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Nutritional value and antioxidant activity of ora-pro-nobis, tamarillo and green banana biomasses

Valor nutricional e atividade antioxidante de ora-pro-nóbis, tamarillo e biomassas de bananas verdes

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Abstract
The consumption of unconventional food plants (UFP) can be a strategy to promote food and nutritional security, for which it is necessary to know their nutritional composition. The objective of this study was to analyze the nutritional value and antioxidant activity of ora-pro-nobis, tamarillo and bananas biomass (*prata* and *nanica*). Using standard methodologies (AOAC, 2005), the following compounds were analyzed in triplicate: protein, lipids, carbohydrate, calories, moisture, total fiber content, calcium, iron, vitamin C (by titrimetry), carotenoids (by High Performance Liquid Chromatography), phenolic compounds (by Folin-Ciocalteau) and antioxidant activities, by DPPH (2,2-diphenyl-1-picrylhydrazyl) and ABTS (2,2'-azino-bis 3-ethylbenzothiacholine-6-sulfonic acid). Ora-pro-nobis stands out as a source of calcium, iron, carotenoids and protein, is low in fat and has good antioxidant activity. Tamarillo showed high antioxidant activity, is a protein source and low in fat. The two banana biomasses had similar results in most nutrients, but the “nanica” banana with more protein and the “prata” with greater antioxidant activity. The unconventional food plants analyzed are potential bioactive foods, because they have phenolic compounds and high antioxidant activity. Thus, UFP have the potential to promote a more diverse and nutritious diet for consumers in general.
Keywords: *Pereskia aculeata. Solanum betaceum. Musa paradisíaca.* Unconventional food plants. Bioactive compounds.

Resumo

O consumo de plantas alimentícias não convencionais (PANC) pode ser uma estratégia para promover a segurança alimentar e nutricional, para a qual é necessário conhecer sua composição nutricional. O objetivo deste estudo foi analisar o valor nutricional e a atividade antioxidante de ora-pro-nóbis, tamarillo e das biomassas de bananas (prata e nanica). Utilizando metodologias padrão (AOAC, 2005), os seguintes compostos foram analisados em triplicata: proteína, lipídios, carboidrato, calorias, umidade, teor total de fibras, cálcio, ferro, vitamina C (por titulação), os carotenoides (por Cromatografia Líquida de Alta Eficiência), os compostos fenólicos (por Folin-Ciocalteau) e as atividades antioxidantes, por DPPH (2,2-difenil-1-picril-hidrazil) e ABTS (ácido 2,2'-azino-bis 3-etilbenzotiacolina-6-sulfônico). Ora-pro-nóbis se destaca como fonte de cálcio, ferro, carotenoides e proteína, é pobre em gordura e tem boa atividade antioxidante. O tamarillo apresentou alta atividade antioxidante, é fonte de proteína e pobre em gordura. As duas biomassas de banana tiveram resultados tiveram resultados similares na maioria dos nutriente, porém a banana nanica com mais proteína e a prata com maior atividade antioxidante. As plantas alimentícias não convencionais analisadas são alimentos bioativos em potencial, porque apresentam compostos fenólicos e alta atividade antioxidante. Desta forma, as PANCs têm potencial para promover uma dieta mais diversificada e nutritiva para os consumidores em geral.
Palavras-chave: *Pereskia aculeata. Solanum betaceum. Musa paradisíaca*. Planta alimentícia não convencional. Compostos bioativos.

1. Introduction

Fruits and vegetables should be included in daily diets as they promote health and help prevent various diseases (Liu, 2013). However, in Brazil, there are more than 3,000 species of Unconventional Food Plants (UFP) with food potential that remain unknown or are not consumed by most of the population. Some examples include ora-pro-nobis (*Pereskia aculeata*), tamarillo (*Solanum betaceum*), and unconventional parts of common or conventional plants, such as green banana fruit (*Musa paradisíaca*) (Kinupp & Lorenzi, 2014).

Pereskia aculeata is popularly known as ora-pro-nobis, *lobrobô*, Barbados gooseberry, among other names. Its leaves, flowers, and fruits are edible (Kinupp & Lorenzi, 2014) and have attracted interest from the food and pharmaceutical industries due to its bioactive compounds and mucilage (Ferreira *et al*., 2024; Porto *et al*., 2021).

Solanum betaceum is popularly known as tamarillo, tree tomato, Indian tomato, or French tomato. It has edible fruit (Kinupp & Lorenzi, 2014) and contains high levels of bioactive compounds, fiber, and protein, as well as antioxidant and anti-hyperglycemic activities, giving it functional value beyond its nutritional value (Orqueda *et al*., 2021).

The banana (*Musa paradisíaca*) is a conventional fruit; however, other parts of this plant are generally not consumed (unconventional), such as the green fruit (Kinupp & Lorenzi, 2014). Green bananas are a source of minerals, vitamins, and resistant starch, which is beneficial against intestinal cell cancer, heart disease, and celiac disease (Feitosa *et al*., 2023). However, studies on quantification of phenolic compounds (Riquette *et al*., 2019; Sena *et al*., 2020) are still scarce, especially with the species "nanica" (Riquette *et al*., 2019) and "prata" (Silva *et al*., 2016). None of this analyzed antioxidant activity.

Additionally, studies that establish daily consumption recommendations for these plants based on their composition are scarce, as are studies analyzing the antioxidant activity of these plants and its correlation with bioactive compounds such as phenolic compounds, carotenoids, and vitamin C.

The consumption of UFP can be a strategy for promoting food and nutritional security, as it encourages a more diverse diet and helps reduce nutritional deficiencies (Jacob *et al*., 2020; MAPA, 2010; Barreira *et al*., 2015). To achieve this, it is necessary to understand their nutritional information and quantify their compounds. In this context, this study aimed to analyze the selected UFP (ora-pro-nobis, tamarillo, and green banana biomass) regarding their levels of proteins, lipids, carbohydrates, moisture, total fiber, calcium, iron, vitamin C, carotenoids, phenolic compounds, and antioxidant activity.

2. Methodology

2.1 Chemical products and reagentes

All reagents are of analytical grade: 2,2-diphenyl-1-picrylhydrazyl radical; 2,2'-azino-bis radical (3-ethylbenzothiacholine-6-sulfonic acid); methanol; gallic acid; ethanol; Trolox; ethyl acetate; acetonitrile; metaphosphoric acid; 2,6-dichlorophenol indophenol; standard ascorbic acid; nitric acid; perchloric acid; acetic acid; trichloroacetic acid; petroleum ether; sulfuric acid; potassium sulfate; copper sulfate; sodium hydroxide; boric acid; Tashiro indicator; hydrochloric acid.

2.2 Equipment, instruments and glassware

Analytical balance (precision of 0.0001 g), heating chamber, muffle furnace, water bath, electric plate, nitrogen distiller (Solab SL-74®), Soxhlet apparatus (Marcon®), rotary evaporator, blender, mechanical shake, spectrometer (ICP-OES; Perkin Elmer Model Optima 8300 DV), high-performance liquid chromatography (HPLC) system, refrigerator, freezer. Desiccator, porcelain capsule, Kjeldahl flask, distillation flask, Erlenmeyer flask, burette, graduated and volumetric pipettes, flat-bottomed flask, glass chromatographic column, kitassatos, glass rod, glass funnel, volumetric flasks, Büchner funnel, measuring cylinder, beakers. Tweezers, metal spatula, tissue paper and cotton.

2. 3 Plant material

The plants were obtained from family farmers in the Zona da Mata region of Minas Gerais, Brazil. ora-pro-nobis and tamarillo (Figure 1) were harvested in the municipality of Brás Pires (20°50’52”S43°14’39”W) and *prata* and *nanica* bananas were obtained in Viçosa – MG (20°47’40”S42°56’11”W). The samples were transported in a polyethylene box protected from light. Then, it was washed in running water, sanitized for 15 min in a 100 ppm chlorinated solution and rinsed in filtered water. Excess moisture was removed with paper towels.

Figure 1 - Ora-pro-nobis (A) and tamarillo (B)

The biomass was prepared by cooking the whole green bananas for 8 min under pressure, using the proportion of water: green banana 1:1 (v: w). The boiling water was added and after 8 min of pressure, the pressure was released naturally. While still hot, the banana was peeled and blended until homogenized. In this way, the biomass was composed of cooked green banana pulp. (Figure 2).

The samples were stored protected from light, under refrigeration (5°C to 8 °C), for up to 7 days or in the freezer (-12 ºC to -18 ºC), for up to 90 days. Analyzes were performed in triplicate.

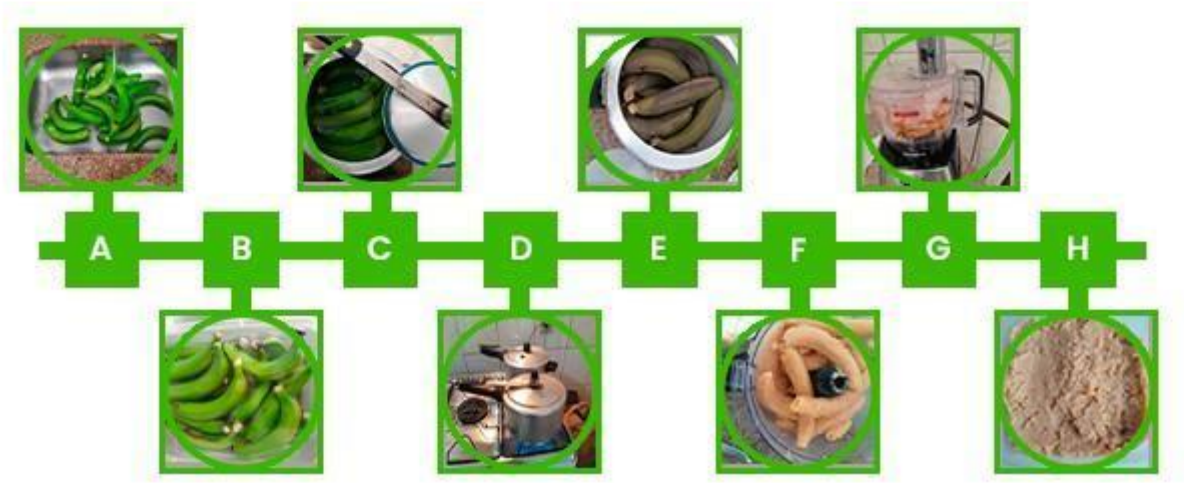

Figure 2 - Green banana biomass processing.

Note: A – Washing; B – Sanitize; C – Put in the pan: green banana and water (1:1); D – Cooking under pressure; E – Drain cooking water; F – Peel; G – Process until homogenized; H – Store.

2. 4 Nutritional composition

The nutritional composition of the plants was determined following the methods recommended by the Association of Official Analytical Chemicals (AOAC, 2005).

Moisture was determined by direct drying in an oven at 105 °C until constant final weight (variation less than 0.01 g). Ash or fixed mineral residue was obtained by incineration in a muffle furnace at 550 °C until constant final weight (variation less than 0.01 g).

Protein was determined by the modified Kjeldahl method. The digester solution contained sulfuric acid, potassium sulfate and copper sulfate. For distillation, 40 % (v/v) sodium hydroxide, 4 % (v/v) boric acid and Tashiro indicator were used in a nitrogen distiller (Solab SL-74®). The titration was carried out with 0.01 N hydrochloric acid (f(HCl) = 0.994) and Tashiro indicator. The nitrogen to protein conversion factor adopted was 6.25.

The lipids were extracted, continuously for 6 h, in a Soxhlet apparatus (Marcon®), using petroleum ether as the solvent. The crude fiber was determined by acid digestion (with acetic, nitric and trichloroacetic acids), followed by incineration (at 550 °C) of the sample until only crude fiber.

The carbohydrate content was calculated by difference using the equation: [100 – (% moisture + % lipid + % protein + % total fiber + % ash)] (Oliveira *et al*., 2019). The caloric value was calculated based on the contents of the protein, lipid, and carbohydrate fractions, using specific coefficients that consider the heat of combustion 4.0; 9.0 and 4.0 kcal, respectively (Dutra de Oliveira; Marchini, 1998).

2. 5 Determination of calcium and iron

For calcium and iron analysis, the samples were dried in forced air circulation ovens for 72 h at a temperature between 68 and 72 °C, and subsequently homogenized by grinding. Digestion was carried out with nitric acid and perchloric acid, on a preheated plate at 80 °C until reaching 200 °C (Sarruge; Haag, 1974). The analysis was performed on an inductively coupled plasma optical emission spectrometer (ICP-OES; Perkin Elmer Model Optima 8300 DV). For quantification, analytical curves were constructed using mineral standards. The results were converted into mineral concentrations, considering the dilutions and their possible difference about in relation to the blank.

2. 6 Determination of C vitamin

Vitamin C was determined using the Tillmans method. The sample of known weight was placed in a beaker with the metaphosphoric acid solution and titrated with the 2,6-dichlorophenol indophenol solution, compared with the standard ascorbic acid solution. The adaptation was carried out with ora-pro-nobis. Due to its solid consistency in its natural state, it was previously ground, diluted in water (1:10, weight), and filtered for subsequent analysis. Vitamin C content was calculated using the Equation 1:

$$Vitamin\ C\ content = \frac{V * F}{A} * 100 \quad (1)$$

Where V is the titration volume, F is the Tillman factor (mass of vitamin C used in titration)/(volume of titrant used in standard titration), and A is the sample volume after titrant addition.

2. 7 Determination of carotenoids

For carotenoid analysis, the samples and extracts were protected from both sunlight and artificial light with the use of amber glass bottles, aluminum foil and blackout curtains. To extract the carotenoids, five grams of sample were added 20 mL of acetone and homogenized in a micro-shredder for 3 min and vacuum filtered. This procedure was repeated 3 times. Then, the filtrate was added to 50 mL of cooled petroleum ether and washed with distilled water to remove acetone. To the carotenoid extract in petroleum ether kept in the funnel, anhydrous sodium sulfate was added to remove residual water. Finally, the extract was concentrated to 10 mL, using a rotary evaporator (Rodriguez-Amaya, 2001). The analysis was carried out using a high-performance liquid chromatography (HPLC) system, at a wavelength of 450 nm (Pinheiro-Sant'Ana *et al*., 1998). The liquid chromatography system used featured a Shimadzu® diode array detector and a Gemini reversed-phase analytical column (250 × 4 mm, 5 µm) preceded by an ODS safety pre-column (C18) (4.0 × 3 .0 mm), both from Phenomenex® (Torrance, CA, USA). The mobile phase was composed of methanol, ethyl acetate and acetonitrile, (80:10:10). The identification of carotenoids was made by comparing their UV spectra and retention times with reference standards. Quantification was carried out using a standard curve established from the same standards. The result was expressed in mg of carotenoid/100 g.

2. 8 Extraction and determination of the phenolic compounds

Total phenolic content was determined using the Folin-Ciocalteu method. Extraction of the compounds was carried out with 1 g of sample in a methanol solution: water 60:40 (v/v), under agitation for 30 min and subsequent centrifugation at 3500 rpm for 5 min (Bloor, 2001). Phenolic compounds were determined by reading on a spectrophotometer, at 765 nm absorbance, based on an analytical curve of gallic acid (0.0025 – 0.03 g/L), previously carried out. The results were expressed as mg of gallic acid equivalent per g of sample (mg GAE/ g) (Singleton *et al*., 1999).

2. 9 Antioxidant activity

Antioxidant activity was determined by 2 methods: DPPH, with 2,2-diphenyl-1-picrylhydrazyl radical and ABTS, with 2,2'-azino-bis radical (3-ethylbenzothiacholine-6-sulfonic acid). Extraction was carried out according to Bloor (2001).

Using the DPPH method, methanolic DPPH solution was added to the extracts, and the extracts, blank and control were read in a spectrophotometer, at 517 nm absorbance, based on a previously performed Trolox analytical curve. The percentage of radical inhibition was calculated using the Equation 2:

$$\%\ \text{radical inhibition} = 100 - \frac{(A_f/A_0)}{A_c} * 100 \quad (2)$$

Where "A_0" is the initial absorbance, "A_f" is the final absorbance, "Ac" is the control absorbance (Blois, 1958).

In the ABTS method, the extraction of compounds was carried out in a 60% methanol solution. The extract was evaporated at 44°C for about 15 min, until the methanol dried. Next, 95° PA ethanol was added, the same solvent as the standard Trolox solution. The antioxidant activity was determined by reading on a spectrophotometer, at 734 nm absorbance, based on a previously performed Trolox analytical curve (100 – 2000 µmol/L) (Boroski *et al.*, 2015; Brasil, 2007). ABTS and DPPH results were expressed in mg/g.

2. 10 Analysis of results

This study was conducted in a completely randomized design with three replicates. Descriptive statistics (mean and standard deviation) were used to present the results. To compare the two banana species, the results of the analyses were compared by analysis of variance, using the One-Way ANOVA test ($p \leq 0.05$). Data on antioxidant activity and bioactive compounds, such as phenolics and carotenoids, were correlated using Pearson's test. Statistical analyses were performed using R software.

The UFP were classified as "source," "good source," and "excellent source" (Philippi, 2008) when they had the potential to provide 5 to 10% of the dietary reference intake (DRI, according to the Institute of Medicine, 2020) in a serving; 10 to 20% of the potential DRI; and more than 20% of the DRI, respectively, as indicated by Philippi (2008), considering the portion of vegetables equivalent to 30 kcal and fruits equivalent to 70 kcal, as proposed by the dietary guidelines for the Brazilian population (Brasil, 2008).

3. Results and Discussion

3.1 Nutritional composition and antioxidant activity of ora-pro-nobis

The recommended daily portion for consumption of ora-pro-nobis was 79 g (Table 1), equivalent to 30 kcal (Brasil, 2008). This vegetable can be considered a source of protein, a good source of vitamin C, and an excellent source of calcium, iron, and carotenoids (5.46%, 18.93%, 100%, 45.25%, and 74.45% DRI/serving, respectively) while being low in lipids (0.34%), according to the daily recommended intake (DRI) proposed by the Institute of Medicine (2020). Additionally, it contains 37.89 kcal/100g, 87.45% moisture, 2.17% ash, 1.3% fiber, and 5.24% carbohydrates (Table 1). Ora-pro-nobis showed a higher protein content (3.46±0.06 g/100g) compared to other studies found in the literature, which reported values ranging from 1.27 to 2.8 g/100g (Barreira *et al.*, 2021 and Oliveira *et al.*, 2019, respectively). Ora-pro-nobis is considered a good source of plant protein, with a composition similar to that of legumes like beans (Silveira *et al.*, 2020), containing all essential amino acids, an abundant supply of tryptophan and lysine, but limited in methionine and cysteine (Santos *et al.*, 2022; Silveira *et al.*, 2020; Takeiti *et al.*, 2009; Zem *et al.*, 2017). Using different protein sources can improve nutritional quality. In this case, to complement amino acids, it is suggested to consume it alongside cereals, as they are rich in the limiting amino acids found in ora-pro-nobis (Silveira *et al.*, 2020).

The content of phenolic compounds and antioxidant activity by ABTS of ora-pro-nobis (Table 1) was also higher than that found in the literature (Table 2). Ora-pro-nobis showed a low lipid content (Table 1), lower than that reported in the literature (Table 2).

The crude fiber and vitamin C levels found in ora-pro-nobis were lower than those available in the literature. It is worth noting that the methodology of this study differs from some other studies that used HPLC for vitamin C and determined dietary fiber rather than crude fiber. The methodologies for crude fiber and vitamin C by Tillmans (AOAC, 2005) are validated and have the advantages of being less costly, faster, and more practical.

The ora-pro-nobis leaves presented a caloric value (Table 1) similar to other leafy vegetables such as broccoli (34 kcal/100 g), cauliflower (25 kcal/100 g), and cabbage (31 kcal/100 g) (Favela-González *et al.*, 2020). However, its fiber content (Table 1) is higher than that of broccoli (2.6 g/100 g), cauliflower (2.0 g/100 g), and cabbage (2.2 g/100 g) (Favela-González *et al.*, 2020). Regarding protein content (Table 1), ora-pro-nobis leaves have higher values compared to leafy vegetables like cabbage. (1,28 g/100 g) (Brito *et al*., 2020).

Table 1 - Nutritional composition, phenolic compounds, and antioxidant activity of ora-pro-nobis leaves.

Parameters	Ora-pro-nobis (in 100 g)	Ora-pro-nobis (portion: 79 g)	%DRI*
Calories (kcal)	37.89±1.17	29.94	-
Moisture (% m/m)	87.45±0.07	69.08	-
Ash (% m/m)	2.17±0.14	1.71	-
Protein (% m/m)	3.46±0.06	2.73	5.46
Lipids (% m/m)	0.34±0.09	0.27	-
Crude Fiber (% m/m)	1.3±0.1	1.03	4.12
Carbohydrate (% m/m)	5.24±0.19	4.14	3.18
Calcium (mg/ 100g)	3384 ± 11.13	2673	> 100
Iron (mg/ 100g)	8.02 ± 0.18	6.34	45.25
Vitamin C (mg/ 100g)	23.97 ± 3.75	18.94	18.93
Carotenoids (mg/ 100g)	62.837±5.871	49.64	74.45
Total phenolic content (mg GAE/ 100g)	180.76±6.63	-	-
Antioxidant activity, DPPH (µmol trolox/g of sample; % AA; mg/g)	6875±187; 87.19±2.37 %;1721±47	-	-
Antioxidant activity ABTS (µmol trolox/g of sample; % AA; mg/g)	57.49±3.60; 64.74±4.36%;14.39±0.9	-	-

Analysis on a wet basis, expressed as mean (of 3 repetitions) ± standard deviation. *%DRI: daily reference intake, based on a 30 kcal portion (79 g) and a daily diet of 2000 kcal (according to Institute of Medicina, 2020)

Table 2 - Nutritional composition, phenolic compounds, and antioxidant activity data of ora-pro-nobis leaves available in the literature.

Parameters	Ora-pro-nobis (results found in other studies)
Calories (kcal)	22.62[1] to 42.0[2]
Moisture (%)	86.65[1] to 91.10±2.24[3]
Ash (%)	0.96 ± 0.01[3] to 2.90±0.51[4]
Protein (%)	1.27 ± 0.07[3] to 2.80±0.11[4]
Lipids (%)	0.40±0.12[4] to 1.45 ± 0.01[3]
Fiber (%)	3.73 ± 0.03[3]
Total dietary fiber	3.88[1]
Crude Fiber	-
Carbohydrate (%)	2.65[1] to 6.70±1.64[4]
Calcium (mg/ 100g)	269.38[1] to 6491.0±132.5[4]
Iron (mg/ 100g)	1.33[1] to 24.1±4.1[4]
Vitamin C	192.21[6] mg/ 100g
Vitamin C (spectrophotometric)	192.21[6] mg/100g
Vitamin C by Tillmans (mg/ 100g)	-
Carotenoids	1190±230.0 to 2100±210.9[5] mg/ 100g
Total phenolic content	7.86±1.59[4] to 151.503 ± 334.5[7] mg GAE/100 g
Antioxidant activity, DPPH	27 ± <1[8] mg of AAE/ g to 106.1±3.9[9] (IC_{50}: µg/ml)
Antioxidant activity ABTS (µmol trolox/g of sample; % AA; mg/g)	40.5 ± 1 (IC_{50}: µg/ml)[10]

Studies with ora-pro-nobis: [1]-Botrel *et al*., 2020; [2]-Monteiro *et al*., 2021; [3]-Barreira *et al*., 2021; [4]-Oliveira *et al*., 2019; [5]-Agostini-Costa *et al*., 2014; [6]-Oliveira *et al*., 2013; [7]-Maciel *et al*., 2021; [8]-Cruz *et al*., 2021; [9]-Souza *et al*., 2014; [10]-Garcia *et al*., 2019

3.2 Nutritional Composition and Antioxidant Activity of Tamarillo

The recommended daily portion for tamarillo consumption was 187.5 g (Table 3), equivalent to 70 kcal (Brazil, 2008). This fruit can be considered a source of protein, a good source of calcium, and an excellent source of fiber, vitamin C, and iron (7,33%; 17,89%; 21,92%; 39,54% e 37,39 % DRI/ portion, respectively) while being low in lipids (0.05%), according to the daily recommended intake (DRI) proposed by the Institute of Medicine (2020). Additionally, the tamarillo fruit contains: 37.33 Kcal/ 100g, 1.11% ash, and 2.9% carbohydrate (Table 3).

Table 3. Nutritional composition, phenolic compounds, and antioxidant activity of tamarillo fruit.

Parameters	Tamarillo (100g)	Tamarillo (portion: 187,5 g)	%DRI*
Calories (kcal)	37.33±1.24	70.0	3.5%
Moisture (% m/m)	86.71±0.33	-	-
Ash (% m/m)	1.11±0.09	-	-
Protein (% m/m)	1.94±0.05	3.66	7.32%
Lipids (% m/m)	0.05±0.01	0.09	0.14%
Crude Fiber (% m/m)	2.9±0.1	5.43	21.72%
Carbohydrate (% m/m)	2.9±0.1	13.67	4.56%
Calcium (mg/ 100g)	94.66 ± 2.88	177.5	17.75%
Iron (mg/ 100g)	2.77 ± 0.06	5.19	37.07%
Vitamin C (mg/ 100g)	20.92 ± 0.11	39.23	39.23%
Carotenoids (mg/ 100g)	49.2±4.66	-	-
Antioxidant Activity, DPPH (mg/g ; % AA)	191±29; 20.81±1.72 %	-	-
Antioxidant Activity ABTS (mg/g)	71.03±0.78	-	-

Analysis on a wet basis, expressed as mean (of 3 repetitions) ± standard deviation. *%DRI: daily reference intake, based on a 70 kcal portion (163 g) and a daily diet of 2000 kcal (according to Institute Medicina, 2020).

For most parameters, the values found (Table 3) were intermediate compared to those mentioned in the literature (Table 4). For antioxidant activity by ABTS and ash content, higher values (Table 3) were obtained compared to those reported in the literature (Table 4).

In the present study, the characterization was performed on the whole fruit. However, Martin *et al*. (2021) observed differences in the chemical composition of different parts of the fruit, with seeds being richer in lipids, pectin, and phenolic compounds; the peel containing fiber, pectin, lipids, higher levels of phenolics, and terpenoids; and the pulp predominantly polysaccharides, fiber, pectin, and phenolic compounds.

Tamarillo has a lower caloric value (37.33 kcal/100 g, as shown in Table 3) compared to various fruits such as pineapple, “Prata” banana, “lima” orange, “Fuji” apple, “Formosa” papaya, “Palmer” mango, and “Italia” grape (48, 96, 46, 56, 45, 72, and 53 kcal/100 g, respectively) (TACO, 2011). The lipid and carbohydrate contents of tamarillo were also lower than those found in the aforementioned fruits (TACO, 2011). On the other hand, the protein, fiber, calcium, and iron contents of tamarillo were higher than those of the listed fruits (TACO, 2011).

Table 4 - Nutritional composition, phenolic compounds, and antioxidant sctivity of tamarillo available in the literature.

Compounds	Tamarillo (results found in other studies)
Calories (kcal)	55.38[3] to 64.9[1]
Moisture (%)	82.9[1] to 88.4±0.4[2]
Ash (%)	0.15±0.05[3] to 1.0[2]
Protein (%)	1.4±0.02[2] to 2.5±0.19[4]
Lipids (%)	0.05±0.005[5] to 1.22±0.29[3]
Fiber (%)	0.91[3] to 4.5[1]
Crude Fiber	4.5[1]
Carbohydrate (%)	3.1±0.02[2] to 9.41±1.76[3]
Calcium (mg/ 100g)	10.6±0.05[5] to 25.56[1]
Iron (mg/ 100g)	0.6±0.03[5] to 0.9[1]
Vitamin C	16.09±1.6[1] to 19.7±0.25[5] mg/ 100g
Vitamin C by Tillmans (mg/ 100g)	16.09±1.6[1]
Total phenolic content	3.62±0.39[6] g/ 100g d.m. to 130±0.08[1] mg GAE/100g
Antioxidant activity, DPPH	82.021 ± 7.240 mg/ g[7] to 853 ± 52 g equivalente trolox / g[1]
Antioxidant activity ABTS (µmol trolox/g of sample)	22 ± 0.4 µmol Trolox/ g (dm)[8] to 853 ± 52 g equivalente trolox / g[1]

Studies on tamarillo: 1-De Carrasco *et al*., 2008; 2-Diep *et al*., 2020; 3-Pantoja *et al*., 2009; 4-Vasco *et al*., 2009; 5-Romero-Rodriguez *et al*., 1994; 6-Acosta-Quezada *et al*., 2015; 7-Ghosal *et al*., 2013; 8-Espin *et al*., 2016.

3.3 Nutritional composition and antioxidant activity of "prata" and "nanica" banana biomasses

A daily portion of 64 g of green banana biomass, corresponding to 70 kcal, would be recommended for nutritional provision and health promotion. From a clinical perspective, studies reported daily biomass consumption of 30 g (Cassettari *et al*., 2019) to 300 g (Rabbani *et al*., 2010), for benefits to gastrointestinal health (Álvarez-Acosta *et al*., 2009; Cassettari *et al*., 2019; Gunasekaran *et al*., 2020; Rabbani *et al*., 2001, 2004, 2009, 2010), body composition (Álvarez-Acosta *et al*., 2009; Costa *et al*., 2019; Lousek *et al*., 2021) and lipid profile (Silva *et al*., 2016; Lotfollahi *et al*., 2020).

The nutritional composition of the two green banana biomasses ("prata" and "nanica") was similar, with no statistical difference ($p>0.05$) for: calories (110.45 and 108.11 g/ 100 kcal / 100g), ash (1.09 and 1.47 g/ 100g), and crude fiber (0.9 and 0.7 g/ 100g), respectively. (Table 5).

However, the "Nanica" banana biomass had a higher content of moisture, protein, iron, and phenolic compounds. In contrast, "Prata" banana biomass was higher in carbohydrate, calcium, vitamin C and carotenoids ($p<0.05$).

In this study, the values obtained for ash, protein, and fiber (Table 5) are intermediate when compared to those found in the literature (Table 6). The lipid content obtained in the biomasses of Prata and Nanica bananas were lower than those reported by all the studies in Table 6 (0.13 to 0.55, in Sena *et al*. (2020) and Silva *et al*. (2016), respectively).

The biomasses showed lower moisture values than other studies, from 71.17 to 78.96 g/100g (Bahado-Singh *et al*., 2006 and Riquette *et al*., 2019, respectively). In this study, during the processing of banana biomass, cooking broth was not added, which may have contributed to obtaining a product with lower moisture content. This result can favor the conservation of the product, considering that the higher moisture content can contribute to the growth of microorganisms.

The content of vitamin C found (Table 5) was lower than in Riquette *et al*. (2019), 54.4 mg/ 100g, (Table 6). The differences found can be attributed to the method for quantifying these compounds. In some studies, include in the discussion, the determination of vitamin C was carried out by HPLC. In this study, the methodology adopted was Tillman.

Table 5 - Nutritional composition, phenolic compounds, and antioxidant activity in biomasses of "Prata" and "Nanica" bananas.

Compounds	"Prata" banana biomass *(Musa sapientum)*	"Nanica" banana biomass *(Musa Cavendish)*	ANOVA (p-value)
Calories (kcal)	110.28±0.76	108.63±1.02	0.0875
Moisture (% w/w)	70.67±0.04	71.35±0.12	0.0007*
Ash (% w/w)	0.93±0.01	0.96±0.04	0.2500
Protein (% w/w)	1.09±0.02	1.47±0.04	0.0001*
Lipids (% w/w)	0.09±0.04	0.03±0.02	0.5900
Crude fiber (% w/w)	0.9±0.1	0.7±0.1	0.0550
Carbohydrate (% w/w)	26.28±0.09	25.32±0.31	0.0067*
Calcium (mg/ 100g)	16.33 ± 1.52	12 ± 1	0.0147*
Iron (mg/ 100g)	0.78 ± 0.02	1.06 ± 0.02	0.0001*
Vitamin C (mg/ 100g)	4.43 ± 0.31	3.72 ± 0.02	0.0166*
Carotenoids (mg/ 100g)	0.616±0.039	Nd	0.0001*
Total phenolic content (mg GAE/ 100g)	51.08±6.15	99.45±7.76	0.0011*
Antioxidant activity: DPPH (mg/g; % AA)	506±157; 43.96±3.86 %	1576±43; 80.88±2.72 %	0.0014*
Antioxidant activity: ABTS (mg/g)	20.95±3.3	10.03±2.55	0.0662

Analysis on a wet basis, expressed as mean ± standard deviation. Nd – not detected, even in more concentrated extracts. *Statistically significant difference ($p < 0.05$).

Table 6 - Studies on nutritional composition, phenolic compounds, and antioxidant activity in green banana and green banana biomass.

Reference	Riquette *et al.* (2019)	Silva *et al.* (2016)	Sena *et al.* (2020)	Bahado-Singh *et al.* (2006)	Bahado-Singh *et al.* (2006)	Costa *et al.* (2017)	Auriema *et al.* (2021)
Green banana	"Nanica" banana biomass	"Prata" banana biomass	"Terra" banana biomass	Green plantain	Green banana	Green banana pulp	Green banana biomass
Moisture (%)	78.78±0.13	77.0	75.37	68.06±0.18	71.17±0.20	76.7±0.76	78.58±0.20
Ash (%)	0.43±0.04	4.53	0.65	1.13±0.04	0.89±0.03	0.8±0.07	0.65±0.04
Protein (%)	1.44±0.13	2.73	0.81	1.67±0.02	1.42±0.18	0.8±0.04	0.94±0.04
Lipids (%)	0.20±0.01	0.505	0.13	0.24±0.02	0.33±0.03	0.2±0.07	0.40±0.03
Fibers (%)			2.55	0.48±0.03	0..59±0.04		4.16±0.20
Crude fiber (%)	2.60±0.02	5.52					
Carbohydrate (%)	16.65 ± 0.09		21.06	19.29	22.20	21.9	19.43±0.47
Calcium (mg/ 100g)							78 ± 4.90
Iron (mg/ 100g)							7.21 ± 0.29
Vitamin C (mg/100g)	54.4±0.8						
Total phenolic content	322.20±1.8 mg GAE/ 100 g		189.9±15.7 mg GAE/100g				

The carotenoid content detected in the samples was low (0.616 mg/ 100g in “Prata” banana biomass and not detected in “Nanica”) and does not represent even 5% of the daily nutritional recommendations in a 100g portion (Institute of Medicine, 2019). Campos *et al*. (2024) observed low levels of carotenoids in the peel of "prata" and "nanica" green bananas and an increase during the ripening process.

The carbohydrate values in our study were higher than others, which ranged from 16,65 to 22,2 g/100g (Riquette *et al*., 2019 and Bahado-Singh *et al*., 2006, respectively). The carbohydrate determination calculated based on the difference in macronutrients may have overestimated the calorie content of the biomass, considering that studies indicate that green banana biomass is a source of resistant starch (Castelo-Branco *et al*., 2017; Falcomer *et al*., 2019), an indigestible polysaccharide, which exerts effects on the body similar to those of fiber (McCleary; Cox, 2017). This starch is physiologically analyzed as soluble fiber and chemically as insoluble fiber (Brown, 2004), which may not have been detected in our analyzes due to the crude fiber methodology (AOAC, 2005). An *in vitro* starch digestion study indicated that of the total starch present in green banana biomass, 21% was slowly digested and 42% was resistant starch (Raveena *et al*., 2022). In a human study, green banana biomass resulted in a much lower glycemic index than ripe bananas (39 and 66, respectively), with the same cooking technique (Bahado-Singh *et al*., 2006), highlighting the beneficial effect of resistant starch present in green banana biomass.

The variations found between the studies (Table 6) can be explained, among other factors mentioned earlier, by the use of different banana species, processing methods, and cooking times. In most studies, the fruit with the peel was cooked under pressure (Auriema *et al*., 2021; Silva *et al*., 2016; Riquette *et al*., 2019; Sena *et al*., 2020). However, Bahado-Singh *et al*. (2006) cooked peeled green bananas over low heat without pressure, and Costa *et al*. (2017) used industrialized biomass and did not provide information about the banana species or processing. The cooking times in the studies varied from 5 (Riquette *et al*., 2019; Sena *et al*., 2020), 8 (Silva *et al*., 2016), 10 (Bahado-Singh *et al*., 2006), to 15 minutes (Auriema *et al*., 2021).

The "Nanica" banana biomass had a higher content of antioxidant activity than in "Prata" (1576 and 506 mg/g of the sample, respectively), using the DPPH method. On the other hand, in ABTS method, it was higher in the biomass of "Prata" banana than in "Nanica" one (20.95 e 10.03 mg/g of the sample, respectively).

The antioxidant activity of cooked green “Prata” banana biomass (DPPH: 506 and ABTS: 20.95 mg/g) and the total phenolic content - TPC (“Prata”: 51.08 mg GAE/ 100g) in our study were higher than that of ripe “Prata” banana (DPPH: 6.4091 and ABTS: 14.2227 mg/g; TPC: 39.69 mg GAE/ 100g) (Maduwanthi; Marapan, 2021). Campos *et al*. (2024) also observed high levels of phenolic acids in the peel of “prata” and “nanica” green bananas and a decrease during the ripening process. We did not find studies analyzing the antioxidant activity of green banana biomass of the species studied. In this way, this work contributes to reducing this knowledge gap.

3.4. Correlation between antioxidant activity and bioactive compounds

The comparative analysis of antioxidant activity and phenolic compounds faces challenges as the result is influenced by several factors, such as the extraction method (in different proportions of solvent, which can be acetone, alcohol, methanol, water), sample care (harvest, transport, storage) and the different units adopted to represent the result (Trolox equivalent per g of sample, gram of extract, % antioxidant activity, CE_{50}).

There was a strong correlation between antioxidant activity by DPPH and bioactive compounds (Phenolics: 0.89; carotenoids: 0,98). These values were higher than those observed in other studies: DPPH x total phenolic content (r = 0.7564), flavonoids (r = 0.6519), proteins (r = 0.7616) and caffeic acid (r = 0.7836) (Cruz *et al*., 2021). Souza *et al*. (2014) also observed that the greater the content of total phenols, the greater the antioxidant activity (lower CE_{50} value), using the DPPH method.

The correlation between antioxidant activity by DPPH and ABTS was 0.62 and non-significant (p=0.381). The variation between methods may occur due to differences in the hydrophilic and/or lipophilic affinity of the radical cation (DPPH and ABTS) and the predominant compounds in each sample (Boroski *et al*., 2015).

3.5. Considerations on the analyzed UFP

The four UFP had low lipid content (0.03±0.02 to 0.34±0.09 g/100g, in nanica banana biomass and ora-pro-nobis), lower than those reported in the literature (Tables 2, 4, and 6). The nanica banana biomass had the lowest lipid content (0.03±0.02 g/100g).

Ora-pro-nobis had the highest protein content (3.46±0.06 g/100g) among the analyzed UFP. The moisture content was similar between ora-pro-nobis and tamarillo (87.45±0.07 to 86.71±0.33 g/100g) and between the two types of biomass (70.67±0.04 for prata and 71.35±0.12 g/100g for nanica). The ash content was similar and lower in the biomass (1.09±0.02 for prata and 1.47±0.04 g/100g for nanica) and higher in ora-pro-nobis (2.17±0.14). Using the ABTS method, tamarillo showed the highest antioxidant activity, and “nanica” banana biomass showed the lowest (283.81±3.11 and 40.06±10.21 µmol trolox/g of sample, respectively).

Using the DPPH method, antioxidant activity was higher in tamarillo (283.81±3.11), followed by “prata” banana (83.70±13.20), ora-pro-nobis (57.49±3.60), and “nanica” banana (40.06±10.21).

Variations in nutrient and bioactive compound levels were observed between the studies presented in the discussion. Several conditions can affect this composition, such as: the type of cultivation (natural, organic, and conventional) (Oliveira *et al*., 2013), soil characteristics, water, external factors (Oliveira & Naozuka, 2021), exposure to sunlight during cultivation (Agostini-Costa *et al*., 2014), among others. Processing methods during storage, freezing, lyophilization (de Souza *et al*., 2021), analysis methods, and others can also influence the levels of compounds.

4. Conclusion

The analyzed unconventional food plants are an important source of nutrients and bioactive potential. They showed promising results regarding nutrient levels, bioactive compounds, and antioxidant activity. Tamarillo stands out as an excellent source of fiber, vitamin C, and iron, a good source of calcium, and a source of protein, in a recommended portion of 189 g of fruit. Ora-pro-nobis is an excellent source of calcium, iron, and carotenoids, a good source of vitamin C, and a source of protein, in a recommended portion of 79 g of fresh leaves. The “Prata" and "Nanica" banana biomasses showed similar nutrient results and stand out for their antioxidant activity, presence of phenolic compounds, and low-fat content.

The use of unconventional food plants is important for greater food diversification, preservation of plant species, rescue of traditional cuisine, and promotion of food security. The inclusion of these UFP in the diet, both for direct consumption or as an ingredient, can contribute to the provision of more sustainable, natural, and healthy foods by the food industry.

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