Chemical characterization and size distribution of sorghum genotypes for human consumption

Caracterização química e distribuição granulométrica de genótipos de sorgo para alimentação humana

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ABSTRACT
The purpose of this paper was to evaluate the approximate composition, size distribution, minerals and vitamin E isomers concentrations in eight sorghum genotypes available for human consumption. The protein concentration of samples ranged from 8.57 to 11.59%, lipids from 1.24 to 3.07% and carbohydrates from 57.3 to 64.7%. The total dietary fiber varied from 9.13% to 15.09%. Sorghum genotytes flours were characterized as hard grain and of coarse granulometry**,** which are the relevant aspects for developing food products. Soghum genotypes were considered as sources of iron, phosphorus, magnesium and zinc. The α and γ-tocopherol isomers were determined in sorghum genotypes grain and flour**,** and γ-tocopherol was predominant. In conclusion, sorghum genotypes evidenced to be as relevant sources of dietary fiber, iron, phosphorus, magnesium and zinc. Furthermore, the sorghum genotypes were classified as hard grain , suitable for formulating bakery products.
Keywords. *Sorghum bicolor L. Moench*, size distribution, vitamin E, minerals, nutritional value.

RESUMO
Foram avaliadas as características de composição centesimal, distribuição granulométrica, concentração de minerais e isômeros de vitamina E de oito genótipos de sorgo destinados à alimentação humana. A concentração proteica das amostras variou de 8,57 a 11,59%, e os lipídios de 1,24 a 3,07% e os carboidratos de 57,3 a 64,7%. A fibra alimentar total variou de 9,13% a 15,09%. As farinhas dos genótipos foram caracterizadas como de granulometria grossa e grão duro, cujos aspectos são relevantes para elaborar produtos alimentícios. Dentre os treze minerais pesquisados, os genótipos foram considerados como fonte de ferro, fósforo, magnésio e zinco. Foram determinados os isômeros α e γ-tocoferol nas amostras de grãos e farinhas dos oito genótipos, sendo predominante o γ-tocoferol. Em conclusão, os genótipos de sorgo destacaram-se como boas fontes de fibra alimentar, ferro, fósforo, magnésio e zinco. Além disso, os genótipos de sorgo foram classificados como duros grãos, adequado para a elaboração de produtos de panificação.
Palavras-chave. *Sorghum bicolor L. Moench*, distribuição granulométrica, vitamina E, minerais, valor nutricional.

INTRODUCTION

Sorghum (*Sorghum bicolor L. Moench*) stands out as fifth most produced cereal in the world and fourth in Brazil[1,2]. Sorghum constitutes the major source of proteins, calories and minerals for millions of people individuals, principally in Africa and Asia[3,4]. However, the human consumption of sorghum in Brazil is not significant and its production is destined mainly for animal feeds[5,6].

Carbohydrates under starch form are the main sorghum macronutrients[7], followed by proteins, typically deficient in the essential amino acids lysine, methionine and cysteine[8]. Lipids content are low and they are present especially under polyunsaturated fatty acids form[9]. The mineral and vitamin composition of sorghum are similar to corn. Potassium and phosphorus are prevalent, as well as B vitamins complex and fat soluble vitamins A, D, E and K[10,11]. It is noteworthy that nutrients composition of sorghum is influenced by its genetics[7]. In this context, the Brazilian Agency of Maize and Sorghum Research (Embrapa Maize and Sorghum, MG, Brazil) is developing sorghum genetic improvement studies in order to select genotypes with nutritional quality and technology, aiming to encourage the use of sorghum in human consumption.

Sorghum is usually consumed as grain or as flour in recipes including fermented and unfermented porridges, bakery products and is also used in the manufacture of alcoholic beverages[12,13]. Sorghum is a cereal devoid of gluten, it can replace wheat in bakery products, especially with the aim of developing food products for individuals with celiac disease[14]. The development of products made from sorghum of different genotypes, which differ mainly in grain color and the presence of tannins, result in foods with high technological and sensory quality[2,15].

Given the potential of sorghum for development of foods and its great variability in composition due to plant genetics, justifies the search for genotypes showing nutritional characteristics suitable for this purpose. The objective of this study was to evaluate the approximate composition, size distribution and concentrations of minerals and vitamin E isomers in eight sorghum genotypes for human consumption.

MATERIALS AND METHODS

Samples

Eight sorghum genotypes were developed and provided by Embrapa Maize and Sorghum, Sete Lagoas, MG, Brazil: BR 501 and BR 506 (white grains without tannin), BRS 700 and BR 305 (grain brown with tannin), BRS 309 (white grains without tannin), BRS 310 (red grains, without tannin), CMSXS 136 (white grains without tannin), BR 007 (red grains, without tannins). The planting of sorghum was conducted using techniques of crop cultivation, where the spacing between rows was 0.70 m with a mean density of 140,000 plants per hectare. Crop fertilization was 350 $kg.ha^{-1}$ of the formula 08-28-16 + 0.5% Zn. Fertilization was 100 $kg.ha^{-1}$ of urea applied 40 days after germination. Planting was done in Sete Lagoas, MG, Brazil, in February 2009.

Preparation and size distribution of the sorghum flours

Sorghum grains were manually selected and subjected to sieving for removal of dirt and impurities. To prepare the integral sorghum flours, the grains were crushed with pericarp in a knives mill (CW Brasender, Dusburg, Germany) with a number zero sieve.

To determine flour distribution size of the sorghum genotypes, 100 g of each flour sample were sieved, in duplicate, for 10 minutes in vibratory sieves with mesh openings of 0.84, 0.42, 0.25, 0.21, 0.17 and 0.14 μm. The amounts retained on each sieve were weighed and expressed in percentages.

Approximate composition

Determination of moisture, protein, lipids and ash content of flour from the eight sorghum genotypes was conducted in triplicate according to the methodology recommended by AOAC[16]. The determination of soluble and insoluble dietary fiber was performed in accordance with the enzymatic gravimetric method[16]. Total dietary fiber was obtained by summing the soluble and insoluble dietary fiber. The carbohydrate content was calculated by difference using the equation: 100 - (moisture + protein + lipid + ash + dietary fiber). The caloric value of the flour was calculated using the Atwater conversion factors: 9 kcal per gram of lipid, 4 kcal per gram of carbohydrate and 4 calories per gram of protein.

Quantification of minerals

The content of aluminum, cadmium, calcium, lead, copper, chromium, sulfur, iron, phosphorus, magnesium, manganese, nickel and zinc were performed in triplicate. The minerals content was analyzed by acid digestion method with a nitropercloric mixture in a block digester and analyzed by atomic emission spectrophotometry with argon inductively coupled plasma (model "OPTIMA 3300 DV", Perkin Elmer brand) under the conditions of 1,300 W, cooling airflow of 15 $L.min^{-1}$, auxiliary air flow rate of 0.7 $L.min^{-1}$, carrier gas flow rate 0.5 $L.min^{-1}$, sample speed introduction of 1.5 $mL.min^{-1}$, observation height of 15 mm and use of a Meinhard nebulizer[17].

Quantification of vitamin E

Occurrence and content of the eight vitamin E isomers (α, β, γ and δ tocopherols and α, β, γ and δ tocotrienol) was investigated in grains and flours of the genotypes. The vitamin E quantification was performed in both the grains and flours of the genotypes, to investigate the content and behavior of the vitamin before and after processing.

The vitamin E extraction was performed in triplicate as performed by Guinaz et al.[18] with modifications, using a solvent mixture composed by hexane and ethyl acetate at a ratio of 85:15, v/v. The analysis of the vitamin E isomers was performed by High Performance Liquid Chromatography (HPLC) utilizing the chromatographic conditions used by Guinaz et al.[18].

The total vitamin E content was calculated as the sum of its isomers identified in sorghum flour, and the results expressed in $\mu g.100g^{-1}$ fresh matter.

Nutritional value of the sorghum genotypes

The content of minerals, dietary fiber and vitamin E in sorghum flour were compared to Dietary Reference Intakes – DRI[19] using the averages recommended for both genders and aged between 19 to 70 years. The references values of Adequate Intake (AI) were used to calcium, manganese and dietary fiber content and the Recommended Dietary Allowance (RDA) was used to the other minerals and vitamin E. The sorghum genotypes were considered sources of minerals, dietary fiber and vitamin E whether nutrients contents were greater than 5% of the specific recommended average of each mineral, as proposed by Philippi[20].

Statistical analysis

Approximate compositions content were expressed as mean content and the minerals and vitamin E content were expressed as the mean and standard deviation.

The in differences at minerals and vitamins content of the sorghum genotypes was analyzed by variance analysis (ANOVA) followed by the Tukey test, with 5% of probability. For the differences in concentration between total vitamin E and vitamin E isomers in the sorghum grains and flours, the student t-test was used with a significance level of 5%.

RESULTS AND DISCUSSION

Sorghum flour size distribution

The greatest percentage of flour was retained on the sieve with a mesh size of 0.42 µm, featuring it as granulometric coarse flour, durum grain, similar to the integral corn flour (Figure 1). This fact is important because the size distribution of raw material is a relevant aspect in the development of food products[21]. The sorghum flour presented granulometric features suitable for making different types of biscuits and pasta, and can be further refined to produce bread and cakes.

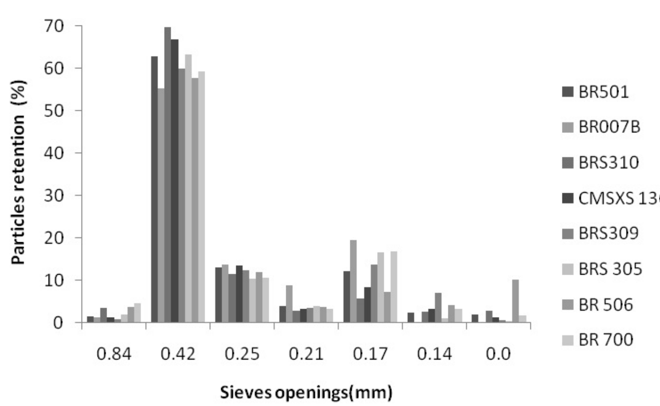

Figure 1. Particle size distribution of flour from eight sorghum genotypes for human consumption

Approximate composition

Protein concentration ranged from 8.6% (BR 700) to 11.9% (BRS 309). However, Antunes et al. [22] obtained a greater variation in proteins (9.9 to 18.0%) among genotypes BR 501, BR 506 and BRS 305, also investigated in this study. The lipid content ranged from 1.2% (CMSXS 136) to 3.1% (BR 501), agreeing with the results of Antunes et al. [22] and Ragaee et al.[23]. However, Mehmood et al.[9] showed higher lipid concentrations, ranging from 5.0 to 8.2% (Table 1).

Carbohydrates corresponded to the main macronutrient in the sorghum genotypes, ranging from 57.3% in the genotype BR 506 to 64.7% in BR 700 (Table

Table 1. Approximate composition of eight sorghum genotypes, intended for human consumption (g.100g^{-1})

Nutrient	Genotype							
	BR 501	BR 007B	BRS 310	CMSXS 136	BRS 309	BRS 305	BR 506	BR 700
Protein	9.91 ± 0.16^{c}	10.31 ± 0.13^{bc}	11.59 ± 0.14^{ab}	10.99 ± 0.79^{abc}	11.97 ± 0.15^{a}	10.11 ± 0.17^{c}	11.43 ± .14^{abc}	8.57 ± 0.17^{d}
Lipids	3,07 ± 0.04^{a}	2,33 ± 0.03^{c}	2.61 ± 0.07^{b}	1.24 ± 0.03^{e}	2.48 ± 0.15^{bc}	2.60 ± 0.08^{b}	2.36 ± 0.01^{bc}	1.94 ± 0.12^{d}
Carbohydrates	62.74	64.48	61.81	64.59	63.76	62.09	57.30	64.70
Soluble Fiber	0.17	0.29	0.70	0.28	0.88	0.15	0.63	0.83
Insoluble Fiber	11.01	9.23	9.01	8.85	8.30	11.28	14.46	10.85
Total Fiber	11.18	9.52	9.71	9.13	9.18	11.43	15.09	11.68
Ash	1.51 ± 0.02^{b}	1.46 ± 0.04^{b}	1.43 ± 0.07^{b}	1.49 ± 0.07^{b}	1.36 ± 0.05^{b}	1.32 ± 0.06^{b}	1.93 ± 0.07^{a}	1.23 ± 0.00^{b}
Moisture	11.59 ± 0.20^{cd}	11.90 ± 0.09^{bc}	12.85 ± 0.11^{a}	12.56 ± 0.35^{a}	11.25 ± 0.07^{d}	12.45 ± 0.03^{ab}	11.89 ± 0.18^{bcd}	11.88 ± 0.12^{bc}
Kcal.g^{-1}	318.23	320.13	317.09	313.48	325.24	312.20	296.16	310.54

Means followed by the same letters in the same rows do not differ by Tukey test ($p < 0.05$).

Table 2. Concentration of minerals in the flour produced from eight genotypes of sorghum for human foods (mg.100g^{-1})

Minerals	Genotypes							
	BR 501	BR 007B	BRS 310	CMSXS 136	BRS 309	BRS 305	BR 506	BR 700
Aluminum	nd	nd	nd	nd	nd	nd	nd	nd
Cadmus	nd	nd	nd	nd	nd	nd	nd	nd
Calcium	13.38^{ab} ± 3.51	12.55^{ab} ± 3.34	8.49^{b} ± 1.35	5.59^{b} ± 0.37	7.87^{b} ± 0.05	8.65^{b} ± 3.71	19.55^{a} ± 5.06	7.31^{b} ± 3.16
Lead	nd	nd	nd	nd	nd	nd	nd	nd
Copper	0.65^{ab} ± 0.25	0.34^{b} ± 0.02	0.37^{b} ± 0.04	0.40^{b} ± 0.06	0.48^{b} ± 0.30	0.33^{b} ± 0.08	1.01^{a} ± 0.26	0.49^{ab} ± 0.08
Chrome	nd	nd	nd	nd	nd	nd	nd	nd
Sulfur	77.42^{a} ± 12.13	85.62^{a} ± 3.73	77.24^{a} ± 7.52	70.32^{a} ± 13.03	66.97^{a} ± 17.76	79.78^{a} ± 9.04	100.85^{a} ± 26.23	75.43^{a} ± 16.95
Iron	1.28^{ab} ± 0.33	1.08^{b} ± 0.18	0.81^{b} ± 0.15	0.95^{b} ± 0.05	0.47^{b} ± 0.45	1.15^{b} ± 0.53	5.87^{a} ± 3.34	1.49^{ab} ± 0.48
Phosphorus	250.33^{ab} ± 17.28	217.13^{b} ± 16.71	187.74^{b} ± 8.17	202.52^{b} ± 64.13	204.55^{b} ± 28.87	179.59^{b} ± 22.30	278.48^{a} ± 28.36	222.63^{ab} ± 23.86
Magnesium	122.32^{ab} ± 16.72	97.16^{b} ± 10.34	79.02^{b} ± 6.75	85.57^{b} ± 18.11	99.93^{ab} ± 26.50	85.58^{b} ± 17.47	147.84^{a} ± 18.04	104.77^{ab} ± 11.77
Manganese	nd	nd	nd	nd	nd	nd	0.06 ± 0.11	nd
Nickel	nd	nd	nd	nd	nd	nd	nd	nd
Zinc	1.85^{a} ± 0.79	1.50^{a} ± 0.10	1.51^{A} ± 0.24	1.34^{a} ± 0.79	1.54^{A} ± 0.50	1.43^{a} ± 0.29	2.7^{a} ± 0.70	1.32^{a} ± 0.57

Means followed by the same letters in the same rows do not differ by Tukey test ($p < 0.05$)
nd = Not detected.

1). These concentrations were higher than those checked by Ragaee et al. (46.69%)[23].

The total dietary fiber content ranged from 9.1% for genotype CMSXS 136 to 15.1% for BR 506. Antunes et al.[22] demonstrated lower concentrations of crude fiber in sorghum genotypes. However, this may be due to the limitation of the method used by the authors[24]. Soluble dietary fiber content ranged from 0.15% for genotype BRS 305 to 0.88% for BRS 309. The insoluble fiber ranged from 8.3% in genotype BRS 309 to 14.5% in BR 506. The insoluble fraction content was greater than the soluble ones. Higher values of total, soluble and insoluble dietary fiber were reported by Ragaee et al. [23] (Table 1).

Ash content in the samples ranged from 1.2% for the genotype BR 700 to 1.9% for BR 506 (Table 1). Antunes et al. [22] showed ash concentrations up to 2.2%.

The approximate composition of sorghum genotypes, compared to commercial wheat flour, presented, on average, lower concentrations of protein, carbohydrate and energy and higher lipid and ash levels[25]. When it was compared to corn flour, sorghum presented lower concentrations of lipids, higher levels of carbohydrates and ash, and similar values for protein [26].

Minerals

The analyzed heavy metals (aluminum, cadmium, lead, chromium and nickel) were not detected in any studied genotype. This result confirm the safety of this cereal in regards to potentially toxic minerals[27]. The heavy metals absence in grains can be explained by the fact that their concentration varies in different plants tissues and generally the grains contain lower concentration than the vegetative parts[28]. Except manganese, which was verified only in the genotype BR 506, the other analyzed minerals (calcium, copper, sulfur, iron, phosphorus, magnesium and zinc) were detected in all genotypes (Table 2).

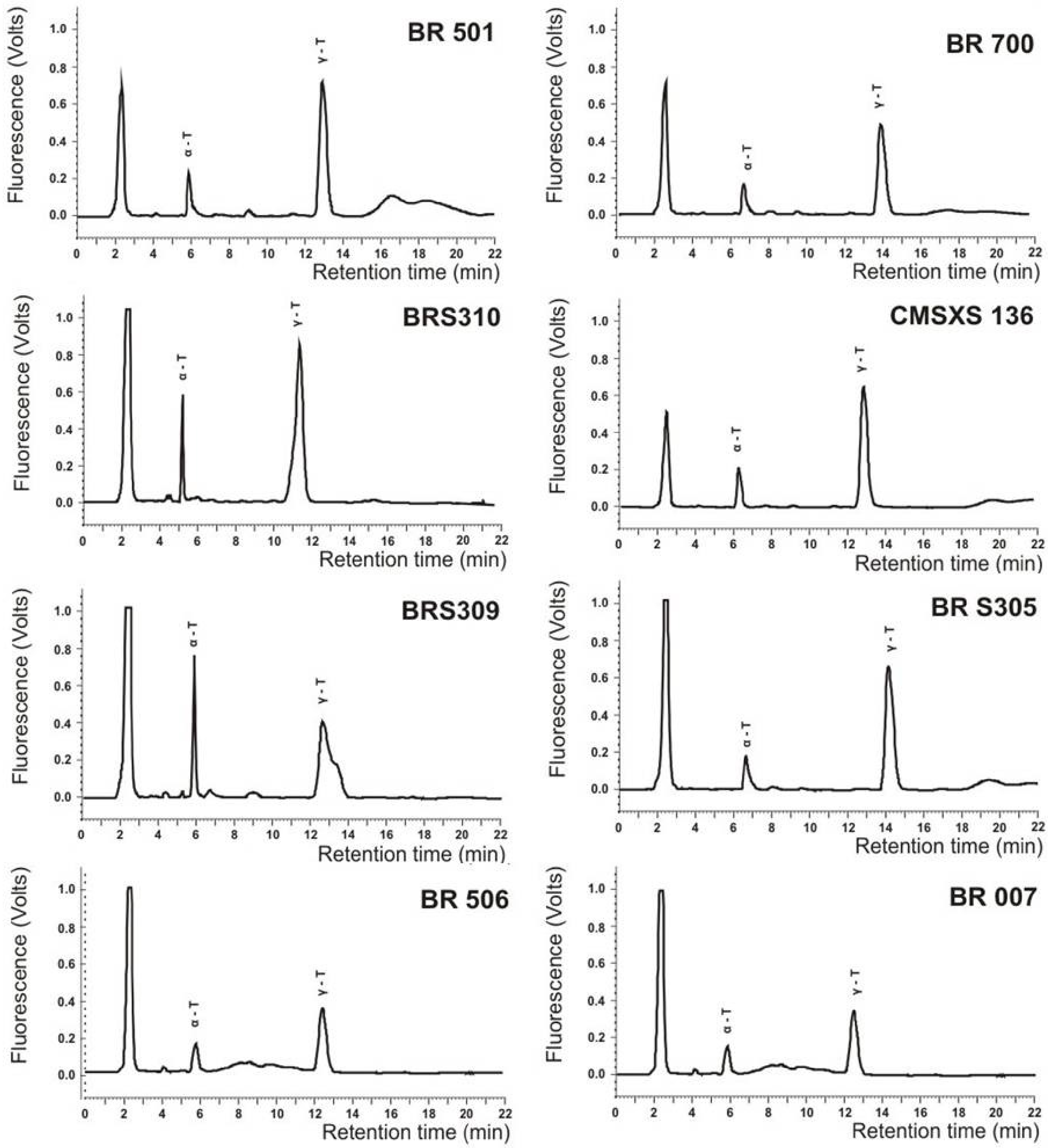

Figure 2. Analysis by High Performance Liquid Chromatography (HPLC) of tocopherols in sorghum flour. Chromatographic conditions: mobile phase – hexane: isopropanol (99.6:0.4), with pH adjusted to 2.5 with glacial acetic acid;-LiChrosorb column) fluorescence detector--chromatography (Si60 Phenomenex 250 × 4 mm, 5 (290 nm excitation and 330 nm emission), mobile phase flow: 1.0 mL.min^{-1}, injection volume: 50 μL. α-T: α-tocopherol, γ-T: γ-tocopherol

Table 3. Concentration of α-tocopherol, γ-tocopherol and total vitamin E (μg.100g^{-1}) in the grain and flour of eight different sorghum genotypes

Sorghum	Vitamin E	Genotypes							
		BR 501	BR 007B	BRS 310	CMSXS 136	BRS 309	BRS 305	BR 506	BR 700
Grains	α -tocopherol	136.79^{ab} ± 19.48*	162.66^{a} ± 26.16*	133.87^{ab} ± 18.65	83.91^{c} ± 31.13	167.95^{a} ± 19.99	109.13^{abc} ± 15.77	119.68^{ab} ± 20.35	84.34^{bc} ± 3.28*
	γ -tocopherol	244.62^{a} ± 20.78	184.22^{a} ± 149.86	321.93^{a} ± 20.75	172.33^{a} ± 69.98	236.49^{a} ± 17.50	270.61^{a} ± 20.00	202.69^{a} ± 46.18	163.35^{a} ± 40.63
	Vitamin E Total	381.40^{a} ± 40.26	346.88^{a} ± 176.02	455.81^{a} ± 39.40	256.24^{a} ± 100.80	404.44^{a} ± 37.47	379.73^{a} ± 35.76	322.37^{a} ± 66.52	247.68^{a} ± 43.89
Flour	α -tocopherol	83.62^{a} ± 11.38*	70.88^{a} ± 5.72*	136.57^{a} ± 78.83	94.20^{a} ± 15.63	122.44^{a} ± 25.52	85.64^{a} ± 7.12	94.86^{a} ± 20.25	60.66^{a} ± 6.32*
	γ -tocopherol	147.33^{a} ± 68.31	149.87^{a} ± 35.71	250.40^{a} ± 100.12	223.18^{a} ± 17.16	224.64^{a} ± 30.57	236.56^{a} ± 46.37	206.48^{a} ± 52.14	168.56^{a} ± 17.03
	Vitamin E Total	230,96^{a} ± 79,69	220,75^{a} ± 41,43	386,97^{a} ± 178,94	317,37^{a} ± 32,77	347,08^{a} ± 56,08	322,20^{a} ± 53,49	301,34^{a} ± 72,38	229,22^{a} ± 23,34

Values represent the average of three repetitions. Means in the same row followed by same letter do not differ at 5% probability by the Tukey test.
* Significant at 5% probability by the Student's t-test for comparisons of the same isomer of the grain and flour.

The BR 506 genotype showed higher contents of copper, iron, phosphorus and magnesium compared to the genotypes BRS 305, BRS 310 and CMSXS 136 (p > 0.05), and did not differ from genotypes BR 501 and BR 700 (p > 0.05). Sulfur and zinc content did not differ among the eight genotypes (p > 0.05).

In an studies performed by Ragaee et al. [23] the contents of phosphorus, magnesium, calcium, copper and zinc (34.99, 18.77, 2.73, 0.02 and 0.31 mg.100g^{-1}, respectively) were lower than the concentrations obtained in this study. The iron content was similar (1.06 mg.100g^{-1}) and manganese was higher (0.12 mg.100g^{-1}).

Vitamin E

The α and γ-tocopherol isomers were analyzed in grain and flours. However, the γ-tocopherol isomer was predominant in all samples. The chromatographic conditions used presented good resolution of α and γ-tocopherol, which allowed the safe quantification of these isomers in the samples (Figure 2). Retention times of α-tocopherol and γ-tocopherol in the grains and flours of sorghum were approximately 5.8 and 13.5 minutes, respectively. Analyses were performed on the grain and sorghum flour in order to verify whether processing would affect the concentration of this nutrient. The concentrations of α-tocopherol, γ-tocopherol and total vitamin E are presented in Table 3.

In grains, the α-tocopherol concentration ranged from 83.9 μg.100g^{-1} in genotype CMSXS 136 to 167.9 μg.100g^{-1} in BRS 309 (Table 3). The concentrations of total vitamin E and γ-tocopherol did not differ between the studied genotypes (p>0.05). For α-tocopherol, genotype CMSXS 136 presented a lower concentration, and did not statistically differ from BRS 305 and BR 700 (p> 0.05) (Table 3).

In the flours, the total concentration of vitamin E ranged from 220.7μg.100g^{-1} for the genotype BR 007B to 386.9μg.100g^{-1} for BRS 310. There was no difference in levels of total vitamin E and α and γ-tocopherol isomers (p > 0.05) of the eight genotypes studies (Table 3).

There was also no difference in the concentrations of γ-tocopherol and total vitamin E among grains and flours of the sorghum genotypes (p > 0.05). However, the concentration of α-tocopherol in the grains was higher in genotype BR 007B, BR 700 and BR 501 (p > 0.05). The α-tocopherol decreased in the flour of genotype BR 007B was 56.4%; for BR 700 this values was 8.3% and for BR 501 was 40%. This reduction may be relevant since the α-tocopherol isomer has the highest *in vivo* biopotency. This is because its plasma concentration is maintained at significant levels in the body, while the other absorbed compounds are almost completely excreted [29].

Nutritional value of sorghum genotypes

Comparing the dietary fiber content of sorghum genopytes with the recommended values, it was demonstrated that 100 g of flour may contribute approximately 30 to 50% of the RDA (genotypes CMSXS 136 and BR 506, respectively). This genopytes may be considered as an excellent source of dietary fiber and show the potential of this cereal for use in the prevention of chronic diseases and also in the regulation of intestinal function[30]. Along with dietary fiber, sorghum contains elevated phenolic compounds concentrations and other components that may also help to prevent chronic diseases[14].

All sorghum genotypes were considered sources of iron, phosphorus, magnesium and zinc, except for iron in genotype BRS 309. In relation to the vitamin E content, all genotypes presented low concentrations and cannot be classified as a source of this nutrient[19].

CONCLUSION

The studied sorghum genotypes stood out as good sources of dietary fiber, iron, phosphorus, magnesium and zinc. Further, sorghum genotypes were classified as durum grain, suitable for elaboration of bakery products.

Further studies will be useful to increase knowledge on the approximate composition of these genotypes, including those related to phenolic compounds, flavonoids and anthocyanins, aiming to explore the functional potential of sorghum.

REFERENCES

1. Instituto Brasileiro de Geografia e Estatística. Grupo de Coordenação de Estatísticas Agropecuárias – GCEA/IBGE, DPE, COAGRO. Levantamento Sistemático da Produção Agrícola. [acesso 2010 fev 22.] Disponível em: [http://www.ibge.gov.br/home/estatistica/indicadores/agropecuaria/lspa/lspa_201001_5.shtm].
2. Sanchez DA. White food-type sorghum in direct-expansion extrusion applications, in Food Science and Technology. Dallas: Texas A&M University; 2003.
3. Dicko MH, Gruppen H, Traoré AS, Voragen AGJ, Berkel WJHv. Review – Sorghum grain as human food in Africa: relevance of content of starch and amylase activities. African J Biotech. 2006;5(5):384-95.
4. Mohammed NA, Mohamed AIA, Babiker EE. Nutritional evaluation of sorghum flour (*Sorghum bicolor* L. Moench) during processing of injera. Int J Biol Life Sciences. 2010; 6(1):35-9.
5. Ítavo CCBF, Morais MG, Ítavo LCV, Souza ARDL, Davy FCA, Biberg FA, et al. Consumo e digestibilidade de nutrientes de dietas com silagens de grãos úmidos de milho ou sorgo, em ovinos. Arq Bras Med Vet Zoot. 2009;61(2):452-9.
6. Menezes LFG, Segabinazzi LR, Brondani IL, Restle J, Arboitte MZ, Kuss F, et al. Silagem de milho e grão de sorgo como suplementos para vacas de descarte terminadas em pastagem cultivada de estação fria. Arq Bras Med Vet Zoot. 2009;61(1):182-9.
7. Boudries N, Belhaneche N, Nadjemi B, Deroanne C, Mathlouthi M, Roger B, et al. Physicochemical and functional properties of starches from sorghum cultivated in the Sahara of Algeria. Carboh Polymers. 2009;78(3):475-80.
8. Mokrane H, Amoura H, Belhaneche-Bensemra N, Courtin CM, Delcour JA, Nadjemi B. Assessment of Algerian sorghum protein quality [*Sorghum bicolor* (L.) Moench] using amino acid analysis and in vitro pepsin digestibility. Food Chem. 2010;121(3):719-23.
9. Mehmood S, Orhan I, Ahsan Z, Aslan S, Gulfraz M. Fatty acid composition of seed oil of different Sorghum bicolor varieties. Food Chem. 2008;109(4):855-9.
10. Anglani C. Sorghum for human food – A review. Plant Foods for Human Nutrition (Formerly Qualitas Plantarum). 1998;52(1):85-95.
11. Barcellos LCG, Furlan AC, Murakami AE, Silva MAAd, Silva RMd. Avaliação nutricional da silagem de grãos úmidos de sorgo de alto ou de baixo conteúdo de tanino para frangos de corte. Rev Bras Zootecnia. 2006;35:104-12.
12. Méndez-Albores A, Martínez-Bustos F, Véles-Medina JJ, Moreno-Ramos C, Río-García JCD, Moreno-Martínez E. Efecto de la adición de ácido cítrico sobre la degradación de las aflatoxinas y las propiedades funcionales de productos extrudidos de sorgo. Interciencia. 2009;4:252-8.
13. Taylor JRN, Schober TJ, Bean SR. Novel food and non-food uses for sorghum and millets. J Cer Science. 2006;44(3):252-71.
14. Dykes L, Rooney LW. Sorghum and millet phenols and antioxidants. J Cer Science. 2006;44(3):236-51.
15. Gonzalez AJP. Specialty sorghums in direct-expansion extrusion. *In* Instituto Tecnológico y de Estudios Superiores de Monterrey. Dallas: Texas A&M University; 2005.
16. Association of Official Analytical Chemists. Official Methods of Analysis of the AOAC International. 17. ed. Gaithersburg: Association of Analytical Communities; 2002.
17. Gomes J, Silva M, Silva C. Análise de alimentos. 2. ed. Viçosa, MG: FUNARBE; 2003.
18. Guinaz M, Milagres RCRM, Pinheiro-Sant'Ana HM, Chaves JBP. Tocoferois e tocotrienois em óleos vegetais e ovos. Quím Nova. 2009;32(8):2098-103.
19. IOM. Dietary Reference Intakes: The Essential Guide to Nutrient Requirements. Washington, DC: NA Press; 2006.
20. Philippi S. Pirâmide dos alimentos: Fundamentos básicos da nutrição. Barueri, SP: Manole; 2008.
21. Borges JTDS, Pirozi MR, Lucia SMD, Pereira PC, Moraes ARFE, Castro VC. Utilização de farinha mista de aveia e trigo na elaboração de bolos. B CEPPA. 2006;4(1):145-62.
22. Antunes RC, Rodriguez NM, Gonçalves LC, Rodrigues JAS, Borges I, Borges ALCC, et al. Composição bromatológica e parâmetros físicos de grãos de sorgo com diferentes texturas do endosperma. Arq Bras Med Vet Zoot. 2007;59:1351-4.
23. Ragaee S, Abdel-Aal E-SM, Noaman M. Antioxidant activity and nutrient composition of selected cereals for food use. Food Chem. 2006;98(1):32-8.
24. Silva D, Queiroz A. Análise de alimentos: métodos químicos e biológicos. Viçosa, MG: UFV; 2002.
25. Wang SH, Oliveira MFd, Costa PdS, Ascheri JLR, Rosa AG. Farinhas de trigo e soja pré-cozidas por extrusão para massas de pizza. Pesq Agrop Bras. 2005;40(4):389-95.

26. Naves MMV, Silva MS, Cerqueira FM, Paes MCD. Avaliação química e biológica da proteína do grão em cultivares de milho de alta qualidade proteica. Pesq Agrop Trop. 2004;34(1):1-8.

27. Tavares T, Carvalho F. Avaliação de exposição de populações humanas a metais pesados no ambiente: exemplos do recôncavo baiano. Quím Nova. 1992;15(2):447-54.

28. Berton R. Riscos de contaminação do agrossistema com metais pesados. *In*: Bettiol W, Camargo O, orgs. Impacto ambiental do uso agrícola do lodo de esgoto. Jaguariúna: Embrapa Meio Ambiente; 2000. p. 259-68.

29. Traber MG. Vitamin E: too much or not enough? Amer J Clin Nutr. 2001;73(6):997-8.

30. Stringheta PC, Oliveira TT, Gomes RC, Amaral MPH, Carvalho AF, Vilela MAP. Políticas de saúde e alegações de propriedades funcionais e de saúde para alimentos no Brasil. Rev Bras Ciênc Farm. 2007;43(2):181-94.