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Comparing sorghum and wheat whole grain breakfast cereals: Sensorial acceptance and bioactive compound content

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ABSTRACT

The sensory acceptance and the content of bioactive compounds of whole-sorghum and whole-wheat breakfast cereals were compared. Sensory acceptance was assessed using the Food Action Rating Scale. 3-Deoxyanthocyanidins, flavones and flavanones were determined by high-performance liquid chromatography (HPLC) with diode array detection, and vitamin E by HPLC with fluorescence detection. Total phenolics and antioxidant activity were determined by spectrophotometry. The sorghum breakfast cereal had better sensory acceptance (70.6%) than wheat breakfast cereal (41.18%). Sorghum had higher 3-deoxyanthocyanidin content (100% higher), total phenolic compounds (98.2% higher) and antioxidant activity (87.9% higher) than wheat breakfast cereal. Flavones and flavanones were not detected in both breakfast cereals. Total vitamin E content was 78.6% higher in wheat than in sorghum breakfast cereal. Thus, consumption of whole sorghum breakfast cereal should be encouraged, since it had good sensory acceptance and is a source of bioactive compounds that can promote benefits to human health.

1. Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is a whole grain cereal that is better known to Western societies as an animal feed rather than a human food source (Stefoska-Needham, Beck, Johnson, & Tapsell, 2015). In countries, such as Australia, United States and Brazil, this cereal is mainly used for animal feed production. In contrast, sorghum is produced and used for human consumption in countries of Africa, Asia and other semi-arid regions of the world (Taylor, Schober, & Bean, 2006).

The use of sorghum for human consumption in Western countries has increased due to its functional potential (Poquette, Gu, & Lee, 2014). Sorghum could be used as a substitute for conventional cereals due to its high bioactive compounds, minerals, dietary fiber, vitamin E and carotenoids content (Cardoso, Pinheiro,

Abbreviations: 3-DXAs, 3-deoxyanthocyanidins; 5-MeO-LUT, 5-methoxy-luteliolinidin; 7-MeO-AP, 7-methoxy-apigeninidin; AP, apigeninidin; DAD, diode array detector; DPPH, 1,1-diphenyl-2-picrylhydrazyl; FACT, Food Action Rating Scale; HPLC, high performance liquid chromatography; LUT, luteolinidin.

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Martino, & Pinheiro-Sant'Ana, 2015a) and its potential to promote health and prevent diseases. This cereal can been used in the preparation of gluten-free products for individuals with celiac disease and other wheat intolerances (Stefoska-Needham et al., 2015). Furthermore, some sorghum genotypes contain tannins, which are bioactive compounds that could attract consumers interested in functional foods (Dlamini, Taylor, & Rooney, 2007).

Expanded extruded products, such as snacks and breakfast cereal, are very popular due to their crispness and ease of use. In the United States and other countries, including Brazil, these products are made typically with corn, although rice and wheat are also used. Although sorghum has a lower cost and is easier to produce than maize, until recently it had not been used for this purpose (Queiroz, Moraes, Martino, Paiva, & de Menezes, 2014). However, studies have been conducted in order to optimize the use of this cereal in the preparation of this type of product.

As far as we know, there are no studies on sensory analysis of whole-grain sorghum breakfast cereals compared to whole-grain wheat breakfast cereals. Sensory properties of a food product are important for its acceptance (Carson, Setser, & Sun, 2000). Sorghum-based products showed good acceptability (Carson et al., 2000; González, 2005; Shin, 1986). Therefore, sorghum has sensory potential to replace traditional cereals, being considered an excellent option for the food industry.

In addition, we found no studies that have assessed and compared the content of bioactive compounds in whole-grain sorghum and wheat breakfast cereals. Thus, the present study aimed to compare the sensory acceptance and the content of bioactive compounds of whole-grains sorghum and wheat breakfast cereals.

2. Materials and methods

2.1. Raw material, preparation and storage

Sorghum grains (genotype SC319) were grown by Embrapa Milho e Sorgo in Nova Porteirinha, MG, Brazil, between May and September 2013. The whole grains were initially milled into flour using a disc mill model 3100 (Perten Instruments, Huddinge, Sweden) set at position 2, added with 10% sucrose as fine granulated sugar and 0.5% of iodized salt (NaCl), and processed in a co-rotating intermeshing twin-screw extruder model Evolum HT 25 (Clextral, Firminy, France) at constant screw speed of 600 rpm and temperature profile of 30, 60, 90, 110, 110, 110, 120, 120, 130 and 140 °C, from feeding to the outlet (Vargas-Solórzano, Carvalho, Takeiti, Ascheri, & Queiroz, 2014). The screw diameter (D) was 25 mm and the total configured screw length (L) was 1000 mm, providing an overall L/D ratio of 40. The die had four round openings of 2.0 mm in diameter each and 9 mm in length. The formulation was placed in the feeding zone by a twin-screw, loss-in-weight gravimetric feeder model GRMD15 (Schenck Process, Darmstadt, Germany), and monitored by Schenck Process Easy Serve software (Schenck Process, Darmstadt, Germany). Distilled water was injected between the first and second feeding zones through a port measuring 5.25 mm in internal diameter from the start of the barrel using a plunger metering pump model J-X 8/1 (AILIPU Pump Co. Ltd., China) set to compensate for moisture differences in the samples and provide a final moisture content of 12%. The samples were collected over 15–20 min and subsequently ground into particles measuring 212 μm.

The whole-grain wheat flour was acquired and extruded by SL Alimentos in Mauá da Serra, PR, Brazil. The wheat flour was added with 10% sucrose as fine granulated sugar and 0.5% of iodized salt (NaCl), which was processed in a co-rotating twin-screw model Evolum BC 72 (Clextral, Firminy, France) at constant screw speed of 200 rpm and temperature profile of 50, 81, 112, 118, 127 and 143 °C, from feeding to the outlet. The other conditions of extrusion were similar to sorghum.

The whole-grain sorghum and whole-grain wheat breakfast cereals (Fig. 1) were stored in polyethylene bags at 10 ± 2 °C until analyses.

2.2. Sensory acceptance

The acceptance of sorghum and wheat breakfast cereals was evaluated by 51 untrained judges (21.6% male, 78.4% female) from the Federal University of Viçosa, Brazil, and surrounding areas. The study protocol was approved by the Human Ethical Committee in Scientific Research (CAAE: 13630513.0.0000.5153) of the Federal University of Viçosa.

The breakfast cereals (10–15 g) were served in plastic 50 ml cups coded with three digit numbers. Mineral water was provided for cleaning the mouth between analyzes of each product formulation. Along with the samples, each judge received a form to evaluate the acceptance of the extrudates. The Food Action Rating Scale (FACT) was used, being assigned score 9 to "I would eat it whenever I had the chance" and the score 1 for "Just eat that if I was forced" (Minim, 2013).

2.3. Determination of bioactive compounds

The occurrence and content of flavonoids (3-DXA, flavones and flavanones) and vitamin E (α, β, γ and δ-tocopherols and tocotrienols) were determined in sorghum and wheat breakfast cereals in five replicates. During all analyses, the samples and the extracts were protected from light (artificial and sunlight) and oxygen using amber glassware, aluminium foil and blackout curtains, and bottles with nitrogen gas environment.

Fig. 1. Whole-grain sorghum breakfast cereal (A) and whole-grain wheat breakfast cereal (B).

2.3.1. Flavonoids

To extract the flavonoids, 20 ml of methanolic HCl solution 1% (v:v) were added to 2 g of sample and stirred for 120 min at 180 rpm. Then, the suspension was centrifuged at 2790*g* for 5 min and the supernatant collected, kept in amber bottle and stored in a freezer (−18 ± 1 °C) until analysis (Dykes, Seitz, Rooney, & Rooney, 2009).

The method described by Yang, Allred, Geera, Allred, and Awika (2012) and modified by Cardoso, Pinheiro, Martino, and Pinheiro-Sant'Ana (2015b) was used to identify and quantify the 3-deoxyanthocyanidins (luteolinidin, apigeninidin, 7-methoxy-apigeninidin and 5-methoxy-luteolinidin), flavones (luteolin and apigenin) and flavanones (naringenin and eriodictyol). Flavonoids were determined in a high performance liquid chromatography (HPLC) system (Shimadzu, SCL 10AT VP, Japan) equipped with diode array detector (DAD) (Shimadzu, SPD-M10A, Japan), high pressure pump (Shimadzu, LC-10AT VP, Japan, autosampler with loop of 500 µl (Shimadzu, SIL-10AF, Japan), and helium degassing system. The following chromatographic conditions were used: Kinetix C-18 column (150 × 4.6 mm id, 5 µm) equipped with a C-18 guard column (4 mm × 3 mm) (Phenomenex, Torrance, CA), column temperature 35 °C, injection volume of 20 µl, scan range 200–700 nm with detection at 480 nm for 3-deoxyanthocyanidins, 360 nm for flavones and 280 nm for flavanones. The mobile phase was composed of 2% formic acid in ultrapure water (line A) and 2% formic acid in acetonitrile (line B). The elution gradient of B was as follows: 0–3 min, 10% isocratic; 3–4 min, 10–12%, 4–5 min isocratic 12%; 5–8 min, 12–18%, 8–10 min, isocratic 18%; 10–12 min, 18–19%, 12–14 min, isocratic 19%; 14–18 min, 19–21%, 18–22 min, 21–26%, 22–28 min, 26–28%, 28–32 min, 28–40%, 32–34 min, 40–60% 34–36 min, isocratic 60%; 36–38 min, 60–10%, 38–45 min, isocratic 10%. To increase the repeatability of the retention time of the peaks it was used the following gradient: of 0–36 min flow 0.55 ml/min; 36–38 min, from 0.55 to 1.1 ml/min, 38–44 min, 1.1 ml/min; 44–45 min, 1.1 to 0.55 ml/min and the mobile phase was degassed with helium gas at 50 kPa before and during runs.

The identification of flavonoids was conducted by comparing the retention time and the absorption spectrum of the peaks of luteolinidin chloride (Sigma-Aldrich, St. Louis, MO, USA), apigeninidin chloride (Chromadex Santa Ana, CA, USA), luteolin, apigenin, naringenin and eriodictyol (Sigma-Aldrich, St. Louis, MO, USA), and samples analyzed under the same conditions. For quantification, analytical curves constructed from injection, in duplicate, of standard solutions with six different concentrations were used. The 5-MeO-LUT and 7-MeO-API were quantified using luteolinidin and apigeninidin standards, respectively, along with the appropriate molecular weight correction factor (Dykes et al., 2009). The compounds were expressed in µg/100 g of sample, as single compounds and as the sum of 3-DXAs.

2.3.2. Vitamin E

The occurrence and content of the eight components of vitamin E were carried out according to Pinheiro-Sant'Ana et al. (2011). Four milliliters (4 ml) of heated ultrapure water (80 ± 1 °C); 10 ml of isopropanol; 1.0 ml of hexane containing 0.05% BHT, 5 g of anhydrous sodium sulfate and 25 ml of extraction solvent mixture (hexane: ethyl acetate, 85:15, v/v) were added to approximately 5 g of sorghum or wheat flour. Subsequently, the suspension was homogenized using a micro grinder for 1 min and it was vacuum filtered on a Buchner funnel using filter paper, maintaining the residue in the extraction tube. The extraction step was repeated, adding to the residue 5 ml of isopropanol and 30 ml of the solvent mixture, with subsequent homogenization and vacuum filtration. Then, the extract was concentrated in a rotary evaporator at 70 ± 1 °C (2 min), transferred to a volumetric flask and made up to 25 ml with solvent mixture.

After extraction, an aliquot of 5.0 ml of extract were dried in nitrogen gas, recovered in 2.0 ml HPLC grade hexane (Tedia, Brazil) and filtered in filter units with porosity of 0.45 µm (Millipore, Brazil). Analyses were performed by injecting 15 µl of the extracts. The following chromatographic conditions were used: HPLC system (Shimadzu, SCL 10AD VP, Japan); fluorescence detector (290 nm excitation and 330 nm emission; Shimadzu, RF10AXL); Phenomenex Luna Si100 column (250 × 4 mm, 5 µm) coupled Si100 Phenomenex guard column (4 × 3 mm). The mobile phase was composed by hexane: isopropanol: glacial acetic acid (98.9:0.6:0.5 v/v/v); flow rate of 1.0 ml/min and run time of 22 min.

The identification of vitamin E compounds was conducted by comparing the retention time of the peaks of the commercial standards and samples analyzed under the same conditions. For quantification, analytical curves constructed from injection, in duplicate, of standard solutions prepared from commercial standards (Calbiochem®, EMD Biosciences, Inc. EUA) with six different concentrations were used.

2.4. Determination of antioxidant activity

The antioxidant activity was determined by spectrophotometry, using the DPPH· radical method (1,1-diphenyl-2-picrylhydrazyl) (Bloor, 2001), in triplicate. Twenty milliliters (20 ml) of acetone solution at 70% was added to 2 g of sorghum or wheat extrudates. Then, the suspension was stirred at 180 rpm (2 h) and centrifuged at 2790*g* (5 min). The supernatant was transferred to an amber bottle and stored in a freezer (−18 ± 1 °C) until analysis.

In a test tube, protected from light, 100 µl of the extract was added to 1.5 ml of methanol solution of DPPH· 0.1 mM and stirred by vortex for 30 s. After 30 min of standing, the absorbance of the solution was read in a spectrophotometer (Thermo Scientific, Evolution 606, USA) at 517 nm. The results were expressed as mmol Trolox equivalent/g sample. The 6-hydroxy-2,5,7,8-tetramethyl chroman-2-carboxylic acid (trolox) was obtained from Sigma-Aldrich (St. Louis, MO, USA).

2.5. Determination of total phenolic

The total amount of phenolic compounds was determined in triplicate using the Folin-Ciocalteu reagent (Singleton, Orthofer, & Lamuela-Raventos, 1999).

For analysis, 500 µl of the extract obtained in item 2.4 were added to 500 µl of Folin-Ciocalteu solution (20%) and 500 µl of sodium carbonate solution (7.5%). Then, the solution was stirred by vortex and incubated at room temperature for 30 min. The reading of absorbance was performed in spectrophotometer Evolution 606 (Thermo Scientific, USA) at 765 nm. Analytical curve of gallic acid (Sigma-Aldrich, St. Louis, MO, USA) (0.005–0.10 mg/ml) was used to quantify the phenolic compounds. The results were expressed in mg of gallic acid equivalents/g of sample (mg GAE/g).

2.6. Experimental design and statistical analysis

For sensory analysis, a randomized block design was used, with the blocks represented by the judges. Data normality was assessed using the Shapiro-Wilk test. The data were analyzed by ANOVA, followed by Tukey test. To compare the content of bioactive compounds between sorghum and wheat extrudates, the Student-*t* test was used. Statistical analyzes were performed using IBM SPSS Statistics software version 20.0 (Chicago, USA), adopting a significance level (α) of 5%.

3. Results and discussion

3.1. Sensory acceptance

Although little known for Brazilian people, the sensorial acceptance of whole-grain sorghum breakfast cereal ("I would eat it frequently") was higher ($p < 0.05$) than the whole-grain wheat breakfast cereal ("I would eat it if it had available, but I do not force myself to eat it") (Table 1).

Only the sorghum breakfast cereal was considered acceptable (Table 2) by presenting index of acceptance greater than 70% (Gularte, 2002). Although not evaluated in the present study, the most attractive colour (Fig. 1) and less dense texture of sorghum breakfast cereal may have contributed to its greater acceptance, as verified in other studies (González, 2005; Sanchez, 2004; Shin, 1986). Studies show that sorghum-based products may have better texture, greater expansion and lower density that wheat-based (Shin, 1986) and maize-based products (Sanchez, 2004).

González (2005) demonstrated that excellent flavour, appearance and texture were obtained from whole grains brown tannin-sorghums, and could be an excellent choice for food processors. Sorghum with tannin also produced good extrudates, making it possible to add value to the product, due to its nutraceutical properties. Moreover, its reddish-brown appearance can be an advantage in special products (González, 2005). Therefore, the whole-grain sorghum breakfast cereal evaluated in the present study could be a good alternative for the food industry, since sorghum used also has a brown colour and the presence of tannins.

3.2. Flavonoids

We found four 3-DXAs (LUT, AP, 5-MeO-LUT and 7-MeO-AP) in the sorghum breakfast cereal (Fig. 2) and none in the wheat breakfast cereal (Table 3). Studies demonstrated that these are the main sorghum 3-DXAs and they are mainly found in grains with dark coloured pericarp (brown > red > yellow) (Awika, Rooney, & Waniska, 2004; Cardoso et al., 2015b; Dykes, Rooney, & Rooney, 2013). The maximum wavelength and retention time of 3-deoxyanthocyanidins in whole-sorghum breakfast cereal are presented in Table 4.

Apigeninidin was the most prevalent compound, comprising on average 36.18% of total DXAs (Table 3). Our result differs from the one verified by Cardoso et al. (2015b), in which 5-methoxyluteolinidin was more prevalent in extruded sorghum flour than apigeninidin. The difference in results can be attributed to environment interaction since the non-methoxylated 3-DXAs are more prone to degradation under weathering conditions (Taleon, Dykes, Rooney, & Rooney, 2012). Furthermore, sorghum used in the Cardoso et al. (2015b) experiment and in the present study were grown at different times.

The presence of 3-DXAs in whole-grain sorghum breakfast cereal may suggest that this cereal has potential to benefit human health, especially due to its antioxidant and anticancer properties (Awika et al., 2004; Cardoso, Pinheiro, Martino, & Pinheiro-Sant'Ana, 2015b). Extracts containing these compounds were able to inhibit the growth of cancer cells, reducing the oxidative stress and inflammation and improve the lipid profile (Awika, Yang, Browning, & Faraj, 2009; Cardoso et al., 2015b). Thus, the consumption of whole-grain sorghum breakfast cereal should be encouraged.

Despite being present in wheat (Hernandez, Afonso, Rodriguez, & Diaz, 2011) and whole-sorghum grains (Cardoso et al., 2015b), flavones and flavanones were not detected in breakfast cereals. In a previous study (Cardoso et al., 2015b), it was demonstrated that flavones and flavanones of sorghum are labile to extrusion cooking. This sensitivity to extrusion can also be the cause of the absence of flavones and flavanones in whole-wheat breakfast cereal in the present study.

Table 1
Medium Attitude Scale FACT for sorghum and wheat breakfast cereals.

Formulations	Mean ± SD
Whole-grain sorghum	6.67 ± 1.58[a]
Whole-grain wheat	5.37 ± 2.03[b]

Data expressed as mean ± standard deviation of the acceptance test responses. Means followed by different letters differ statistically at 5% probability by Tukey test.

Table 2
Distribution of percentage of rejection, indifference and acceptance of sorghum and wheat breakfast cereals.

Formulations	% Rejection (score ⩽ 4)	% Indifference (score = 5)	% Acceptance (score ⩾ 6)
Whole-grain sorghum	1.96	27.45	70.59
Whole-grain wheat	33.33	25.49	41.18

3.3. Vitamin E

The whole-grain wheat breakfast cereal showed a higher total vitamin E content than the sorghum breakfast cereal ($p < 0.05$) (Table 3). As in unprocessed whole-grain sorghum (Cardoso, Pinheiro, da Silva, et al., 2015c; Cardoso et al., 2014; Martino et al., 2012), the sorghum breakfast cereal showed a higher content of γ-tocopherol (59.5% of total vitamin E), followed by α-tocopherol (28.9% of total vitamin E) (Table 3).

The α-tocopherol isomer has the highest *in vivo* biopotency, because its plasma concentration is maintained at significant levels in the body, while the other absorbed compounds are almost completely excreted (Martino et al., 2012; Traber, 2001). α-tocopherol and γ-tocopherol content was higher in whole-grain breakfast sorghum compared to the whole-grain wheat breakfast cereal in the present study ($p < 0.05$).

Tocotrienols were more predominant than tocopherols in whole-grain wheat breakfast cereal, especially the β-tocotrienol (80.4% of total vitamin E), as well as reported by others authors (Lampi, Nurmi, Ollilainen, & Piironen, 2008).

Tocopherols and tocotrienols naturally occur in cereals and are potent antioxidants with lipoperoxyl radical-scavenging activities (Jiang, 2014; Nielsen & Hansen, 2008). These vitamin E forms scavenge reactive nitrogen species, inhibit cyclooxygenase- and 5-lipoxygenase-catalyzed eicosanoids, and suppress proinflammatory signaling (Jiang, 2014). They are associated with a lower risk for cardiovascular diseases, cancer and dyslipidemia (Nielsen & Hansen, 2008). The content of vitamin E of sorghum and wheat breakfast cereals contributed to the antioxidant activity of theses cereals.

3.4. Phenolic compounds and antioxidant activity

Sorghum breakfast cereal showed a higher content of phenolic compounds than wheat breakfast cereal (Table 3). It is important to note that the content of phenolic compounds in both cereals may be overestimated due to the action of interferents, such as proteins, nucleic acids and amino acids, which can react with Folin-Ciocalteu reagent (Granger, Gallagher, Fuerst, & Alldredge, 2011; Naczk & Shahidi, 2006).

Sorghum has the highest content of phenolic compounds among cereals (Cardoso et al., 2015b). Phenolic compounds are

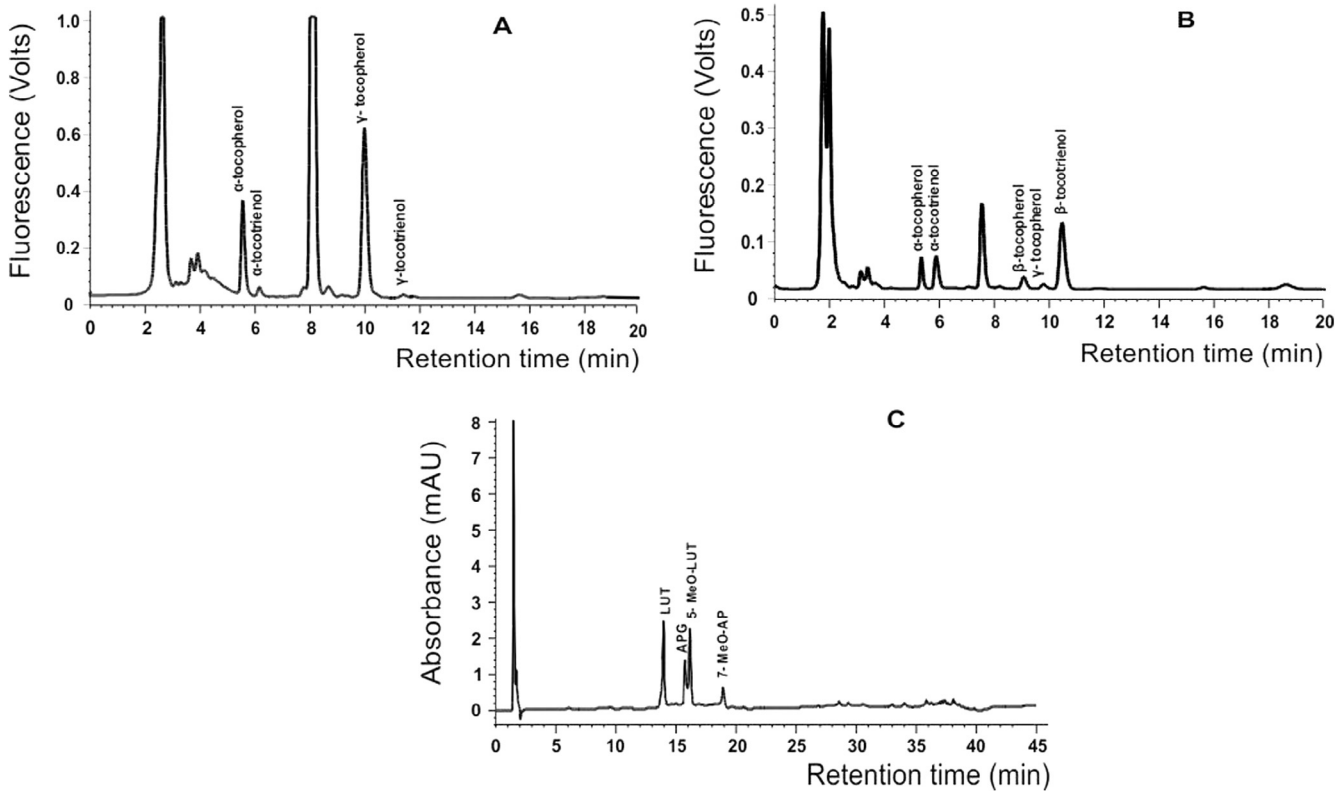

Fig. 2. HPLC analyses of vitamin E in sorghum (A) and in wheat (B), and 3-deoxyanthocianidins in sorghum breakfast cereal (C). LUT: Luteolinidin; APG: apigeninidin; 5-MeO-LUT: 5-methoxy-luteolinidin; 7-MeO-AP: 7-methoxy-apigeninidin.

Table 3
Profile and content of 3-deoxyanthocyanidins, vitamin E, phenolic compounds and antioxidant activity in whole-grain sorghum and wheat breakfast cereals.

Compounds	Whole-grain sorghum breakfast cereal	Whole-grain wheat breakfast cereal
Total 3-DXAs (μg/100 g)	366.46 ± 79.91[a]	nd[b]
Luteolinidin	94.77 ± 7.28[a]	nd[b]
Apigeninidin	132.61 ± 27.68[a]	nd[b]
5-MeO-LUT	41.15 ± 18.16[a]	nd[b]
7-MeO-API	111.64 ± 18.19[a]	nd[b]
Total vitamin E (μg/100 g)	796.90 ± 33.72[b]	3727.50 ± 352.0[a]
α-tocopherol	230.90 ± 11.80[a]	116.08 ± 4.33[b]
α-tocotrienol	70.62 ± 2.94[b]	463.52 ± 20.02[a]
β-tocopherol	nd[b]	83.70 ± 3.90[a]
β-tocotrierol	nd[b]	2997.60 ± 289.50[a]
γ-tocopherol	474.06 ± 21.52[a]	66.56 ± 9.11[b]
γ-tocotrienol	5.88 ± 0.58[a]	nd[b]
δ-tocopherol	nd	nd
δ-tocotrienol	nd	nd
Total phenolic compounds (mg GAE/g)	1.11 ± 0.06[a]	0.33 ± 0.02[b]
Antioxidant activity (mmolTrolox/g)	4.05 ± 0.04[a]	0.49 ± 0.08[b]

5-MeO-LUT: 5-methoxy-luteolinidin; 7-MeO-API: 7-methoxy-apigeninidin; 3-DXAs: 3-deoxyanthocyanidins; nd: not detected. The results were expressed as fresh matter as the average of five replicates ± standard deviation. Same letters on the line do not differ by *t* test at 5% probability.

Table 4
Maximum wavelength and retention time of 3-deoxyanthocyanidins in whole-sorghum breakfast cereal.

Compounds	λ_{max} (nm)	Retention time (min)
Luteolinidin	239	13.4
Apigeninidin	240	14.7
5-Methoxy-Luteolinidin	240	15.0
7-Methoxy-Apigeninidin	240	17.4

widely distributed in plants and their antioxidant activity and free radical scavenging ability have potential beneficial implications in human health (Hernandez et al., 2011).

The whole-grain sorghum breakfast cereal presented higher antioxidant activity than the extruded wheat ($p < 0.05$) (Table 3).

The high sorghum antioxidant capacity, from the phenolic compounds, has been demonstrated by others studies (Awika et al., 2009; Cardoso et al., 2015b). Furthermore, it should be noted that the sorghum SC319 genotype contains tannins, which is the major antioxidant in sorghum (Dlamini et al., 2007). In addition, sorghum grains contain carotenoids and are a vitamin E source, which contribute to its antioxidant activity. Cardoso et al. (2014) observed that the antioxidant activity of sorghum flours correlated positively with the content of α-and γ-tocopherols, total vitamin E, total phenolic compounds, luteolinidin, apigeninidin and total 3-DXAs.

Consumption of whole-grain sorghum breakfast cereal should be encouraged since it contains high content of phenolic compounds and antioxidant activity that can beneficially modulate variables related to diabetes, obesity, dyslipidemia, oxidative stress and inflammation (Awika et al., 2009; Cardoso et al., 2015a; Yang et al., 2012).

4. Conclusion

The whole-grain sorghum breakfast cereal showed better sensory acceptance, higher 3-deoxyanthocyanidin and phenolic compounds content which contributes to its higher antioxidant

capacity. The whole-grain wheat breakfast cereal presented higher vitamin E content than whole-sorghum breakfast cereal.

The consumption of whole-grain sorghum breakfast cereal should be encouraged since it had good sensory acceptance and is a source of bioactive compounds that can promote benefits to human health.

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References

Awika, J. M., Rooney, L. W., & Waniska, R. D. (2004). Properties of 3-deoxyanthocyanins from sorghum. *Journal of Agricultural and Food Chemistry, 52*, 4388–4394.

Awika, J. M., Yang, L., Browning, J. D., & Faraj, A. (2009). Comparative antioxidant, antiproliferative and phase II enzyme inducing potential of sorghum (Sorghum bicolor) varieties. *LWT-Food Science and Technology, 42*, 1041–1046.

Bloor, S. J. (2001). Overview of methods for analysis and identification of flavonoids. *Methods in Enzymology, 335*, 3–14.

Cardoso, L. M., Montini, T. A., Pinheiro, S. S., Pinheiro-Sant'Ana, H. M., Martino, H. S. D., & Moreira, A. V. B. (2014). Effects of processing with dry heat and wet heat on the antioxidant profile of sorghum. *Food Chemistry, 152*, 210–217.

Cardoso, L. M., Pinheiro, S. S., Carvalho, C. W. P., Queiroz, V. A. V., Menezes, C. B., Moreira, A. V. B., et al. (2015a). Phenolic compounds profile in sorghum processed by extrusion cooking and dry heat in a conventional oven. *Journal of Cereal Science, 65*, 220–226.

Cardoso, L. M., Pinheiro, S. S., da Silva, L. L., de Menezes, C. B., de Carvalho, C. W. P., Tardin, F. D., et al. (2015b). Tocochromanols and carotenoids in sorghum (Sorghum bicolor L.): Diversity and stability to the heat treatment. *Food Chemistry, 172*, 900–908.

Cardoso, L. M., Pinheiro, S. S., Martino, H. S. D., & Pinheiro-Sant'Ana, H. M. (2015c). Sorghum (Sorghum bicolor l.): nutrients, bioactive compounds, and potential impact on human health. *Critical Reviews in Food Science and Nutrition*.

Carson, L., Setser, C., & Sun, X. S. (2000). Sensory characteristics of sorghum composite bread. *International Journal of Food Science & Technology, 35*, 465–471.

Dlamini, N. R., Taylor, J. R., & Rooney, L. W. (2007). The effect of sorghum type and processing on the antioxidant properties of African sorghum-based foods. *Food Chemistry, 105*, 1412–1419.

Dykes, L., Rooney, W. L., & Rooney, L. W. (2013). Evaluation of phenolics and antioxidant activity of black sorghum hybrids. *Journal of Cereal Science, 58*, 278–283.

Dykes, L., Seitz, L. M., Rooney, W. L., & Rooney, L. W. (2009). Flavonoid composition of red sorghum genotypes. *Food Chemistry, 116*, 313–317.

González, A. J. P. (2005). *Specialty sorghums in direct-expansion extrusion* (p. 103). Texas: Texas A&M University.

Granger, K. L., Gallagher, R. S., Fuerst, E. P., & Alldredge, J. R. (2011). Comparison of seed phenolic extraction and assay methods. *Methods in Ecology and Evolution, 2*, 691–698.

Gularte, M. A. (2002). *Manual de análise sensorial de alimentos* (Vol. 29). Universidade Federal de Pelotas.

Hernandez, L., Afonso, D., Rodriguez, E. M., & Diaz, C. (2011). Phenolic compounds in wheat grain cultivars. *Plant Foods for Human Nutrition, 66*, 408–415.

Jiang, Q. (2014). Natural forms of vitamin E: Metabolism, antioxidant, and anti-inflammatory activities and their rolein disease prevention and therapy. *Free Radical Biology and Medicine, 72*, 76–90.

Lampi, A.-M., Nurmi, T., Ollilainen, V., & Piironen, V. (2008). Tocopherols and tocotrienols in wheat genotypes in the HEALTHGRAIN diversity screen. *Journal of Agricultural and Food Chemistry, 56*, 9716–9721.

Martino, H. S. D., Tomaz, P. A., Moraes, É. A., Conceiçãol, L. L. d., Oliveira, D. d. S., Queiroz, V. A. V., et al. (2012). Chemical characterization and size distribution of sorghum genotypes for human consumption. *Revista do Instituto Adolfo Lutz (Impresso), 71*, 337–344.

Minim, V. P. R. (2013). *Análise sensorial estudos com consumidores, 3 ed*.

Naczk, M., & Shahidi, F. (2006). Phenolics in cereals, fruits and vegetables: Occurrence, extraction and analysis. *Journal of Pharmaceutical and Biomedical Analysis, 41*, 1523–1542.

Nielsen, M. M., & Hansen, Å. (2008). Rapid high-performance liquid chromatography determination of tocopherols and tocotrienols in cereals. *Cereal Chemistry, 85*, 248–251.

Pinheiro-Sant'Ana, H. M., Guinazi, M., da Silva Oliveira, D., Della Lucia, C. M., de Lazzari Reis, B., & Brandão, S. C. C. (2011). Method for simultaneous analysis of eight vitamin E isomers in various foods by high performance liquid chromatography and fluorescence detection. *Journal of Chromatography A, 1218*, 8496–8502.

Poquette, N. M., Gu, X., & Lee, S. O. (2014). Grain sorghum muffin reduces glucose and insulin responses in men. *Food & Function, 5*, 894–899.

Queiroz, V. A. V., Moraes, É. A., Martino, H. S. D., Paiva, C. L., & de Menezes, C. B. (2014). Potencial do sorgo paro uso na alimentação humana. *Informe Agropecuário Belo Horizonte, 35*, 7–12.

Sanchez, D. A. (2004). *White food-type sorghum in direct-expansion extrusion applications*. Texas A M University.

Shin, L. (1986). *Sorghum based breakfast cereal*. Lincoln, NE: University of Nebraska-Lincoln.

Singleton, V. L., Orthofer, R., & Lamuela-Raventos, R. M. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. *Methods in Enzymology, 299*, 152–178.

Stefoska-Needham, A., Beck, E. J., Johnson, S. K., & Tapsell, L. C. (2015). Sorghum: An underutilized cereal whole grain with the potential to assist in the prevention of chronic disease. *Food Reviews International, 31*, 401–437.

Taleon, V., Dykes, L., Rooney, W. L., & Rooney, L. W. (2012). Effect of genotype and environment on flavonoid concentration and profile of black sorghum grains. *Journal of Cereal Science, 56*, 470–475.

Taylor, J. R., Schober, T. J., & Bean, S. R. (2006). Novel food and non-food uses for sorghum and millets. *Journal of Cereal Science, 44*, 252–271.

Traber, M. G. (2001). Vitamin E: Too much or not enough? *The American Journal of Clinical Nutrition, 73*, 997–998.

Vargas-Solórzano, J. W., Carvalho, C. W. P., Takeiti, C. Y., Ascheri, J. L. R., & Queiroz, V. A. V. (2014). Physicochemical properties of expanded extrudates from colored sorghum genotypes. *Food Research International, 55*, 37–44.

Yang, L., Allred, K. F., Geera, B., Allred, C. D., & Awika, J. M. (2012). Sorghum phenolics demonstrate estrogenic action and induce apoptosis in nonmalignant colonocytes. *Nutrition and Cancer, 64*, 419–427.