

Effect of processing on the centesimal and bioactive composition of 'Beauregard' sweet potato and its derivatives

Felipe Sousa da Silva¹
Sheyla Maria Barreto Amaral²
Raimunda Valdenice da Silva Freitas³
Maria Jéssica de Almeida Souza⁴
Luana Guabiraba Mendes⁵
Maria Aparecida Liberato Milhome⁶
Virna Luiza de Farias⁷

ABSTRACT

'Beauregard' is a sweet potato cultivar that has been widely studied as a method of food biofortification. The objective of this study was to evaluate the centesimal composition, bioactive compounds and antioxidant activity of 'Beauregard' potato and its derivatives (flour and its application in cake). The samples were submitted to analyses regarding moisture, ash, lipids, proteins, carbohydrates, carotenoids, polyphenols and antioxidant activity. The heating during flour elaboration promoted carotenoid and polyphenol losses; however, the ingestion of flour (190.03 µg/g carotenoids and 23.21 mg/g polyphenols) ensures greater contribution of these bioactive compounds when compared with raw potato (69.30 µg/g carotenoids and 10.87 mg/g polyphenols). 'Beauregard' potato flour is a viable alternative for incorporation into cakes, increasing the minerals, carbohydrates, carotenoids, and polyphenol contents, as well as the antioxidant activity. In addition, its incorporation allows ingesting less than 50 g of flour and 60 g of the F1 cake, which corresponds to one serving, in order to reach the recommended daily intake of vitamin A.

Index terms: biofortification, carotenoids, *Ipomoea batatas* (L.) Lam., provitamin A.

Efeito do processamento na composição centesimal e de bioativos de batata-doce 'Beauregard' e de seus derivados

RESUMO

A 'Beauregard' é uma cultivar de batata-doce que tem sido amplamente estudada como método de biofortificação de alimentos. O objetivo deste estudo foi avaliar a composição

¹ Food Technologist, master in Food Technology, work as Food Technologist, Limoeiro do Norte, Ceará. E-mail: fesosi2005@gmail.com

² Food Technologist, master in Food Technology, doctoral student in Food Science and Technology at Universidade Federal do Ceará (UFC). Fortaleza, Ceará. E-mail: sheylaamaral82@gmail.com

³ Food Technologist, doctor in Food Science and Technology, substitute professor of the Federal Institute of Education, Science and Technology of Rio Grande do Norte (IFRN). Pau dos Ferros, Rio Grande do Norte. E-mail: valdenice2006@yahoo.com.br

⁴ Bachelor in Nutrition, work as Nutritionist in Limoeiro do Norte. Limoeiro do Norte, Ceará. E-mail: jessicaaalmeida16@gmail.com

⁵ Food engineer, doctor in Biotechnology, postdoctoral student of the National Postdoctoral Program (PNPD/CAPES) in the Federal Institute of Education, Science and Technology of Ceará (IFCE). Limoeiro do Norte, Ceará. E-mail: luanagmendes@gmail.com

⁶ Chemist, doctor in Civil Engineering/Environmental Sanitation, professor of the Federal Institute of Education, Science and Technology of Ceará (IFCE), Limoeiro do Norte, Ceará. E-mail: maria.milhome@ifce.edu.br

⁷ Food engineer, doctor in Chemical Engineering, professor of the Federal Institute of Education, Science and Technology of Ceará (IFCE), Limoeiro do Norte, Ceará. E-mail: virna@ifce.edu.br

Ideias centrais

- Viabilidade tecnológica da aplicação da farinha de batata Beauregard em bolo;
- A secagem promoveu perda de compostos bioativos, mas aumentou a atividade antioxidante da farinha;
- Bolo de farinha de batata Beauregard para atingir a ingestão diária recomendada de vitamina A;
- A farinha de batata aumentou os teores de minerais, carboidratos, carotenoides e polifenóis no bolo;
- Maior atividade antioxidante no bolo com farinha de batata devido aos carotenoides e polifenóis.

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centesimal, os compostos bioativos e a atividade antioxidante dessa variedade de batata e dos seus derivados (farinha e bolo). As amostras foram submetidas a análises de umidade, cinzas, lipídios, proteínas, carboidratos, carotenoides, polifenóis e atividade antioxidante. O aquecimento para elaboração da farinha promoveu perdas de carotenoides e de polifenóis; entretanto, a ingestão da farinha (190,03 µg/g carotenoides e 23,21 mg/g polifenóis) garante maior aporte desses compostos bioativos em comparação com a batata in natura (69,30 µg/g carotenoides e 10,87 mg/g polifenóis). A farinha da batata 'Beuaregard' é uma alternativa viável para incorporação em bolos, aumentando os teores de minerais, carboidratos, carotenoides, polifenóis, bem como a atividade antioxidante. Além disso, a incorporação permite ingerir menos de 50 g de farinha e 60 g de bolo F1, que correspondem a uma porção, para atingir a ingestão diária recomendada de vitamina A.

Termos para indexação: biofortificação, carotenoides, *Ipomoea batatas* (L.) Lam., provitamina A.

INTRODUCTION

Public agencies have promoted scientific studies using biofortification technology to produce agricultural products from seeds to meet the nutritional needs of low-income people. Food biofortification consists of increasing the micronutrient content through agronomic practices or genetic improvement. Sweet potatoes are one of the target foods of the biofortification process in Brazil and they have been encouraged to be included in public nutritional policies (Loureiro et al., 2018; Carvalho & Rodrigues, 2020).

Fortification of foods with vitamin A and iron is a strategy in some Latin American countries to combat the deficiency of these micronutrients, especially in children with diets lacking β-carotene, iron and zinc, which can cause anemia, reduced work capacity, immune system problems, developmental delay and even death. With the growing demand for food products with high nutritional value, with preferably low cost for the food industry and accessible to consumers, the use of biofortified sweet potatoes for this purpose is considered a way to meet the technological needs and improve the nutritional value of food products (Sousa et al., 2018; Carvalho & Rodrigues, 2020).

The biofortified sweet potato of the Beuaregard cultivar is well known for having orange pulp, with its application being widely studied as a biofortification method for food products. According to the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística – IBGE), Brazil's national production was 776,285 tons in 2017, being the sixth most cultivated vegetable, with the Northeastern and Southern regions standing out. A portion of 23 to 29 tons per hectare was produced by family farmers in the Northeastern region. (Rodrigues, 2013; Fuentes Jaime et al., 2020).

Sweet potato is rich in starch and is a favorable source of bioactive compounds for producing functional foods. There is an emphasis on β-carotene with an average value of 115 µg/g per potato, which is 10 times higher than in other sweet potatoes (Sousa et al., 2018; Niu et al., 2019). Total carotenoid concentrations of 130 µg/g and 185 µg/g in the fresh root have also been reported (Rodriguez-Amaya et al., 2011).

Carotenoids are constituents associated with food quality because in addition to providing pleasant color characteristics and some of them showing pro-vitamin A activity, they can also confer beneficial effects to human health, reducing the risk of development of some degenerative diseases such as cancer and eye diseases (Krinsky & Johnson, 2005).

In addition to carotenoids, biofortified sweet potatoes may contain high levels of other bioactive compounds such as phenolic compounds (Vizzotto et al., 2017). They can be simple phenols or polyphenols, which are secondary metabolites produced by the plant, usually related to the defense of the plant against pests, and influence its color, oxidative stability, and flavor. They are chemically formed by aromatic rings added to one or more hydroxyls and can be classified into several chemical classes according to their molecular structure, quantity of aromatic rings, and hydroxyls. They generally exert an antioxidant function that results in benefits to the body, requiring good digestion, absorption, and metabolism of these compounds (Arnoso et al., 2019).

According to the literature, the physical removal of raw biofortified sweet potato skins, the double bond isomerization of the molecules and enzymatic oxidation are factors that can cause a decrease in bioactive compounds during processing and storage. In addition, cooking can degrade or leach compounds into cooking water, causing changes in the color, in the antioxidant activity and in the bioavailability of the food nutrients (Melo et al., 2009).

The development of 'Beauregard' sweet potatoes in the form of flour is an alternative to increase its shelf life and facilitate its incorporation into several other products such as cakes, breads and cookies (Rodriguez-Amaya et al., 2011; Alves et al., 2012). However, it is desirable that both the flour and other derivatives maximally maintain the beneficial characteristics of the raw material from which they were made.

Therefore, the objective of this study was to evaluate the proximate composition, the main bioactive compounds and the antioxidant activity of the 'Beauregard' biofortified sweet potato and the derivatives (flour and cake) made from it.

MATERIAL AND METHODS

Reagents and solvents

Analytical grade standards and reagents were used. The solutions were also prepared using analytical grade reagents. Folin-Ciocalteu, standard gallic acid monohydrate, anhydrous sodium carbonate, citric acid, methyl alcohol, ethyl alcohol, acetone, ferric chloride hexahydrate, and ferrous sulfate heptahydrate were purchased from Dinâmica. TPTZ (2,4,6-Tris(2-pyridyl)-s-triazine), Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid), DPPH (2,2-diphenyl-1-picrylhydrazil) and ABTS (2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt) were obtained from Sigma-Aldrich.

Raw material and ingredients

The biofortified sweet potato (Beauregard cultivar) was purchased from street markets in the city of Aracati, state of Ceará, Brazil. The other ingredients (rice flour, sugar, eggs, margarine, milk and chemical yeast) were purchased from local markets in the city of Limoeiro do Norte, Ceará, Brazil.

Flour preparation

The methodology suggested by Silva (2010) was used to prepare the sweet potato flour. First, 5 kg of sweet potatoes were acquired and then transported to the Pilot Plant of Fruits and Vegetables (Planta Piloto de Frutas e Hortaliças – PPFH) of the Federal Institute of Education, Science and Technology of Ceará (IFCE), in the Limoeiro do Norte campus, where they were washed and then sanitized in chlorinated solution (100 mg/L) for 15 minutes. After the rinsing and peeling, they were manually cut into chips approximately 3 cm thick, and the material was distributed into stainless steel trays and taken to a greenhouse with forced air circulation (Heraeus Instruments UT-12), remaining there for a period of 24 hours at 60 °C. Next, the material was processed in a knife mill (Fritsch D-55743) to obtain the flour. The flour was stored in previously sanitized and properly coded polyethylene containers with a lid and wrapped in aluminium foil to protect them from light.

Cake preparation

Two cake formulations were prepared: the formulation F0 (control), without the use of sweet potato flour; and F1, with replacement of 50% of rice flour by sweet potato flour (Table 1).

Table 1. Quantity and percentage of ingredients used in the cake formulations⁽¹⁾.

Ingredients	Quantity (g)		Percentage (%)	
	F0 Cake	F1 Cake	F0 Cake	F1 Cake
Rice flour	400	200	32.79	15.75
'Beauregard' sweet potato flour	-	200	-	15.75
Sugar	200	200	16.39	15.75
Eggs	180	180	14.75	14.17
Margarine	30	30	2.46	2.36
Milk	400	450	32.79	35.43
Chemical yeast	10	10	0.82	0.79

⁽¹⁾F0: formulation of the control cake; F1: cake formulation with replacement of 50% of rice flour by 'Beauregard' sweet potato flour.

The cakes were processed at the pilot plant of cereals of the IFCE Limoeiro do Norte campus. The dry ingredients were initially hydrated with a liquid mixture (eggs, margarine and milk), and then they were homogenized with a manual whisk. The finished dough was placed on baking sheets (molds) and baked in an electric oven (Tedesco FTT 240F) for about 40 minutes at an average temperature of 180 °C. The cakes were stored in previously sanitized and properly coded polyethylene containers with a lid, and wrapped in aluminium foil to protect them from light. In addition to the flour, all the other samples were grounded before the analyses.

Approximate centesimal composition

The moisture analysis (M) consisted of drying approximately 3 g of the sample in an oven (Heraeus Instruments UT-12) at 105°C until constant weight was obtained (method 934.06) (Horwitz, 2005). The ash analysis (A) was carried out by eliminating the organic matter from the sample by incineration in a muffle furnace (ElektroTherm LM 312-10) at 550°C for 6 hours (method 940.26) (Horwitz, 2005).

The samples were then analysed for protein content (P) according to the Kjeldahl method, which consists of determining total nitrogen. The conversion factor used to obtain proteins was 6.38, which was multiplied by the total nitrogen value (method 920.152) (Horwitz, 2005). The Soxhlet method was used for the extraction and determination of lipids (L), using hexane as a solvent (method 930.09) (Horwitz, 2005). The total carbohydrate concentration (TC) was calculated by the difference between 100 and the values of M, A, P and L (Tabela..., 2008) according to Equation 1. Since fiber was not analysed, this content is included in the TC fraction.

$$TC = 100 - (M + A + P + L) - \text{Equation 1}$$

The energetic value (Kcal/100g) was calculated by multiplying the conversion values for carbohydrates (for 4.0 kcal), lipids (for 9.0 kcal) and proteins (for 4.0 kcal), and then summing the values of the multiplications, according to Equation 2 (Anvisa, 2003).

$$\text{Energetic value} = (TC \times 4) + (L \times 9) + (P \times 4) - \text{Equation 2}$$

Evaluation of the samples based on the Recommended Daily Intake (RDI) of vitamin A

The Resolution No. 269, of September 22, 2005 (Anvisa, 2005b), establishes that 1 µg β-carotene corresponds to 0.167 µg retinol equivalent (RE), and that the recommended daily intake (RDI) of vitamin A, expressed in RE, is 600 µg. Thus, the RE concentration in each sample was calculated using Equation 3 and the β-carotene values, considering that all the carotenoids in the samples are β-carotene. Then, based on the previous data, the amount (g) of each analyzed food (raw sweet potato,

sweet potato flour and cakes) that must be consumed to reach the RDI was calculated, as indicated in Equation 4. Next, the percentage of the portion to be consumed to reach the RDI was calculated using Equation 5 to correlate the RDI with the portion of each product, as established in the Resolution No. 359, of December 23, 2003 (Anvisa, 2003).

$$\mu\text{g } \beta\text{-carotene} \times 0.167 = \mu\text{g RE/g} - \text{Equation 3}$$

$$600 \mu\text{g} \div \mu\text{g RE/g of sample} = \text{g food} - \text{Equation 4}$$

$$(\text{g food} \div \text{recommended portion}) \times 100 = \% \text{ portion} - \text{Equation 5}$$

Bioactive compounds and antioxidant capacity

Total carotenoids expressed as β -carotene

The carotenoid content was quantified using the spectrophotometric method proposed by Rodriguez-Amaya (1999). Thus, 1 g of sample was crushed with Celite[®] in the presence of cooled acetone, and then the material was vacuum filtered for the pigment extraction. This procedure was repeated until the sample was completely discolored. The filtrates were transferred to a separating funnel to recover the carotenoids in petroleum ether by adding approximately 30 mL of this solvent and distilled water. The phase containing water and acetone was discarded, and water was added to the separation funnel again. This procedure was performed 3 times. The ethereal phase was collected in a 250 mL Erlenmeyer flask, anhydrous sodium sulfate was added to remove water and then transferred to a 100 mL volumetric flask with its volume being completed with petroleum ether. The absorbance readings were performed at 450 nm in a UV-Vis spectrophotometer (FEMTO 600 Plus), and the results were expressed in $\mu\text{g } \beta\text{-carotene/g}$ of sample.

Total extractable polyphenols (TEP)

The method described by Larrauri et al. (1997) and Obanda et al. (1997) was used to quantify TEP. Sample extracts that were used for both the analysis of total extractable polyphenols and for those of antioxidant activity were initially prepared. Samples of 10 to 25 g were weighed in centrifuge tubes, 20 mL of 50% methanol (v/v) was added, the mixture was left to stand for 1 hour, and then centrifuged (Eppendorf 5804) at 4,200 g for 20 minutes. The supernatant was filtered into a 50 mL volumetric flask. Next, 20 mL of 70% acetone (v/v) was added to the residue, and the rest of the process and the centrifugation were repeated. The new supernatant was filtered into the same volumetric flask that contained the first supernatant, and the volume was completed with distilled water.

Next, 1 mL of the sample, 1 mL of the reagent Folin-Ciocalteu, 2 mL of sodium carbonate 20% and 2 mL of distilled water were added to quantify TEP. The mixture was left to stand at room temperature (25 °C), protected from light, for 30 minutes, and then the absorbances were measured in a spectrophotometer (FEMTO 600 Plus) at 700 nm. The blank was prepared in the same way, replacing the sample aliquot with distilled water. The concentrations were obtained using a gallic acid calibration curve, and the results were expressed in mg/g of sample.

Antioxidant activity

The antioxidant activity analyses were carried out following the methodologies described by Rufino et al. (2010): ABTS^{•+} radical capture capacity; ferric reducing antioxidant power (FRAP); and DPPH radical scavenging capacity.

In the ABTS^{•+} radical capture capacity method, a calibration curve was constructed using Trolox as standard. Ethyl alcohol was used as blank and the readings were performed in a spectrophotometer (FEMTO 600 Plus) at 734 nm. The results were expressed in μM Trolox/g.

In the ferric reducing antioxidant power (FRAP) method, a calibration curve was constructed using ferrous sulfate (FeSO_4) as standard. The FRAP reagent was prepared by mixing 2.5 mL of 10 mM TPTZ solution with 25 mL of 0.3 M acetate buffer and 2.5 mL of a 20 mM aqueous solution of ferric chloride and was used as the blank, with the readings then being performed in a spectrophotometer (FEMTO 600 Plus) at 595 nm. The results were expressed in μM FeSO_4 /g of sample.

In the DPPH radical scavenging capacity method, a calibration curve was constructed using the DPPH radical as standard. Methyl alcohol was used as the blank and the readings were taken in a spectrophotometer (FEMTO 600 Plus) at 595 nm after absorbance stabilization, which occurred after approximately 30 minutes. The results were expressed in EC_{50} , which corresponds to the amount of sample needed to reduce the initial concentration of the DPPH radical by 50% (g sample/g DPPH).

Statistical analysis

All laboratory analyses were performed in triplicate. The obtained results were subjected to statistical analysis of variance (ANOVA) ($\alpha = 0.05$) to identify significance statistical differences, and the Student's t-test was used at the 5% significance level to compare the means. The Pearson's correlation was performed to determine the contribution of bioactive compounds in the antioxidant activity. The Statistica 10 program (Statsoft, 2011) was used for all statistical analyses.

RESULTS AND DISCUSSION

Tables 2 and 3 show the centesimal composition, bioactive compounds and antioxidant activity results, while Table 4 shows the correlations between bioactive compounds and antioxidant activity.

A significant difference ($p < 0.05$) was observed between the moisture results of fresh sweet potatoes and flour (Table 2) due to the dehydration process; however, there was no statistically significant difference ($p \geq 0.05$) in the water content between the F0 and F1 cake formulations (Table 3).

Table 2. Results obtained from the analyses performed on fresh biofortified sweet potatoes and potato flour (derivative)⁽¹⁾.

	Fresh potato	Flour
Centesimal composition (on wet basis)		
Moisture (g/100 g)	75.52 \pm 0.08 ^a	5.52 \pm 0.02 ^b
Proteins (g/100 g)	1.05 \pm 0.12 ^b	3.05 \pm 0.05 ^a
Ashes (g/100 g)	0.94 \pm 0.02 ^b	2.83 \pm 0.03 ^a
Lipids (g/100 g)	0.31 \pm 0.09 ^b	0.77 \pm 0.17 ^a
Carbohydrates (g/100 g)	22.18	87.83
Energetic value (Kcal/100 g)	95.71	370.45
Bioactive compounds (on dry basis)		
Total carotenoids (μg β -carotene/g)	283.66 \pm 4.24 ^a	201.12 \pm 0.57 ^b
Total polyphenols (mg/g) ⁽²⁾	44.51 \pm 1.02 ^a	24.57 \pm 0.80 ^b
Antioxidant activity		
ABTS (μM Trolox/g)	1.53 \pm 0.46 ^b	3.75 \pm 0.82 ^a
FRAP (μM FeSO_4 /g)	2.52 \pm 0.55 ^b	7.41 \pm 1.62 ^a
DPPH (EC_{50}) ⁽³⁾	317.60 \pm 12.47 ^a	68.45 \pm 5.05 ^b

⁽¹⁾Means \pm standard deviation followed by equal letters on the same line do not significantly differ ($p \geq 0.05$) using the Student's T-test. ⁽²⁾Expressed in gallic acid equivalent.

⁽³⁾Amount of sample needed in grams to reduce the initial DPPH radical concentration by 50% (g sample/g DPPH).

The moisture content in the raw material was lower than that reported by Marangoni Júnior et al. (2020), who obtained 83.36 g/100 g in fresh 'Beauregard' sweet potatoes in their study on β -carotene retention after frying this type of potato from Campinas, São Paulo. Different soil types and climatic conditions for cultivation may justify the differences in the results obtained in the present study, since they are factors that directly influence its proximate composition.

The flour moisture content was lower than that of the fresh 'Beauregard' potato (5.52 g/100 g) due to the higher temperature gradient between the product and the drying air, which provides greater heat transfer and consequently greater water evaporation and dehydration of the product (Phisut, 2012). This improves the stability of the flour against possible microbial spoilage and reduces handling and transportation costs.

Moisture is an important quality parameter for flour, which can directly influence microbial development, and consequently flour's shelf life (Amajor et al., 2014). Thus, RDC No. 263 of the Brazilian Health Regulatory Agency (Agência Nacional de Vigilância Sanitária – Anvisa) (Anvisa, 2005a) establishes that flours must contain maximum moisture of 15 g/100 g. Therefore, the flour prepared in the present study is in accordance with that established by the current legislation.

It is important to note that the dough was denser when partially replacing the rice flour by the biofortified sweet potato flour during the preparation of the F1 cake, probably due to the greater capacity of the sweet potato flour to bind to water, so it was necessary to add more milk to this formulation when compared to the F0 cake (Table 3). Despite this, the moisture of the F1 cake did not change.

According to the Brazilian Food Composition Table (Tabela Brasileira de Composição de Alimentos – TACO) (Tabela..., 2011), raw sweet potato should have 118 Kcal/100 g. Thus, the biofortified potato under study has lower energy content than the common sweet potato. Souza et al. (2021) found that 'Beauregard' potatoes grown in southwestern Paraná had a higher caloric value (156 Kcal/g).

Fuentes Jaime et al. (2020) obtained biofortified sweet potato flours using the Beauregard cultivar from São Paulo and Minas Gerais. Regarding the energy value, the flours presented 351.92 Kcal/100 g and 339.35 Kcal/100 g, respectively, which are close to the values in the present study. Thus, the elaborated 'Beauregard' sweet potato flour can be considered as an energy source, since its energy content is similar to that of wheat flour (360 Kcal/100 g) (Tabela..., 2011).

These results show the disparities in the centesimal composition between different cultivars of the same food; they are not only influenced by genetic variation, but also by other factors such as climatic conditions and place of cultivation and can even occur within the same cultivar, but grown in different places (Hernández Suárez et al., 2016).

The fresh sweet potatoes and flour, as well as the F0 and F1 cakes, significantly differed from each other ($p < 0.05$) in terms of protein and lipid parameters (Tables 2 and 3). A higher concentration of these components, as well as ashes, was observed in the flour due to the dehydration process of the raw potato, which can be proven by the reduced moisture, highlighting the increased carbohydrate content.

In a study on obtaining biofortified sweet potato flour, Fuentes Jaime et al. (2020) found protein contents of 9.85 g/100 g and 7.38 g/100 g in potato flours from states of Minas Gerais and São Paulo, respectively. These values are higher than those of the study in question, bearing in mind (as previously mentioned) that the proximate composition can vary depending on both the cultivar of the culture and the place where they are planted.

Table 3. Results obtained in the analyses performed on products made with and without potato flour⁽¹⁾.

	F0 Cake	F1 Cake
Centesimal composition (on wet basis)		
Moisture (g/100 g)	41.74 ± 0.67 ^a	40.26 ± 1.52 ^a
Proteins (g/100 g)	6.51 ± 0.25 ^a	5.11 ± 0.43 ^b
Ashes (g/100 g)	0.97 ± 0.03 ^a	1.28 ± 0.22 ^a
Lipids (g/100 g)	4.56 ± 0.01 ^a	4.29 ± 0.05 ^b
Carbohydrates (g/100 g)	46.22	49.05
Energetic value (Kcal/100 g)	251.96	255.25
Bioactive compounds (on dry basis)		
Total carotenoids (µg β-carotene/g)	10.18 ± 0.37 ^b	65.46 ± 1.09 ^a
Total polyphenols (mg/g) ⁽²⁾	21.68 ± 0.35 ^b	59.92 ± 0.29 ^a
Antioxidant activity		
ABTS (µM Trolox/g)	2.25 ± 0.70 ^a	2.84 ± 0.42 ^a
FRAP (µM FeSO ₄ /g)	4.56 ± 1.48 ^a	6.51 ± 2.42 ^a
DPPH (EC ₅₀ ⁽³⁾)	80.44 ± 8.88 ^a	58.31 ± 1.29 ^a

⁽¹⁾Means ± standard deviation followed by equal letters on the same line do not significantly differ ($p \geq 0.05$) using the Student's T-test. F0: formulation of the control cake; F1: cake formulation with replacement of 50% of rice flour with biofortified sweet potato flour. ⁽²⁾Expressed in gallic acid equivalent. ⁽³⁾Amount of sample needed in grams to reduce the initial DPPH radical concentration by 50% (g sample/g DPPH).

The ash contents significantly differed ($p < 0.05$) between fresh potatoes and flour (Table 2), but there was no significant difference ($p \geq 0.05$) between the cake formulations (Table 3). The highest concentration was observed in the flour (2.83 g/100 g), constituting relatively close content to that obtained by Fuentes Jaime et al. (2020), who found 3.66 g/100 g in biofortified sweet potato flours grown in Minas Gerais and São Paulo. The content obtained in the fresh potato was higher than that observed by Marangoni Júnior et al. (2020), with 0.65 g/100 g in biofortified sweet potatoes grown in Campinas (state of São Paulo).

The protein and lipid contents in cakes mainly come from the formulation ingredients such as eggs, milk and margarine. However, even with more added milk and with the partial replacement of rice flour with potato flour, these components were smaller in the F1 cake when compared to the F0 cake, with a reduction of 21.5% for protein and 5.92% for lipids. Although very subtle, the main increments attributed to the partial replacement of rice flour by potato flour were carbohydrates and ash, which were significantly different ($p < 0.05$) from the F0 cake.

The energetic value of the F1 cake was higher than that of the F0 cake, showing that the addition of flour has an influence on the centesimal composition of the food. Ramos et al. (2019) also prepared two cake formulations, A (control) and B (replacement of wheat flour with 'Beauregard' sweet potato flour), with energetic content of 329.90 and 289.80 Kcal/g, respectively. As a result, the energetic value of cake A was higher than that of the F0 cake (Table 3), justified by the fact that rice flour has a lower energy value (320 Kcal/100 g) than wheat flour (360 Kcal/100 g).

Santos et al. (2021) developed food products (bread, cake and sweets) with 'Beauregard' sweet potato flour. The amount of flour added to the cake formulation was 25% and its energy value corresponded to 242.1 Kcal/100 g, similar to the one of the present study. Azevedo et al. (2020) produced and characterized gluten-free and lactose-free cake formulations with 'Beauregard' sweet potato flour at different concentrations (B1: 10.23%; B2: 15.35%; B3: 20.46%). The total energetic value was 250.25, 240.15 and 244.04 Kcal/100 g, respectively, also close to that obtained in this study. It should be noted that the energetic value of a product depends on the calories in the ingredients used in the formulation.

As rice flour and potato flour have different centesimal compositions, the replacement may have influenced the F1 cake, mainly for carbohydrates and ashes, which increased when compared to the

F0 cake. However, it is important to consider the possible effect of heating for protein and lipids, as these molecules are known to undergo degradation reactions when submitted to high temperatures, as those used in baking.

In its turn, it was found that the flour proximate composition presented greater results in the protein, ash, lipid and carbohydrate levels when compared with the results for fresh sweet potatoes due to water removal during the dehydration process, and it was also found that its incorporation in the cake provided an increase in minerals. As people do not usually consume this potato in its fresh form, preparing flour for application in confectionery and bakery products is an excellent alternative for people to acquire the benefits of the biofortified sweet potato, in addition to adding commercial value to the vegetable. Since the sweet potato under study can provide the main substrates of energy and biomolecules for preservation of the body, and vitamins and minerals for the proper functioning of the body, including the prevention of diseases such as obesity, anemia, and diabetes, among others.

The results of the total carotenoid and total polyphenol analyses were expressed on dry basis for a more realistic comparison between the samples as they have different moisture contents. The wet basis data (data not shown) was used to analyse the recommended daily intake.

A significant difference ($p < 0.05$) was observed in the total carotenoids, expressed as β -carotene, on dry basis, between fresh potatoes and flour and between the F0 and F1 cakes (Tables 2 and 3). Even though the flour has lower moisture content, meaning that it is more concentrated due to oven drying, the heating caused losses of these thermosensitive compounds with their decrease in the flour. The carotenoid concentration was significantly higher ($p < 0.05$) in the cake with potato flour added as it is a source of these pigments, which guarantees that at least part of the added carotenoids were not destroyed by heat.

Vizzotto et al. (2017) mentions that the loss of carotenoids after processing may be associated with the exposure time to heat, since the thermal processing method can reduce the β -carotene content as a result of the susceptibility of this compound to degradation and isomerization under high temperatures. Contact with light, heat, oxidizing compounds, and other reactive chemical species has a significant influence on the stability of carotenoids, modifying their isomerization pattern, and causes changes in their properties, such as oxidation reactions. The intensity of photo-oxidation will depend on factors such as concentration, type of carotenoids, and food matrix (Arimboor et al., 2015; Bemfeito et al., 2020). The results of the present study showed this when a higher value of carotenoids (283.66 $\mu\text{g/g}$) was observed in fresh potatoes than in flour (201.12 $\mu\text{g/g}$) obtained by heat dehydration.

In a study to evaluate the effects of cooking (boiling, steam, microwave, roasting and frying) for 15, 25, 35 and 45 minutes at 100-160°C (1,150 Watts) on orange pulp sweet potatoes from Hebei (China) (Pushu 32 cultivar), Kourouma et al. (2019) obtained 152.09 $\mu\text{g/g}$ in β -carotene before cooking, and from 19.15 to 107.70 $\mu\text{g/g}$ in β -carotene after 45 minutes. These values are lower than those found in the present study, which applied a different heating method and temperature/time binomial. Despite the difference between the cultivars analyzed, the samples were similar, as both consisted of orange-fleshed sweet potatoes.

Only 10.18 $\mu\text{g/g}$ of carotenoids were detected in the control cake, which may be mainly associated with the eggs and the margarine present in the formulation. The partial substitution by biofortified sweet potato flour in the F1 cake resulted in an increase of 84.45% in carotenoids when compared to the control cake. The consumption of foods that have carotenoids in their composition can contribute to improve human health because of their antioxidant action, as they contribute to strengthen the body's defense mechanisms. They can inhibit the proliferation of cancer cells and induce their death. They play an important role in reducing the risk of cardiovascular diseases (lycopene), and protect the macula from oxidative stress damage, improving vision (lutein and zeaxanthin) (Mesquita & Torquillo, 2016).

There was a significant difference ($p < 0.05$) for total polyphenols between fresh potatoes and flour (Table 2), making it possible to see how much the thermal processing influences the final concentration of these compounds in the derivative. The F1 cake showed a higher and statistically more significant ($p < 0.05$) concentration than the F0 cake due to the presence of potato flour. The presence of polyphenols in the control cake is due to the other ingredients in the formulation.

It is noteworthy that the heat treatment may induce significant changes in the chemical composition of the vegetable, which may affect the bioavailability and the content of bioactive compounds, such as vitamin C and polyphenols (Filipiak-Florkiewicz et al., 2012). Other factors that can influence the concentration of polyphenols are pre-preparation methods such as peeling, since these substances are often present in higher concentrations on the outer part. Removing the peels may reduce the content of these compounds (Manach et al., 2004; D'Archivio et al., 2007). The same occurs with post-processing methods, such as the oxidation state, location of the compounds in the cell and interactions with other components (van Boekel et al., 2010).

Kourouma et al. (2019) analysed raw orange sweet potato pulp and found a significantly lower content of phenolic compounds (2.59 mg/g) than that found in the present study (44.58 mg/g). When evaluating the effects of various forms of heating, the authors obtained between 1.50 and 1.94 mg/g of polyphenol compounds. The results found in the present study are satisfactory, as they indicate that the biofortified sweet potato evaluated herein has a higher concentration of phenolic compounds, and these bioactive compounds are still present in higher concentrations after drying to prepare the flour and with the processing of the F1 cake than those in the aforementioned study.

The phenolic compound concentrations can vary depending on factors such as part of the analysed vegetable, which generally goes from the skin to the leaves, environmental conditions, cultivar, and degree of maturity. Technological processes and domestic techniques such as cooking under immersion in water, steam and microwaves, as well as frying and baking, can also influence the behavior of polyphenols and the antioxidant activity through heat-induced molecule isomerization (Jung et al., 2011).

In checking Resolution No. 359 of December 23, 2003 (Anvisa, 2003), which establishes the portions of packaged foods for nutrition labeling purposes, one portion of approximately 150 kcal of each food must contain: 150 g/mL for the fresh potato; 50 g/mL for the flour; and 60 g/mL for the cakes. In correlating the RDI with the determined portion of each product, it would be enough for the consumer to eat less than one portion of these three products to achieve the RDI, being 2.99% for fresh potatoes, 1.19% for flour, and 24.03% for the F1 cake. In its turn, 10.30 portions would need to be consumed to reach the RDI for the F0 cake. The data used to obtain those results are presented in the supplementary material.

These results are quite satisfactory from the nutritional point of view for the analysed biofortified potato, the flour and the F1 cake that has the potato flour, as they indicate that the portion to be eaten for each product in order to achieve the equivalent retinol RDI is much lower than that recommended by legislation. In other words, the consumption of small daily portions of these foods already guarantees the necessary daily intake levels.

Thus, the use of biofortified potato flour can be considered an important tool in terms of obtaining essential micronutrient content for human health, as well as in the supplementation of vitamin A to combat malnutrition, especially regarding the poorest populations and children. The orange-fleshed potato contains carotenoids, especially β -carotene, a considerable precursor of vitamin A, and they are recognized for their antioxidant activity and other benefits to human health, such as improved immunity, and decreased amount of degenerative diseases, cardiovascular diseases and cancer (Fagundes et al., 2021; Severo et al., 2021).

Thus, it is greatly important and feasible to develop food products with the insertion of biofortified sweet potato with high β -carotene levels, thus providing added value to the raw material, and development and innovation in the food sector based on combating vitamin A deficiency.

It is observed that a smaller portion of the flour than that of the potato is needed to reach the RDI, which highlights the advantage of adding the flour into confectionery, bakery or meat products. There is a great difference in portions between the cakes, in which the F0 cake (which did not have the potato flour) requires a much higher amount than the F1 cake, which has the sweet potato in its composition, evidencing the benefits of incorporating the flour of this tuber in food products.

The polyphenol contents on wet basis also showed a greater benefit of eating flour than fresh potato (23.21 ± 0.76 ; and 10.87 ± 0.25 , respectively), and of eating the F1 cake over the F0 cake (14.85 ± 0.38 ; and 12.54 ± 0.20 , respectively), since flour and the F1 cake showed higher concentrations of these bioactive compounds. The contribution of potato flour in the carotenoid and polyphenol levels was evident in the cake, with an increase of 84.45% and 18.4%, respectively.

It is observed that the antioxidant activity of the flour by the three methods evaluated was significantly higher ($p < 0.05$) than in fresh potato (Table 2). Despite the cakes not having significant differences between them ($p \geq 0.05$) by the three methods, the antioxidant activity increased in the F1 cake (Table 3). It is important to note that the lower the EC_{50} value, the greater the sample's capacity to capture the DPPH free radical, indicating the need for a smaller amount of sample for this, and therefore greater antioxidant activity.

Nowadays, there is an increase in the incorporation of flours in the development of functional foods, and sweet potato is an example of this. Many factors influence the quality of the raw material and consequently the quality of products made from it, such as the cultivar and degree of maturity of the vegetable, the technique, and the processing stages. The sample extraction method also exerts influence regarding the quantification of bioactive compounds and antioxidant activity, since it is possible to find different methodologies in the literature that vary depending on the type of solvent and the analytical steps (Dereje et al., 2020).

Phenolic compounds are also important for preserving health because they have antioxidant properties: they can delay or inhibit the oxidation of molecules, by capturing, absorbing, or neutralizing free radicals, which generate oxidative stress. Moreover, phenolic compounds (anthocyanins, carotenoids, and catechins, among others) exert other biological maintenance activities, such as antimicrobial, anti-inflammatory, and vasodilatory actions. The performance of these activities depends on factors such as the type of free radicals present, where they are located in the body, and the proper concentration to act against the disease (Oliveira et al., 2014; Refosco et al., 2019).

Padda & Picha (2007) found the highest antioxidant activity values when evaluating 'Be-auregard' sweet potatoes in four maturation stages – on average, $9.5 \mu\text{M Trolox/g}$ on dry basis in the first stages of the tuber. This value is higher than that detected in the present work, even for the flour ($3.74 \pm 0.82 \mu\text{M Trolox/g}$), which has a reduced moisture content. The bioactive compound extraction method for the antioxidant analysis is one of the main factors that influence the results, and it is highlighted that the authors only used methanol as solvent, which remained in contact with the samples at rest, and under heating in a water bath at 80°C for 10 minutes. Thus, differing from the extraction method used in the present study.

In view of the observed results, the greater antioxidant activity in potato flour reinforces the benefit of its incorporation in confectionery products, as proven by the greater antioxidant activity in the cake in which it was incorporated (F1). In addition, a Pearson's correlation analysis was performed to verify the influence of bioactive compounds on the antioxidant activity of the studied samples. The correlation coefficients are shown in Table 4, being divided into two groups of samples: fresh potatoes and potato flour; and the F0 and F1 cakes.

Table 4. Pearson's correlation coefficients between bioactive compounds and antioxidant activity in the two study stages.

Fresh potatoes and potato flour					
	^a TEP ⁽¹⁾	Carotenoids	ABTS	FRAP	DPPH
^a TEP	1				
Carotenoids	0.9997*	1			
ABTS	0.9592	0.9660	1		
FRAP	0.9860	0.9815	0.8986	1	
DPPH	-1.0000**	-0.9996*	-0.9580	-0.9867	1
F0 cake and F1 cake					
	^a TEP	Carotenoids	ABTS	FRAP	DPPH
^a TEP	1				
Carotenoids	0.9785*	1			
ABTS	0.2109	0.4068	1		
FRAP	0.4909	0.6597	0.9457	1	
DPPH	-0.9214	-0.9273	-0.2788	-0.5759	1

⁽¹⁾^aTEP – total extractable polyphenols.

*Significant correlation (strong) ($p < 0.05$). **Significant correlation (very strong) ($0.01 \leq p \leq 0.05$).

The correlation results between total extractable polyphenols (TEP) and total carotenoids for fresh potato and potato flour ($r = 0.9999$; $p = 0.016$) and for cakes ($r = 0.9785$; $p = 0.021$) demonstrated a positive and significantly strong ($p < 0.05$) correlation, meaning that high TEP concentrations tend to indicate high carotenoid concentrations in these samples.

The bioactive compounds showed a positive, non-significant correlation ($p \geq 0.05$) with the antioxidant activity by the ABTS and FRAP methods in the two sample groups. The correlation with bioactive compounds was negative by the DPPH method for both sample groups, but as the interpretation of antioxidant activity by this method is reversed, it means that higher TEP and carotenoid concentrations are related to greater antioxidant activity. This correlation was still significantly strong ($p < 0.01$) for total polyphenols, and significantly strong ($p < 0.05$) for carotenoids for the fresh potato and the potato flour groups. However, these correlations were not significant for the cakes ($p \geq 0.05$).

The correlation, when comparing the results of the antioxidant activity between the ABTS and FRAP methods, was positive, but without significant correlation ($p \geq 0.05$) for the two sample groups. In this case, the negative correlation of the DPPH method with the FRAP method, as well as with the ABTS method, also informs that high antioxidant activity by the DPPH method indicates high activity by the other two methods; but the correlations were not significant between both ($p \geq 0.05$).

Liao et al. (2019) also identified a positive and strong ($p < 0.01$) correlation between antioxidant activities by the ABTS and FRAP methods when studying the effects of domestic cooking methods (boiling, steam, cooking, microwave, frying, air-frying and stir-frying) on anthocyanins and on the antioxidant activity of purple-fleshed sweet potato (GZ9).

Kourouma et al. (2019) found a negative, non-significant correlation ($r = -0.0250$; $p = 0.9142$) between total carotenoid content and antioxidant activity by the DPPH method when evaluating the effect of cooking processes (boiling, steaming, microwave, roasting and frying) on the carotenoid content in orange pulp. This behaviour was similar to the results found in the current study.

Thus, it is possible to state that the fresh potato and the flour antioxidant activities, mainly due to the ability to eliminate the DPPH free radical, are related to the presence of polyphenols and carotenoids, and that the addition of these compounds to the cake in the form of flour contributed to the antioxidant activity increase in the F1 cake. The antioxidants obtained through the diet, such as vitamins A, C and E, flavonoids, carotenoids, selenium and zinc, are compounds with great

antioxidant potential, which have the role of promoting reduced oxidative damage and excessive generation of free radicals, because they participate in various natural processes of the human body and are normally produced by metabolism. However, under certain conditions, such as in the presence of chemical compounds foreign to the biological system, they can cause high production of reactive oxygen species (ROS), leading to oxidative stress and chronic non-communicable diseases (Prevedello & Comachio, 2021).

CONCLUSIONS

As it is a little known potato cultivar in the state of Ceará, ‘Beauregard’ sweet potato flour is a viable alternative for consumption of this raw material through its incorporation into bakery, confectionery and even meat products. Thus, it is possible to take advantage of its excellent nutritional, bioactive and antioxidant characteristics with minerals, carbohydrates, carotenoids, polyphenols and antioxidant activity increments in the products to which it is incorporated, in addition to its proven technological viability for application in cakes as a partial substitute for conventional flour. The benefits of consuming derivatives made with ‘Beauregard’ sweet potato flour go beyond the need to eat 1.19% of one portion of flour; and 24.03% of one portion of F1 cake to achieve the recommended daily intake of vitamin A.

Sensory tests on the cakes are suggested to be conducted in future studies to verify acceptance and purchase intention by consumers and to evaluate the possible market entry of these products.

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