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FOOD TECHNOLOGY

Physicochemical and antioxidant capacity analysis of colored sweet potato genotypes: *in natura* and thermally processed

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ABSTRACT: *Sweet potato (**Ipomoea batatas** (L.) Lam) is one of the most popular and ancient roots of Brazil and it can be consumed at different forms such as boiled, roasted or as sweets. Its cooking can lead to physicochemical transformations altering the nutritional properties. The objective of this study was to evaluate the physicochemical characteristics, bioactive compounds and antioxidant capacity of twelve sweet potato genotypes of varying pulp color* in natura *and roasted. Soluble solids, acidity, sugars, carotenoids, anthocyanins, phenolic compounds and antioxidant capacity were analyzed in the following sweet potatoes genotypes: cream pulp (Rubissol, Cuia, ILS03, ILS10, ILS12, ILS24 and ILS44); orange pulp (Amelia and Beauregard); and purple pulp (ILS56, ILS16 and ILS71). According to the results, it was observed a wide variation among the sweet potato genotypes for all analyzed parameters, in both preparation forms. The antioxidant capacity was a parameter with wide variation among genotypes, 210.29 to 7870.57µg trolox equivalent/g in* in natura *form and 673.26 to 17306.22µg trolox equivalent/g in roasted form. Soluble solids, acidity, sugars and bioactive compounds, with the exception of carotenoids, tended to be concentrated, also increases the total antioxidant capacity, in roasted sweet potatoes. In conclusion, genotype and the color of sweet potatoes were parameters that had an influence on its chemical composition. Cultivars such as Amelia and Beauregard stood out by the amounts of total soluble solids and carotenoids, respectively. The selections ILS 16 and ILS 56 are recommended as sources of anthocyanins. Thermal process influenced the concentration of antioxidant compounds and changed some physicochemical characteristics.*
Key words: *carotenoids, anthocyanins, processing, bioactive compounds, **Ipomoea batatas**.*

Análises físico-químicas e capacidade antioxidante de genótipos coloridos de batata-doce *in natura* e termicamente processados

RESUMO: *A batata-doce (**Ipomoea batatas** (L.) Lam) é uma das raízes mais populares e antigas do Brasil, podendo ser consumida cozida, assada ou na forma de doces. A sua cocção pode levar à transformações físico-químicas alterando as propriedades nutricionais. O objetivo deste trabalho foi avaliar as características físico-químicas, compostos bioativos e atividade antioxidante de doze genótipos de batata-doce, de coloração de polpa variada, na forma* in natura *e assada. Foram determinados sólidos solúveis totais, acidez, açúcares, carotenoides, antocianinas, compostos fenólicos e atividade antioxidante nos seguintes genótipos de batatas-doces: polpa creme (Rubissol, Cuia, ILS03, ILS10, ILS12, ILS24 e ILS44); polpa laranja (Amélia e Beauregard) e polpa roxa (ILS56, ILS16 e ILS71). Quanto aos resultados foi observada ampla variação entre os genótipos de batata-doce, para todos os parâmetros analisados, em ambas as formas de preparo. A atividade antioxidante foi um parâmetro que demonstrou grande variação entre os genótipos, de 210,29 a 7870,57µg de equivalente trolox/g nos genótipos* in natura *e de 673,26 a 17306,22µg de equivalente trolox/g nos genótipos assados. Foi observado que em batatas-doces assadas os sólidos solúveis, acidez, açúcares e os compostos bioativos, com exceção dos carotenoides, tenderam a ser concentrados, elevando também a atividade antioxidante total. Em conclusão, o genótipo e a coloração da batata-doce foram parâmetros que exerceram influência sob a sua composição química. Cultivares como Amélia e Beauregard se destacaram pela quantidade de sólidos solúveis totais e carotenoides, respectivamente. Como fonte de antocianinas, as seleções ILS 16 e ILS 56 são recomendadas. O processo térmico influenciou a concentração de compostos antioxidantes e alterou algumas características físico-químicas.*
Palavras-chave: *carotenoides, antocianinas, processamento, compostos bioativos, **Ipomoea batatas**.*

INTRODUCTION

Sweet potato (***Ipomoea batatas*** (L.) Lam.), original from tropical America, is a very popular and ancient root in Brazil where its production reached 479000 tons in 2013 (FAO, 2013). Characteristics such as wide adaptability, high tolerance towards drought, rusticity and easiness cultivation enables the sweet potatoes production throughout the national territory. Thus, this crop is present in family farming and has been an important food supply for most needy population, since it is a source of calories and has high vitamins and minerals contents (SILVA et al., 2008). Brazil possesses a great genetic diversity of sweet potatoes, where roots with different forms (AZEVEDO et al., 2015) and colors can be found.

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Besides vitamins and minerals, sweet potatoes also have high levels of bioactive compounds such as anthocyanins and β-carotene that are described with antioxidant and anti-mutagenic properties (BOVELL-BENJAMIN, 2007). The concentration of nutrients in sweet potatoes pulp depends on their color; however, purple sweet potatoes have high levels of phenolic compounds, as anthocyanins, and consequently, high antioxidant capacity (LIM et al., 2013). This fact shows the potential of purple varieties as healthy food and also as source of natural colorants. Conversely, orange sweet potatoes are an excellent source of carotenoids that are responsible for the yellow, orange and red pigments of plants and some animals (TANAKA et al., 2012). The main characteristic of carotenoids present in sweet potatoes is their provitamin A activity (BURRI, 2011).

Antioxidants compounds, normally reported in functional food, are capable of inhibit or delay injuries caused by free radicals, which are molecules with one or more unpaired electron that reacts rapidly with different cellular targets causing damages that are associated with degenerative diseases and aging (PEREIRA & CARDOSO, 2012). The reactions caused by free radicals can be compensated by the action of antioxidants obtained through the diet, such as ascorbic acid, α-tocopherol, carotenoids, and polyphenols (CERQUEIRA et al., 2007), some of these antioxidants are abundant in sweet potatoes.

The literature has demonstrated the potential use of sweet potatoes for health maintenance. For instance, extracts of purple sweet potatoes, rich in anthocyanins, may protect against colorectal cancer due to different mechanism such as cell cycle arrest, anti-proliferative activity, and apoptosis (LIM et al., 2013).

Sweet potatoes can be consumed at different forms, such as cooked, roasted or as sweet; however, preparation of sweet potatoes for consumption, such as cooking, provides chemical, physical and structural changes due to heat effect which may alter the content of bioactive compounds and consequently the antioxidant capacity (MIRANDA et al., 1995; CAMPOS et al., 2008).

The goal of this study was to determine the physicochemical characteristics, the content of bioactive compounds and the antioxidant capacity in genotypes (cultivars and advanced selections) of sweet potatoes *in natura* and the alterations after the heat process (roasting).

MATERIALS AND METHODS

The following cultivars of sweet potatoes were studied: Rubissol (white pulp), Cuia (cream pulp), Amélia (yellow pulp) and Beauregard (orange pulp) and also the following advanced selections: ILS 03 (white pulp), ILS 10 (white pulp), ILS 12 (white pulp), ILS 24 (white pulp), ILS 44 (cream pulp), ILS 56 (purple pulp), ILS 16 (purple pulp) and ILS 71 (purple pulp). Samples were cultivated on the experimental field of the Embrapa Clima Temperado (31° 42'S; 52° 24'W; altitude 7m).

Planting was carried out in the first half of January 2013, using seedlings with high sanity, obtained from vegetative multiplication of matrices derived from the meristem culture. The spacing used for the production of roots in the seedbed was 0.80 to 1.00m between furrows, and 0.25 to 0.50m between plants, and spacing of 2.00 to 3.00 meters between different cultivars seedbeds. Only chemical fertilizer was applied, insecticides, fungicides and herbicides were not used. The crop was harvested approximately 140 days after planting. The climatic characteristics of this period had an average rainfall of 142.1, 177.3, 109.0, 133.6 and 113.9mm from January to May, and average maximum temperatures of 27.8, 28.1, 25.3, 24.3 and 19.5°C for the same period.

Sweet potatoes were collected and stored under refrigeration, between 7°C to 9°C, for approximately three months. The preparation of roasted sweet potatoes with peel was carried out in a conventional oven, at 250°C for approximately 90 minutes. All analyzes were performed in triplicate.

For physicochemical analysis of fresh samples, each genotype were sliced and weighed, and the amount of juice, enough to perform the analysis, was obtained in domestic centrifuge. The roasted samples were weighed and homogenized for analysis procedures. All analysis was carried out on peeled sweet potatoes.

For phytochemical analysis, equatorial portions were used (1.5 to 2.0cm) for both *in natura* and roasted forms, samples were peeled of, and radial sliced (for each slice cuts were made from the center until the extremity).

Physicochemical analysis

Soluble solids content: It was carried out according to AOAC "2005", based on direct reading of samples on digital refractometer at 20ºC and results expressed in ºBrix. Total acidity: carried by titration and expressed in percentage (%) of citric acid according to method AOAC, 2005. Sugars: sugar content was obtained using the method described by NELSON (1944).

Phytochemical analysis

Total carotenoids: carotenoids were quantified according to the method adapted from

TALCOTT & HOWARD (1999). Total carotenoid content was measured spectrophotometrically at 470nm. β-Carotene was used as reference for the calibration curve (0-0.01mg mL^{-1}) and results were expressed as mg of equivalent in β-carotene per 100g of sample. Total anthocyanins: the quantification was carried out according to the method adapted from FULEKI & FRANCIS (1968). Determination was made with spectrophotometer at 535nm. Cyanidin-3-glucoside was used as reference for the calibration curve (0-0.04mg mL^{-1}) and results were expressed as mg of equivalent in cyanidyn-3-glucoside per 100g of sample. Total phenolic compounds: phenolic compounds were quantified according to the method adapted from SWAIN & HILLIS (1959). The absorbance at 725nm was read in a spectrophotometer. Chlorogenic acid was used as reference for the calibration curve (0-0.35mg mL^{-1}). Total phenolic compounds content was expressed as mg of equivalents in chlorogenic acid per 100g of sample.

Total antioxidant capacity

Total antioxidant capacity was determined by the method adapted from BRAND-WILLIAMS et al. (1995) using the stable radical 2,2-difenil-1-picrilhidrazil (DPPH). Absorbance at 515nm was read in a spectrophotometer. Trolox was used as reference for the calibration curve (0-0.8mg mL^{-1}) and results were expressed as µg of equivalent of trolox per g of sample.

Statistical analysis

Obtained results were submitted to variance analyses and variables with significant effect for the genotype factor and preparation form (mean values) were further compared by Tukey test at 5% confidence level. Statistical analysis was run using Winstat - 2.11 version.

RESULTS AND DISCUSSION

Soluble solids content (ºBrix) (Table 1), varied from 7.30 (ILS 24) to 14.57 (ILS 03), in sweet potato *in natura*, and the ILS 03 showed significant higher values among the genotypes ($P<0.05$). The obtained results were lower than those reported by SILVEIRA et al. (2011), which studied 10 clones of orange sweet potatoes *in natura* (9°Brix to 17.33°Brix). Superior values were reported in the roasted sweet potatoes, with values varying from 23.26ºBrix (Beauregard) to 42.23ºBrix (Amélia). Amelia cultivar showed the highest value among the studied genotypes.

In relation to the cooking method effect on soluble solids, a significant increase in its content was observed for all genotypes of sweet potatoes after roasting, due to their concentration. The combination of high temperatures and time of processing promotes alterations on the cell wall structure leading to water loss and consequently accumulation of sugars (TONON et al., 2006).

Acidity, expressed as citric acid percentage, ranged from 0.12 (Beauregard and ILS 44) to 0.18 (ILS 16) in sweet potatoes *in natura* and from 0.09 (Cuia) to 0.32 (ILS 16) in the roasted form. Values of acidity were higher in roasted sweet potatoes, for the majority of the genotypes, than in sweet potatoes *in natura* form. The exceptions were Cuia and the selection ILS 56 that showed higher values in *in natura* form, while Amélia and Beauregard did not change with processing (Table 1). Roasted sweet potatoes tended to show higher values for acidity, which can be related to the concentration of compounds caused by loss of moisture and changes in the cellular structure.

Concentration of sugars, expressed as percentage (%), varied from 0.42 (ILS 16) to 1.96 (Beauregard) in sweet potatoes *in natura* form. In contrast, all genotypes showed higher values for the roasted form with concentrations ranging from 1.60 (ILS 12) to 2.24 (ILS 24). Beauregard cultivar showed the highest value of sugars among all genotypes for *in natura* form; however, no significant difference was observed for the selections ILS 24, ILS 71 and ILS 16 after roasting. Cooking in dry heat (roasting process) leads to the concentration of both energy and mineral values due to water loss, which is characteristic in this type of preparation (ORNELLAS, 2007).

Anthocyanins, expressed in mg of equivalent of cyanidin-3-glucoside per 100g of sample (fresh weight), were detected in three selections with concentrations varying from 149.53 (ILS 71) to 229.20 (ILS 16) for sweet potatoes in *in natura* form, with high values reported for ILS 16 (Table 2). The concentration of anthocyanins reported in this study for purple sweet potatoes *in natura* was superior to those reported in the literature (JIAO et al., 2012).

Concentration of anthocyanins in the roasted sweet potatoes varied from 106.51 (ILS 71) to 328.92 (ILS 16), and ILS 16 and ILS 56 were not statistically different ($P<0.05$). It could be observed that the dry heat process leads to the concentration of anthocyanins for the sweet potatoes selections ILS 16 and ILS 56, due to the elimination of free water. In the case of the ILS 71 there was a decrease in the concentration

Table 1 - Total soluble solids (TSS), total titrible acidity (TTA) and total sugars (TS) in sweet potatoes genotypes *in natura* and roasted forms.

Genotype	Pulp color	----------TSS (ºBrix)----------		--------TTA (% citric acid) --------		----------TS (%)----------	
		In natura	Roasted	*In natura*	Roasted	*In natura*	Roasted
ILS 03	Cream	14.57 a B	40.73 b A	0.14 bc B	0.24 c A	0.71 e B	2.08 cd A
ILS 10	White	13.63 b B	40.80 b A	0.14 bc B	0.27 b A	0.92 c B	2.02 de A
ILS 12	Cream	10.67 f B	33.67 g A	0.13 bc B	0.22 c A	0.89 c B	1.60 h A
ILS 16	Purple	13.57 b B	34.87 f A	0.18 a B	0.32 a A	0.42 f B	2.16 abc A
ILS 24	White	7.30 h B	29.77 j A	0.13 c B	0.16 e A	1.67 b B	2.24 a A
ILS 44	Cream	7.60 h B	31.87 h A	0.12 c B	0.27 b A	0.93 c B	1.98 e A
ILS 56	Purple	12.00 e B	30.73 i A	0.18 a A	0.16 e B	0.79 d B	1.85 f A
ILS 71	Purple	7.43 h B	39.16 c A	0.15 b B	0.19 d A	0.93 c B	2.20 ab A
Amélia	Orange	13.07 c B	42.23 a A	0.13 bc A	0.13 f A	0.97 c B	2.09 cd A
Beauregard	Orange	10.03 g B	23.26 k A	0.12 c A	0.13 f A	1.96 a B	2.19 ab A
Cuia	Cream	11.77 e B	38.77 d A	0.13 bc A	0.09 g B	0.67 e B	1.72 g A
Rubissol	Cream	12.73 d B	37.90 e A	0.13 bc B	0.15 ef A	0.48 f B	2.12 bc A

Embrapa Clima Temperado, Pelotas, RS, 2015. Means (n=3) followed by the same lower case letters in a column and capital letters on the lines do not differ significantly by the Tukey test (P<0.05).

of these compounds, which could be attributed to a degradation process for a specific anthocyanin present in this genotype. According to the literature the main anthocyanins identified in colored sweet potatoes are acylated cyanidins and peonidins and its glycosides (GODA et al., 1997; GOULD et al., 2009).

Results reported in the literature regarding the anthocyanins present after and before thermal process were divergent. The concentration of anthocyanins can increase after the roasting process (LACHMAN et al., 2012), or a slight reduction can occur (KIM et al., 2012).

The variation of carotenoids in sweet potatoes *in natura*, expressed as mg of equivalent of β-carotene per 100g of sample (fresh weight), was from 0.21 (ILS 16 e ILS 24) to 21.79 (Beauregard). This genotype presented the higher values of β-carotene equivalent (Table 2). Beauregard is a biofortified sweet potato cultivar where carotenoids concentration can be 10 times higher than other cultivars (white and cream pulp). According to HAYASE & KATO (1984), β-carotene is the major carotenoid reported in orange sweet potatoes and it is responsible for their pulp orange color, this compound is transformed in the organism in vitamin A, which is important for health promotion (LIMA et al., 2012).

These results are in agreement with other studies comparing genotypes of different colors, where high amounts of total carotenoids were reported for orange cultivars when compared with sweet potatoes with lighter colors (ROSE & VASANTHAKAALAM, 2011).

Concentration of carotenoids in roasted sweet potatoes ranged from 0.14 (Cuia) to 23.97 (Beauregard) (Table 2). No difference was observed between sweet potatoes *in natura* and roasted in relation to the concentration of carotenoid in most genotypes, except for Amelia and Beauregard cultivars, where, for the former there was a decrease after dry heat, and for the last, there was the concentration of these compounds.

Studies related to this theme are divergent, since the carotenoid content can be reduced (GAYATHRI et al., 2004), do not change, or even increase (VIMALA et al., 2011) after cooking. Normally, heat processing method can reduce the carotenoid content as a result of the susceptibility of these compounds to degradation and isomerization under high temperatures. At the same time, the heating process can be beneficial for the release and solubilization of carotenoids, once the matrix is breakdown, thus increasing their bioavailability (MAIANI et al., 2009).

Concentration of phenolic compounds, expressed as mg of equivalent in chlorogenic acid per 100 grams of sweet potato (fresh weight), varied from 51.26 (Amélia) to 663.48 (ILS 16) for samples *in natura*. Selection ILS 16, purple pulp, stood out with higher concentrations of phenolic compounds for both forms, *in natura* and roasted (Table 3). A great genetic variability concerning the phenolic compounds concentration has been already reported for sweet potatoes (JUNG et al., 2011), and the highest concentrations are usually observed in purple sweet potato (AMARO et al., 2013).

Table 2 - Total anthocyanins and carotenoids in sweet potatoes genotypes *in natura* and roasted forms.

Genotype	Pulp color	----------Total anthocyanins[1]----------		----------Total carotenoids[2]----------	
		In natura	Roasted	*In natura*	Roasted
ILS 03	Cream	nd	nd	1.23 ef A	0.59 efg B
ILS 10	White	nd	nd	4.66 c A	5.13 c A
ILS 12	Cream	nd	nd	0.51ef B	1.19 efg A
ILS 16	Purple	229.20 a B	328.92 a A	0.21 f B	1.33 ef A
ILS 24	White	nd	nd	0.21 f B	1.35 ef A
ILS 44	Cream	nd	nd	2.33 d A	2.86 d A
ILS 56	Purple	208.97 a B	316.15 a A	0.65 ef A	1.21 efg A
ILS 71	Purple	149.53 b A	106.51 b B	0.90 ef A	0.22 fg B
Amélia	Orange	nd	nd	10.26 b A	6.78 b B
Beauregard	Orange	nd	nd	21.79 a B	23.97 a A
Cuia	Cream	nd	nd	0.85 ef A	0.14 g B
Rubissol	Cream	nd	nd	1.37 de A	1.50 e A

Embrapa Clima Temperado, Pelotas, RS, 2015. Means (n=3) followed by the same lower case letters in a column and capital letters on the lines do not differ significantly by the Tukey test (P<0.05). nd: not detected.[1]Total anthocyanins expressed as mg of equivalents of cyanidin-3-glucoside/100g (fresh weight).[2]Total carotenoids expressed in mg of equivalents of β-carotene/100g (fresh weight).

Sweet potato processing using dry heat influenced the concentration of phenolic compounds that ranged from 124.39 (ILS 24) to 1268.33 (ILS 16). As previously mentioned, these compounds can be concentrated by water loss after dry heat cooking. Presence of anthocyanins in selections ILS 16 and ILS 56, purple selections, can influenced the reading of total phenolic compounds (LIMA et al., 2000). Chlorogenic acid is reported as the major phenolic compound in sweet potatoes (HAYASE & KATO, 1984).

Antioxidant capacity, expressed in µg of equivalent of Trolox per gram of sample (fresh weight), is presented in table 3, indicating a variation from 210.29 (Cuia) to 7870.57 (ILS 16) for sweet potatoes *in natura* and from 673.26 (ILS 24) to 17306.22 (ILS 16) for the roasted samples.

The selection ILS 16 showed higher antioxidant capacity for both forms (*in natura* and roasted), confirming the results obtained for phenolic compounds. Regarding the antioxidant capacity a wide variation was reported among the

Table 3 - Total phenolic compounds and antioxidant activity in sweet potatoes genotypes *in natura* and roasted forms.

Genotype	Pulp color	----------Phenolic compounds[1]----------		----------Antioxidant capacity[2]----------	
		In natura	Roasted	*In natura*	Roasted
ILS 03	Cream	156.28 d B	313.01 c A	733.43 d B	2584.55 cd A
ILS 10	White	143.17 de B	396.93 c A	366.28 d B	4244.57 c A
ILS 12	Cream	73.29 fg B	172.74 d A	562.68 d A	787.17 d A
ILS 16	Purple	663.48 a B	1268.33 a A	7870.57 a B	17306.22 a A
ILS 24	White	93.18 efg A	124.39 d A	704.47 d A	673.26 d A
ILS 44	Cream	138.51 de B	195.78 d A	764.09 d A	1688.31 cd A
ILS 56	Purple	547.03 bB	1155.40 b A	5411.17 bB	16053.76 a A
ILS 71	Purple	440.17 c A	191.60 d B	2689.04 c B	15854.29 a A
Amélia	Orange	51.26 g B	132.28d A	3732.53 c B	8376.76 b A
Beauregard	Orange	80.90 fg B	407.26 c A	574.59 d B	1770.41 cd A
Cuia	Cream	97.63 efg B	182.21 d A	210.29 d A	1091.32 d A
Rubissol	Cream	109.84 def B	191.67 d A	238.23 d A	1278.01 d A

Embrapa Clima Temperado, Pelotas, RS, 2015. Means (n=3) followed by the same lower case letters in a column and capital letters on the lines do not differ significantly by the Tukey test (P<0.05). [1]Total phenolic compounds expressed in mg of equivalents of chlorogenic acid/100g (fresh weight). [2]Antioxidant activity expressed in µg of equivalents of trolox/g (fresh weight).

sweet potato genotypes, although samples of purple pulps can be highlighted, fact that was confirmed by TEOW (2006).

In a general way, dry heat processing do not influence or increase the sweet potato antioxidant capacity. This occurs due to the concentration of various bioactive compounds during processing, caused by water loss, characteristic of this type process.

Besides, the cell wall disruption during the cooking process can facilitated the release of bioactive compounds promoting their extraction as reported by (KAO et al., 2014). This fact was observed by the increase of total phenolic compounds content and it was positively correlated with the antioxidant capacity.

The different genotypes of sweet potatoes under analysis showed varied characteristics. Cultivars Amélia and Beauregard can be highlighted due to their high concentrations of carotenoids which can have health benefits, and also the purple sweet potatoes, with high levels of anthocyanins in combination with good physicochemical characteristics. Purple sweet potatoes can be good sources of anthocyanins for both colorant extraction and for food consumption by the population. In addition, it is an accessible source of bioactive compounds well known as health promoters that can improve the human quality of life.

CONCLUSION

The sweet potato genotype influenced the concentration of analyzed compounds. Amélia cultivar stood out by their high levels of total soluble solids in roasted sweet potatoes. Color is a factor responsible for the differentiation of genotypes and their quality characteristics. Beauregard cultivar stood out regarding carotenoids, followed by Amélia, and both can be indicated as a source of provitamin A. Genotypes ILS 16 and ILS 56 can be indicated as sources of anthocyanins. Heat processing affects the concentration of the antioxidant compounds and changes the physicochemical characteristics.

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