical potential of “CIP BRS Nuti” in this study, given its rich content in 9-*cis*- $\beta$ -carotene, a form of higher absorption after digestion (Tao et al. 2021).

In Mello et al.’s (2022b) study, the  $\beta$ -carotene content of “CIP BRS Nuti” was compared to two other orange-fleshed cultivars, “Beauregard” and “Clone 11.” The results for  $\beta$ -carotene were higher in cv. “CIP BRS Nuti” (112.8 to 217.8 mg/kg), compared to the other cultivars (71.9 to 155.1 mg/kg). In the study by Alam et al. (2020), three carotenoids were quantified in different sweet potato genotypes, with  $\beta$ -carotene being the primary compound. However, lycopene was also present (0.41 and 3.11 mg/kg). These findings, as the “CIP BRS Nuti” cv, corroborate those of the present study, showing lycopene values ranging from 5.69 to 11.77 mg/kg.

### 3.2.3 | Antioxidant Capacity and Bioactive Compounds

In this study, antioxidant capacity was determined using the Folin-Ciocalteu reactive substance method, expressed in mg GAE/kg (FW); free radical scavenging with DPPH, expressed in mmol TE/kg (FW), and Ferric Reducing Antioxidant Power (FRAP), the results of which were presented in mmol Fe<sup>2+</sup>/kg (FW). The values for these analyses are shown in Table 2.

The Folin-Ciocalteu values obtained for the “CIP BRS Nuti” cv. were 946.05 and 1228 mg GAE/kg (FW) for the 2024 and 2023 harvests. These are normal values for orange potato cultivars, as in the study by Dung et al. (2024) on the characterization of

different potato cultivars, an average value of 1130.0 mg GAE/kg (FW) was obtained.

For the FRAP method, the values ranged from 13.82 to 17.52 mmol Fe<sup>2+</sup>/kg dry weight. These values fall within the range reported by Cisneros et al. (2025) and M. Y. Kim et al. (2019), where the values for FRAP ranged from 4.04 to 28.57 mmol Fe<sup>2+</sup>/kg in flours and extracts of orange-fleshed sweet potatoes. The DPPH method's values ranged from 4.60 to 5.80 mmol TE/kg and did not differ between harvests ( $p < 0.05$ ).

The relative distribution of the bioactive compounds quantified in the sweet potato cv. "CIP BRS Nuti" is shown in Figure 2, of which 9-*cis*- $\beta$ -carotene, hesperidin, and chlorogenic acid stand out as the main bioactive compounds in quantity. The study of the correlation between the compounds analyzed and the antioxidant capacity is shown in Figure 3 to assess those responsible for the measured activity. The three analysis methods used showed positive correlations with most of the phenolic compounds quantified. Hesperidin, chlorogenic acid, and kaempferol stood out for their strong positive Pearson correlations ( $> 0.80$ ) with the DPPH, FRAP, and Folin-Ciocalteu methods, and these are the main antioxidants in the "CIP BRS Nuti" variety. About carotenoids, despite their higher values, the correlations obtained were moderate. Our findings demonstrate a significant influence of phenolics on the antioxidant potential of the potato studied, corroborating those observed by Pérez et al. (2023), who found that polyphenols are the primary compounds associated with antioxidant capacity in carrots, a food source of carotenes.

### 3.3 | Simulation of Sweet Potato Digestion and Bioaccessibility of Phenolics and Carotenoids

The beneficial effects of phytochemicals on human health depend on intestinal digestion and absorption (Dantas et al. 2023). This

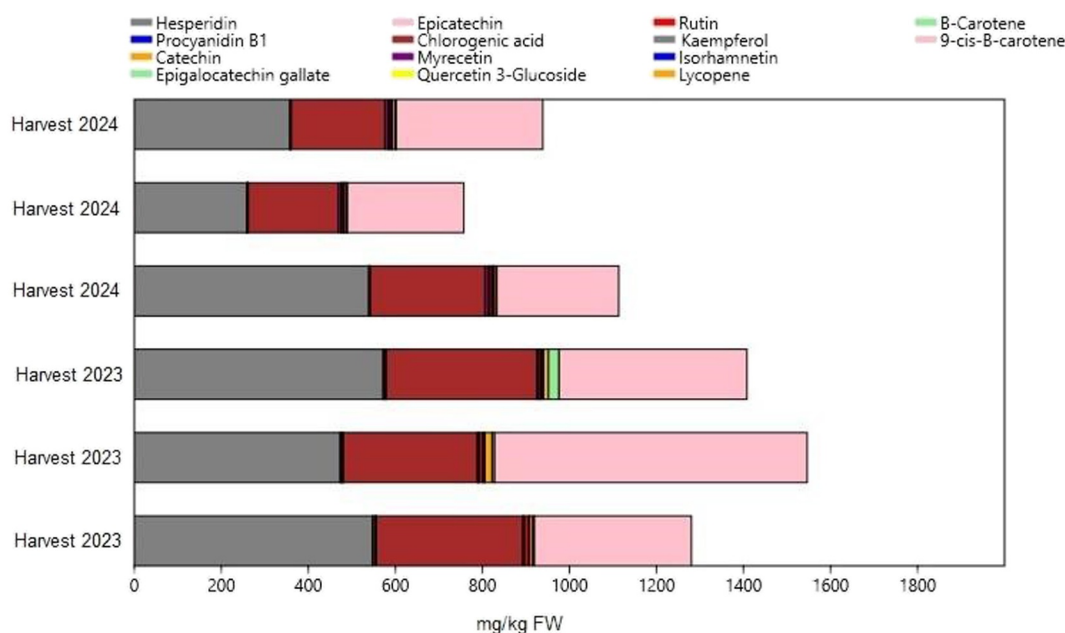
evaluation is important for determining the bioactive potential of the CIP BRS Nuti variety. Table 3 shows the behavior of the bioactive compounds during the simulated gastric and intestinal digestion stages to analyze the behavior of these substances in the sweet potato studied.

Flavanols were the phenolics present in the lowest concentration in the undigested potato. Still, they were the molecules that showed the greatest stability during the digestion stages, being present in the gastric and intestinal phases and, therefore, being bioaccessible. The highest levels of bioaccessibility were obtained for epicatechin (172.9  $\pm$  3.5%), procyanidin B1 (135.9  $\pm$  1.2%), and catechin (104.8  $\pm$  2.5%). Among the flavonols, kaempferol 3-glucoside was the only bioaccessible compound (59.6  $\pm$  1.3%). On the other hand, the phenolics with the highest levels in the undigested matrix, such as hesperidin and chlorogenic acid, did not withstand the digestion conditions and were not directly bioaccessible.

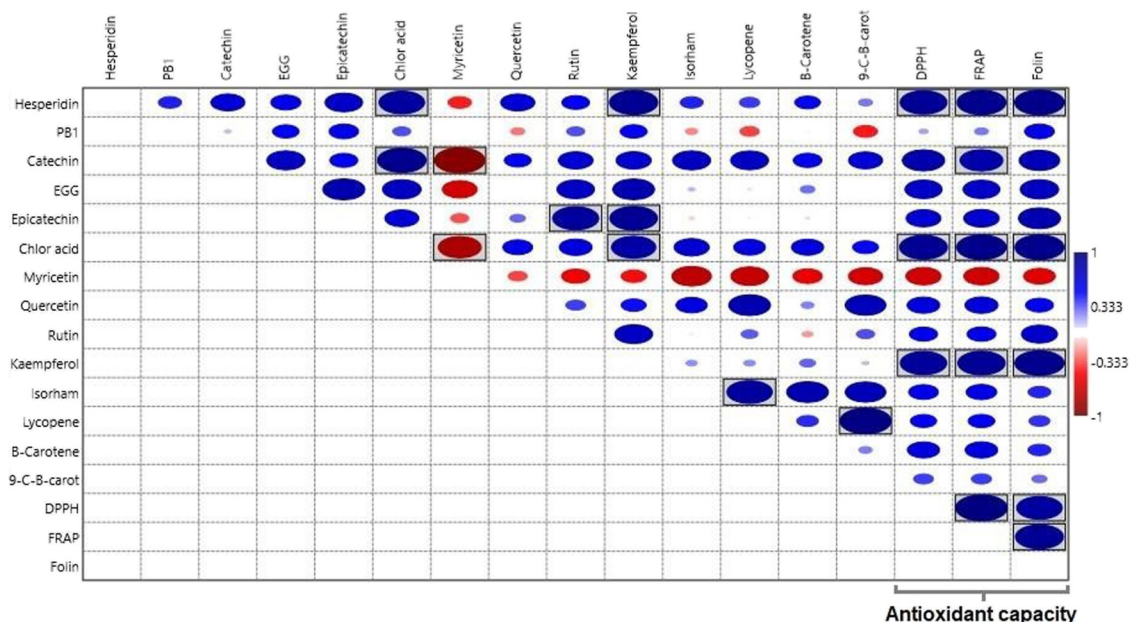
The bioaccessibility of phenolic compounds is related to various factors, including their molecular weight, polarity, glycosylation, and esterification, as well as interactions with other components of the food matrix (lipids, polysaccharides, and proteins) (Raigond et al. 2024). In this context, a food's bioaccessibility depends on its specific composition.

Previous studies evaluating the bioaccessibility of phenolics in potatoes of different cultivars have been limited to analyzing phenolic acids, primarily chlorogenic acid, yielding values ranging from 12% to 82% depending on the cultivar (Andre et al. 2015; Raigond et al. 2024).

Carotenoids are lipophilic pigments that are highly susceptible to oxidation reactions. Due to this sensitivity, several studies have sought to assess the impact of the digestive process on these molecules (Trancoso-Reyes et al. 2016; He et al. 2025; Tao et al. 2021). Among the carotene molecules analyzed in this



**FIGURE 2** | Distribution of the main bioactive compounds quantified by RP-HPLC/DAD in sweet potato "CIP BRS Nuti."



**FIGURE 3** | Correlations between antioxidant capacity and the main bioactive phenolic compounds quantified in “CIP BRS Nuti” sweet potatoes.

**TABLE 3** | Sweet potato cv. “CIP BRS Nuti” bioaccessibility of phenolics and carotenoids during simulated digestion.

Bioactive compounds mg/kg	Fresh sweet potato	Gastric phase	Intestinal phase	Bioaccessibility (%)
<b>Flavanols</b>				
Catechin	4.0 ± 0.2	2.1 ± 0.3	4.2 ± 0.1	104.8 ± 2.5
Epicatechin	2.0 ± 0.4	1.2 ± 0.2	3.4 ± 0.1	172.9 ± 3.5
Epicatechin gallate	ND	2.6 ± 0.2	2.2 ± 0.1	NC
Epigallocatechin gallate	0.2 ± 0.3	ND	ND	
Procyanidin A2	ND	2.2 ± 0.8	1.8 ± 0	NC
Procyanidin B1	1.5 ± 0.3	2.4 ± 0.5	2.1 ± 0.1	135.9 ± 1.2
Procyanidin B2	ND	1.0 ± 0.1	4.6 ± 0.3	NC
<b>Flavonols</b>				
Quercetin 3-glucoside	3.3 ± 0.4	0.4 ± 0.1	ND	
Myricetin	1.3 ± 0.1	ND	ND	
Rutin	8.2 ± 1.4	0.4 ± 0.2	ND	
Kaempferol 3-glucoside	1.6 ± 0.3	0.8 ± 0.03	1.0 ± 0.02	59.6 ± 1.3
Isorhamnetin	2.3 ± 1.0	ND	ND	
<b>Isoflavone</b>				
Hesperidin	510.5 ± 52.6	ND	ND	
<b>Phenolic acids</b>				
Gallic acid	ND	12.4 ± 0.7	35.8 ± 1.4	NC
Chlorogenic acid	322 ± 19	1.8 ± 0.8	ND	
<b>Carotenoids</b>				
β-carotene	4.5 ± 1.9	ND	ND	
9-cis-β-carotene	432.1 ± 52.87	15.3 ± 0.1	18.2 ± 0.04	4.2 ± 0.2
Lycopene	12.1 ± 2.2	ND	ND	

Abbreviations: NC, not calculated; ND, not detected or < LOD.

study, 9-*cis*- $\beta$ -carotene was the only pigment to be bioaccessible ( $4.2 \pm 0.2\%$ ).

The results obtained for the bioaccessibility of carotenoids in “CIP BRS Nuti” were considered low. The low bioaccessibility of *trans*- $\beta$ -carotene was also demonstrated by Andre et al. (2015), who found that carotenes were not bioaccessible in 12 cultivars. The research by Tao et al. (2021) showed that *trans*- $\beta$ -carotene exhibited greater degradation during the digestive process compared to 9-*cis*- $\beta$ -carotene.

Studies indicate that cooking potatoes increases intestinal absorption during digestion (He et al. 2025; Trancoso-Reyes et al. 2016). Due to their apolar nature, the absorption of carotenoids is considerably enhanced when consumed in conjunction with lipids, which form a protective barrier and increase bioaccessibility (Andre et al. 2015). These observations suggest that studies with this cultivar subjected to processing should be expanded.

## 4 | Conclusion

This study investigated the molecular composition and bioactive potential of the Brazilian sweet potato cultivar “CIP BRS Nuti” for the first time. This cultivar has high levels of starch and the presence of simple sugars, such as glucose and fructose, as well as organic acids, including citric acid. The main phenolic compounds present were hesperidin and chlorogenic acid, which are strongly correlated with antioxidant capacity. The carotenoids present were  $\beta$ -carotene, lycopene, and 9-*cis*- $\beta$ -carotene in high quantities. The simulation of potato digestion showed that phenolic compounds were the most bioaccessible compounds. Our results show the nutritional and bioactive potential of the “CIP BRS Nuti” potato, providing essential information for its use in food and industrialization, with an applied view to nutrition and food science.

### Author Contributions

**Maria Carla Cândido da Silva:** investigation, formal analysis, data curation. **Larissa Iris da Silva Monteiro:** writing – review and editing. **Darlanna de Souza Prado:** investigation, formal analysis, data curation. **Ana Júlia de Brito Araújo Carvalho:** formal analysis, visualization. **Marciane Magnani:** visualization, writing – review and editing. **Alexandre Furtado Silveira Mello:** visualization, resources. **Erbs Cintra de Souza Gomes:** resources, funding acquisition. **Marcos dos Santos Lima:** conceptualization, validation, writing – review and editing, project administration.

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### Ethics Statement

The authors have nothing to report.

### Conflicts of Interest

The authors declare no conflicts of interest.

### Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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### Supporting Information

Additional supporting information can be found online in the Supporting Information section.

**Supporting Information S1:** fci270041-sup-0001-suppl-data.docx.