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Growing location and root maturity impact on the phenolic compounds, antioxidant activity and nutritional profile of different sweet potato genotypes

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ABSTRACT

This study aimed to analyze the phenolic compounds, antioxidant activity, and the main nutritional components of different colored-fleshed sweet potato genotypes grown in Argentina. Three cultivars of standard size were compared to undersized ones, currently discarded. Furthermore, four genotypes grown in different agroecological locations in Tucuman, Argentina, were evaluated. Chlorogenic and 3,5-dicaffeoylquinic acids were identified as the prevailing phenolic compounds in all samples. Undersized roots had significantly higher phenolics, antioxidant activity and carotenoids than standard. Therefore, they can confer healthy attributes to processed foods and, additionally, reduce waste. Genotypes from Tucuman grown under water stress conditions presented the lowest phenolics, anthocyanins and antioxidant activity, but the highest carotenoid contents. Orange-fleshed cultivars showed the highest protein percentages (6.0–11.7 %) and carotenoid contents ranging between 310 and 1012 μg β-carotene/g dw, with more than 90 % β-carotene. These findings could help to promote the cultivation of local genotypes with high added value.

1. Introduction

Sweet potato (*Ipomoea batatas* (L.) Lam.) is a widely produced food crop, with an annual production of 89,487,835 tonnes. Particularly in Argentina, the production in 2020 was 339,872 tonnes and it was the fourth producer in America (FAOSTAT, 2020). The sweet potato production is distributed in different regions of the country: the Pampas, the Littoral and the Northwest. San Pedro, a city located in the Pampas, is a traditional area for this crop. In the Northwest, Tucumán is one of the main provinces in which sweet potato is produced, being grown under multiple climates and soils (Zamudio, Borioni, Leiva, & Cusumano, 2014). Generally, yellow, cream and white fleshed sweet potatoes are chosen by the local producers across the country. However, in some specific areas orange-fleshed ones, like *Beauregard* cultivar, have been introduced.

Sweet potatoes provide phenolic compounds, such as phenolic acids and anthocyanins, which are considered to promote human health. Because of these compounds, sweet potatoes have been related to hepatoprotective, anticancer, antidiabetic, immunomodulatory, antimicrobial, anti-inflammatory and antioxidant effects (Rodrigues de Albuquerque, Sampaio, & de Souza, 2019; Wang, Nie, & Zhu, 2016). These promising features make sweet potato an interesting crop whose consumption should be encouraged. β-Carotene, the main vitamin A precursor, is present in high contents in orange-fleshed roots, contributing to its nutritional profile (Rodrigues de Albuquerque et al., 2019). Therefore, promoting the production and consumption of sweet potatoes with high contents of β-carotene could help to reduce vitamin A deficiency in developing countries. Sweet potatoes are also a rich source of carbohydrates, being starch the most abundant one. This characteristic is of industrial interest thanks to the large and cheap supply of starch this crop can provide.

Growing conditions and genetic factors play a crucial role in the concentration of some compounds in sweet potato roots. Different genotypes may be related to diverse flesh colors and bioactive compounds:

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while purple-fleshed sweet potatoes have higher anthocyanin contents and antioxidant activities, orange-fleshed ones have higher concentrations of carotenoids (Kurata et al., 2019; Wang et al., 2016). Sweet potatoes can be adapted to marginal soils and regions with low resources, demanding little supervision from their producers (Rodrigues de Albuquerque et al., 2019). However, different agro-ecological conditions have also been reported to alter the concentration of bioactive compounds (Motsa, Modi, & Mabhaudhi, 2015; Rautenbach, Faber, Laurie, & Laurie, 2010). Very few studies have analyzed the effect of location conditions on the proximate composition of the sweet potatoes roots and their findings were diverse (Gurmu, Shimelis, Laing, & Mashilo, 2020; Tumwegamire et al., 2011; Tumwegamire et al., 2016). Furthermore, the root development stage at the moment of harvest may also play an important role in its antioxidant compounds and nutritional profile. Despite being grown under the same conditions, some roots reach maturity faster than others. As a result, since harvest is carried out for all roots at the same time, some are collected before reaching their full size. Sweet potatoes that reach a minimum weight are classified as standard and are then commercialized. The rest are left on the field or used for animal feeding, being classified as undersized. Despite the increasing concern on food wastes because of their environmental impact, insufficient research has been carried out on undersized sweet potato roots composition (Mitra, Tarafdar, & Palaniswami, 2010; Padda & Picha, 2007).

In the last decade, the Instituto Nacional de Tecnología Agropecuaria (INTA), through a sweet potato genetic breeding program, began to study the characteristics and the agronomic adaptation of different genotypes, with the aim to select those cultivars with high productivity, tolerance to pests and abiotic stress and with better chemical and nutritional properties. In particular, some orange-fleshed cultivars were evaluated: *Beauregard*, widely consumed in USA and recently introduced to the Argentinean market, and *Boni INTA* and *Colorado INTA*, developed by the aforementioned program carried out by INTA. In Argentina, no previous study was performed on the chemical composition and antioxidant activity of different sweet potato cultivars.

In this study, the antioxidant activity, phenolic compounds, total carotenoids and the main nutritional components, such as protein, starch, dietary fiber and β-carotene were compared in different sweet potato genotypes. Three cultivars from San Pedro were characterized: *Beauregard,* which currently became the most widespread orange-fleshed cultivar in Argentina, *Boni INTA*, another orange-fleshed cultivar recently placed on the market that showed good agronomic characteristics and *Arapey*, a yellow-fleshed cultivar widely consumed in the region. Undersized roots of these three genotypes, currently discarded, were also analyzed in order to evaluate a possible usage according to their composition. Then, four sweet potato genotypes from San Pedro were grown in three agro-ecological regions of the Tucumán province with the goal of identifying those that showed the highest content of phenolic compounds, the best nutritional profiles and a good adaptation to any of the growing locations studied. The cultivars evaluated were the aforementioned *Beauregard*, *SP-950*, a yellow-fleshed cultivar under experimental stage, and other two cultivars needing to improve its diffusion: *Colorado INTA*, an orange-fleshed cultivar and *Morada INTA*, a yellow-fleshed cultivar, both of limited consumption.

2. Materials and methods

2.1. Reagents

Trolox, caffeic acid, 3- and 4-caffeoylquinic acids, 3,4-, 3,5- and 4,5-dicaffeoylquinic acids, and β-carotene (≥97.0 %, UV) standards, thermostable α-amylase, amyloglucosidase, protease, Folin-Ciocalteu, ABTS (2,2′-azinobis-(3-ethylbenzothiazoline-6- sulphonic acid)) and DPPH (2,2-diphenyl-1-picrylhydazyl) reagents were obtained from Sigma-Aldrich (St. Louis, MO, USA). Cyanidin-3-glucoside and chlorogenic acid standards were purchased from Fluka (St. Louis, MO, USA). Acetonitrile, methanol, ethylacetate, triethylamine and acetic acid were HPLC grade. The rest of the chemicals were of analytical grade.

2.2. Sample preparation

Three sweet potato cultivars (*Beauregard* and *Boni INTA,* both orange-fleshed, and *Arapey,* a yellow-fleshed one) were collected from experimental fields of San Pedro (INTA Experimental Station, Buenos Aires, Argentina). Those under 150 g were assigned as undersized and those between 150 g and 500 g as standard (Fig. 1A). Standard and undersized sweet potato roots of the three mentioned genotypes were analyzed. Furthermore, four sweet potato genotypes (*Beauregard*, *Morada INTA*, *Colorado INTA* and *SP-950*) cultivated in experimental fields of three agro-ecological locations of Tucumán, Argentina (Amaicha del Valle (AM), Famaillá (FA) and La Cocha (LC)) were analyzed. All sweet potatoes were planted at the same time (October 2017) and harvested after 150 days (March 2018). The meteorological conditions of the three Tucuman locations are listed in Table S1. AM is an arid and temperate location; in LC the climate is warm with mild water deficit and in FA the climate is also warm but without water deficiency. Along with *Beauregard*, *Colorado INTA* is also an orange-fleshed genotype, while *Morada INTA* and *SP-950* are yellow-fleshed (Fig. 1B). Each sample consisted of ten healthy sweet potato roots taken randomly from each genotype and each location. They were washed with tap water, peeled, freeze dried during 48 h at 4 Pa and −55 °C using an ALPHA 1–4 LD2 Martin Christ Gefriertrocknungsanlagen GMBH lyophilizer (Osterode am Harz, Germany), ground and stored at −20 °C until analysis. The moisture content of fresh and freeze-dried material was determined in triplicate using a vacuum oven at 65 °C up to constant weight.

2.3. Extraction and analysis of total phenolics and phenolic acids

Between 0.7 and 1.2 g of the freeze-dried powder was extracted with 80:20 ethanol:water for 10 min at 50 °C and centrifuged 15 min at 960 × g. The residue was extracted once again with the same solvent and the combined supernatants were diluted to 10 mL. Extractions were performed in duplicate. The extracts were later used for the analysis of the phenolic compounds and the antioxidant activity.

Total phenolics were measured according to the procedure described by Singleton, Orthofer, and Lamuela-Raventós (1999) with minor modifications. An aliquot of 250 μL of the extract was mixed with 4 mL of distilled water and 250 μL of the Folin-Ciocalteu reagent, and 3 min later, 500 μL of sodium carbonate 1 N was added. After 120 min, absorbance was read at 750 nm using a UV/Vis Lambda 25 spectrophotometer (Perkin Elmer, Waltham, MA, USA). Each extract was analyzed in triplicate. Chlorogenic acid was used as standard.

Phenolic acids were identified and quantified using HPLC as described by Tian et al. (2016) with modifications. An aliquot of 5 μL of each ethanol:water extract, previously filtered in a 0.45 μm membrane, was injected in a ZORBAX Eclipse XDB-C18, 4.6 × 250 mm, 5 μm column (Agilent Technologies, Waldbronn, Germany), in an Agilent 1200 Series equipment. The mobile phase was a mixture of A: 0.1 % (v/v) acetic acid in ultrapure water and B: 0.1 % (v/v) acetic acid in acetonitrile. The following gradient was applied: 90 to 75 % of A the first 35 min and 75 to 50 % of A from 35 up to 50 min. A constant flow rate of 0.7 mL/min was utilized. UV–vis 1260 Infinity Multiple Wavelength Detector was set at 320 nm. The corresponding phenolic acids were identified according to the retention times of their standards and were quantified according to their respective calibration curves. This analysis was conducted in triplicate.

2.4. Antioxidant activity

The antioxidant activity was analyzed according to the DPPH and the ABTS assays described by Ozgen, Reese, Tulio, Scheerens, and Miller (2006). Both methods were carried out in triplicate and free radical

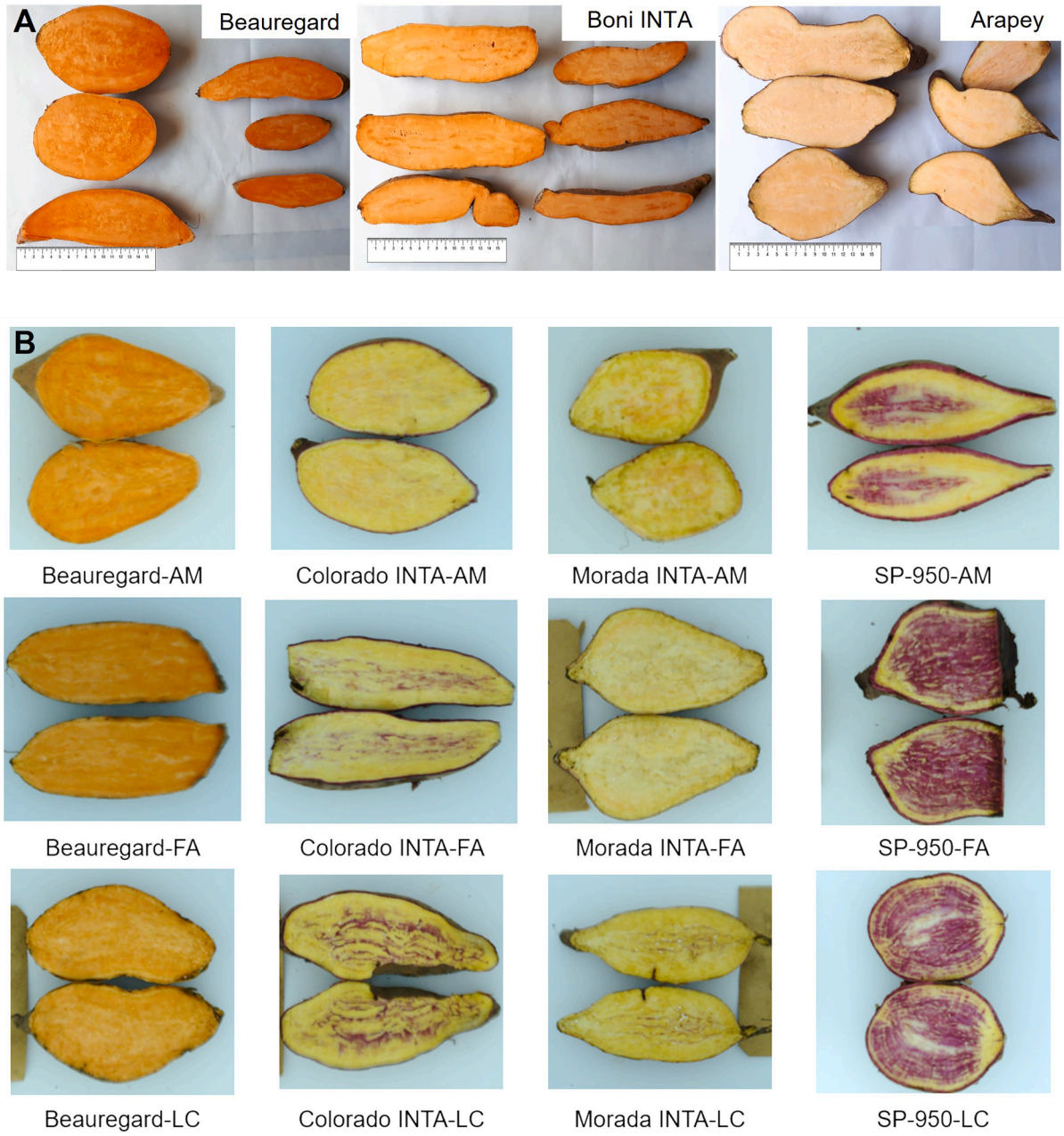

Fig. 1. Sweet potato genotypes analyzed in this study grown in A) San Pedro in standard (left) and undersized (right) roots and in B) three Tucumán locations: Famaillá (FA), La Cocha (LC) and Amaicha (AM).

scavenging activity was calculated using a Trolox standard curve (18–75 mg/mL and 180–750 mg/mL for DPPH and ABTS assays respectively).

2.5. Total anthocyanins

Total anthocyanin content was analyzed in the samples belonging to three agro-ecological locations of Tucumán. The procedure by the pH differential method of Fuleki and Francis (1967) was followed with slight modifications. Sweet potato powder (0.25 g) was extracted in triplicate for one hour with ethanol 95 %: hydrochloric acid (1.5 M) (85:15) at 80 °C, the extracts were centrifuged at 3230 × g and diluted to 10 mL. An aliquot (400 μL) of the obtained extracts was mixed with 1.6 mL of buffer pH 1 (hydrochloric acid 0.2 N, potassium chloride 0.025 M). Also, 400 μL of the extract was mixed with 1.6 mL of buffer pH 4.5 (sodium acetate 0.4 M, hydrochloric acid 1 N). The absorbance was read in duplicate in both solutions at 529 and 700 nm. Cyanidin-3-glucoside was used as a reference standard.

2.6. Total carotenoids and β-carotene

The extraction and quantification of total carotenoids was performed as described by Kimura, Kobori, Rodriguez-Amaya, and Nestel (2007). Extractions were done in triplicate and absorbance was read in duplicate at 450 nm. β-Carotene was used as standard.

β-Carotene content in the orange-fleshed samples was analyzed by HPLC following the method explained by Kimura et al. (2007) with slight modifications. The extracts obtained by the total carotenoid method were dried with nitrogen and dissolved in the mobile phase (80 % acetonitrile: 10 % methanol: 10 % ethyl acetate with 0.05 % triethylamine). Analysis was carried out on an Agilent 1100 HPLC system equipped with a degasser G1322A, an autosampler G1313A, a

temperature controller G1316A and a quaternary pump G1311A. A Phenomenex C18 column, 250 × 4.6 mm × 5 μm (Torrance, CA, USA) was used and the UV Variable Wavelength Detector G1314A was set at 450 nm. Each analysis was performed in duplicate.

2.7. Chemical composition

Nitrogen content was analyzed by the Kjeldahl method and dietary fiber was determined following an enzymatic–gravimetric method (AOAC, 2006). Starch was analyzed using polarimetry as described by the European Community (1999). Each measurement was performed in triplicate.

2.8. Statistical analysis

Analysis of variance (ANOVA) was carried out with the aid of the program InfoStat, 2018 version (Universidad de Córdoba, Córdoba, Argentina). Tuckey's test was conducted to compare the obtained values for the different genotypes, locations and root sizes. All data of the genotypes from Tucumán were also subjected to two-way ANOVA to analyze the effect of genotype, location and their interaction (genotype × location).

3. Results and discussion

3.1. Total phenolics, total anthocyanins, antioxidant activity and phenolic acids

Total phenolics and antioxidant activity (DPPH and ABTS assays) in *Beauregard*, *Arapey* and *Boni INTA* cultivars in their standard and undersized roots harvested in San Pedro are shown in Table 1. Significant differences were detected for the different cultivars and sizes ($p < 0.05$). The obtained values were comparable to the ones presented in literature for similar color-fleshed sweet potatoes: 2–10 mg chlorogenic acid/ g dry weight (dw) for total phenolics, 0.5–8.5 mg Trolox/ g dw for DPPH and 4.0–7.5 Trolox/ g dw for ABTS (Makori, Mu, & Sun, 2020; Rodrigues de Albuquerque et al., 2019; Wang et al., 2016). Among the three studied cultivars in their standard sizes, yellow-fleshed *Arapey* sweet potatoes presented the highest total phenolic content and antioxidant activity ($p < 0.05$). Undersized sweet potatoes had significantly higher values than those of the standard size in most of the cases ($p < 0.05$). The maximum differences were found in the orange-fleshed sweet potatoes, especially in the *Boni INTA* genotype: 121 % in total phenolics and 95 % and 69 % in DPPH and ABTS assays, respectively. On the other hand, the differences observed in both *Arapey* sweet potato sizes were significant only in total phenolics and in ABTS values, and lower than in orange-fleshed cultivars. Ravi and Saravanan (2012) suggested that auxins might play a crucial role in the sweet potato root development, while De Klerk, Guan, Huisman, and Marinova (2011) reported that phenolics would protect auxins by inhibiting their decarboxylation. This could explain the synthesis of these compounds at the initial stage of the growth period and therefore the higher concentration found in undersized roots.

Phenolic acids were analyzed in *Beauregard*, *Arapey* and *Boni INTA* sweet potatoes in their commercial size (Table 2). 3-caffeoylquinic acid, chlorogenic acid and 3,5-dicaffeoylquinic acid were found in the three cultivars. Chlorogenic acid was identified as the main phenolic acid in the three cultivars, constituting more than the 50 % of the sum of the phenolic acids. The sum of the chlorogenic and 3,5-dicaffeoylquinic acids represented between the 80 and 90 % of all phenolic acids. The *Arapey* genotype showed the highest concentrations in these two phenolic acids ($p < 0.05$), consistently with the total phenolic values. Previous studies have already identified the same phenolic acids in sweet potato roots and have also stated that chlorogenic acid was the most abundant one (Grace et al., 2014; Lebot, Michalet, & Legendre, 2016). However, the prevalence of this acid was, in general, lower than in the samples of the present study.

Beauregard sweet potatoes were also cultivated in different agro-ecological regions in order to evaluate its capacity of adaptation. Along with the *Beauregard* cultivar, *Morada INTA*, *Colorado INTA* and *SP-950* genotypes were grown in three locations of the Tucumán province (LC, AM and FA) and were analyzed according to their antioxidant activities, total phenolics and total anthocyanins. The three latter mentioned genotypes were originally developed in INTA San Pedro, where particularly *SP-950* did not show good adaptation. In consequence, there was interest in evaluating its performance in other areas. The effect of genotype, location and genotype × location on the parameters analyzed in the sweet potatoes of Tucumán was performed by two-way ANOVA (Table S2). The genotype, location and their interaction significantly affected all parameters ($p < 0.01$) and the main source of variation was the genotype. Among the different genotypes, the *SP-950* sweet potatoes had the highest values of antioxidant activity, total phenolics and total anthocyanins, especially those grown in the FA and LC regions (Table 3). Values found in these two genotype-location combinations were close to those reviewed by Alam (2021) for purple-fleshed sweet potatoes (4–15 mg chlorogenic acid/ g dw for total

Table 1
Total phenolics, antioxidant activity and total carotenoids in three genotypes grown in San Pedro in both standard and undersized sweet potatoes.

Genotype	Size	Total phenolics (mg ChA/ g dw)	Antioxidant activity (mg Trolox/g dw)		Total carotenoids (μg β-carotene/g dw)
			DPPH	ABTS	
Boni INTA (OF)	Standard	1.45 ± 0.40^{bC}	1.73 ± 0.06^{bC}	1.30 ± 0.12^{bC}	887 ± 26^{bA}
	Undersized	3.21 ± 0.06^{a}	3.37 ± 0.20^{a}	2.20 ± 0.11^{a}	1012 ± 23^{a}
Beauregard (OF)	Standard	1.88 ± 0.16^{bB}	2.41 ± 0.14^{bB}	1.71 ± 0.16^{bB}	554 ± 22^{bB}
	Undersized	3.27 ± 0.07^{a}	3.25 ± 0.17^{a}	2.70 ± 0.18^{a}	975 ± 42^{a}
Arapey (YF)	Standard	2.74 ± 0.47^{bA}	3.27 ± 0.14^{aA}	2.03 ± 0.04^{bA}	123 ± 24^{aC}
	Undersized	3.18 ± 0.06^{a}	3.08 ± 0.26^{a}	2.11 ± 0.07^{a}	95 ± 21^{a}

Data are expressed as mean ± SD (n = 6). Values within a column for the same genotype with different lowercase letters between standard and undersized samples are significantly different ($p < 0.05$); values within a column with different uppercase letters between different standard genotypes are significantly different ($p < 0.05$). ChA: chlorogenic acid. OF: orange-fleshed. YF: yellow-fleshed.

Table 2
Phenolic acids (mg/ g dw) of three sweet potato genotypes grown in San Pedro in their standard size.

Phenolic acids	*Boni INTA (OF)*	*Beauregard (OF)*	*Arapey (YF)*
3-caffeoylquinic acid	0.042 ± 0.013^{a}	0.061 ± 0.043^{a}	0.074 ± 0.028^{a}
Chlorogenic acid	0.393 ± 0.013^{c}	0.519 ± 0.021^{b}	0.773 ± 0.044^{a}
Caffeic acid[1]	0.047 ± 0.010	nd	nd
4,5- dicaffeoylquinic acid[2]	nd	nd	0.217 ± 0.034
3,5-dicaffeoylquinic acid	0.083 ± 0.009^{b}	0.135 ± 0.018^{b}	0.366 ± 0.060^{a}

Data are expressed as mean ± SD (n = 6). Values in the same row with different letters are significantly different ($p < 0.05$).
nd: not detected. OF: orange-fleshed. YF: yellow-fleshed.
[1] Detection Limit (DL): 0.013 mg/g dw and Quantitation Limit (QL): 0.040 mg/g dw.
[2] DL: 0.013 mg/g dw and QL: 0.040 mg/g dw.

Table 3
Bioactive contents and antioxidant activity in sweet potato genotypes from the Tucumán province.

Genotype	Location	Total phenolics (mg ChA/ g dw)	Antioxidant activity (mg Trolox/ g dw)		Total anthocyanins (μg cyanidin-3-glucoside/g dw)	Total carotenoids (μg β-carotene/g dw)
			DPPH	ABTS		
Beauregard	AM	3.70 ± 0.13^{bB}	2.95 ± 0.13^{cB}	1.52 ± 0.15^{bB}	nd	601 ± 24^{aA}
(OF)	FA	5.32 ± 0.14^{aB}	5.65 ± 0.14^{aB}	2.39 ± 0.15^{aB}	nd	412 ± 25^{bA}
	LC	3.53 ± 0.19^{bD}	3.42 ± 0.26^{bC}	0.89 ± 0.08^{cD}	nd	310 ± 17^{cA}
Colorado INTA	AM	3.30 ± 0.26^{bC}	1.30 ± 0.08^{cD}	0.70 ± 0.10^{cC}	32.1 ± 4.2^{aA}	93 ± 10^{bC}
(OF)	FA	2.09 ± 0.22^{cD}	2.24 ± 0.33^{bD}	1.92 ± 0.37^{bC}	20.8 ± 5.3^{bB}	61 ± 4^{cC}
	LC	5.44 ± 0.30^{aC}	5.04 ± 0.16^{aB}	2.48 ± 0.32^{aC}	16.7 ± 2.1^{bB}	137 ± 13^{aB}
Morada INTA	AM	3.07 ± 0.21^{cC}	1.77 ± 0.15^{cC}	0.78 ± 0.15^{cC}	36.6 ± 8.6^{aA}	126 ± 6^{aB}
(YF)	FA	4.04 ± 0.16^{bC}	3.81 ± 0.12^{bC}	1.65 ± 0.27^{bC}	15.2 ± 4.1^{bB}	79 ± 9^{bB}
	LC	6.91 ± 0.35^{aB}	4.87 ± 0.32^{aB}	3.23 ± 0.27^{aB}	nd	77 ± 5^{bC}
SP-950	AM	5.05 ± 0.27^{cA}	4.52 ± 0.31^{cA}	1.90 ± 0.40^{cA}	30.1 ± 6.1^{cA}	48 ± 5^{aD}
(YF)	FA	9.52 ± 0.19^{bA}	11.07 ± 0.53^{bA}	5.02 ± 0.14^{bA}	303.7 ± 35.9^{bA}	30 ± 4^{cD}
	LC	16.47 ± 0.24^{aA}	18.52 ± 0.70^{aA}	8.50 ± 1.28^{aA}	511.1 ± 29.6^{aA}	40 ± 3^{bD}

Data are expressed as mean ± SD (n = 6). Values within a column for the same genotype with different lowercase letters are significantly different ($p < 0.05$); values within a column with different uppercase letters from the same location are significantly different ($p < 0.05$).
AM: Amaicha del Valle; FA: Faimallá; LC: La Cocha; ChA: chlorogenic acid. OF: orange-fleshed. YF: yellow-fleshed.

phenolics; 11–12 mg Trolox/ g dw for DPPH; ABTS: 6–8 mg Trolox/ g dw for ABTS). It is noticeable that these roots have developed highly dense purple veins (Fig. 1B), indicating that their high total phenolics and antioxidant activity could be attributed to this feature. Also, purple-fleshed sweet potatoes were linked to higher anthocyanin contents. As can be seen in Table 3, total anthocyanin concentrations of these samples were one order of magnitude higher than the concentrations in the rest of the sweet potatoes analyzed in the present study. However, the content of these compounds compared to total phenols was not significant, since the proportion in terms of molar ratio, was about 2 % in both SP-950 samples. When total phenolics and antioxidant activities in the genotypes from the different locations of Tucumán were compared, in most of them, the higher values were found in those cultivated in LC and the lower in AM ($p < 0.05$). The annual precipitation levels in each location probably played a crucial role in phenolic content and antioxidant activity of the roots. Our results could indicate that total phenolics and antioxidant activity decrease under water stress and lower temperatures. Other researchers have also related these aspects to climate conditions, but their conclusions were somewhat contradictory. Although phenolic compounds and antioxidant activity were reported by Rautenbach et al. (2010) to be enhanced in roots by stress conditions, Motsa et al. (2015) have related higher concentrations to favourable growing environments and hypothesized that sweet potatoes grown under stress conditions need to spend their secondary metabolites as a defense mechanism against oxidative damage and, as a result, they contain lower concentrations at the moment of harvest.

Since the *SP-950* cultivar grown in AM, FA and LC regions and most genotypes grown in LC presented the higher phenolic concentrations among the sweet potatoes from Tucumán, phenolic acids were analyzed in those samples. 3-caffeoylquinic, chlorogenic, caffeic, 4,5-dicaffeoylquinic, 3,5-dicaffeoylquinic and 3,4-dicaffeoylquinic acids were identified in most extracts, as it is presented in Table 4. As it was observed in the samples grown in San Pedro, the sum of chlorogenic and 3,5-dicaffeoylquinic acids also represented between 80 and 90 % of the identified phenolic acids. Nevertheless, in this case, the percentages of chlorogenic acid were lower, representing in most of the samples approximately the 40 and 50 % of the acids. The most significant differences between the studied samples were observed when comparing the concentrations of the two major phenolic acids. On the other hand, differences in contents for the rest of the acids were, in general, not significant. The *SP-950* sweet potatoes grown in LC had the highest chlorogenic and 3,5-dicaffeoylquinic acids concentrations, when comparing the values obtained for that same genotype grown in the other two locations ($p < 0.05$). Also, when comparing the four genotypes all cultivated in the same site, the higher concentrations of these acids were found in the *SP-950* genotype ($p < 0.05$). These results are consistent with the reported findings for total phenolics.

A positive correlation was noticed between total phenolics and antioxidant activity, measured by the DPPH and ABTS methods, of all samples analyzed ($R^2 = 0.959$ and $R^2 = 0.936$ respectively). This would indicate that phenolic compounds are primary responsible for antioxidant activity. Despite being in lower or similar concentrations to the chlorogenic acid, the 3,5-dicaffeoylquinic acid showed a stronger correlation with DPPH and ABTS parameters ($R^2 = 0.961$ and $R^2 = 0.979$) than the formerly mentioned acid ($R^2 = 0.795$ and $R^2 = 0.899$), indicating a prevailing effect of 3,5-dicaffeoylquinic acid on the antioxidant activity. Probably, on account of its two caffeoyl groups.

Table 4
Phenolic acids (mg/ g dw) in the *SP-950* sweet potato genotype from three locations of the Tucumán province and in the four sweet potato genotypes cultivated at LC location.

Phenolic acids	*SP-950(YF)*-AM	*SP-950(YF)*-FA	*SP-950(YF)*-LC	*Morada INTA(YF)*-LC	*Beauregard(OF)*-LC	*Colorado INTA(OF)*-LC
3-caffeoylquinic acid	0.105 ± 0.031^{a}	0.155 ± 0.043^{a}	0.31 ± 0.13^{aA}	0.095 ± 0.030^{A}	0.102 ± 0.034^{A}	0.078 ± 0.022^{A}
Chlorogenic acid	0.598 ± 0.053^{c}	1.54 ± 0.13^{b}	2.84 ± 0.43^{aA}	1.87 ± 0.14^{B}	0.568 ± 0.072^{C}	0.96 ± 0.12^{C}
Caffeic acid[1]	0.123 ± 0.025^{a}	0.149 ± 0.049^{a}	0.31 ± 0.12^{aA}	nd	0.048 ± 0.001^{B}	nd
4,5- dicaffeoylquinic acid[2]	nd	0.159 ± 0.008^{a}	0.238 ± 0.070^{aA}	0.209 ± 0.037^{A}	0.046 ± 0.001^{B}	0.066 ± 0.004^{B}
3,5-dicaffeoylquinic acid	0.462 ± 0.043^{c}	1.24 ± 0.11^{b}	2.60 ± 0.62^{aA}	0.883 ± 0.066^{B}	0.290 ± 0.051^{C}	0.707 ± 0.086^{B}
3,4-dicaffeoylquinic acid[3]	0.085 ± 0.007^{b}	0.173 ± 0.005^{ab}	0.35 ± 0.11^{aA}	nd	nd	0.156 ± 0.018^{A}

Data are expressed as mean ± SD (n = 6). Values in the same row for *SP-950* genotype samples with different lowercase letters are significantly different ($p < 0.05$); values in the same row with different uppercase letters in sweet potatoes from the LC location are significantly different ($p < 0.05$).
AM: Amaicha del Valle; FA: Faimallá; LC: La Cocha; nd: not detected. OF: orange-fleshed. YF: yellow-fleshed.
[1] Detection Limit (DL): 0.013 mg/g dw and Quantitation Limit (QL): 0.040 mg/g dw.
[2] DL: 0.013 mg/g dw and QL: 0.040 mg/g dw.
[3] DL: 0.017 mg/g dw and QL: 0.050 mg/g dw.

3.2. Carotenoids

Total carotenoid contents in *Beauregard*, *Arapey* and *Boni INTA* cultivars (standard and undersized) from San Pedro are shown in Table 1. Significant differences were noticed between cultivars and root sizes. Orange-fleshed cultivars had the higher contents. Particularly, *Boni INTA* presented a considerably high concentration ($p < 0.05$) with almost one order of magnitude over the *Arapey* genotype. The range of total carotenoid concentrations in orange-fleshed sweet potato roots found in previous studies is wide (16–1331 μg β-carotene/g dw) (Kim et al., 2015; Koala et al., 2013; Oloniyo, Omoba, & Awolu, 2021; Othman, Kammona, Jaswir, Jamal, & Mohd Hatta, 2017). Remarkably, the content in *Boni INTA* was comparable to the higher values of that range. Although the total carotenoid concentration in Arapey was low, it was higher than other values reported in bibliography for yellow-fleshed genotypes (<50 μg β-carotene/g dw) (Grace et al., 2014; Kim et al., 2015). Comparing standard and undersized sweet potatoes, significantly higher amounts of total carotenoids were found in the undersized roots in both orange-fleshed cultivars ($p < 0.05$). Therefore, it is possible to hypothesize a larger synthesis of carotenoids at the early stages of the orange-fleshed sweet potato development. Supporting these results, Mitra et al. (2010) also found that during the first stages of growth the carotenoid concentration in orange-fleshed sweet potatoes increased, but decreased when reaching maturity. The difference in carotenoid contents between both sizes in *Arapey* sweet potatoes was not significant, while slight variations were observed in phenolics and antioxidant activity measurements. These results would indicate that the synthesis of bioactive compounds during the maturation process could be genotype dependent.

Due to the high total carotenoid content found in *Boni INTA* and *Beauregard* sweet potatoes and their nutritional importance, the percentage of β-carotene, the main vitamin A precursor, was also analyzed in these cultivars in both commercial and discarded sizes. In *Beauregard* samples, β-carotene represented 95 and 94 % of total carotenoids in standard and undersized roots repectively, while it constituted 93 and 92 % in *Boni INTA* sweet potatoes. These high proportions of β-carotene with respect to total carotenoids in orange-fleshed cultivars was also reported by other researchers (Alam, Sams, Rana, Akhtaruzzaman, & Islam, 2020; Kim et al., 2015). It is noticeable that in both cultivars, the percentage remained stable in the two root sizes, reinforcing the idea that higher carotenoid concentrations in undersized sweet potatoes are related to high early synthesis and not to its degradation while growing. Otherwise, the degradation rate would have been different for each carotenoid compound and the percentages of β-carotene in relation to total carotenoids would unlikely remain stable.

In regard to total carotenoids in the sweet potatoes grown in the three locations of Tucumán, the effect of genotype, location and their interaction were significant ($p < 0.01$). However, the influence of the former was much stronger than that of the others (Table S2). The results are shown in Table 3. *Beauregard* roots presented significantly higher concentrations than the other three cultivars ($p < 0.05$). The *SP-950* sweet potatoes, the ones with higher total phenolics and antioxidant activities, had the lowest concentrations of total carotenoids. Regarding the *Colorado INTA* genotype, it developed a yellow flesh while being grown in these three Tucumán locations, in spite of being registered as an orange-fleshed cultivar (Fig. 1B). Therefore, this particular feature is consistent with the lower levels of total carotenoids detected in these samples. In three of the four genotypes, higher total carotenoids were found in those grown in AM ($p < 0.05$), the driest and coldest location in comparison with the other two sites evaluated in this research. It could be then hypothesized that drought conditions would promote the synthesis of carotenoids, in opposition to the results regarding total phenolics and antioxidant activity.

β-Carotene percentages were evaluated in *Beauregard* sweet potatoes grown in the three locations and in the *Colorado INTA*-LC, since they presented the highest total carotenoid concentrations. As it was found in San Pedro samples, β-carotene represented in *Beauregard* sweet potatoes between 91 and 94 % of total carotenoids. Nevertheless, *Colorado INTA* had a considerably lower percentage (47 %) of β-carotene in relation to its total carotenoids. Grace et al. (2014) have already stated β-carotene percentages around the 50 % for yellow-fleshed sweet potatoes. Therefore, the low percentage detected in the *Colorado INTA* cultivar could be linked to the yellow flesh developed while being grown in Tucumán.

3.3. Dry matter, protein, starch and dietary fiber

Table 5 shows the dry matter, protein, starch and dietary fiber contents for the *Arapey*, *Beauregard* and *Boni INTA* sweet potatoes grown in San Pedro in their standard and undersized roots. Despite having found significant differences among the samples, only in some specific cases those differences were of relevance. The values obtained in this study were among the wide ranges reported in bibliography (Alam, 2021; Ellong, Billard, & Adenet, 2014; Ji, Zhang, Li, & Li, 2015; Neela & Fanta, 2019; Wang et al., 2016). Comparing the different cultivars in their standard size, it was noticed that the two orange-fleshed cultivars had a similar composition, while the yellow-fleshed showed some differences. The *Arapey* sweet potato stood out because of its higher dietary fiber content, with a value 65 % and 80 % over the *Beauregard* and *Boni INTA* cultivars, respectively. On the other hand, these two orange-fleshed cultivars had higher protein contents, with similar or even higher contents compared to the top values of the range reported by the previously cited studies (0.6–9.5 % dw). When comparing standard to undersized sweet potatoes, the differences found between the contents of the analyzed components were relevant only in very few cases. In particular, it could be highlighted the 54 % higher dietary fiber content in *Arapey* standard roots in comparison to the undersized sweet potatoes of the same cultivar. This genotype also presented the highest starch contents in undersized roots. In regard to protein, *Boni INTA* was the only cultivar with higher concentration in undersized sweet potatoes, with a 23 % difference in comparison with the commercial size. Therefore, it was not possible to assert a decreasing or increasing kinetic synthesis of the main components throughout the sweet potato growth.

Beauregard, *Morada INTA*, *Colorado INTA* and *SP-950* sweet potatoes grown in the three different locations in Tucumán were also analyzed according to their main components (Table 5). Protein and dry matter were measured in all the samples. In order to evaluate dietary fiber and starch in the different growing environments, *Colorado INTA* roots cultivated in the three Tucumán locations were analyzed. Also, these components were determined in the four sweet potato genotypes cultivated in the LC location, so that the effect of the genotype could be studied. The *Colorado INTA* cultivar and the LC location were selected because of their high levels of dry matter. Also, most of the genotypes from LC showed the highest antioxidant activity and total phenolic contents. Moreover, as the protein contents in the roots from this location were not high, it was expected to have higher concentrations of these other components. The two-way ANOVA analysis for these components (Table S2) showed that the effects of genotype, location and, when it was possible to evaluate, their interaction, were significant ($p < 0.01$) in all cases, except for the effect of genotype on dietary fiber (p greater than 0.05). Starch and dry matter variations were mainly due to genotype whereas protein and dietary fiber were mostly affected by the location. Comparing the different genotypes, it was noticeable that the *Beauregard* cultivar had the highest protein content in the three analyzed locations. Once again, the protein content in the orange-fleshed genotype was higher than in the other cultivars, as it was noticed in the San Pedro samples. Regarding dry matter and starch, the higher values were found in *Colorado INTA* and *Morada INTA* roots. The differences found in the dietary fiber and starch content were not relevant. The variations of the different compounds among the three locations did not always follow the same pattern. The roots harvested in the AM location, the driest and coldest site, had the lowest dry matter. However, all the genotypes grown in this location presented significantly higher protein

Table 5
Protein, dietary fiber, starch content (% dw) and dry matter (%) in three genotypes grown in San Pedro in standard and undersized sweet potatoes and in four genotypes cultivated in three locations of the Tucumán province.

Genotype	Proteins			Dietary fiber			Starch			Dry matter		
San Pedro	Standard	Undersized		Standard	Undersized		Standard	Undersized		Standard	Undersized	
Boni INTA (OF)	8.8 ± 0.7^{bA}	10.9 ± 0.1^{a}		6.4 ± 0.1^{aB}	6.3 ± 0.1^{a}		48.5 ± 0.6^{aB}	45.8 ± 0.7^{b}		18.2 ± 2.0^{aB}	20.7 ± 1.7^{a}	
Beauregard (OF)	8.9 ± 0.1^{aA}	8.6 ± 0.1^{b}		7.0 ± 0.4^{aB}	6.3 ± 1.1^{a}		57.1 ± 0.2^{aA}	45.2 ± 2.0^{b}		19.7 ± 1.9^{aAB}	22.0 ± 1.7^{a}	
Arapey(YF)	5.7 ± 0.2^{aB}	5.8 ± 0.1^{a}		11.6 ± 0.7^{aA}	7.4 ± 0.4^{b}		46.4 ± 1.4^{bB}	58.3 ± 0.6^{a}		24.2 ± 2.4^{aA}	26.8 ± 3.5^{a}	
Tucumán	AM	FA	LC	AM	FA	LC	AM	FA	LC	AM	FA	LC
Beauregard (OF)	11.7 ± 0.1^{aA}	6.0 ± 0.1^{bA}	6.0 ± 0.3^{bA}	–	–	8.3 ± 0.4^{A}	–	–	52.4 ± 1.0^{B}	17.9 ± 0.1^{bD}	18.5 ± 0.5^{abC}	19.0 ± 0.1^{aC}
Colorado INTA(OF)	9.4 ± 0.1^{aC}	4.6 ± 0.1^{cC}	6.3 ± 0.1^{bA}	5.9 ± 0.1^{ab}	5.1 ± 0.6^{b}	7.6 ± 0.1^{aAB}	58.4 ± 1.3^{b}	70.1 ± 0.7^{a}	63.2 ± 2.0^{bA}	21.3 ± 0.2^{bB}	30.6 ± 3.9^{aA}	24.7 ± 1.8^{abAB}
Morada INTA (YF)	6.7 ± 0.1^{aD}	4.2 ± 0.1^{cD}	5.3 ± 0.1^{bB}	–	–	7.3 ± 0.3^{AB}	–	–	62.2 ± 0.8^{A}	25.3 ± 0.2^{bA}	28.1 ± 1.8^{aBA}	26.9 ± 0.2^{abA}
SP-950(YF)	10.1 ± 0.1^{aB}	4.8 ± 0.1^{cB}	5.2 ± 0.1^{bB}	–	–	6.9 ± 0.1^{B}	–	–	50.3 ± 0.2^{B}	19.9 ± 0.3^{cC}	24.0 ± 0.7^{aCB}	22.1 ± 0.8^{bB}

Data are expressed as mean ± SD (n = 3). Values with different lowercase letters in the same row for each measurement are significantly different ($p < 0.05$); values with different uppercase letters in the same column are significantly different ($p < 0.05$). AM: Amaicha del Valle; FA: Faimallá; LC: La Cocha. OF: orange-fleshed. YF: yellow-fleshed.

values than the sweet potatoes cultivated in the other sites. The highest dietary fiber values were found in the LC location and the highest starch content was found for the *Colorado INTA* roots in the FA location, the site with higher level of precipitations. Starch, the main component, showed a positive correlation with the dry matter contents in all samples from Tucumán. Therefore, the analysis of dry matter could be an indirect way to identify high starch cultivars.

4. Conclusion

Sweet potato proved to be a versatile crop, showing different characteristics depending on the genotype, the stage of development and the growing location. Results found in our study revealed that undersized sweet potatoes are a valuable source of phenolic compounds and nutrients. Orange-fleshed sweet potatoes, in particular the cultivar Boni INTA, were high in proteins and β-carotene. Therefore, the utilization of these roots as a food ingredient could confer healthy attributes to processed foods like bread, chips or sweets and, in addition, could contribute to reduction of waste. The undersized *Arapey* cultivar can also be considered a good source of starch. Significant differences in bioactive contents were noticed in sweet potatoes grown in different locations of Tucumán. Those from locations that did not suffer from water stress had the highest phenolic concentrations and antioxidant activity. Particularly, the genotype SP-950, when grown in FA and LC locations, showed significantly higher values in comparison with the other genotypes. On the other hand, sweet potatoes cultivated in arid regions could provide higher levels of proteins and carotenoids. The high provitamin A contents in cultivars from these locations could contribute to increased well-being in regions with nutritional deficiencies, like Tucumán and other areas of Latin America. These findings could help to improve the cultivation of local genotypes with high added value.

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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochms.2022.100125.

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