ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.28, n.2, e275946, 2024
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v28n2e275946 ORIGINAL ARTICLE

Quality of packaged refrigerated biofortified sweet potato cultivars[1]

Qualidade de cultivares de batata-doce biofortificadas refrigeradas e embaladas

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HIGHLIGHTS:

Refrigeration combined with packaging maintained the quality of Beauregard sweet potatoes for 26 days.
The BRS-Amélia cultivar is more susceptible to dehydration during storage.
Sweet potatoes of the cultivar Beauregard are more suitable for export.

ABSTRACT: Combining refrigeration with packaging is a commonly used technique for fruits intended for export. Thus, the objective of this study was to adapt the post-harvest management of biofortified sweet potato cultivars, using packaging and refrigeration, focused on reaching distant export markets while maintaining the commercial quality. Sweet potatoes of the cultivars BRS-Amélia and Beauregard were selected after harvesting, washed, and packaged. The experimental design used was completely randomized, in a 4 × 7 factorial arrangement consisted of 4 treatments (cultivar BRS-Amélia with and without packaging; and cultivar Beauregard with and without packaging) and 7 evaluations under storage conditions: at 0, 7, 14 (under refrigeration at approximately 8 °C), 17, 20, 23, and 26 days (under room temperature conditions at approximately 25 °C). Each experimental unit contained 500 g of tubbers. The results showed that the refrigerated storage combined with packaging extended the shelf life of the evaluated sweet potatoes: 17 days for BRS-Amélia and 26 days for the cultivar Beauregard. The BRS-Amélia cultivar maintained higher firmness, soluble solids and carbohydrate contents, chroma, and antioxidant activity (FRAP method), and total phenolic contents, in both raw and cooked tissues. The cultivar Beauregard presented less dehydration and greater stability in vitamin C, total phenolic, total carotenoid, soluble carbohydrate, and starch contents in raw and cooked potatoes. Therefore, the combination of packaging and refrigeration preserved the commercial quality of biofortified sweet potatoes for export markets.

Key words: *Ipomoea batatas*, phenolic compounds, vitamin C

RESUMO: Combinar refrigeração com embalagem é uma técnica comumente utilizada para frutas destinadas à exportação. Assim, o objetivo deste estudo foi adequar o manejo pós-colheita de cultivares de batata-doce biofortificadas, utilizando embalagem e refrigeração, com foco em atingir mercados de exportação distantes e mantendo a qualidade comercial. As batatas-doces das cultivares BRS-Amélia e Beauregard foram selecionadas após a colheita, lavadas e embaladas. O delineamento experimental utilizado foi inteiramente casualizado, em arranjo fatorial 4 × 7 composto por 4 tratamentos (cultivar BRS-Amélia com e sem embalagem; e cultivar Beauregard com e sem embalagem) e 7 avaliações nas condições de armazenamento: aos 0, 7, 14 (sob refrigeração a aproximadamente 8 °C), 17, 20, 23 e 26 dias (sob condições de temperatura ambiente a aproximadamente 25 °C). Cada unidade experimental continha 500 g de tubérculos. Os resultados mostraram que o armazenamento refrigerado aliado à embalagem prolongou a vida útil da batata-doce avaliada: 17 dias para BRS-Amélia e 26 dias para a cultivar Beauregard. A cultivar BRS-Amélia manteve maior firmeza, solúveis sólidos e teor de carboidratos, croma e atividade antioxidante (método FRAP) e teor de fenólicos totais, tanto nos tecidos crus quanto cozidos. A cultivar Beauregard apresentou menor desidratação e maior estabilidade nos teores de vitamina C, fenólicos totais, carotenóides totais, carboidratos solúveis e amido em batatas cruas e cozidas. Portanto, a combinação de embalagem e refrigeração preservou a qualidade comercial da batata-doce biofortificada para os mercados de exportação.

Palavras-chave: *Ipomoea batatas*, compostos fenólicos, vitamina C

• Ref. 275946 – Received 25 Jun, 2023
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• Accepted 26 Oct, 2023 • Published 17 Nov, 2023
Editors: Geovani Soares de Lima & Hans Raj Gheyi

Introduction

Sweet potatoes are nutritious tubbers rich in starch, fibers, vitamins, and minerals; some cultivars had a colored flesh containing bioactive compounds (Alam, 2021). Orange- and yellow-fleshed cultivars are rich in carotenoids, including β-carotene, which is an important source of provitamin A (Bergmann et al., 2021). Biofortification improves sweet potato nutritional quality, especially regarding vitamin A (Coelho, 2021). The cultivars BRS-Amélia (a Brazilian cultivar) and Beauregard stand out; BRS-Amélia is rich in vitamin A and fibers, but less resistant to pests and diseases, whereas Beauregard is aromatic and soft, but can become very sweet and sticky when not properly cooked (Weirich Neto et al., 2023).

Sweet potatoes exporters in Brazil use refrigerated containers (Quintam et al., 2023). Maritime transport under refrigeration at temperatures between 10 and 15 °C is the most used. These products are packaged and transported for approximately 15 days under refrigeration, ensuring quality for international markets. Sweet potatoes are usually marketed on shelves under ambient conditions in Brazil, without refrigeration. Nonetheless, they can remain suitable for marketing for approximately 10 days, depending on the environmental conditions. The Brazilian cultivar BRS-Amélia has an orange, sweet flesh with a good texture after cooking, as well as significant carotenoid contents, which are similar characteristics to those of the cultivar Beauregard, which was developed in the United States. Therefore, the combination of packaging with refrigeration is one of the main techniques to extend the shelf life of these tubers while maintaining their quality (Watanabe et al., 2021). However, some sweet potato cultivars are susceptible to cold damage (Xia Li et al., 2018).

Studies and adaptations of post-harvest technologies are necessary to enable export markets for these tubbers. Thus, the hypothesis raised is that the use of packaging combined with refrigeration can extend the commercial quality of biofortified sweet potato cultivars to 26 days, a sufficient period for their consumption by European consumers. Thus, the objective of this study was to adapt the post-harvest management of biofortified sweet potato cultivars, using packaging and refrigeration, focused on reaching distant export markets while maintaining commercial quality.

Material and Methods

Sweet potatoes (*Ipomoea batatas*) of the cultivars BRS-Amélia and Beauregard were harvested from a multiplication field in the Escola Agrícola de Jundiái (EAJ) of the Universidade Federal do Rio Grande do Norte (UFRN), in Macaíba, RN, Brazil (5°51'36"S and 35°20'59"W, with an altitude of 15 m). The climate of the region is tropical with a dry season, according to the classification described by Silva et al. (2022), with mean annual rainfall depth, annual air temperature, and relative air humidity of 1,134 mm, 25.9 °C, and 76%, respectively.

The sweet potato tubers were washed with running water after harvesting, left to dry at room temperature, and then separated according to quality for the experiment. The experiment was conducted in a completely randomized design, using a 4 × 7 factorial arrangement consisted of 4 treatments (BRS-Amélia sweet potatoes with and without packaging; and Beauregard sweet potatoes with and without packaging) and 7 evaluations under two different storage conditions: at 0, 7, 14 days under refrigeration at temperature of approximately 8 °C; after 14 days under refrigeration, the materials were transferred to an environment with temperature at approximately 25 °C and then evaluated at 17, 20, 23, and 26 days under this condition. Each experimental unit consisted of a 500 g package of tubbers; polypropylene bags (30 × 50 cm) were used for packaging the tubers. Samples from these materials were subjected to a cooking process in a microwave oven at 1200-W power for 5 minutes (Vianello & Alves, 1991).

The flesh firmness of these tubers was determined using a traction device (IMPAC, IP–AELA 50, São Paulo, Brazil), with the aid of a 5 mm diameter tool and the software Auto Forte Teste Ver 1.0.0.181106. Three perforations were made in each of the evaluated tuber: one in the middle and one at each end of the tuber, at a speed of 100 mm min^{-1}.

Fresh weight loss was determined using a semi-analytical balance, based on the percentage difference between the initial weight (0 day) and the final weight (at 26 days), corresponding to the evaluation days (0, 7, 14, 20, 23, and 26 days). The percentage of fresh weight loss was determined using Eq. 1:

$$WL = \frac{(Min - Mfi)}{Min} \times 100 \quad (1)$$

where:

WL - fresh weight loss (%);

Min - initial fresh weight (g); and,

Mfi - final fresh weight at the evaluations at 0, 7, 14, 20, 23, and 26 days (g).

Visual evaluations were performed at 0, 7, 14, 17, 20, 23, and 26 days after the beginning of the experiment, based on the Likert scale.

The color on the surface of the tubers was determined using a colorimeter with an RGB system (RS-232 with RGB-1002 serial output). The data obtained were converted to the CIELAB color scale, represented by L*, a*, and b* (Alvarenga et al., 2016), where L* corresponds to variations in sample luminosity from 0 to 100, ranging from darkest to lightest. The obtained values were converted using the website: http://www.easyrgb.com/en/convert.php#R esult. Subsequently, the *a** and *b** data set was converted and expressed as chroma saturation (C*), according to the methodology of Espino-Díaz et al. (2010), using Eq. 2:

$$C^* = \left(a^{*2} + b^{*2}\right) \times \frac{1}{2} \quad (2)$$

where:

C* - chroma, representing the intensity or saturation of the color;

a* - corresponds to variations from green (-a) to red (+a); and,

b* - corresponds to variations from blue (-b) to yellow (+b).

The starch content was determined according to Miller (1959), with modifications. A sample of 3 g of pulp of each cultivar was homogenized with distilled water and the volume was completed to 100 mL. An aliquot of 3 mL of a calcium chloride/acetic acid solution (40% calcium chloride solution adjusted to pH 3.0 with 0.033 mM acetic acid solution) were added to each flask. After homogenization, 1 mL of the solution was taken and added to a test tube, sealed, and left to rest for 15 minutes. They were then cooled to room temperature, kept on a bench at approximately 20 °C, and then 3 mL of a 0.033 mM acetic acid solution were added to each tube (1.5 mL of deionized water for the blank). Except for the blank, 2 mL of a potassium iodide/iodate solution (10.0 mL of 10% potassium iodide solution, 90 mL of deionized water, and 100 mL of a 0.017 mM potassium iodide solution) were added and the volume was completed with deionized water until it reached 100 mL. After homogenization, the absorbance of the solutions was measured at 700 nm in an interval of 10 to 20 minutes after the addition of the iodide/iodate solution.

The total soluble solids content was determined using a sample of approximately 30 g from sweet potato material, which was macerated with the aid of a porcelain mortar and pestle. The juice obtained was added to the prism of a refractometer and the result was expressed as percentage.

The total soluble carbohydrate content was determined in test tubes containing 500 µL of crude pulp extract, 500 µL of 5% phenol, and 2.5 mL of concentrated sulfuric acid (H_2SO_4); H_2SO_4 was quickly added, with the flow directly against the solution surface and not against the test tube wall, for obtaining a good mixture. The tubes were then left to rest for approximately 10 min. Subsequently, the tubes were vortexed and left to rest on a tray containing water at room temperature of 25 °C for 10 to 20 minutes. Readings were taken on a spectrophotometer at 490 nm; a test tube containing 500 µL of deionized water, 500 µL of 5% phenol, and 2.5 mL of concentrated sulfuric acid as a blank. The calculation for determining the concentration of carbohydrates was based on the spectrophotometric readings, using an engineering approach developed from the standard curve. The resulting concentration was expressed as mols of carbohydrates per gram of fresh weight (mmol g^{-1}).

The antioxidant potential by scavenging free radicals DPPH (2,2-Diphenyl-1-picrylhydrazyl) was determined as proposed by Brand-Williams et al. (1995), with adaptations. An aliquot of 840 µL of a DPPH solution (0.1 mM) and 60 µL of the supernatant was added to a sample, homogenized on a tube shaker, and left to rest for 30 minutes (determined by monitoring the test every 10 minutes to assess the reduction of absorbance until stabilization). Subsequently, readings were taken on a spectrophotometer (Biochrom, Libra S8, Cambridge, UK) at 517 nm. The decrease in absorbance of the samples corresponds to the percentage of free radical scavenging (% DPPH) obtained using Eq. 3:

$$DPPH(\%) = \frac{\left(Abs_{DPPH} - Abs_{sample}\right)}{Abs_{DPPH}} \times 100 \quad (3)$$

where:

DPPH (%) - percentage of antioxidant activity of the sample on DPPH;

Abs_{DPPH} - absorbance (or optical density) of the DPPH free radical; and

Abs_{sample} - absorbance of the sample.

Antioxidant activity by the ferric-reducing antioxidant power (FRAP) method was determined following the methodology proposed by Benzie & Strain (1996), with adaptations. An aliquot of 900 µL of FRAP reagent (25 mL of 0.3 M acetate buffer at pH 3.6, 2.5 mL of 10 mM 2,4,6-tripyridyl-s-triazine acid (TPTZ) solution, and 2.5 mL of an aqueous solution containing 20 mM ferric chloride) was mixed with 90 µL of distilled water, resulting in a total volume of 30 µL of supernatant. This mixture was homogenized on a tube shaker and left to rest in the dark at 37 °C for 30 minutes. Readings were taken on a spectrophotometer (Biochrom, Pound S8, Cambridge, England) at 594 nm and 25 °C after incubation. The blank consisted of 900 µL of FRAP reagent, 90 µL of distilled water, and 30 µL of extractant (AR methanol). The antioxidant potential of the extracts was evaluated using a limitation that uses ferrous sulfate ($FeSO_4.7\ H_2O$) at concentrations ranging from 0 to 1,500 µM. The results were expressed as millimoles of Fe^{2+} per kilogram (mmol Fe^{2+} kg^{-1}).

Vitamin C and total phenolic (TPC) contents were determined simultaneously through a Folin-Ciocalteu (F-C) assay, according to Sanchez-Rangel et al. (2013), with adaptations. The tuberous root extract was mixed with the F-C reagent, reacting ascorbic acid (AA) at the beginning of the assay. AA in the extract was quantified by spectrophotometrically measuring the formation of blue after adding the F-C reagent at the beginning of the assay. Samples of 0.3 g of tissue from the tuber surface (0-5 mm) were macerated and homogenized with 1.5 mL of methanol. Subsequently, the samples were left to rest in the dark at 4 °C for 24 hours. Each sample was then centrifuged at 10,000 × g at 2 °C for 21 minutes.

In the assay, 150 µL of extract, 150 µL of 0.25 M Folin-Ciocalteu reagent, and 2,400 µL of distilled water were pipetted into a tube. The mixture was then homogenized on a stirrer for 3 minutes. The vitamin C readings were taken at 765 nm before adding sodium carbonate. AA was quantified based on a curve from 0.1 to 3 mM of AA. An aliquot of 300 µL of 1 M sodium carbonate was added and the solution was kept in the dark for 2 hours. The blank consisted of 150 µL of methanol to replace the supernatant. Readings were taken on a spectrophotometer (Libra S8, Biochrom Cambridge, UK) at 725 nm. The results were expressed as milligrams of gallic acid equivalent per gram of fresh weight (mg $100g^{-1}$), obtained by quantification based on a standard curve of gallic acid.

The total carotenoid content was determined through an analytical methodology for separation and extraction of compounds using organic solvents. A 0.25-gram sample from tuber pulp was added to 1.25 mL of acetone, 1.25 mL of methanol, and 2.5 mL of hexane. The extract was then kept in the dark for 24 hours. Subsequently, it was centrifuged at 9,000 rpm at 4 °C for 5 minutes. The total carotenoid content

was determined as described by Rodriguez-Amaya & Delia (2004), using Eq. 4:

$$\text{Carotenoids}\left(\text{mg } 100\text{g}^{-1}\right) = \frac{\text{A} \times \text{V} \times 1{,}000{,}000}{\text{A}_{1\text{cm}}^{1\%} \times \text{M} \times 100} \quad (4)$$

where:

A - absorbance of the solution at a wavelength of 470 nm for lycopene and 450 nm for beta-carotene;

V - final volume of the solution;

$A_{1cm}^{1\%}$ - molar extinction coefficient or molar absorptivity; and,

M - weight of the sample taken for analysis.

The normality of the data was assessed using the Shapiro-Wilk test, whereas data homogeneity was assessed using the maximum F-test, followed by analysis of variance. Data presenting significant differences were subjected to the Tukey's test at a 0.05 probability. Statistical analyses were performed using the software SAS. Graphs were developed using Sigma Plot 10.0 (Cohen, 2021).

Result and Discussion

Sweet potatoes of the cultivar BRS-Amélia, whether raw or cooked, initially showed higher flesh firmness compared to those of the cultivar Beauregard (Figure 1A). The pattern of flesh firmness remained similar after 14 days of storage under refrigeration at 8 °C; therefore, raw BRS-Amélia potatoes presented higher flesh firmness compared to Beauregard potatoes, regardless of the packaging condition (packaged or unpackaged) (Figure 1A). These differences were not found for cooked potatoes, with BRS-Amélia and Beauregard presenting statistically similar flesh firmness means (Figure 1B). The sweet

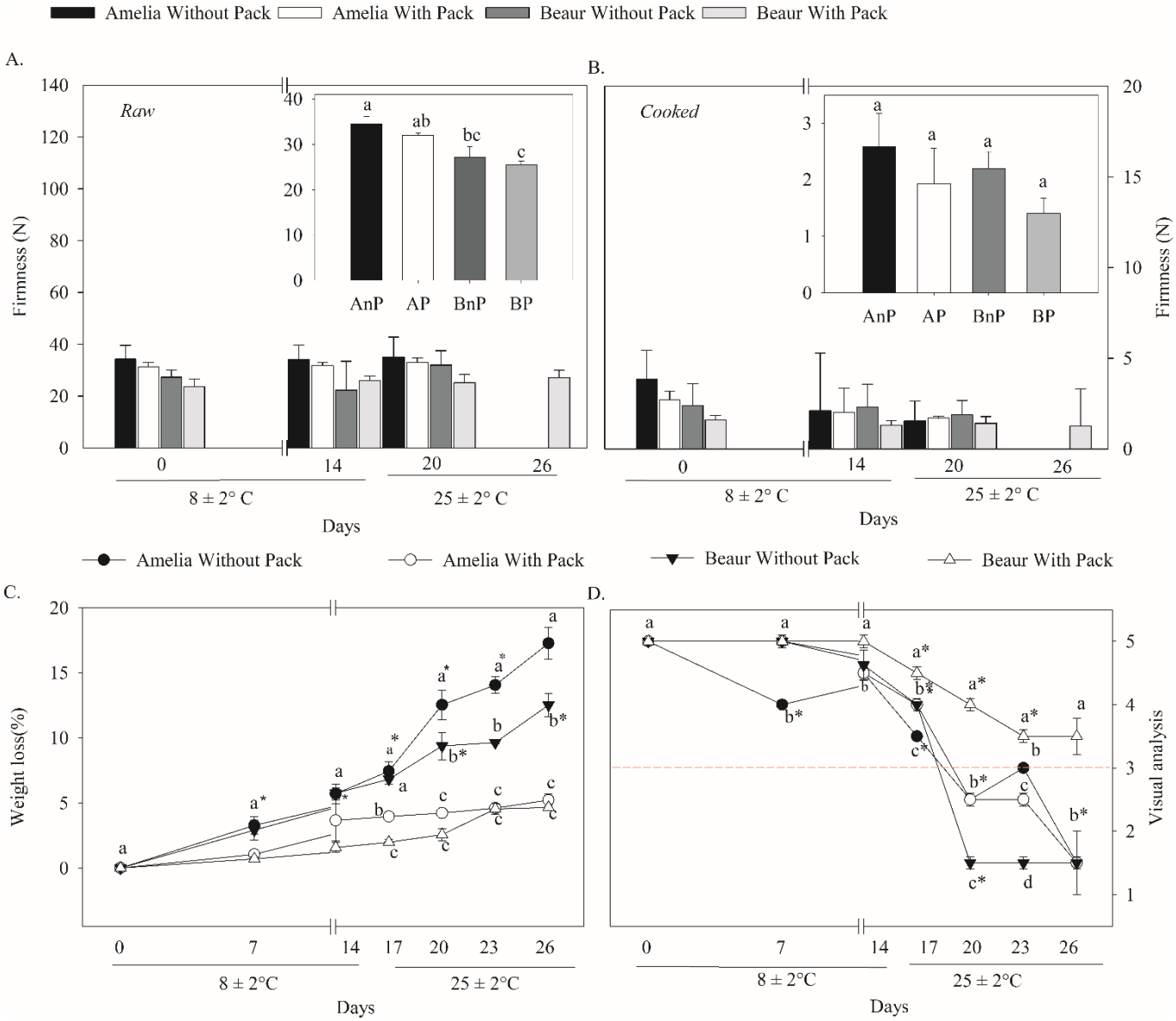

Figure 1. Flesh firmness (raw, A; cooked, B), weight loss (raw samples; C), and visual evaluation (raw, D) in packed and unpacked sweet potatoes of the cultivars BRS-Amélia and Beauregard (Beaur) stored for 14 days under refrigeration at 8 °C, followed by 12 days of storage at room temperature (27 °C). AnP: unpackaged BRS-Amélia sweet potatoes; APA: packaged BRS-Amélia sweet potatoes; BnP: unpackaged Beuaregrad sweet potatoes; and BP: packaged Beuaregrad sweet potatoes. *Bars represent the standard deviation of the mean (n = 4). Different lowercase letters indicate significant differences between the evaluated treatments

potatoes that remained presenting commercial quality at the end of the experiment (26 days of storage, at 25 °C) where those of the cultivar Beauregard in the treatment with packaging; thus, only their means of flesh firmness (raw and cooked) were presented (Figures 1A and B).

Raw BRS-Amélia potatoes showed greater firmness during storage possibly due to a higher dehydration (Figure 1C), resulting in a rubberier texture and greater resistance to penetration. Possibly, the periderm of BRS-Amélia potatoes is more susceptible to dehydration for some reason (Miano et al., 2019), which requires further investigations in subsequent studies. Furthermore, cooking reduced flesh firmness and starch and total soluble carbohydrate contents (Figures 1B, 2B, and C). BRS-Amélia sweet potatoes are firmer due to a combination of factors, including a higher starch content (Figure 2B); starch is a complex carbohydrate that contributes to firmness in cooked vegetables (Almeida et al., 2022). Cell structure also has an important function in promoting firm textures to vegetables. Cooking sweet potatoes in a microwave reduced their firmness due to water loss from cells, starch gelatinization, and collapse of the cell structure caused by intense heat (Gonçalves et al., 2023).

Unpackaged BRS-Amélia potatoes showed a reduced quality in the visual evaluations at 7 days of storage under refrigeration compared to the others potatoes (Figure 1D). All sweet potatoes presented scores higher than 3 at 14 days under refrigeration and were considered suitable for marketing (Figure 1D). All potatoes showed similar commercial quality at 17 days of storage, although unpackaged BRS-Amélia potatoes had the lowest visual quality scores (Figure 1D). Only packaged Beauregard sweet potatoes had scores higher than 3 after 20 days of storage, making them suitable for marketing (Figure 1D). These results were not found for the other treatments due to wilting, occurrence of wrinkles, dark spots, and surface discoloration and bruising, as well as early rotting resulting in softer and stickier textures and areas of rot. Thus, refrigerated storage of BRS-Amélia sweet potatoes for 14 days provided them with 3 days of shelf life under ambient conditions, totaling 17 days of storage (Figure 1D). Contrastingly, packaged Beauregard sweet potatoes maintained their quality for 12 days at room temperature after 14 days under refrigerated storage, thus totaling 26 days of storage (Figure 1D), which were considered suitable for distant and demanding markets, such as the European market.

The luminosity (L*) did not significantly vary between cultivars, packaging conditions, and storage periods (Table 1), i.e., the color on the surface of the potatoes was not affected by the evaluated factors. However, the chromaticity was higher for packaged BRS-Amélia potatoes, whereas the unpackaged potatoes of this cultivar exhibited the lowest chromaticity. High chroma values tend to make potatoes whiter and acquire more yellow hues, with a significant color variation, which may contribute to the chroma formula and cause issues for the cultivar (Table 1). Larsen & Molteberg (2022) evaluated the use of packaging for different sweet potato cultivars, including BRS-Amélia, and found similar results. They reported that potatoes tend to present higher chromaticity, especially when packaged, expressing a stronger saturation in terms of color pigments.

Table 1. Luminosity (L*) and Chroma (C*) on the surfaces of raw sweet potatoes of the cultivars BRS-Amélia and Beauregard, with the use of packaging under modified atmosphere and without packaging, stored for up to 14 days under refrigeration (8 °C), followed by 12 days of storage at room temperature of 25 °C

Treatments	Day	L*	C*
BRS-Amélia without packaging	0	35.3 ± 5.63 aA	22.23 ± 3.33 b
	7	31.46 ± 2.79 aA	43.89 ± 24.65 b
	14	41.45 ± 15.67 aA	28.09 ± 11.34 b
	17	37.17 ± 1.08 aA	25.84 ± 1.14 b
	20	30.46 ± 1.25 aA	23.79 ± 1.12 b
	23	33.74 ± 3.39 aA	23.72 ± 2.15 b
	26	30.67 ± 6.03 aA	19.76 ± 3.2 b
BRS-Amélia with packaging	0	35.3 ± 5.63 aA	22.23 ± 3.33 a
	7	28.88 ± 1.87 aA	24.28 ± 2.72 a
	14	26.09 ± 2.87 aA	20.99 ± 2.67 a
	17	37.28 ± 3.2 aA	26.80 ± 1.48 a
	20	34.52 ± 5.27 aA	43.50 ± 21.12 a
	23	40.16 ± 3.78 aA	29.09 ± 1.83 a
	26	31.26 ± 1.92 aA	46.58 ± 22.29 a
Beauregard without packaging	0	40.73 ± 4.91 aA	22.48 ± 1.67 ab
	7	39.97 ± 3.33 aA	25.87 ± 1.33 ab
	14	27.81 ± 2.71 aA	23.50 ± 3.70 ab
	17	34.39 ± 2.41 aA	22.71 ± 0.88 ab
	20	35.96 ± 6.19 aA	21.79 ± 2.28 ab
	23	32.68 ± 2.93 aA	21.68 ± 1.42 ab
	26	27.76 ± 4.72 aA	15.86 ± 1.49 ab
Beauregard with packaging	0	40.73 ± 4.91 aA	22.48 ± 1.67 ab
	7	35.89 ± 3.53 aA	23.58 ± 1.80 ab
	14	33.51 ± 4.21 aA	23.73 ± 1.82 ab
	17	42.91 ± 5.43 aA	30.39 ± 2.38 ab
	20	43.82 ± 4.5 aA	29.18 ± 1.24 ab
	23	31.02 ± 1.46 aA	24.58 ± 1.27 ab
	26	36.61 ± 3.03 aA	30.32 ± 4.07 ab

*L refers to the mean and standard deviation, and C refers to chroma and standard deviation. Means followed by uppercase letters indicate differences between days of storage, while different lowercase letters indicate differences between treatments (cultivars and packaging) at a significance level of 0.05

Starch contents at the beginning of the experiment presented no variations between treatments (cultivars and packaging). Packaged Beauregard potatoes presented lower contents (17%) only at 17 days of storage (at 25 °C) compared to the other treatments (Figure 2A). Beauregard potatoes remained presenting commercial quality at 23 days of storage, when those subjected to packaging presented the highest starch contents (Figure 2A). The decreases in starch contents at 17 days (Figure 2A) was accompanied by increases in soluble solids and carbohydrate contents (Figure 2C and D). This denotes that part of the starch was degraded and converted into sugars, as a relative increase in total soluble carbohydrates was found (Figure 2D). This can occur when sweet potatoes are refrigerated, causing the starch to be converted into sugars by the activity of enzymes such as amylase and sucrose synthase, resulting in a sweeter taste. Furthermore, raw BRS-Amélia potatoes presented higher soluble solids and carbohydrate contents at 20 days compared to Beauregard potatoes (Figure 2C and D). This indicates that BRS-Amélia potatoes are sweeter than Beauregard. Although the BRS-Amélia cultivar presented a shorter marketing period (17 days), it is still a well-accepted cultivar in the local market due to its flavor (Basílio et al., 2022). However, the 17-day storage period found for BRS-Amélia potatoes may be an insufficient time for shelf life when considering export markets. Contrastingly, Beauregard

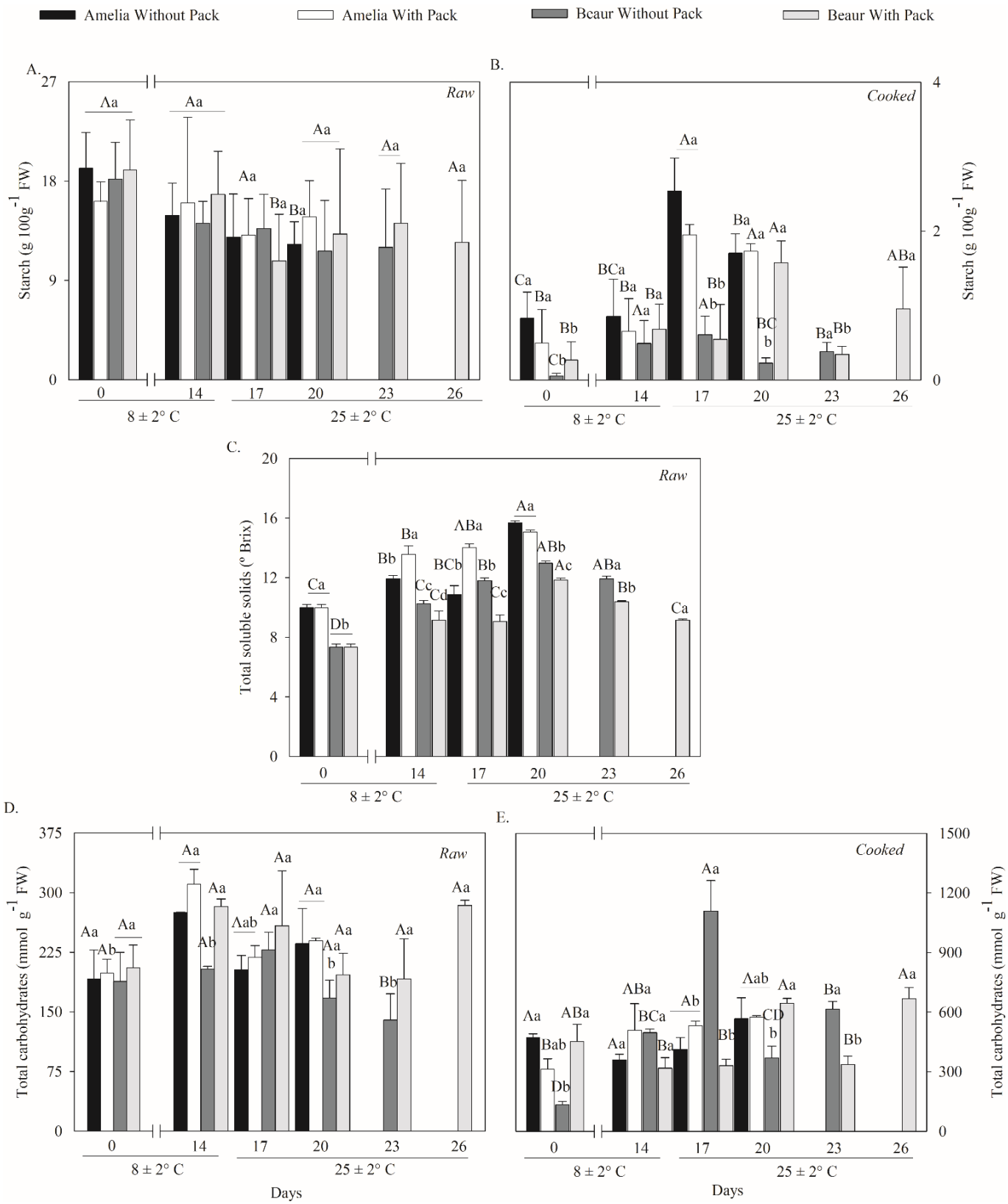

Figure 2. Contents of starch (raw, A; cooked, B), total soluble solids - ° Brix (raw, C), and total soluble carbohydrates (raw, D; cooked, E) in packed and unpacked sweet potatoes of the cultivars BRS-Amélia and Beauregard (Beaur) stored for 14 days under refrigeration at 8 °C, followed by 12 days of storage at room temperature (27 °C). *Bars represent the standard deviation of the mean (n = 4). Different lowercase letters indicate significant differences between the evaluated treatments (cultivars and packaging) at a significance level of 0.05

potatoes were more suitable for export, as they reached 26 days of storage while maintaining commercial quality.

A significant reduction in starch and total soluble carbohydrate contents was found after cooking the sweet potatoes, regardless of the treatment (Figure 2B and E). The microwave cooking process significantly reduced starch and total soluble carbohydrate contents due to the intense and rapid heat (Corrêa et al., 2016). This can be attributed to

gelatinization of starch, which is then converted into simpler sugars, while the loss of soluble carbohydrates is due to a rapid water evaporation during the cooking process (Alencar & Koblitz, 2008). Cooking for a shorter time or at a lower power can reduce these losses, as well as other cooking methods, such as steaming and baking, may better preserve nutrients (Formaggio et al., 2020). Therefore, cooking sweet potatoes in a microwave changes the starch structure, resulting in a significant decrease in starch contents (Kolarič et al., 2020).

The antioxidant activity (measured by the DPPH method) in BRS-Amélia sweet potatoes (with and without packaging) remained stable for up to 14 days under refrigeration (Figure 3A), in both cooked and raw sweet potatoes. However, the antioxidant activity (DPPH method) in both cultivars (raw and cooked potatoes) decreased after subjecting the potatoes to room temperature (Figure 3A and B). Packaged Beauregard sweet potatoes showed a less intense decrease (Figure 3A and B). On the other hand, the antioxidant activity in BRS-Amélia sweet potatoes (raw and cooked) significantly increased when measured by the FRAP method (Figure 3C and D). Potatoes of both cultivars reached their highest antioxidant activity at 17 and 20 days, regardless of packaging (Figure 3C and D). Interestingly, the BRS-Amélia potatoes presented the highest phenolic compound contents during this same period (Figure 4A and B). The antioxidant activity (by the FRAP method) in Beauregard potatoes refrigerated for 14 days slightly increased in raw tissues (Figure 4C); regarding cooked tissues, the antioxidant activity remained more stable in packaged potatoes (Figure 4D). Stability in antioxidant activity was found at the end of the experiment (at 26 days) when measured by the FRAP method and compared to the first day, for both raw and cooked potatoes (Figure 4C and D).

The antioxidant activity measured by the DPPH method did not decrease even after cooking (Figure 3B). This may be due to the presence of heat-resistant antioxidants that do not degrade even after cooking, such as anthocyanins, carotenoids, vitamin C, and vitamin E (Fagundes et al., 2023). The antioxidant activity in cooked sweet potatoes, measured by the FRAP method, showed a significant increase (Figure 3D). This may be attributed to differences between DPPH and FRAP methods in assessing the antioxidant activity of water-soluble substances such as vitamin C and phenolic compounds

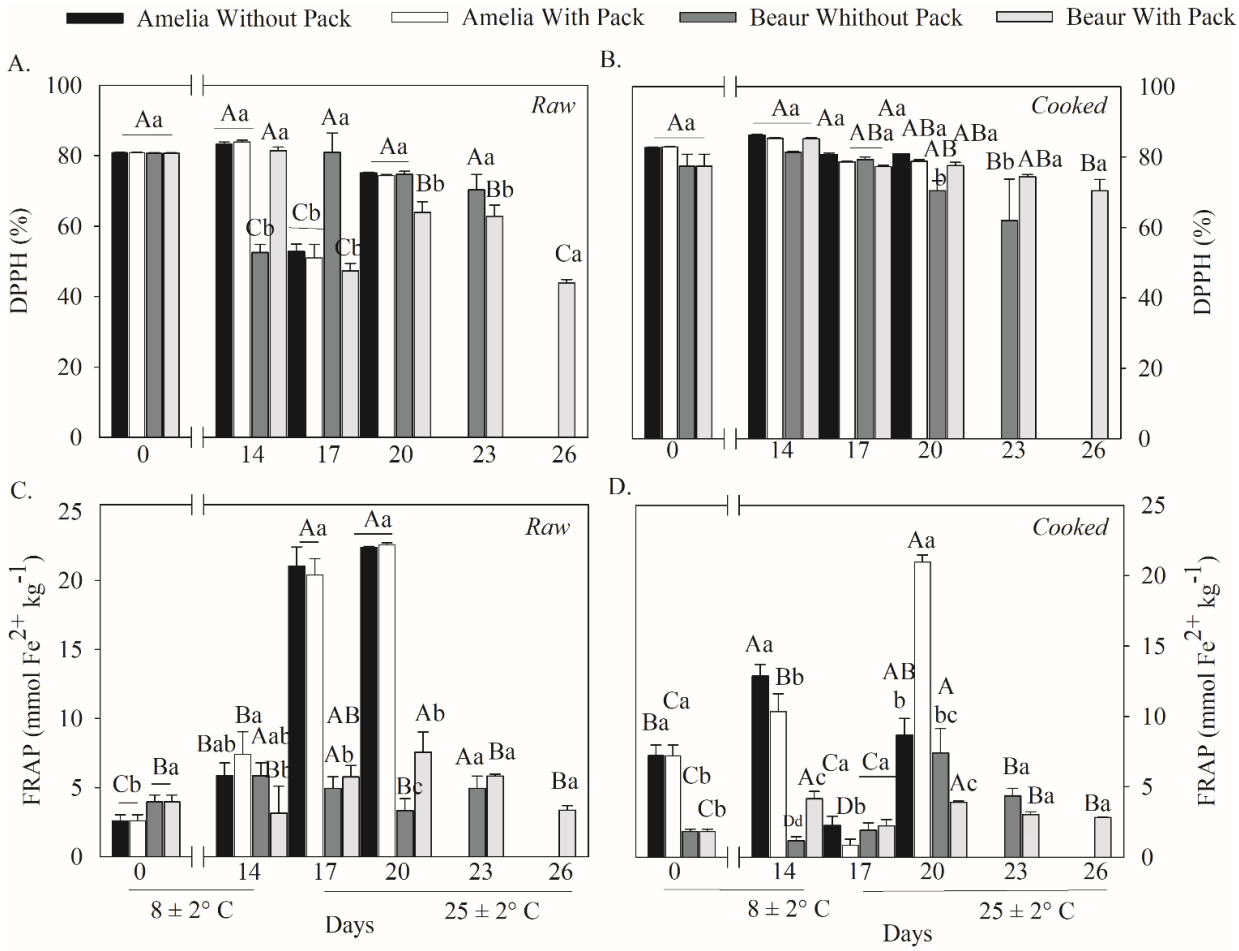

Figure 3. Antioxidant activity obtained by DPPH (raw, A; cooked, B) and FRAP (C raw, D cooked) methods, in packed and unpacked sweet potatoes of the cultivars BRS-Amélia and Beauregard (Beaur) stored for 14 days under refrigeration at 8 °C, followed by 12 days of storage at room temperature (27 °C). *Bars represent the standard deviation of the mean (n = 4). Different lowercase letters indicate significant differences between the evaluated treatments (cultivars and packaging) at a significance level of 0.05

(Morikawa & Nishinari, 2000). The DPPH method is used to assess the potential of an antioxidant substance to donate an electron to neutralize DPPH free radicals, whereas the FRAP method assesses the potential of an antioxidant substance to reduce the ferric iron (Fe^{3+}) to ferrous iron (Fe^{2+}). However, both methods are complementary and provide valuable information about the antioxidant potential of a substance (Kaymak-Ertekin & Gedik, 2004). This was also observed in the analyses of the present study.

Vitamin C contents in raw and cooked sweet potatoes of both cultivars remained significantly stable (Figure 4C and D). The transfer of the potatoes to room temperature conditions resulted in a significant decrease in Vitamin C in both raw and cooked BRS-Amélia potatoes (Figure 4C and D). Regarding

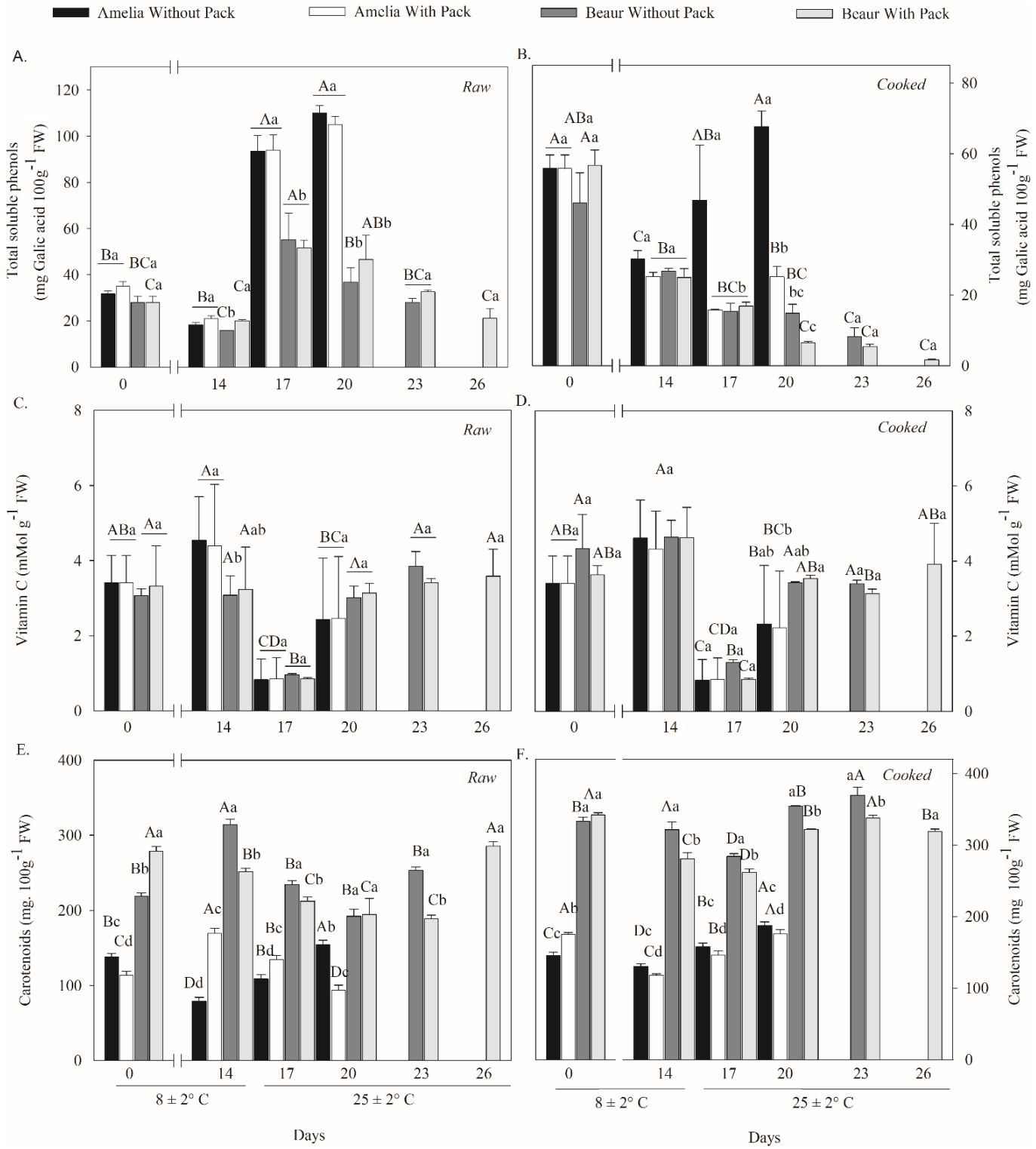

Figure 4. Contents of total soluble phenols (TSP) (raw, A; cooked, B), ascorbic acid (Vitamin C) (raw, C; cooked, D), and total carotenoids (raw, E; cooked F) in packed and unpacked sweet potatoes of the cultivars the BRS-Amélia and Beauregard stored for 14 days under refrigeration at 8 °C, followed by 12 days of storage at room temperature (27 °C). *Bars represent the standard deviation of the mean (n = 4). Different lowercase letters indicate significant differences between the evaluated treatments (cultivars and packaging) at a significance level of 0.05

the Beauregard cultivar, the vitamin C content remained more stable for up to 26 days in packaged sweet potatoes (Figure 4D).

The Beauregard cultivar exhibited higher total carotenoid contents in both raw and cooked potatoes, and cooked potatoes presented higher contents than the raw ones throughout the storage period (Figure 4E and F). Total carotenoid contents in cooked Beauregard potatoes tend to increase during storage compared to those in raw potatoes (Tanka et al., 2017). This may be due to release and migration of carotenoids, which are facilitated by cooking and the breakdown of cell structures. Furthermore, chemical transformations such as isomerization and oxidation can lead to the accumulation of carotenoids in cooked tissues (Vargas et al., 2017).

Overall, BRS-Amélia sweet potatoes appeared firmer and exhibited higher results for contents of solid and soluble carbohydrates and phenolic compounds, as well for color, chromaticity, and antioxidant activity (by FRAP method). However, their physiognomic characteristics were not attractive after 17 days of storage, including 3 days at room temperature, when simulating environmental conditions for marketing on supermarket shelves. Contrastingly, packaged Beauregard sweet potatoes maintained a good visual appearance for marketing purposes during 26 days of storage, exhibiting a striking color (assessed by instrumental color measurement) and higher total carotenoid contents. This may be attributed to the protection provided by the packaging against environmental factors such as light, humidity, and oxygen. Additionally, the packaging helped preserve their striking color and high total carotenoid contents, contributing to the attractiveness of the product during the storage period. Therefore, the appropriate choice of packaging is significantly important for maintaining the visual and nutritional quality of sweet potatoes of the cultivar Beauregard during storage.

Conclusions

1. The combination of refrigerated storage (8° C) with packaging for 14 days extended the quality of sweet potatoes of the cultivar Beauregard for an additional 12 days at room temperature (approximately 25 °C), totaling 26 days of storage while maintaining commercial quality. This period is suitable for marketing and consumption in European markets;

2. Beauregard sweet potatoes exhibited higher starch contents, less dehydration, and stable contents of antioxidant phytochemicals, including vitamin C, phenolic compounds, and carotenoids, even after cooking;

3. BRS-Amélia sweet potatoes stored for 14 days under refrigeration maintained their quality for an additional 3 days under room temperature conditions, totaling an adequate storage period of 17 days.

Acknowledgments

This research was supported by the CAPES- Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Proc. 88881-159183/2017-01); FACEPE- Fundação de Amparo à Ciência e Tecnologia do Estado de Pernambuco (PQ-0795-5.01/16); UFRPE Universidade Federal Rural de Pernambuco (PRPPG 015/2018), Universidade Federal Rural do Semiárido and Conselho Nacional de Desenvolvimento Científico e Tecnológico (423100/2018-1).

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