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HARVEST TIME AS A MODULATOR OF PHYTOCHEMICALS IN SWEET POTATO CULTIVARS FOR THE INDUSTRY[1]

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ABSTRACT - As a fresh food, sweet potatoes are highlighted for their taste and appearance. In the industry, they are valued for their starch and sugar content. In both scenarios, much attention has been given to the composition of bioactive compounds. The application of abiotic stresses seems to induce an overproduction of these compounds in some vegetables. The objective was to examine the influence of harvest time on the synthesis and accumulation of bioactive compounds in varieties of minimally processed sweet potatoes with different flesh colors. Sweet potato cultivars (Beterraba, Jerimum, Mãe de Família Roxa, and BRS Cuia) were harvested at 120, 150, and 180 days after planting, then subjected to minimal processing and stored at 5 ºC for 10 days. The most recommended time for harvesting sweet potatoes in semi-arid conditions for minimal processing by the industry is between 150 and 180 days. This is the period when the sweet potatoes exhibit the best quality for fresh consumption, as detected in 'Mãe de Família Roxa' and 'Jerimum'. 'BRS Cuia' harvested at 120 days showed the highest phenolic compound levels, the highest polyphenol oxidase and peroxidase enzyme activities, and the most intense browning symptoms. In addition to its starch content, it can be used as a raw material for the extraction of phenolic compounds of interest. 'Beterraba' showed low sugar values, rendering them unfavorable for fresh consumption or minimal processing. However, this cultivar also exhibited a high content of carotenoids, making them bio-factories for the food and pharmaceutical industries.

Keywords: *Ipomoea batatas* (L.) Lam. Browning. Carotenoids. Phenolic compounds.

TEMPO DE COLHEITA COMO MODULADOR DE FITOQUÍMICOS EM CULTIVARES DE BATATA DOCE PARA A INDÚSTRIA

RESUMO - Como alimento fresco, a batata-doce se destaca pelo sabor e aparência. Na indústria, é valorizado por seu teor de amido e açúcar. Em ambos os cenários, muita atenção tem sido dada à composição dos compostos bioativos. A aplicação de estresses abióticos parece induzir uma superprodução desses compostos em algumas hortaliças. O objetivo foi examinar a influência da época de colheita na síntese e acúmulo de compostos bioativos em variedades de batata-doce minimamente processadas com diferentes cores de polpa. As cultivares de batata-doce: Beterraba, Jerimum, Mãe de Família Roxa e BRS Cuia foram colhidas aos 120, 150 e 180 dias após o plantio, submetidas ao processamento mínimo e armazenadas a 5 ºC por 10 dias. A época mais recomendada para a colheita da batata-doce em condições semi-áridas para a indústria de processamento mínimo foi entre 150 e 180 dias, período em que a batata-doce apresentou melhor qualidade para consumo in natura em destaque para 'Mãe de Família Roxa' e 'Jerimum'. A 'BRS Cuia' colhida aos 120 dias apresentou os maiores teores de compostos fenólicos, as maiores atividades das enzimas polifenoloxidase e peroxidase e os sintomas de escurecimento mais intensos, podendo ser utilizado como matéria-prima para a extração de compostos fenólicos de interesse, além do amido. A 'Beterraba' apresentou baixos valores de açúcar, tornando-os desfavoráveis para consumo in natura ou processamento mínimo. No entanto, esta cultivar também apresentou um alto teor de carotenóides, tornando-os biofábricas para as indústrias alimentícia e farmacêutica.

Palavras-chave: *Ipomoea batatas* (L.) Lam. Escurecimento. Carotenóides. Compostos fenólicos.

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INTRODUCTION

Minimal processing has stood out as a promising alternative for sweet potatoes due to the increased phenolic compound content and antioxidant activity (REYES; VILLARREAL; CISNEROS-ZEVALLOS, 2007). However, the processing of sweet potatoes in the food industry is still practiced on a small scale. Their by-products have distinguished values in relation to other roots because the pulp of sweet potatoes is rich in phenolic compounds and carotenoids which contribute to high antioxidant capacity and constitute a possible alternative dietary supplement to address vitamin-A deficiency problems (TANG; CAI, XU, 2015; NEELA; FANTA, 2019).

In semi-arid conditions, the sweet potato crop faces limiting factors such as high temperatures and low water availability (VILLORDON et al., 2010). Agronomic practices also impact the darkening of sweet potatoes (FUKUOKA et al., 2019). In the semi -arid region of Brazil, sweet potatoes are harvested at 90 to 150 days after planting, depending on the market (ALBUQUERQUE et al., 2018). Delayed harvesting allows for sugars, starch, and vitamin C to accumulate in the plant (ALBUQUERQUE et al., 2018). These are quality characteristics affecting fresh consumption and industrial uses. This management practice can also increase the accessibility of bioactive compounds such as polyphenols, all of which are found in sweet potatoes, especially when the root is stressed by cutting (LÓPEZ-MARTÍNEZ et al., 2020; EJAZ et al., 2017; REYES; VILLARREAL; CISNEROS-ZEVALLOS, 2007; JACOBO-VELÁZQUEZ; CISNEROS-ZEVALLOS, 2012).

Therefore, in semi-arid climate conditions, delayed harvesting is suggested to be an important modulator for the biosynthesis and accumulation of bioactive compounds in sweet potatoes. As a result, this practice might improve the quality and add value to sweet potatoes for different uses.

MATERIAL AND METHODS

Plant material and minimal processing

Sweet potato cultivars (Beterraba, Jerimum, Mãe de Família Roxa, and BRS Cuia) were acquired from the Didactic Sweet Potato Germplasm Collection of the Federal Rural University of the Semi-Arid, located in Mossoró – Rio Grande do Norte, Brazil (5° 11’ S 37° 20‘ W, 18 m above sea level). Sweet potatoes were harvested at 120, 150, and 180 days after planting. Once harvested, the roots were selected and washed, and the periderm was removed. Subsequently, they were sliced approximately 20 mm thick. The roots were then immersed in water at 5 °C for 10 s, sanitized for 10 min in chlorinated water (200 mg L^{-1}) at 5 °C, and rinsed for 10 in chlorinated water (5 mg L^{-1}) at 5 °C. After the water was drained for 10 minutes outdoors, using perforated plastic trays, the slices were placed in polypropylene packages (150 x 200 x 0.0005 mm thick) and stored at 5 °C for 10 days.

Visual assessment (VA)

The visual assessment was determined by the method developed by Simões et al. (2020). It is based on a subjective five-point Likert-type scale which was used to define the visual quality of the minimally processed sweet potatoes: 5 = slices with a uniform surface, 0% browning and whitening, good appearance for consumption and sale; 4 = slices showing mild browned or whitened areas in the central and/or peripheral region that do not exceed 5% of the surface, deemed still suitable for consumption and sale; 3 = slices showing moderately browned or whitened areas in the central and/or peripheral region, affecting more than 10% of the surface, considered the threshold of acceptance for consumption and sale; 2 = slices with browning or whitening and discoloration covering more than 50% of the surface, deemed unsuitable for consumption or sale; and 1 = slices with intense browning or whitening covering more than 50% of the surface, considered unsuitable for consumption.

Total soluble phenol (TSP) compounds

TSP content was determined according to the method of Simões et al. (2020) with some adaptations. An 0.25 g aliquot of fresh tissue was macerated with 1.5 mL methanol. The extract was left to stand for 20 h in the dark at 4 ºC, and then it was centrifuged at 10.000 x *g*, at 2 ºC, for 21 min. Subsequently, 150 µL of the supernatant, 2.400 µL distilled water, and 150 µL Folin Ciocalteu reagent (0.25 N) were mixed during 3 min. Then, 300 µL of sodium carbonate (1N) were added and the mixture was kept in the dark at room temperature for 2 h. Readings were taken at 725 nm, and the results were expressed in mg of gallic acid equivalents 100 g^{-1} fresh weight (mg^{-1} GAE FW).

Polyphenol oxidase (PPO) and peroxidase (POD)

The extractions and assays were carried out as proposed by Almeida et al. (2019), with adaptations. Briefly, 0.25g samples were macerated in 6 mL of cold 0.2 M sodium phosphate buffer (pH 6.0), and the extract was then centrifuged at 7.960 g for 23 min at 4 ºC. The PPO assay was performed by adding 20 μL of the supernatant to the reaction medium containing 1.480 mL of 0.2 M phosphate buffer (pH 6.0) and 1.5 mL of 0.2 M catechol. Readings were taken at thirty-second intervals for three minutes using a spectrophotometer at 425 nm. The PPO activity was expressed in μmol min^{-1} g^{-1} FW.

The POD assay was carried out by adding 20 μL of the supernatant to the reaction medium containing 1.780 mL of 0.2 M phosphate buffer (pH 6.0), 100 μL guaiacol (0.5%), and 100 μL hydrogen peroxide (0.08%). Readings were taken at thirty-second intervals using a spectrophotometer at 470 nm. The peroxidase activity was expressed in μmol min^{-1} g^{-1} FW.

Total carotenoid (TC)

The TC content was determined according to Lichtenthaler (1987), with modifications. Eight grams were weighed and macerated, and 5 mL acetone (80%) were added. The samples were then centrifuged at 6.000 g, at 4 ºC, for 15 min. The supernatant was collected and the absorbance was measured using a spectrophotometer. The TC content (μg $100g^{-1}FW^{-1}$) was calculated by the following equations 1, 2 and 3:

$$\text{Chlorophyll a} = 12.25 \text{ x } A_{663} - 2.79 \text{ x } A_{645} \quad (1)$$

$$\text{Chlorophyll b} = 12.25 \text{ x } A_{645} - 2.79\text{x } A_{663} \quad (2)$$

$$\text{Carotenoids} = (1000 \text{ x } A_{455} - 11.62 \text{ x Chlorophyll a} - 94.89 \text{ x Chlorophyll b}/198) \quad (3)$$

Starch and total soluble sugar (TSS)

The TSS content was determined according to Miller (1959), with modifications. The TSS content was determined by the anthrone method, following Albuquerque et al. (2018). A 1 g sample was diluted in a 50 mL volumetric flask. A 25-μL aliquot was then removed for analysis and readings were taken using a spectrophotometer at 620 nm. All results were expressed in percent.

Experimental design and statistical analysis

The experiments were carried out in a randomized-block design with a 3 × 3 factorial arrangement consisting of three harvest and three storage times for each cultivar. The data were subjected to ANOVA and Tukey's test, 5%.

RESULTS AND DISCUSSION

Delayed harvest improves quality

The scores assigned in the subjective VA decreased throughout the storage time (Figure 1-I), and they were most marked at the earliest harvest time (120 days), especially in 'BRS Cuia' which exhibited signs of browning and a threshold score for acceptance (3) was detected at the start of the experiment (Figure 1-ID). In the 'Beterraba', whitening was the main reason for the declining scores (Figure 1-I). Delaying the harvest maintained the scores equal to or higher than 3 for all cultivars at 10 days of storage. The visual scores detected by 'Jerimum' and 'Mãe de Família Roxa' remained within the acceptance threshold (score 3) up to the tenth day (Figure 1-I).

The white-pulp cultivars harvested at 120 days were found to be more sensitive to browning (Figure 1-II). At the start of the storage period, those cultivars were already at the threshold for commercial acceptance. This is an indication that harvest at 120 days is inadequate for those cultivars if they are intended for minimal processing. On the other hand, the scores remained stable when the harvest was delayed, meaning that the sweet potatoes would be marketable for up to 10 days (Figures 1-I and II). The colored-pulp cultivars were better able to express symptoms to whitening during storage, which compromises their quality in the minimally processed form (Figures 1-I and II). This was also observed by Simões et al. (2020).

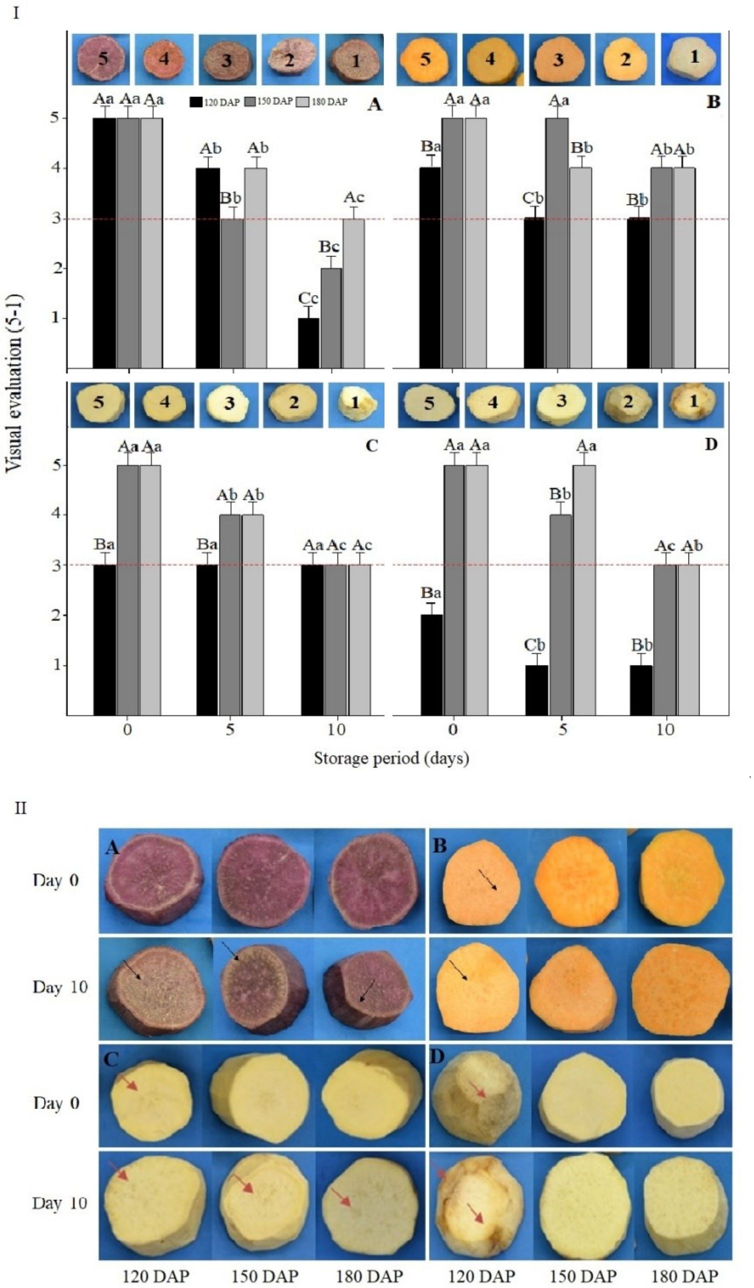

Figure 1. Visual scores (I) and appearance (II) of minimally processed sweet potatoes harvested at different times (120, 150, and 180 days after planting, DAP) and stored at 5 °C for 10 days. The cultivars were Beterraba (A), Jerimum (B), Mãe de Família Roxa (C), and BRS Cuia (D). Images above the graphs represent the notes (5-1) of the visual scores for each cultivar (I). Black arrows indicate symptoms of superficial whitening of the tissue, and red arrows indicate symptoms related to browning of the tissue (II). The bars represent the means ± the standard deviation. Means followed by the different letters indicate a significant difference according to Tukey test ($p < .05$). Capital letters compare the times of harvest, and lowercase letters compare the storage days.

TSP compounds, PPO and POD enzymes are involved in the browning of white-pulp sweet potatoes

The TSP content increased during storage. In all cultivars, the greatest increases were detected in the roots which were harvested at 120 days (Figure 2), followed by 150 and 180 days (Figure 2). Among the white-pulp cultivars, those which browned most were the varieties that showed the greatest increases in TSP contents, mainly ‘BRS Cuia’ (Figure 2 and Figure 1-II). A strong negative correlation was observed between TSP and VA (Table 1). This high correlation was observed for ‘BRS Cuia’ (Table 1), as opposed to the low correlations observed in the colored pulp cultivars (Figure 1-II), indicating the importance of this phytochemical for the quality of a sweet potato. By contrast, from the perspective of being a source of those phytochemicals for the pharmaceutical industry, harvesting at 120 days was the best strategy, especially for ‘BRS Cuia’. As such, those cultivars would function as bio-factories for compounds of interest (JACOBO-VELÁZQUEZ;CISNEROS-ZEVALLOS, 2012).

Table 1. Pearson's simple correlation coefficient values were calculated between the variables Visual Assessment (VA), Total Soluble Phenols (TSP), Polyphenol Oxidase (PPO), and Peroxidase (POD) in sweet potatoes from different minimally processed cultivars harvested at different times (120, 150, and 180 DAP) and stored at 5 °C for 10 days.

Correlated variables	Beterraba	Jerimum	Mãe de Família Roxa	BRS Cuia
VA/TSP	-0.65^{ns}	-0.59^{ns}	-0.59^{ns}	-0.90*
VA/PPO	-0.84*	-0.78*	-0.58^{ns}	-0.75*
VA/POD	-0.35^{ns}	-0.61^{ns}	-0.78*	-0.88*

*Significant at $p < 0.05$; ns Note significant

In this study, harvest time was evidently a pre -harvest factor that increased TSP contents. However, caution is warranted in recommending sweet potato varieties because those TSP compounds induced browning in white-pulp cultivars (Figure 1-II), indicating the existence of a fine line between browning and loss of quality versus gains in quality by increases in bioactive compounds. The same behavior was observed in the ‘Beterraba’ and ‘Jerimum’ harvested at 120 days (Figure 2). This was confirmed by the low Pearson’s correlation coefficient (Table 1). Pigments likely either mask browning or act as antioxidants preventing the synthesis of substances that cause browning.

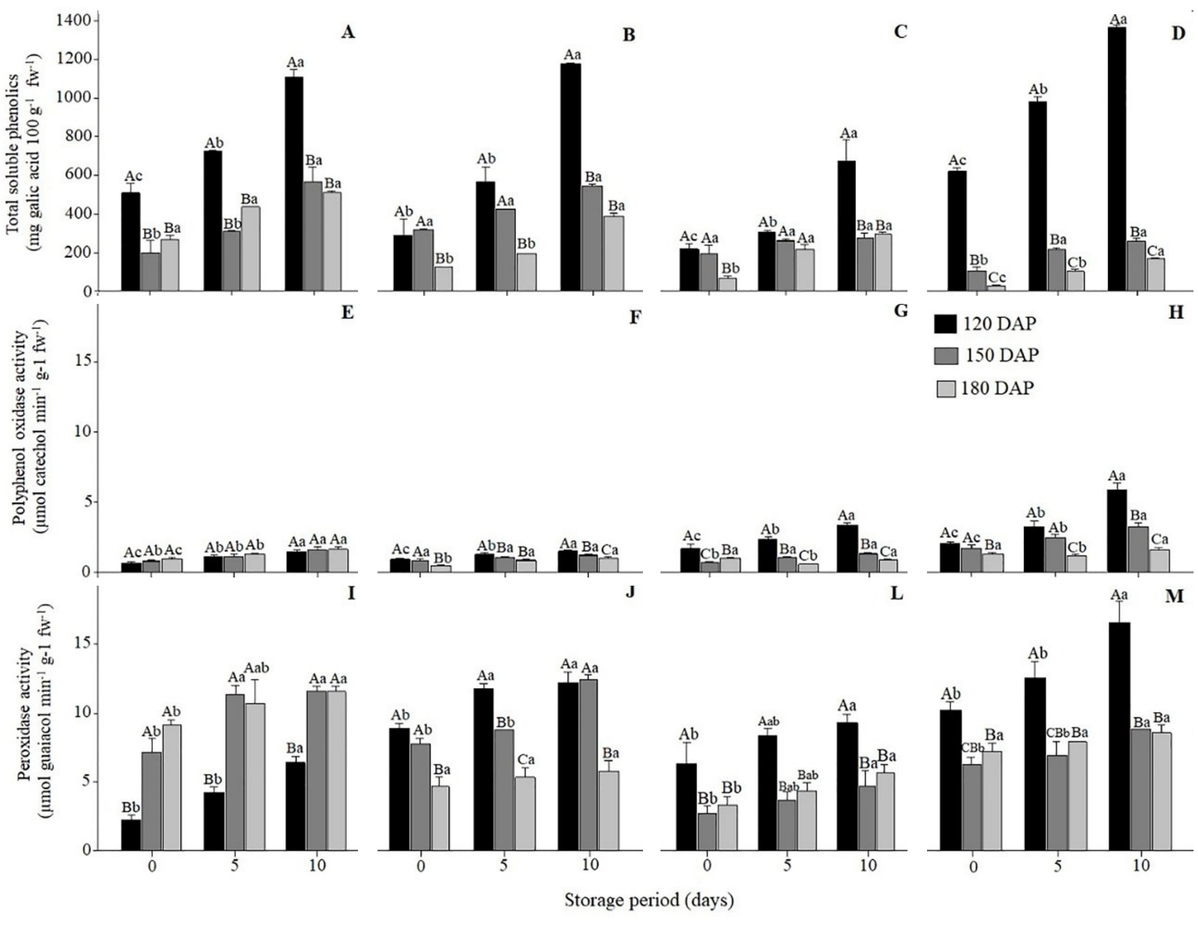

Figure 2.Total soluble phenols, polyphenol oxidase activity, and peroxidase activity in minimally processed sweet potatoes harvested at different times (120, 150, and 180 DAP) and stored at 5 ºC for 10 days. Cultivars: Beterraba (A, E, and I), Jerimum (B, F, and J), Mãe de Família Roxa (C, G, and L) and BRS Cuia (D, H, and M). The bars represent the means ± standard deviation. Means followed by the different letters indicate a significant difference according to Tukey test ($p < 0.05$). Capital letters compare the times of the harvest and lowercase letters compare the storage days.

As for the PPO and POD activities in the white-pulp cultivars, PPO activity was higher when the roots were harvested at 120 days. No such difference was observed, however, in colored-pulp 'Beterraba' and 'Jerimum', which showed barely noticeable symptoms of browning (Figure 2). Once again, this demonstrates the complexity of the browning phenomenon mediated by the PPO and POD enzymes in those colored-pulp cultivars. On this basis, harvesting at 120 days was a management practice that provided increases in the activity of those enzymes, which might have been a "trigger" to induce browning in some of the white-pulp roots. This was not observed for 'Jerimum' which possess high levels of carotenoids (Figure 3). Carotenoids are considered important inhibitors of singlet oxygen. Carotenoids have conjugated double bonds in the extended chain of their molecular structure. This allows them to easily accept electrons, preventing oxidation (NICOLETTO; TOSINI; SAMBO, 2012). It is possible that colored-pulp cultivars have greater antioxidant defenses than non-colored varieties (CEVALLOS-CASALS; CISNEROS-ZEVALLOS, 2003).

Harvest time and storage may modulate phytochemicals

The late harvest provided an increase in the TC content on the first day of storage of 'Jerimum'. This did not occur in 'BRS Cuia' and 'Mãe Família Roxa' (Figure 3). During storage, there was no difference in the TSP content between harvest times for the 'Beterraba' (Figure 3). However, 'Jerimum' harvested at 180 days after planting showed higher levels of carotenoids on the first day and after 5 days of storage, (Figure 3). The TC contents remained stable throughout the storage in all white pulp cultivars. In colored pulp cultivars, however, the TC content generally decreased with the storage (Figure 3).

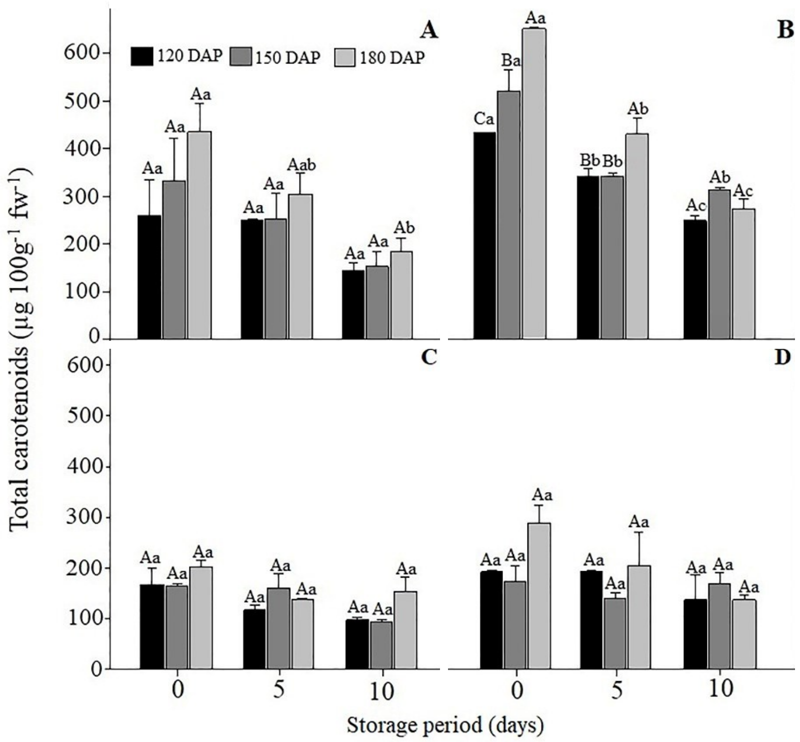

Figure 3. Total carotenoid content in minimally processed sweet potato cultivars Beterraba (A), Jerimum (B), Mãe de Família Roxa (C) and BRS Cuia (D) harvested at different times (120, 150, and 180 DAP) and stored at 5 °C for 10 days. The bars represent the means ± standard deviation. Means followed by the different letters indicate a significant difference according to Tukey test ($p < 0.05$). Capital letters compare the times of harvest, and lowercase letters compare the storage days.

The colored-pulp cultivars exhibited higher TSP contents (Figure 3). A significant increase in TSP content was detected with a delay in the harvest time for the colored-pulp 'Jerimum', with carotenoid levels above 600 µg 100 g FW^{-1} (Figure 3). This shows the potential of this management strategy to further enrich sweet potatoes with bioactive compounds, granting it the title of "super potato". As such, enriched sweet potatoes can be used as a raw material for the extraction of that pigment and incorporation into other foods, as in the biofortification of cookies (AYENSU et al., 2019).

Delaying the harvest from 120 to 180 days did not result in higher starch or TSS content, except for 'Mãe de Família Roxa' (Table 2). Additionally, when we compare the start of the storage with the tenth day, the starch content was found not to differ between the harvest times. These components are important, as they are part of the parameters used to measure the quality of sweet potatoes (ALBUQUERQUE et al., 2018). Sweet potatoes with higher sugar content are usually intended for fresh consumption (ALBUQUERQUE et al., 2018), whereas varieties with higher starch content are destined to industry for the extraction of starch. The present study showed that the change in harvest time was not an elicitor of significant changes in those compounds.

Table 2. Starch content and total soluble sugars (%) in minimally processed sweet potato roots from different cultivars harvested at different times and stored at 5 °C for 10 days.

Harvest time (days)	Storge (days)	'Beterraba'	'Jerimum'	'Mãe de Família Roxa'	'BRS Cuia'
Starch (%)					
120	0	20^{Aa}	18.4^{Aa}	20.6^{Ba}	19.3^{Aa}
	10	19.3^{Ba}	18.9^{Aa}	19.8^{Ba}	18.8^{Aa}
150	0	21.8^{Aa}	18.9^{Aa}	23.1^{Aa}	18.5^{Aa}
	10	21.6^{Aa}	17.5^{Aa}	20.9^{Ab}	19.6^{Aa}
180	0	21.4^{Aa}	19.3^{Aa}	20.5^{Ba}	20.2^{Aa}
	10	20.4^{Aba}	18.7^{Aa}	20.2^{Ba}	19.6^{Aa}
Total soluble sugar (%)					
120	0	2.5^{Aa}	3.3^{Ab}	2.7^{Aa}	3^{Ab}
	10	2.6^{Ba}	5.4^{Aa}	2.6^{Ba}	4.8^{Aa}
150	0	2.2^{Ab}	4.3^{Aa}	3.1^{Aa}	2.7^{Aa}
	10	4^{Aba}	3.5^{Aa}	5.7^{Aa}	3.3^{Aa}
180	0	3.1^{Aa}	4.5^{Aa}	3.2^{Aa}	3.4^{Aa}
	10	4.4^{Aa}	4.9^{Aa}	5.5^{Aa}	3.5^{Aa}

Means followed by the different letters indicate a significant difference according to the Tukey test ($p < .05$). Capital letters compare times of harvest and lowercase compare the storage days.

CONCLUSIONS

Delaying the harvest of the minimally processed 'Mãe de Família Roxa' and 'Jerimum' to 150 or 180 days provides greater stability of PPO and POD activities and TSP compounds during storage. Additionally, this management strategy provides increased resistance to browning, and thus, it is recommended for the minimal processing industry.

Colored 'Beterraba' exhibited high concentrations of antioxidant compounds such as carotenoids and TSP, whereas white-pulp 'BRS Cuia' showed the highest phenol and starch contents. As such, those cultivars, especially the colored pulp ones, have great potential for use in industries aimed at the extraction of nutraceutical compounds or in the manufacture of medicines.

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