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Bioactive compounds of two orange-fleshed sweet potato cultivars (*Ipomoea batatas* (L.) Lam.) in fresh, stored and processed roots

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ABSTRACT

Sweet potatoes are a rich source of bioactive compounds, which are considered to promote human health. This study aimed to analyse the main bioactives of two orange-fleshed sweet potato cultivars, *Beauregard* and *Colorado INTA*, freshly harvested, after storage, and after processing of sweet potato paste, a solid dessert widely consumed in Argentina. In the flesh, phenolic compounds, carotenoids, anthocyanin contents, and radical scavenging activity were significantly higher in *Colorado INTA* cultivar. The carotenoid contents were 555 and 712 μg *β*-carotene/g dw in the flesh of *Beauregard* and *Colorado INTA,* respectively. In the peel of both cultivars, phenolic contents and antioxidant activities were notably higher than in the flesh. Extended storage has markedly increased phenolics and antioxidant properties in the flesh of *Colorado INTA*, further accentuating the differences between both cultivars. Paste processing negatively affected all parameters, particularly in *Beauregard*. The major phenolic compounds in both cultivars, chlorogenic and 3,5-dicaffeoylquinic acids, were the most affected by processing. The main reductions of bioactives stemmed from sugar addition. The inclusion of the peel, traditionally discarded during processing, could confer an additional value to the paste. The high bioactive contents of *Beauregard* and *Colorado INTA* cultivars, especially the latter, can contribute to provide health benefits and to reduce vitamin A deficiency. The valuable attributes of these cultivars could represent a useful tool for sweet potato producers to add value to this product and to foment its consumption.

1. Introduction

Sweet potato (Ipomoea batatas (L.) Lam.) is cultivated in tropical, subtropical and temperate regions, encompassing more than 100 countries in the world. In Argentina, the sweet potato cultivated area in 2020 was about 22800 ha with a production of 339900 tons and an apparent consumption per capita per year of 7.5 kg (FAOSTAT, 2020). The sweet potato is a crop sensitive to low temperatures; therefore, it is cultivated during the warm season. Although the roots can be consumed immediately after harvest, they can also be stored for several months. The recommended storage conditions are 12 - 15 ºC and 85 - 90% relative humidity; lower temperatures may induce chilling injury in roots and higher temperatures can shorten storage life (Sugri et al., 2017).

Sweet potato roots can be considered a good source of dietary fiber, minerals, some vitamins and compounds with antioxidant activity (Rodrigues de Albuquerque et al., 2019; Wang et al., 2016). Antioxidant compounds act as free radical scavengers or inhibitors of reactive oxygen species (ROS), which are formed naturally during human metabolism. These ROS cause damage in proteins, lipids and nucleic acids of biological structures, inducing a variety of chronic diseases associated with oxidative stress (Liguori et al., 2018). Sweet potato, as a relevant source of antioxidants, such as phenolic acids, anthocyanins and carotenoids, can provide various health benefits (Alam, 2021). Anthocyanins and carotenoids, besides acting as antioxidants, confer different colors to the flesh (cream, yellow, orange or purple). Orange-fleshed sweet potatoes are rich in *β*-carotene, the main precursor of vitamin A. Anthocyanins confer a purple color to the sweet potato peel and in certain cultivars, also to the flesh (Rodrigues de Albuquerque et al., 2019; Wang et al., 2016). The composition and content of bioactive compounds vary widely among different cultivars of sweet potatoes and even according to the part of the root (Makori et al., 2020; Wang et al., 2016). Extrinsic factors, particularly, storage after harvest,

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can also modify the metabolism of the roots affecting their bioactive contents and antioxidant properties (Bechoff et al., 2010; Ishiguro et al., 2007). A limited proportion of sweet potato roots is consumed in the harvest season, whereas the rest are usually stored for long periods of time. Very few papers analyzed the changes of bioactive compounds in fresh sweet potatoes after long-term storage, and the contents largely varied depending on the genotype (Bechoff et al., 2010; Grace et al., 2014).

In the last years, in Argentina, the San Pedro Experimental Station of the Instituto Nacional de Tecnología Agropecuaria (INTA) began to study the agronomic adaptation and nutritional quality of two orange-fleshed sweet potato cultivars. One of them, *Beauregard*, is widely consumed in USA and recently introduced in the Argentinean market. The other, *Colorado INTA*, belongs to a sweet potato genetic breeding program carried out by INTA. This latter cultivar is characterized by purple peel, orange flesh with purple spots and semi moist texture.

In Argentina, an important segment of the sweet potato production is used to make sweet potato paste, a traditional solid dessert. This paste is prepared by cooking the flesh with high amounts of sucrose while the peel is discarded. However, thermal treatment can modify the content of bioactive compounds (Musilova et al., 2020; Palermo et al., 2014). Therefore, paste processing could affect their health-promoting effects. On the other hand, the discarded peel generates a great amount of waste, causing an important environmental problem.

The aim of this work was to characterize and quantitate the main bioactive compounds in the flesh and the peel of the two orange-fleshed cultivars, *Beauregard* and *Colorado INTA*. The radical scavenging activity in the methanolic extract of both cultivars was also compared. The same parameters were also analyzed after 90 days of storage under controlled conditions in order to evaluate the effect of long-term storage on those phytochemicals. Variations of phenolic compounds, antioxidant activity and total carotenoids after paste processing of peeled and not peeled sweet potato cultivars were also analyzed. The possible factors affecting the stability of each parameter were discussed.

2. Materials and methods

2.1. Materials

2.1.1. Chemicals

Caffeic acid, 3- and 4-caffeoylquinic acids, 3,4-, 3,5- and 4,5-dicaffeoylquinic acids, Trolox, and β-carotene (≥ 97.0%, UV) standards, Folin-Ciocalteu and DPPH (2,2-diphenyl-1-picrylhydazyl) reagents were purchased from Sigma–Aldrich (MO, USA). Chlorogenic acid and cyanidin-3-*O*-glucoside standards were supplied by Fluka (MO, USA). Acetic acid, acetonitrile, methanol, ethylacetate, and triethylamine were HPLC grade (Sintorgan S.A., Buenos Aires, Argentina). Food grade agar was from Argendiet (Buenos Aires, Argentina). All other chemicals were of analytical grade.

2.1.2. Vegetables samples

Two orange-fleshed sweet potato cultivars (*Beauregard* and *Colorado INTA*) grown in experimental fields (San Pedro Experimental Station-INTA) were harvested in March 2018. Roots freshly harvested and after 90 days storage in a dark chamber at 13 ± 2 ºC and 90% relative humidity were analyzed. Each sample was formed taking randomly ten healthy sweet potatoes of each cultivar, with uniform size and weight (ca. 300 g), at harvest time and after 90 days storage. The roots were washed with tap water and peeled with a manual peeler. Both peel and flesh were frozen separately in liquid nitrogen. The samples were freeze dried over 48 h at -55 ºC and 4 Pa using a freeze drier ALPHA 1–4 LD2 Martin Christ Gefriertrocknungsanlagen GMBH (Osterode am Harz, Germany), powdered and stored at -20 ºC until analyzed.

2.1.3. Paste processing

Sweet potato pastes from *Beauregard* and *Colorado INTA* cultivars were prepared taking five quarters of different roots after 90 days of storage, with uniform size and weight (ca. 300 g). Two types of paste were formulated: one using just the flesh and another with the whole roots (not peeled sweet potato paste). The process simulated that of the paste industry. The fleshed and not peeled sweet potatoes were steamed on a stainless-steel strainer placed into a cooking pot for 28 min at 94.5˚C (steamed samples). Then they were mashed to obtain individual purees. The pastes were formulated by mixing 100 g of the purees with 70 g of commercial sucrose and cooking at 105.0 ± 1.0˚C for 10 min until obtain a homogenized paste. Then, 2 g of agar dissolved in 50 mL of hot water (90˚C) were added, the mixture was homogenized and cooked again for 5 min and it was refrigerated until gelation (paste samples). The same procedure was carried out in parallel, omitting the addition of sucrose (cooked samples) to compare the effect of the sugar added. The samples were stored at -20 ºC until analyzed. Total and individual phenolics, antioxidant activity, and total carotenes were analyzed in all samples. Results obtained after each treatment were expressed /g sweet potato dry weight (dw) to compare them with those of raw roots.

2.2. Analytical methods

2.2.1. Moisture content

The moisture content of fresh, freeze-dried, and processed samples was determined gravimetrically in triplicate at 65˚C using a vacuum oven (JP Selecta, Spain) up to constant weight (AOAC, 2006).

2.2.2. Extraction of phenolics

Freeze-dried sweet potatoes (1 g) or processed (steamed, cooked and paste) samples (10 g) were extracted with 80% methanol during 15 min at 60 ºC and centrifuged 15 min at 550 x g (Heraeus Biofuge, Thermo Scientific, USA) according to Ojeda et al. (2017) with slight changes. The remaining pellet was extracted again by the same procedure and the combined extracts were brought to a final volume of 10 mL. The extractions were carried out in triplicate for the determination of total phenolics, antioxidant capacity and phenolic acids.

2.2.3. Determination of total phenolic content

Total phenolic content was analyzed according to the method of Singleton et al. (1999) with slight modifications. A solution was prepared with 250 µL of extract, 250 µL of Folin-Ciocalteau reagent (2 N) and 4 mL of distilled water. After 3 min, 500 µL of Na_2CO_3 (42 g/L) was added, keeping the solution for 120 min at room temperature. Then, the absorbance was measured at 750 nm using an UV/Vis Perkin Elmer Lambda 25 spectrophotometer (Shelton, USA). A standard curve of chlorogenic acid was used and the total phenolic content was expressed as mg chlorogenic acid/g sweet potato dw. All extracts were analyzed in triplicate.

2.2.4. Determination of radical scavenging activity

The radical scavenging activity in the methanol extract was analyzed in triplicate using the radical DPPH in accordance with the method described by Brand-Williams et al. (1995) with modifications. An aliquot of 400 μL extract was mixed with 3.6 mL of DPPH (39.4 mg/L in methanol) and kept in the dark for 30 min at room temperature. The absorbance was read at 517 nm. The radical scavenging activity was calculated using a Trolox standard curve and the results were expressed as mg Trolox/g sweet potato dw.

2.2.5. Identification and quantification of phenolic acids

Phenolic acids were analyzed in duplicate by high performance liquid chromatography (HPLC), as reported by Padda and Picha (2008a) with some modifications. An aliquot of each extract was filtered through a 0.45 µm membrane. A sample volume of 5 µL was injected in a ZORBAX Eclipse XDB-C18 4.6×250 mm, 5 µm column (Agilent Technologies, Waldbronn, Germany), using an Agilent 1200 Series equipment (Agilent Technologies, Waldbronn, Germany) connected to a quaternary pump. The mobile phase consisted of A: ultrapure water

containing 1 mL/L acetic acid; B: acetonitrile with acetic acid (1 mL/L) using the following gradient: 10 to 25% B from 0 to 35 min and 25 to 50% B from 35 to 50 min. The flow rate was 0.7 mL/min. Peaks were detected with an UV/Vis 1260 Infinity Multiple Wavelength Detector at 320 nm. Phenolic compounds were identified comparing the retention times with their respective standards. Their contents were calculated by external standard calibration curves and expressed as mg of each respective acid/g sweet potato dw.

2.2.6. Determination of total anthocyanin content

Total anthocyanin content was determined by the pH differential method (Fuleki & Francis, 1967) with some modifications. Samples were extracted in triplicate with ethanol: HCl 1.5 N (85:15) for 1 h at 80 ºC and the supernatant was separated by centrifugation at 3230 x g, 15 min. An aliquot of 400 μL extract was added to 1.6 mL of KCl-HCl, buffer pH 1 (HCl 0.2 N, KCl 0.025 M). In parallel, 400 μL of extract was added to 1.6 mL of sodium acetate, buffer pH 4.5 (sodium acetate 0.4 M, HCl 1 N). In both solutions the absorbance was read at 529 nm and 700 nm. All readings were performed in triplicate and the results were expressed as mg cyanidin-3-glucoside/g sweet potato dw.

2.2.7. Determination of total carotenoids and β-carotene

Total carotenoid content was determined following the method explained by Kimura et al. (2007). The standard curve was performed using β-carotene and the results were expressed as µg β-carotene/g sweet potato dw. The extractions were carried out in triplicate and readings were performed in triplicate at 450 nm.

β-carotene content was analyzed by the HPLC method described by Kimura et al. (2007) with some modifications. Duplicate aliquots of each extract in petroleum ether used to determine total carotenoids were dried under nitrogen and dissolved in the mobile phase (80% acetonitrile: 10% methanol: 10% ethyl acetate with 0.05% triethylamine). A sample volume of 5 µL was injected in a Phenomenex C18 column, 250 × 4.6 mm × 5 µm (Torrance, CA, USA) using an Agilent 1100 HPLC system connected to a quaternary pump G1311A and equipped with a degasser G1322A, a temperature controller G1316A and an autosampler G1313A. The peaks were detected at 450 nm with a UV Variable Wavelength Detector G1314A.

2.3. Statistical analysis

The experimental data were analyzed by the analysis of variance (ANOVA) using the program InfoStat, 2018 version (Universidad de Córdoba, Argentina) and the significant differences were evaluated by the DGC test ($p < 0.05$). The calibration curves for total and individual phenolics, radical scavenging activity, total anthocyanins, and total carotenoids, as well as their respective coefficients of determination, were calculated by linear regression analysis.

3. Results and discussion

3.1. Fresh sweet potato roots

Table 1 shows the total phenolics, anthocyanins, and the antioxidant activity in the flesh and in the peel of freshly harvested sweet potato roots of *Beauregard* and *Colorado INTA* cultivars. The antioxidant activity of the different samples was compared using DPPH assay. This method was selected according to Tošović et al. (2017) and Mathew et al. (2015), who analyzed different mechanisms of antioxidative action of phenolic compounds and observed a higher reactivity toward DPPH than to other radicals. In the flesh, the total phenolic content and the DPPH value in *Colorado INTA* were approximately two-fold higher than in *Beauregard*. The results recorded in the latter were comparable to those reported by Padda and Picha (2008a) for the same cultivar grown in the United States. However, the Colorado INTA cultivar showed higher values than those reported for most genotypes of orange-fleshed sweet potatoes (0.4 – 3.4 mg chlorogenic acid/g sweet potato dw for total phenolics and 0.1 – 3.6 mg Trolox/g sweet potato dw for DPPH) (Grace et al., 2014; Motsa et al., 2015; Padda & Picha, 2008a; Teow et al., 2007). Purple-fleshed sweet potatoes were reported to have higher concentrations of phenolics and antioxidant activities than orange, yellow or white-fleshed cultivars (Wang et al., 2016). Therefore, the highest total phenolic content and radical scavenging activity in *Colorado INTA* could be associated with the presence of purple spots in the flesh, not noticeable in the *Beauregard* cultivar. The presence of anthocyanins in the former but not in the latter (Table 1) may be explained by the same reason. Other authors did neither detect anthocyanins in *Beauregard* nor in other orange-fleshed cultivars (Kuan et al., 2016; Teow et al., 2007). It should be noted that none of the papers cited above, described orange-fleshed cultivars with purple spots like those observed in *Colorado INTA*.

As for the peel, no significant differences between both cultivars were found neither in the total phenolic contents nor in the DPPH values. All the values were one order of magnitude higher than those detected in the flesh. The anthocyanin content in the peel of the *Colorado INTA* cultivar was also ten-fold higher than in the flesh and also ten-fold higher than in the peel of *Beauregard* cultivar. Despite these differences, the anthocyanin content in the peel of the former cultivar cannot be considered relevant, as it represents a small proportion (ca. 6%) of total phenolic content. These noteworthy differences in those bioactive contents between the peel and the flesh of sweet potatoes were earlier reported by other researchers, analyzing different sweet potato cultivars (Naz et al., 2017; Padda & Picha, 2008b). The higher phenolic contents and DPPH values recorded in the peel can be associated to an induction of the biosynthesis in response to wound or other types of stress (Dixon & Paiva, 1995). The exceptionally high phenolic content in the peel of *Beauregard* and *Colorado INTA* cultivars could generate interest in the food industry for the use of natural antioxidants obtained from the waste of paste processing.

Phenolic compounds were analyzed in the flesh and the peel of the freshly harvested roots of *Beauregard* and *Colorado INTA* cultivars (Table 2). Seven phenolic acids were identified: caffeic acid, chlorogenic acid and their isomers, 3- and 4-caffeoylquinic acids, and 3,4-, 3,5- and 4,5-dicaffeoylquinic acids. In all the samples, the major components were chlorogenic and 3,5-dicaffeoylquinic acids, with considerably higher contents than the others. The sum of both compounds accounted for 65-70% of the total phenolic acids, in the flesh and in the peel of both cultivars. The content of the different phenolic acids reported in previous papers covered a wide range of values, even among orange-fleshed cultivars. Nevertheless, in all of them chlorogenic and 3,5-dicaffeoylquinic acids were also identified as the major phenolic compounds both in the flesh and the peel of sweet potato roots (Grace et al., 2014; Ishiguro et al., 2007; Jung et al., 2011; Lebot et al., 2016). In the flesh of the *Colorado INTA* cultivar, the contents of all the phenolic acids identified were significantly higher than in *Beauregard*. Particularly, chlorogenic and 3,5-dicaffeoylquinic acids, the prevailing phenolic compounds, were two-fold higher, in accordance with the results indicated above for total phenolics. It can also be noted that the ratios between these major phenolic acids in the flesh were quite similar for both cultivars. In the peels, the contents of each phenolic compound in the two cultivars were dissimilar, although the total phenolics were alike. The ratios between the phenolic acids were also different for each cultivar, unlike what was observed in the flesh. In accordance with the total phenolic values, the content of each acid was significantly higher in the peel than in the flesh of both cultivars. The greatest difference occurs with caffeic acid. It showed the lowest content in the flesh of *Colorado INTA* and was not detected in the flesh of the *Beauregard* cultivar. However, in the peel, although it was a minor component, the ratio of this compound to the others was considerably higher than in the flesh Harrison et al. (2003). also detected higher contents of caffeic acid in the peel of different sweet potato cultivars. They suggested

Table 1
Total phenolics, radical scavenging activity, total anthocyanins and total carotenoids in the flesh and the peel of *Beauregard* and *Colorado INTA* cultivars freshly harvested and after 90 days storage at 13 ºC ± 2°C and 90 % relative humidity

	Cultivar	Total phenolics (mg ChA/g)		DPPH (mg Trolox/g)		Total anthocyanins (mg C3G/g)		Total carotenoids (μg β-carotene/g)	
		0 days	90 days	0 days	90 days	0 days	90 days	0 days	90 days
Flesh	***Colorado INTA***	3.59 ± 0.27^{a}	$5.78 \pm 0.19^{a*}$	4.64 ± 0.33^{a}	$7.1 \pm 0.23^{a*}$	0.16 ± 0.01	0.19 ± 0.03	712 ± 25^{a}	$579 \pm 29^{b*}$
	Beauregard	1.90 ± 0.10^{b}	2.15 ± 0.13^{b}	2.05 ± 0.22^{b}	$2.6 \pm 0.24^{b*}$	nd	nd	555 ± 14^{b}	$633 \pm 25^{a*}$
Peel	***Colorado INTA***	21.7 ± 2.4^{A}	$14.3 \pm 1.5^{A*}$	22.2 ± 2.1^{A}	$14.2 \pm 1.5^{A*}$	1.72 ± 0.13^{A}	$0.49 \pm 0.05^{*}$	-	-
	Beauregard	21.2 ± 1.4^{A}	$14.1 \pm 1.4^{A*}$	23.8 ± 0.6^{A}	$16.0 \pm 1.3^{A*}$	0.16 ± 0.04^{A}	nd	-	-

Data are expressed as mean ± SD (n=9). Different lowercase letters or different capital letters in the same column represent significant differences ($p<0.05$). Superscript * means significant changes after storage ($p<0.05$). ChA: chlorogenic acid; C3G: cyanidin 3-glucoside. nd: not detected.

Table 2
Phenolic acids (mg/g) in the flesh and the peel of freshly harvested *Beauregard* and *Colorado INTA* cultivars

	Cultivar	3-CQA	ChA	4-CQA	CA	3,4-diCQA	3,5-diCQA	4,5-diCQA
Flesh	***Colorado INTA***	0.137 ± 0.023^{a}	0.420 ± 0.040^{a}	0.056 ± 0.005^{a}	0.008 ± 0.001	0.022 ± 0.002^{a}	0.285 ± 0.032^{a}	0.094 ± 0.016^{a}
	Beauregard	0.050 ± 0.003^{b}	0.185 ± 0.019^{b}	0.041 ± 0.004^{b}	nd	0.019 ± 0.002^{a}	0.133 ± 0.021^{b}	0.032 ± 0.003^{b}
Peel	***Colorado INTA***	0.698 ± 0.041^{A}	2.73 ± 0.12^{A}	0.213 ± 0.016^{B}	0.455 ± 0.023^{A}	0.204 ± 0.013^{B}	2.07 ± 0.11^{B}	0.675 ± 0.047^{B}
	Beauregard	0.463 ± 0.038^{B}	2.25 ± 0.23^{B}	0.275 ± 0.018^{A}	0.471 ± 0.060^{A}	0.699 ± 0.072^{A}	4.28 ± 0.34^{A}	0.95 ± 0.12^{A}

Data are expressed as mean ± SD (n=6). Different lowercase letters or different capital letters in the same column represent significant differences ($p<0.05$). CQA: caffeoylquinic acid; CA: caffeic acid; ChA: chlorogenic acid. nd: not detected.

that this compound may contribute to the protection provided by the sweet potato periderm against root pathogens. A noticeable difference was also observed between the contents of the dicaffeoylquinic acids in the flesh and the peel of the *Beauregard* cultivar.

The total carotenoid content (Table 1) in the flesh of *Colorado INTA* cultivar was also higher (28%) than in *Beauregard*. In addition, both values were higher than those reported for other orange-fleshed sweet potatoes (De Moura et al., 2015; Grace et al., 2014; Koala et al., 2013). β-carotene, the most efficient precursor of vitamin A, represented 94.7 ± 0.3 and 90.5 ± 0.3% of total carotenoids in *Beauregard* and *Colorado INTA* cultivars respectively. Consequently, these orange-fleshed cultivars can be considered a valuable source of vitamin A Leal et al. (2017). estimated a 24% (average) vitamin A deficiency in Argentina for children aged under five years, reaching 40% in some regions. Argentine population consumes mainly white, cream or yellow cultivars. Therefore, the promotion of orange sweet potato consumption could represent a suitable strategy for preventing vitamin A deficiency in vulnerable populations.

3.2. Sweet potato roots after 90 days storage

The total phenolics, anthocyanins, and DPPH values in the flesh and in the peel of *Beauregard* and *Colorado INTA* cultivars after 90 days storage at 13 ± 2 ºC are listed in Table 1. Total phenolic contents in the flesh and in the peel of the two cultivars varied similarly to DPPH radical scavenging activity after storage. However, the variations of both parameters in the flesh were different than in the peel. In the flesh, total phenolics and DPPH values increased with the storage, improving their antioxidant properties. While the changes in the flesh of *Beauregard* cultivar were slight, those of *Colorado INTA* exhibited relevant increments, enlarging the differences between both cultivars in the stored sweet potatoes. Conversely, in the peel of the two cultivars the levels decreased more than 30%. As both parameters lessened in the same proportion, total phenolics and radical scavenging activity after storage remained alike. Previous studies showed contradictory results in relation to changes in the phenolic content and antioxidant activity during storage of sweet potatoes. However, they all agreed that the effect depends on the storage conditions and were also genotype-dependent (Grace et al., 2014; Ishiguro et al., 2007).

Total anthocyanins did not change significantly in the flesh of the *Colorado INTA* cultivar after storage Lachman et al. (2012). analyzed different coloured-flesh potato cultivars after six months of cold storage and, in agreement with these results, found slight or not negligible variations in anthocyanin content, depending on the cultivar. On the contrary, in the peel of both cultivars, it decreased significantly, reaching a very low value in *Colorado INTA* and becoming undetectable in *Beauregard*. This noticeable decrease could be attributed to oxidative degradation as was pointed out by Patras et al. (2010). In the flesh of *Colorado INTA*, these compounds remained stable, probably because of the lower interaction with oxygen.

Variation of phenolic acids in the flesh and in the peel of *Beauregard* and *Colorado INTA* cultivars after storage (Table 3) agreed with the changes of total phenolics. In the flesh of *Beauregard*, the only significant increase was recorded in 3-caffeoylquinic acid (94%). Instead, in the flesh of *Colorado INTA* cultivar, the main compounds, chlorogenic and 3,5 dicaffeoylquinic acids, have increased significantly. The greatest increment noticed occurred for the 3,5-dicaffeoylquinic acid (193%), becoming the main compound after storage. In addition, the 3,4- and 4,5-caffeoylquinic isomers, increased about 100%. In the peel of both cultivars, the contents of most phenolic acids lessened in a great extent, in accordance with the aforementioned decrease of total phenolics. Caffeic was the only acid of the peel which increased in both cultivars (71% and 80% in *Beauregard* and *Colorado INTA* respectively), becoming one of the major phenolics after storage. This considerable increment could be attributed to the hydrolysis of caffeoylquinic acids.

Total carotenoids (Table 1) varied slightly but significantly in both cultivars, increasing 14% in *Beauregard* and decreasing 19% in *Colorado INTA* Grace et al. (2014). also observed minor variations of these compounds after storage of sweet potatoes. In agreement with the changes reported for the other bioactive compounds, they stated that retention of carotenoids after storage was dependent on the genotype. On the other hand, De Moura et al. (2015) observed lower retention levels after storage of sweet potato chips. However, in the intact roots, carotenoids are protected within the tissue and are less exposed to degradation.

3.3. Sweet potato pastes

Fleshed and not peeled sweet potato pastes were prepared using *Beauregard* and *Colorado INTA* cultivars stored for 90 days. Unlike the fleshed paste, the not peeled products are not commercially produced. However, taking into account the high phenolic content of the peel, sweet potato paste was also prepared using the whole root with the aim of improving the antioxidant properties of this product and reducing waste. Total phenolics, DPPH radical scavenging activity and total

Table 3
Phenolic acids (mg/g) in the flesh and the peel of *Beauregard* and *Colorado INTA* cultivars after 90 days storage (13 ºC ± 2˚C; 90 % relative humidity)

	Cultivar	3-CQA	ChA	4-CQA	CA	3,4-diCQA	3,5-diCQA	4,5-diCQA
Flesh	***Colorado INTA***	0.201 ± 0.030^{a}	0.627 ± 0.034^{a}	0.049 ± 0.012^{a}	0.012 ± 0.003	0.041 ± 0.009^{a}	0.835 ± 0.034^{a}	0.189 ± 0.040^{a}
	Beauregard	0.097 ± 0.004^{b}	0.195 ± 0.013^{b}	0.033 ± 0.006^{a}	nd	0.018 ± 0.002^{a}	0.131 ± 0.048^{b}	0.043 ± 0.012^{b}
Peel	***Colorado INTA***	0.240 ± 0.038^{B}	0.439 ± 0.060^{B}	0.231 ± 0.023^{B}	0.821 ± 0.043^{A}	0.172 ± 0.014^{B}	1.29 ± 0.17^{A}	0.236 ± 0.049^{B}
	Beauregard	0.395 ± 0.048^{A}	0.942 ± 0.097^{A}	0.303 ± 0.028^{A}	0.807 ± 0.088^{A}	0.397 ± 0.029^{A}	1.71 ± 0.33^{A}	0.649 ± 0.090^{A}

Data are expressed as mean ± SD (n=6). Different lowercase letters or different capital letters in the same column represent significant differences ($p<0.05$). CQA: caffeoylquinic acid; CA: caffeic acid; ChA: chlorogenic acid. nd: not detected.

Table 4
Total phenolics, radical scavenging activity and total carotenoids in fleshed and not peeled sweet potato (SP) pastes prepared with *Beauregard* and *Colorado INTA* cultivars and their % loss after processing

Paste	Cultivar	Total phenolics (mg ChA/g SP dw)	% loss	DPPH (mg Trolox/g SP dw)	% loss	Total carotenoids (μg β-carotene/g SP dw)	% loss
Fleshed	***Colorado INTA***	3.95 ± 0.15^{bA}	32*	4.29 ± 0.21^{bA}	40*	114 ± 7^{A}	80*
	Beauregard	0.87 ± 0.07^{bB}	60*	1.24 ± 0.20^{bB}	51*	108 ± 11^{A}	83*
Not peeled	***Colorado INTA***	4.40 ± 0.16^{aA}	28*	5.14 ± 0.22^{aA}	32*	-	
	Beauregard	1.34 ± 0.10^{aB}	51*	1.82 ± 0.09^{aB}	46*	-	

Data are expressed as mean ± SD (n=9). Values in the same column with different lowercase letters between fleshed and not peeled samples for the same cultivar are significantly different ($p<0.05$). Values in the same column with different uppercase letters between *Beauregard* and *Colorado INTA* samples for the same type of paste are significantly different ($p<0.05$). Superscript * means significant loss after process ($p<0.05$). ChA: chlorogenic acid; C3G: cyanidin 3-glucoside.

carotenoids in fleshed and not peeled sweet potato pastes of both cultivars are listed in Table 4. Total phenolics and antioxidant activity values were higher in *Colorado INTA* than in *Beauregard* pastes while the values in not peeled sweet potato pastes of both cultivars were higher than in the fleshed ones. Total carotenoid content in *Beauregard* fleshed sweet potato paste was similar to that of *Colorado INTA*. Losses after processing all pastes were considerably high, particularly in the *Beauregard* cultivar. It can be noted that the decrease in antioxidant activity and in total phenolics were alike for all samples. Carotenoid losses after processing were also equivalent for both cultivars and even higher than those of total phenolics.

Regarding the significant reduction of phenolics, antioxidant activity, and carotenoids observed in all sweet potato pastes, variations in these parameters were analyzed at each step of the paste processing in order to identify the treatment that induced the major loss of bioactive compounds. Total phenolics, antioxidant activity, and total carotenoids were evaluated after steaming (steamed) and after the cooking process without (cooked) and with the addition of sugar (paste) in fleshed and not peeled samples of both cultivars (Fig. 1A, 1B and 1C). As can be seen, total phenolics varied similarly to antioxidant activity in all samples and for all treatments. Steaming was applied to inactivate enzymes and to soften the tissue. This treatment showed a different effect on both cultivars: phenolic contents and antioxidant activity values markedly decreased in the *Beauregard* sweet potato (22 to 55%), while in *Colorado INTA* the changes were less important, but still significant. All cooked sweet potatoes showed significantly higher phenolic contents and DPPH values (17 to 49%) as compared to the respective steamed samples. It should be noted that, although steaming lasted longer than the cooking treatment, the former was carried out with the roots cut into quarters while before cooking, the sweet potatoes were mashed into a puree. Such process could enhance the release of phenolics from the cell matrix and contribute to their extractability. Conversely, total carotenoids varied in a different way than the former parameters by thermal treatment. Carotenoid contents increased significantly by steaming *Beauregard* (28%) and *Colorado INTA* (47%) sweet potato flesh, while after cooking, total carotenoids decreased 22% in *Beauregard* and did not change significantly in *Colorado INTA*. As carotenoids are sensitive to light and oxygen, steaming large pieces of roots can preserve these compounds and affect positively their extraction from the matrix. In general, previous studies about thermal treatments of sweet potatoes, like steaming and cooking, showed contradictory results regarding their effect on the variation of these parameters Jung et al. (2011). and Tang et al. (2015) observed lower values of phenolics and antioxidant activity after thermal treatment of sweet potatoes, with higher losses after boiling than by steaming. In contrast, other researchers reported positive effects on these parameters after steaming (Xu et al., 2016) or boiling sweet potato roots (Bellail et al., 2012; Rautenbach et al., 2010). Unlike the trials carried out in those researches, in our study the sweet potatoes were not submerged into water. Therefore, losses by leaching of phenolic compounds into water could have not ocurred. The effect of thermal processing on carotenoids showed also a great variability as was pointed out by Palermo et al. (2014).

It can be clearly observed in Fig. 1 that the major reduction of all parameters during processing stemmed from the addition of sugar. Differences between steamed sweet potatoes cooked without and with sucrose ranged from 41 to 53% for phenolic contents, from 28 to 52% for the antioxidant activity and from 83 to 88% for total carotenoids. To the best of our knowledge, no previous studies analyzed the effect of thermal processing of sweet potatoes combined with the addition of sugar on bioactive compounds. In regard to other vegetables cooked with sugar, Kamiloglu et al. (2015) and Renna et al. (2013) observed a significant decrease of total phenolics and antioxidant activity after processing carrot jams. However, the former reported an increase of β-carotene in the product. This different result could be attributed to the lower sugar content in those jams than in the sweet potato pastes of the present study. With regards to fruit jams, results about the effect of processing on bioactive compounds varied with the type of fruit, process conditions and jam composition (Nayak et al., 2015; Shinwari & Rao, 2018). Nevertheless, none of the aforementioned papers analyzed the effect of the addition of sugar. It is well known that the addition of solutes, like sugars, decreases the water activity (a_w) in food systems. For bimolecular reactions, the reaction rate is affected by the concentration of reactants in aqueous solution. With the reduction of a_w, the concentration of reactants increases and, in consequence, the reaction rate also increases (Bell, 2007; Walstra, 2003). Therefore, the considerable losses of bioactive compounds after heating sweet potatoes with high amounts of sucrose could be attributed to the occurrence of bimolecular reactions like Maillard, between oxidized phenolic compounds and amino acids and/or phenolic-phenolic interactions promoted by the reduction of a_w.

The main phenolic acids (chlorogenic, 3-caffeoylquinic, 3,4-, 4,5- and 3,5-dicaffeoylquinic acids) in raw, steamed, cooked and paste sam-

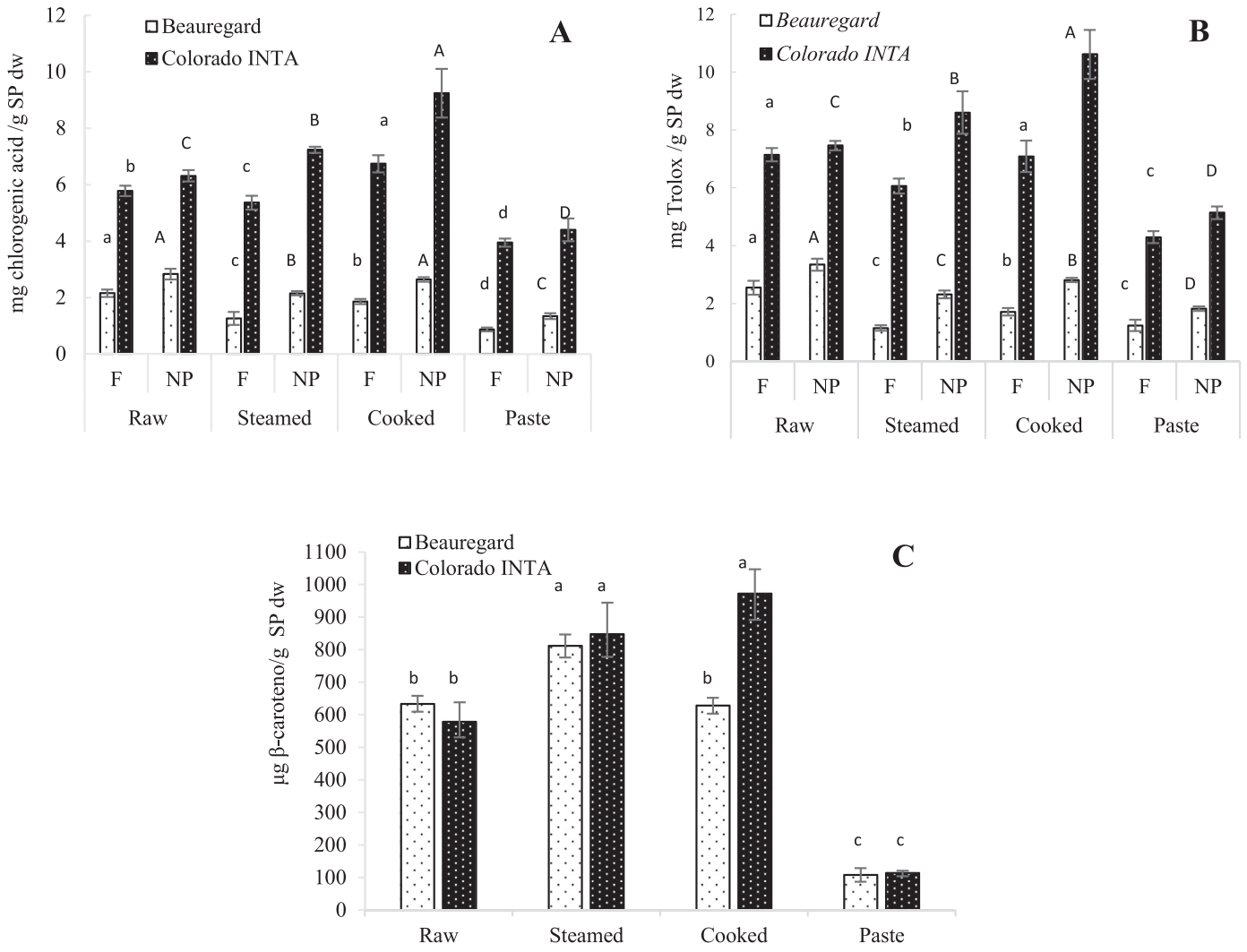

Fig. 1. Variation of total phenolics (A) and antioxidant activity (B) in fleshed (F) and not peeled (NP) sweetpotatoes and of total carotenoids (C) in fleshed sweetpotatoes after the different treatments of *Beauregard* and *Colorado INTA* cultivars during thermal processing of paste: steamed, cooked without sugar (Cooked) and cooked with sugar (Paste) (n=9). Different lowercase letters represent significant differences between treatments in F samples for the same cultivar ($p<0.05$). Different uppercase letters represent significant differences between treatments in NP samples for the same cultivar ($p<0.05$).

ples were also evaluated. The effect of the different treatments in fleshed and not peeled sweet potatoes of *Beauregard* cultivar are shown in Fig. 2A and 2B, respectively and those of *Colorado INTA* are represented in Fig. 2C and 2D. A significant reduction of all compounds was observed in the four pastes, particularly in chlorogenic and 3,5-dicaffeoylquinic acids, those with higher contents in raw sweet potatoes. However, the former remained as the main phenolic compound in the pastes. In regard to the steaming treatment, the reduction of phenolic acids was higher in the fleshed than in not peeled *Beauregard* sweet potatoes, in agreement with results reported for total phenolics. In *Colorado INTA* cultivar, the slight variations of total phenolics in steamed samples can be explained by the concomitant decrease of 3,5-dicaffeoylquinic acid and the increase of other caffeoylquinic acids. Previous studies have already detected a reduction of 3,5-dicaffeoylquinic acid after heating sweet potatoes, regardless of the treatment applied (Bellail et al., 2012; Jung et al., 2011; Padda & Picha, 2008b). Regarding the variation of each phenolic acid at each step of the process, the greatest difference was observed between cooked and paste samples. The decrease cannot be attributed to the hydrolysis of the identified caffeoylquinic acids to quinic and caffeic acids, as caffeic acid content in all pastes was negligible. Such decrease could be associated to the reduction of a_w by the addition of sucrose, as was explained with the reduction of total phenolics.

3.4. Correlation between total phenolics and radical scavenging activity

The total phenolic content in all samples analyzed showed a very high correlation with the radical scavenging activity, being the coefficient of determination (R^2) 0.992. In fruits and vegetables, the antioxidant activity has been mostly associated to phenolics, anthocyanins and carotenoids (Kaur & Kapoor, 2001). In sweet potatoes, the antioxidant activity was attributed to the different bioactive compounds present in the roots, such as anthocyanins, carotenoids, phenolic compounds, or, to a synergistic effect of various components (Wang et al., 2016). However, as observed in the current work, most authors agreed that total phenolics show a good correlation with antioxidant activity in different sweet potato genotypes (Donado-Pestana et al., 2012; Jung et al., 2011; Padda & Picha, 2008b), suggesting that polyphenols would be primarily responsible for the antioxidant activity in this vegetable. Regarding each phenolic compound, chlorogenic acid showed the higher correlation with DPPH values (R^2 = 0.937), exceeding that of 3,5 di-

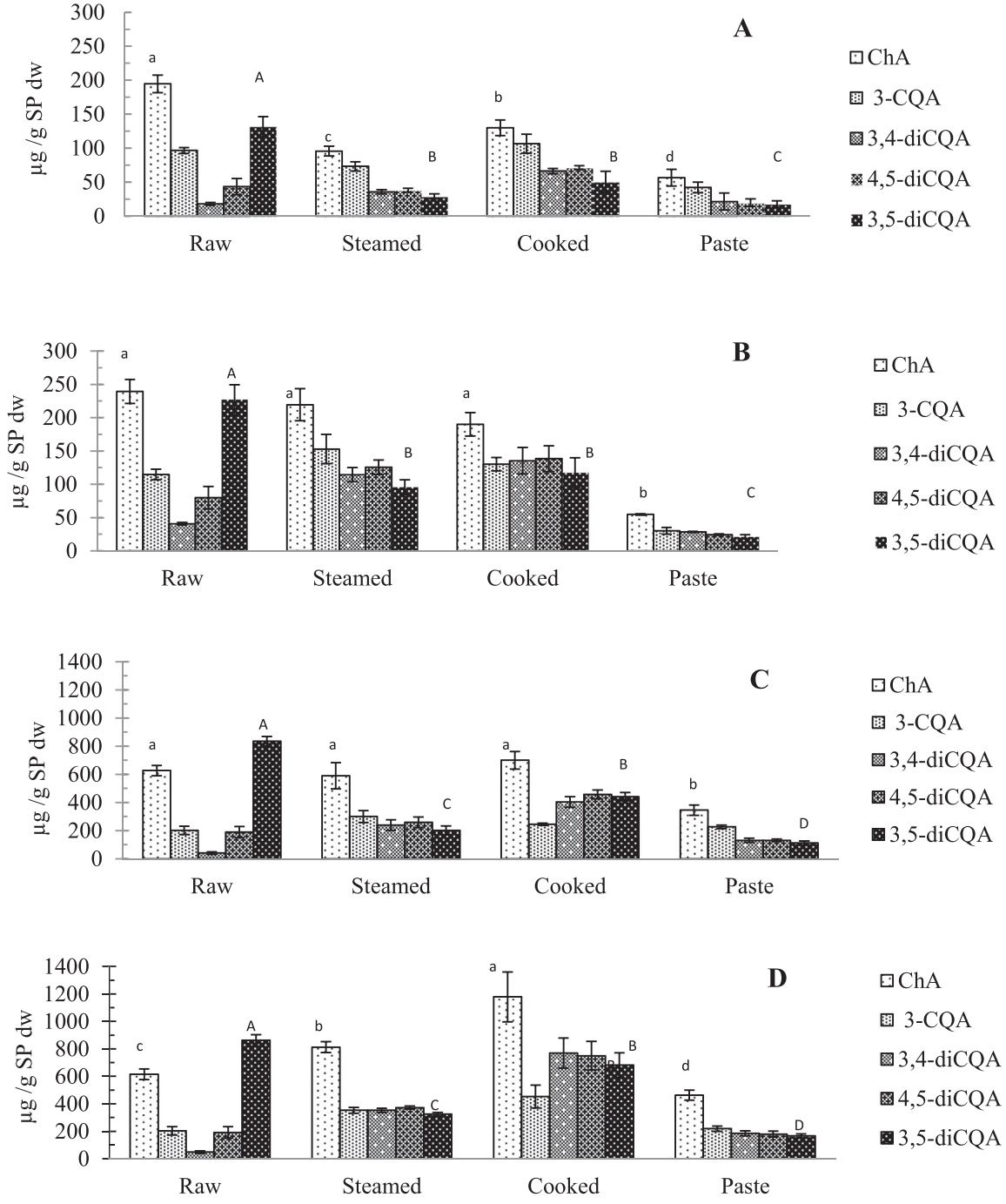

Fig. 2. Variation of chlorogenic, 3-caffeoylquinic, and 3,4- 4,5- and 3,5-dicaffeoylquinic acids in *Beauregard* ((A) fleshed and (B) not peeled sweet potatoes) and *Colorado INTA* cultivars ((C) fleshed and (D) not peeled sweet potatoes) after the different treatments during thermal processing of paste: steamed, cooked without sugar (Cooked) and cooked with sugar (Paste) (n=6). ChA: chlorogenic acid; CQA: caffeoylquinic acid. Note the difference in scale for each cultivar. Different lowercase letters and different capital letters represent significant differences between treatments for ChA and 3,5-diCQA respectively ($p<0.05$).

caffeoylquinic acid ($R^2 = 0.843$), despite the two caffeoyl groups in the chemical structure of the later compound.

4. Conclusion

This study compared the main bioactive compounds of two sweet potato cultivars, and their variation after storage and by paste processing. To our knowledge, this is the first report on the characterization, quantitative analysis and stability of phenolic compounds, carotenoids and antioxidant activity in orange-fleshed sweet potatoes grown in Argentina. Both cultivars showed very good carotenoid and phenolic contents. The main phenolic compounds were chlorogenic and 3,5-dicaffeoylquinic acids, and the prevalent carotenoid was β-carotene. The *Colorado INTA* cultivar stood out fot its significantly higher values than the widely consumed *Beauregard*. It should also be highlighted the high phenolic content and antioxidant activity in the peel of both cultivars. Therefore, they can be used as a source of natural antioxidants in foods. Unlike the peel, in the flesh of these cultivars the bioactive compounds and antioxidant properties did not significantly decrease after 90 days of storage. Moreover, there was a marked increase of those parame-

ters in the *Colorado INTA* cultivar. On the other hand, paste processing negatively affected all parameters, particularly in *Beauregard* cultivar. Reduction of cooking time after sugar addition should be accomplished to minimize losses of provitamin A and antioxidant compounds. This feature should be also considered during processing of other products containing high amounts of sugar, like fruit jam, to preserve their bioactive compounds. The inclusion of the peel, traditionally discarded during processing, could increase the antioxidant content of sweet potato paste, conferring an additional value to the product. At the same time, would contribute to reduce waste. The results of this study revealed the potential of *Beauregard* and *Colorado INTA* cultivars, especially the latter, to provide health benefits and to reduce vitamin A deficiency. The excellent attributes of these cultivars could represent a useful tool for sweet potato producers to add value to this product and to promote the consumption of these orange-fleshed sweet potatoes.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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