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Quality characterization, phenolic and carotenoid content of new orange, cream and yellow-fleshed sweetpotato genotypes

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ABSTRACT

Sweetpotato (*Ipomoea batatas*) is a root crop grown in many countries. This tuberous root is a source of energy, nutrients, and phytochemicals. In this study, bioactive compounds and physical and physicochemical qualities of sweetpotato genotypes were evaluated. Eight new genotypes of sweetpotato produced by Embrapa Hortaliças (orange-fleshed: MD09026-OF and MD09024-OF; cream-fleshed: MD09011-CF, MD09004-CF, MD10039-CF, and MD10004-CF; yellow-fleshed: MD09017-YF and MD12002-YF) and two cultivars used as controls (Beauregard and Brazlândia Roxa) were evaluated for color, soluble solids, dry matter, phenolic compounds, total carotenoids and β-carotene. Hue angles differed even between those sweetpotatoes with the same flesh color. The orange-fleshed genotypes MD09024-OF, MD09026-OF, and Beauregard, had the lowest L*, showing to be darker than the others. These sweetpotatoes also had the brightest flesh colors with higher C*. The orange-fleshed genotypes MD09026-OF and MD09024-OF were sweeter (10.55°Brix and 9.23°Brix) than Beauregard (5.12°Brix). Brazlândia Roxa had the highest dry matter content (38.05%), followed by the genotypes MD10004-CF, MD09017-YF, MD09026-OF MD10039-CF, and MD09011-CF, which showed similarity, ranging from 32.33% to 29.12%. The highest contents of total carotenoids were found for the orange-fleshed genotypes MD09026-OF (80.06 mg g^{-1}) and MD09024-OF (70.56 mg g^{-1}) and Beauregard (73.12 mg g^{-1}). These same genotypes showed the highest total phenolic compounds (0.815 mg g^{-1} and 0.686 mg g^{-1}, respectively). MD09026-OF showed the highest content of β-carotene (46.47 mg g^{-1}). MD09026-OF was the most prominent genotype among those evaluated, as it showed the highest total carotenoid, β-carotene, phenolic compounds, and soluble solids content, in addition to a high dry matter content.

Keywords: *Ipomoea batatas*, β-carotene, color, dry matter.

RESUMO

Caracterização da qualidade, teor de fenólicos e carotenoides de novos genótipos de batata-doce de polpa laranja, creme e amarela

A batata-doce (*Ipomoea batatas*) é uma raiz cultivada em vários países. Esta raiz tuberosa é fonte de energia, nutrientes e fitoquímicos. Nesse estudo, foram avaliados compostos bioativos e qualidades físicas e físico-químicas de genótipos de batata-doce. Foram avaliados oito genótipos de batata-doce produzidos pela Embrapa Hortaliças (polpa alaranjada: MD09026-OF e MD09024-OF; polpa creme: MD09011-CF, MD09004-CF, MD10039-CF e MD10004-CF; e polpa amarela: MD09017-YF e MD12002-YF) e dois controles (Beauregard e Brazlândia Roxa) quanto à cor, sólidos solúveis, matéria seca, compostos fenólicos, carotenoides totais e β-caroteno. Os ângulos hue diferiam mesmo entre as batatas-doces com a mesma cor de polpa. Os genótipos de polpa laranja MD09024-OF, MD09026-OF e a Beauregard, apresentaram o L* mais baixo, mostrando-se mais escuros que os demais. Essas batatas-doces também apresentaram as cores de polpa mais intensas, com C* mais altos. Os genótipos de polpa laranja MD09026-OF e MD09024-OF apresentaram-se mais doces (10,55°Brix e 9,23°Brix) do que a Beauregard (5,12°Brix). A Brazlândia Roxa apresentou o maior teor de matéria seca (38,05%), seguido pelos genótipos MD10004-CF, MD09017-YF, MD09026-OF MD10039-CF e MD09011-CF, que apresentaram similaridade, variando de 32,33% a 29,12%. Os maiores teores de carotenoides totais foram encontrados para os genótipos de polpa laranja MD09026-OF (80,06 mg g^{-1}) e MD09024-OF (70,56 mg g^{-1}) e Beauregard (73,12 mg g^{-1}). Esses mesmos genótipos apresentaram os maiores compostos fenólicos totais (0,815 mg g^{-1} e 0,686 mg g^{-1}, respectivamente). O genótipo MD09026-OF apresentou o maior teor de β-caroteno (46,47 mg g-1). O MD09026-OF foi o genótipo que mais se destacou entre os avaliados, pois apresentou os maiores teores de carotenoide total, β-caroteno, compostos fenólicos e sólidos solúveis, além de teor mais alto de matéria seca.

Palavras-chave: *Ipomoea batatas*, β-caroteno, cor, matéria seca.

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Distributed and grown in several countries, sweetpotato (*Ipomoea batatas*) is an important vegetable for the human diet. It is widely adapted and grown in more than 110 countries, being the second most important tropical root crop (Grüneberg *et al*., 2015), and consisting of an alternative to supply the deficiency of vitamin A and energy in the human diet in resource-poor regions (Islam *et al*., 2016).

Sweetpotatoes are a source of

energy due to their high starch content (Roy & Chakrabarti, 2003), nutrients, and phytochemicals (Hussein *et al*., 2014). This tuberous root has color variations due to the presence of different bioactive compounds, such as carotenoids, anthocyanins, phenolics, and flavonoids (Shekhar *et al*., 2015; Wang *et al*., 2018; Frond *et al*., 2019). These phytochemicals are important for their potential role in human health and disease prevention (Kibe *et al*., 2017; Chen *et al*., 2020). Orange-fleshed sweetpotatoes are predominantly rich in β-carotene, the most relevant provitamin A carotenoid (Teow *et al*., 2007). Carotenoids from vegetables, as a source of provitamin A, represent 80-85% of dietary vitamin A supply, in addition to its antioxidant potential (Zakaria-Rungkat *et al*., 2000).

The annual consumption of sweetpotatoes is still considered low in Brazil (639 g/year) (IBGE, 2019a) when compared to other countries despite the current indicative of growth in the harvested area and production volume (IBGE, 2019b). Consumers' access to sweetpotatoes is still limited for lower-income families and in a particular region, for example, in the North (IBGE, 2019a). Among the factors that restrict access may be the low production (IBGE, 2019b) and eating habits, commonly associated with preferences for pale-fleshed and drier texture types. The relevance of understanding and meet consumer preferences is particularly significant for the promotion of orange-fleshed sweetpotatoes and new market opportunities (Mwanga *et al*., 2017). Making those sweetpotatoes more accessible and preferable, with information to the consumers about the nutritional benefits of higher vitamin A intake, could be an approach towards reducing the prevalence of vitamin A deficiency, especially in low-income regions (Kidmose *et al*., 2007). In Brazil, this nutritional deficiency persists as a moderate public health problem, especially in the Northeast and in some places in the Southeast and North (Lima *et al*., 2018; BRASIL, 2020a).

From the 29 cultivars registered in the RNC (National Cultivars Registry), Beauregard, licensed from LSU (Louisiana State University), is the only one with orange-flesh color available in the Brazilian market (BRASIL, 2020b). Although Beauregard shows stability in different climatic conditions with high yields (Amaro *et al*., 2019), this cultivar is susceptible to diseases and insect damage.

Therefore, the development of new orange-fleshed genotypes with high commercial root yield, quality (mainly high soluble solids and dry matter contents), and also pest resistance to supplant Beauregard can benefit the producers and attend the demands for national market and exportation. The cream and yellow-fleshed genotypes have been developed in the same crossing block and period as the orange-fleshed and are part of the advanced selection trial in the Embrapa Hortaliças Breeding Program for release as cultivars.

The genetic range and heritability of critical nutritional components of the sweetpotato provide the opportunity to alter the elemental chemical composition through plant breeding (Kays & Kays, 1998), and efforts are being made by national R&D institutions to achieve this goal. Thus, the objective of this study was to assess the physicochemical quality and total carotenoids, β-carotene, and phenolic compounds contents of eight sweetpotato genotypes developed by Embrapa Hortaliças' breeding program and two commercial cultivars used as control.

MATERIAL AND METHODS

Reagents and analytical standards

Folin-Ciocalteu reagent, β-carotene, and acetonitrile were purchased from Sigma-Aldrich Chemical Co. (St. Louis, MO, USA). Gallic acid, sodium carbonate, ethyl acetate, and methanol were purchased from Vetec Química Fina Ltd. (Duque de Caxias, RJ, Brazil). Petroleum ether was purchased from Neon Comercial (Suzano, SP, Brazil). Acetone and ethanol were purchased from Synth Ltd. (Diadema, SP, Brazil).

Plant material

The experiment was carried out in the 2018 growing season, conducted at Embrapa Hortaliças (15°56'S, 48°08'W, altitude 996 m), Brasília, Federal District, Brazil. The soil was classified as a Dystrophic Red Latosol. The agronomic management of the crop (fertilization, irrigation, and cultural handling) was carried out according to the recommendation for the region with supplemented irrigation when necessary. The planting date was January 17, with a 140 days cycle until harvest. Eight new sweetpotato genotypes, obtained from the 2016 polycross breeding nursery, and chosen from two generations of clonal selection, were evaluated with two control cultivars (Beauregard and Brazlândia Roxa) in a field trial performed as a Randomized Complete Block Design with four replicates. The samples were transferred to the Food Science and Technology Laboratory for analysis. Sweetpotato genotypes of different flesh colors were used, as follow: 1) MD09026-OF (orange-fleshed), 2) MD09024-OF (orange-fleshed), 3) MD09011-CF (cream-fleshed), 4) MD09004-CF (cream-fleshed), 5) MD10039-CF (cream-fleshed), 6) MD10004-CF (cream-fleshed), 7) MD09017-YF (yellow-fleshed), 8) MD12002-YF (yellow-fleshed), 9) Control 1: Beauregard (orange-fleshed), and Control 2: Brazlândia Roxa (cream-fleshed). The sweetpotatoes were washed under running water and brushed gently using a soft brush before being cut for analysis.

Flesh color

Color values of the sweetpotato flesh were measured with a colorimeter Chroma Meter CR-400 (Konica Minolta, Inc., Chiyoda-ku, Tokyo, Japan). The color was measured using the CIE system: L* (lightness), C* (chroma), h^o (hue angle). Hue angle ($h^o = \tan^{-1}[b^*/a^*]$), and chroma ($C^* = [a^{*2} + b^{*2}]^{1/2}$) were calculated from a* and b* values (McGuire, 1992). The sweetpotatoes were transversely cut and the flesh immediately analysed. Three roots were used per replicate, with one side reading per root.

Soluble solids content

Soluble solids content (SS) was

determined with a refractometer (PR-101, Atago Co. Ltd., Tokyo, Japan) and expressed in °Brix. Three roots were used for replicate. The flesh from each root was shredded (3.5 g) and squeezed with a manual squeezer. A 0.5-mL liquid portion was used for direct refractometer reading and SS determination.

Dry matter content

Dry matter (DM) content was determined by weighing before and after oven drying (Quimis, São Paulo, SP, Brazil) of duplicate 5-g samples at 90°C for 4 h. The dishes were cooled in a desiccator until they have reached room temperature and then weighed. This operation was repeated until the constant sample weight. Dry matter percentage was calculated according to the equation: DM% = 100 x dry sample weight/sample weight before drying.

Carotenoids content

The method reported by Rodrigues-Amaya (1999) was used for measuring carotenoid content. Samples of 2 g of orange-fleshed genotypes or 4 g of yellow-fleshed genotypes and 40 mL of acetone solution (10°C) were homogenized (Turratec Tecnal TE-102, Piracicaba, SP, Brazil) for 1 min before vacuum filtration in a Buchner funnel and Whatman® Filter Paper N°. 4. The filtration was repeated until the residue is devoid of any color, and the washings were colorless. The filtrate was transferred into a separatory funnel with 40 mL petroleum ether, where the carotenoids were partitioned. Acetone was removed from the funnel with three successive washes with distilled water. The petroleum ether phase was filtered through a glass funnel containing 15 g of anhydrous sodium sulfate for wastewater removal. Volume was adjusted to 50 mL with petroleum ether. The spectrophotometer (Bioespectro® SP220, Curitiba, PR, Brazil) was blanked with petroleum ether, and the absorbance of the petroleum ether phase was measured at 450 nm. Carotenoid was calculated based on its extinction coefficient ($E^{1\%}_{1cm}$ 2592) in petroleum ether, using the formula: ($Abs.V.10^4/E^{1\%}_{1cm}.W$), being: Abs the maximum λ absorbance, V the dilution volume (mL), and W the weight of samples (g). Results were expressed as μg g^{-1} FW.

β-Carotene content

Identification and quantification of β-carotene were performed in an HPLC system SPD-M20A (Shimadzu Co., Kyoto, Japan). Samples were injected onto a Spherisorb C_{18} reverse-phase column (4.6 x 150 mm, 3 μm particle size) (Waters Associates, Milford, MA, USA). A 20-μL sample was diluted in acetone and filtered in polyvinylidene fluoride (PVDF) membranes. The separation was performed at 22°C with a mobile phase of acetonitrile, methanol, and ethyl acetate (80:10:10, v/v/v). The total run time was 22.5 min. The flow rate was maintained at 0.8 mL min^{-1}. Detection of β-carotene was performed at 450 nm with a Diode Array Detector. The concentration was calculated from a β-carotene standard (Sigma-Aldrich Chemical Co., St. Louis, MO, USA) curve and expressed as μg g^{-1} FW. LCSolution Software (version 5.57) was used to process the data.

Total phenolics content

Phenolic content was evaluated following the procedure of Singleton & Rossi (1965) with modifications. Samples of 1 g were homogenized with 20 mL of 70% ethanol using a shaker (Marconi, Piracicaba, SP, Brazil) for 20 min and filtered in Whatman® Filter Paper. A 400-mL extract was mixed with 400 mL of 70% ethanol, 400 mL of Folin-Ciocalteu reagent (1:3, v/v diluted with distilled water), and 2,800 mL of 10% sodium carbonate solution. Homogenates were centrifuged (Sorvall™ RC 6 Plus, Thermo Fisher Scientific Inc., Waltham MA, USA) at 14,000 rpm for 3 min at 5°C. The mixture was incubated for 20 min at darkroom temperature before absorbance was measured at 735 nm using a spectrophotometer (Bioespectro® SP220). A blank prepared with 70% ethanol was used as control. Total phenolic content was expressed as gallic acid equivalents (GAE) in mg g^{-1} FW.

Statistical analysis

In the laboratory, completely randomized design was used. The treatments were 10 different genotypes. Analyses were done using four replicates. Data were analyzed using a one-way analysis of variance - ANOVA (GLM-ANOVA) of SAS® Statistical Analysis System v. 8.0. Means were compared using Tukey test at $p>0.05$.

RESULTS AND DISCUSSION

Flesh color

The orange-fleshed sweetpotatoes MD09024-OF, MD09026-OF, and Beauregard had the lowest L* (71.71, 73.77 and 76.08, respectively) (Figure 1), showing to be darker than the others (Table 1). Orange-fleshed sweetpotatoes showed the most vivid flesh colors with higher C* (saturation), ranging from 48.58 to 51.47 (Figure 1). Hue angles differed ($p<0.05$) even between those sweetpotatoes with the same flesh color (Figure 1). However, they were quite close in the CIELAB color space. The hue angle of orange-fleshed genotypes ranged between 66.55 and 69.95, located in the first quadrant of the color space (red/yellow). Cream-fleshed sweetpotatoes showed hue angle values between 95.03 and 103.22, located in the second quadrant (yellow/green) (Figure 1). Yellow and orange color in sweetpotato roots is determined by carotenoids (Grüneberg *et al*., 2015). The β-carotene content in sweetpotato is highly correlated with the hue angle in genotypes with yellow to deep orange color (Simonne *et al*., 1993).

Soluble solids content and dry matter

Soluble solids measured by a refractometer mostly include sugars and also other compounds, such as organic acids, soluble pectin, ascorbic acid, and phenolics (Kader, 2008). The orange-fleshed genotypes, MD09026-OF and MD09024-OF, differed significantly from Beauregard for soluble solids (Table 1). These two genotypes showed higher soluble solids than Beauregard, with 10.55°Brix and 9.23°Brix, respectively, while Beauregard had a content of 5.12°Brix. MD09026-OF and MD09024-OF also had higher

Table 1. *F*-value and coefficient of variation (CV) for lightness (L*), chroma (C*), hue angle (h°), soluble solids (SS), dry matter (DM), total phenolics (PHE), total carotenoids (CAR) and β-carotene (βCAR) of the sweetpotatoes genotypes evaluated. Brasília, Embrapa Hortaliças, 2018.

	L*	C*	h°	SS	DM	PHE	CAR	βCAR
F-value	242.7***	44.60***	266.27***	23.06**	67.57***	42.66***	565.22***	363.29***
CV (%)	0.73	6.48	1.47	8.33	3.58	10.79	6.31	8.07

***Significant at p<0.001; **Significant at p<0.01.

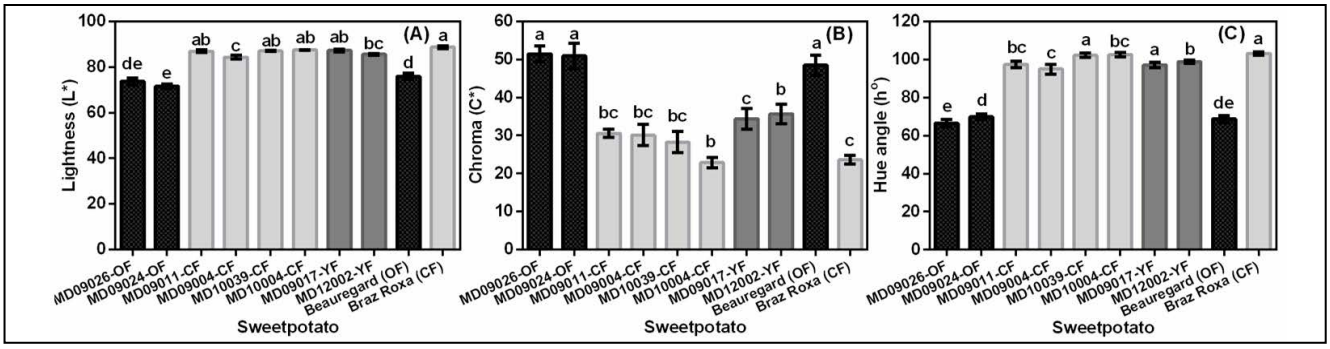

Figure 1. A) Lightness (L*), B) chroma (C*), and C) hue angle (ho) of new sweetpotato genotypes from Embrapa Hortaliças, with Beauregard and Brazlândia Roxa as controls. Letters show mean comparisons between treatments by the Tukey test (p>0.05). OF= orange flesh, YF= yellow flesh, CF= cream flesh. Brasília, Embrapa Hortaliças, 2018.

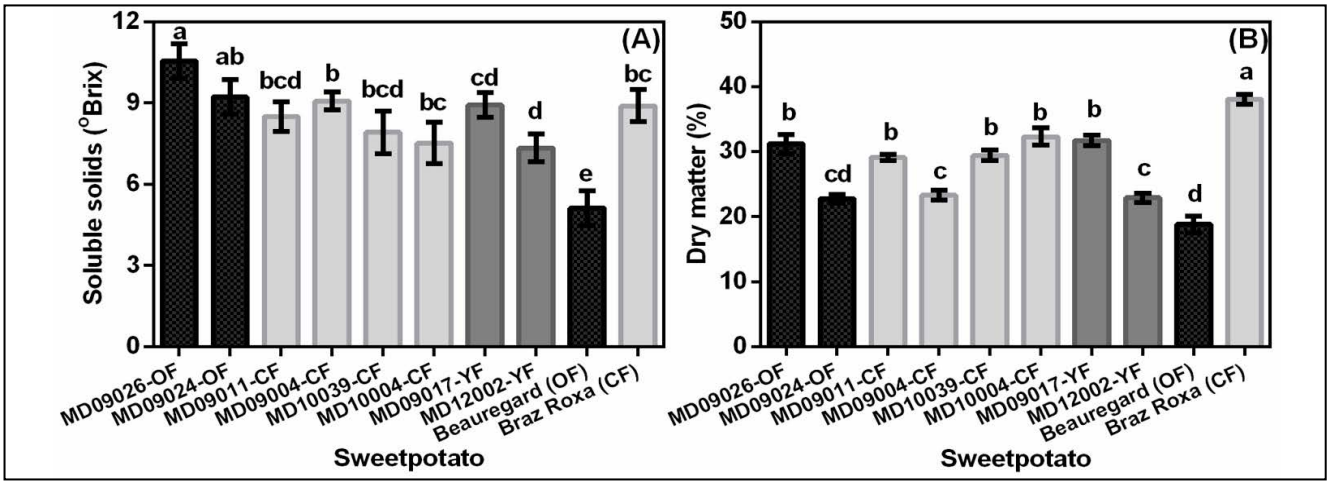

Figure 2. A) Soluble solids content (°Brix) and B) dry matter (%) of new sweetpotato genotypes from Embrapa Hortaliças, with Beauregard and Brazlândia Roxa as controls. Letters show mean comparisons between treatments by the Tukey test (p>0.05). OF= orange flesh, YF= yellow flesh, CF= cream flesh. Brasília, Embrapa Hortaliças, 2018.

soluble solids than the yellow-fleshed sweetpotatoes MD09017-YF and MD12002-YF, which had contents of 7.53°Brix and 7.35°Brix, respectively. Cream-fleshed genotypes showed soluble solids ranging from 7.53°Brix to 9.08°Brix (Figure 2). Vizzotto *et al*. (2017) found higher soluble solids content for orange and cream-fleshed genotypes.

Brazlândia Roxa had the highest dry matter content (38.05%). The other cream-fleshed genotypes did not differ significantly from each other, showing dry matter contents from 29.12% to 32.33%, not including the genotype MD09004-CF, which showed a content of 23.29% (Figure 2). Laurie *et al*. (2013) found similar dry matter content on 20 cream-fleshed sweetpotato genotypes, which ranged from 18.20% to 32.70%. Except for genotype MD09026-OF in the group of orange-fleshed sweetpotatoes, Beauregard and MD09024-OF showed the lowest dry matter of 18.85% and 22.78%, respectively (Figure 2). Other studies have also demonstrated lower dry matter content in orange-fleshed genotypes with high carotenoid content (Kidmose *et al*., 2007; Tomlins *et al.*, 2012).

Dry matter content varies according to genetic factors, soil and climatic conditions, cultivation methods, harvest time, and storage (Silva *et al*., 1995). Ali *et al*. (2015) found varied contents for 116 sweetpotato genotypes from 13.27% to 40.21%. Cultivars with dry matter

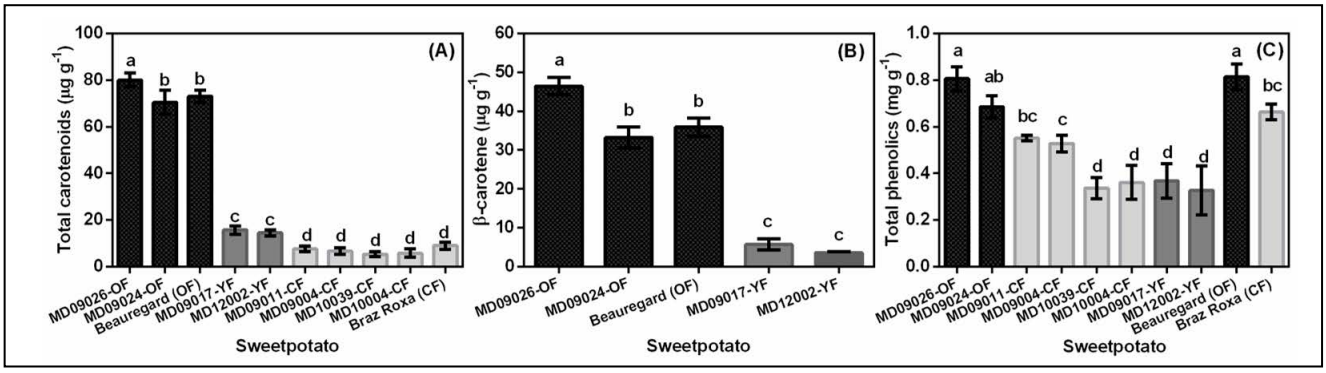

Figure 3. A) Total carotenoids (µg g-1 FW), B) total phenolics (mg g-1 FW), and C) β-carotene (µg g-1 FW) contents of new sweetpotato genotypes from Embrapa Hortaliças, and Beauregard and Brazlândia Roxa as control. Letters show mean comparisons between treatments by the Tukey test (p>0.05). OF= orange flesh, YF= yellow flesh, CF= cream flesh. Brasília, Embrapa Hortaliças, 2018.

content above 20% are more suitable for food industries as it increases the raw material yield efficiency (Truong *et al*., 2018).

Total carotenoids content, β-carotene and total phenolics content

Sweetpotatoes with higher total carotenoid contents were those of orange flesh color. Genotypes MD09026-OF and MD09024-OF, and cultivar Beauregard showed contents of 80.06 mg g^{-1}, 70.56 mg g^{-1}, and 73.12 mg g^{-1}, respectively (Figure 3). Higher contents of carotenoids in orange-fleshed genotypes substantiated their hue value in the color space (Figure 1). The intensity of the yellow or orange flesh color of the sweetpotato is directly correlated to the carotenoid content, which is important for disease prevention due to its antioxidant potential (Zakaria-Rungkat *et al*., 2000; Kibe *et al*., 2017).

The yellow-fleshed genotypes MD09017-YF (15.76 mg g^{-1}) and MD12002-YF (14.56 mg g^{-1}) had lower carotenoids content than orange-fleshed and did not differ from each other (Figure 3). Islam *et al*. (2016) found total carotenoids content ranging from 61.94 mg g^{-1} to 19.31 mg g^{-1} for orange-fleshed sweetpotatoes and 5.64 mg g^{-1} to 3.28 mg g^{-1} for yellow-fleshed. The lowest carotenoid contents were found for the cream-fleshed genotypes, MD10039-CF (5.35 mg g^{-1}), MD10004-CF (5.83 mg g^{-1}), MD09004-CF (6.67 mg g^{-1}), MD09011-CF (7.66 mg g^{-1}), and Brazlândia Roxa (9.01 mg g^{-1}) (Figure 3), which differed from those of orange and yellow-fleshed (Table 1). Although they had a low carotenoids content, they showed a good dry matter content, which provides a more firm texture for sweetpotatoes, an important attribute especially for the industry.

The flesh color of the root was directly associated with the β-carotene content. β-carotene content found for MD09026-OF, MD09024-OF, and Beauregard were 46.47 mg g^{-1}, 33.29 mg g^{-1}, and 35.92 mg g^{-1}, respectively. For the yellow-fleshed genotypes, MD09017-YF and MD12002-YF, the β-carotene concentrations found were 5.72 mg g^{-1} and 3.57 mg g^{-1}, respectively. Teow *et al*. (2007) found lower β-carotene contents in two yellow-fleshed genotypes (1.5 mg g^{-1} and 2.3 mg g^{-1}) and contents ranging from 44.9 mg g^{-1} to 226.0 mg g^{-1} in seven orange-fleshed genotypes.

The highest amounts of phenolic compounds were found for the orange-fleshed sweetpotatoes MD09026-OF (0.806 mg g^{-1}) and Beauregard (0.815 mg g^{-1}). Shekhar *et al*. (2015) reported a higher phenolic content (1.49 mg g^{-1}) in orange-fleshed sweetpotatoes. Wu *et al*. (2004) analyzed sweetpotatoes in both the raw and cooked forms, and they found 0.74 mg g^{-1} for raw sweetpotatoes. Color and cultivar can influence phenolic compounds' levels and profiles. Teow *et al*. (2007) found the highest phenolic compounds content for purple-fleshed sweetpotatoes, followed by those of orange, yellow, and light yellow flesh.

Thus, MD09026-OF was the most prominent genotype among those evaluated, as it showed the highest total carotenoid, β-carotene, phenolic compounds, and soluble solids content, in addition to a high dry matter content. This orange-fleshed genotype seems to have the potential for industrial use for its good dry matter content and may also become an option for export. Therefore, this genotype will be advanced to become a cultivar and to be used in the sweetpotato breeding program.

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