Effect of radiation and/or traditional processings on antinutrients and HCl extractability of calcium, phosphorus and iron of sorghum cultivars

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Abstract Whole flours of sorghum cultivars Dabar, WadAhmed and Karamaka were irradiated and then fermented and/or cooked. Tannin and phytic acid contents were assayed for all treatments. Traditional processings (fermentation and cooking) were significantly ($P \geq 0.05$) decreased tannin and phytate of the cultivars and further reduction was observed when the flour was irradiated before processing for all cultivars. Radiation process alone had no great effect on tannin and phytate contents but when followed by traditional processing the reduction level was significant ($P \geq 0.05$) for all cultivars. Radiation alone had no significant ($P \geq 0.05$) effect in increment of total and extractable calcium (Ca). However, radiation followed by fermentation and/or cooking significantly ($P \geq 0.05$) increased both total and extractable Ca. Total phosphorus (P) was not significantly ($P \geq 0.05$) increased at all levels of radiation and/or processing but the extractable P was increased. Total iron (Fe) was not affected by radiation and/or processings but the extractable Fe was increased significantly ($P \geq 0.05$) with the radiation dose for all cultivars.

Keywords Calcium · Iron · Phosphorus · Irradiation · HCl extractability · Sorghum

Introduction

Sorghum (*Sorghum bicolor* L. Monech) is one of the major food crops of the semiarid regions of Africa and Asia (Correia et al. 2005). Sudanese people consumed sorghum as fermented flat bread (Kisra), thick porridge (Aceda), thin fermented gruel (Nasha), boiled grains (Balella) and beverages (Abreh and Hulumur), which provide about 97 % of the protein and 75 % of the calories in the diet of the people residing in central and western Sudan. Sorghum nutritional quality is dictated mainly by its chemical composition and one of the constraints on the utilisation of sorghum grain as food or feed is the occurrence of phytate and tannins. Phytate and tannin bind minerals that are necessary as cofactors, thus interfering with several essential metabolic processes, especially the utilization of protein (Idris et al. 2007). Removal of undesirable components such as phytate and tannin is essential to improve the nutritional quality of sorghum and effectively utilize its full potential as human food by processing methods such as germination (Idris et al. 2007; AbdelRahaman et al. 2007), soaking (Babiker and El Tinay 1993), cooking (Mohiedeen et al. 2010), fermentation (Sokrab et al. 2012a, b; Osman et al. 2010) and gamma irradiation (Mohamed et al. 2010; Osman et al. 2012) which are known to reduce anti-nutritional factors effectively and upgrade the nutritional quality of cereals. However, most of these treatments adversely affect the sensory characteristics of the final product. Food irradiation has been recognized as a reliable, safe and cheap method for preservation of food; improve hygienic quality and nutritional value of foods (Mohamed et al. 2010; Osman et al. 2012; Al-Kaisey et al. 2002). It has been reported that irradiation of phytate (IP6), known to bind essential minerals in beef, soy and soy-extended beef, at an absorbed dosage of less than 4 kGy caused no difference ($P \geq 0.05$) in the level of IP3-6 compared to non-irradiated samples (Engeljohn et al. 1999). Research on the basic interaction of radiation with biological

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systems has contributed to human society through applications in medicine, agriculture, pharmaceutical uses and other technological developments. In agricultural science and food technology, recent research has elucidated new potential applications for radiation. For example, high doses of ionising radiation have been shown to inhibit growth of microbial infestations in seeds. There are also many reports supporting the use of gamma irradiation as a fungicidal agent (Aziz et al. 2007; Al-Bachir and Laham 2002; Dogbevi et al. 2000). However, the viability, and sometimes the developmental process, of the seedling or the plant has been seriously hampered by radiation (Casarett 1996). There are insufficient reports about possible effects of gamma radiation on nutritional value of the seeds associated with seed radiation. Seeds of different plants that are consumed as food have varying nutrient values, which are dependent on the basic constituents of seed proteins. The chemical structure of irradiating food is less modified than heat-treated food and this technique avoids the use of potentially harmful chemicals (Siddhuraju et al. 2002). Sorghum flour had a severe problem during storage and was observed to produce off-flavor. In order to minimize losses occurring during storage of sorghum flour, the radiation process emerges as an attractive and healthy alternative when compared with chemical conventional treatments. Therefore, in this study we would like to investigate the effect of radiation process followed by traditional processings on the antinutritional factors and total and extractable Ca, P and Fe of sorghum cultivars flour.

Materials and methods

Sample collection and preparation Grains of sorghum cultivars (Dabar, WadAhmed and Karamaka) were collected from Department of Agronomy, Faculty of Agriculture, University of Khartoum, Sudan. Collected seeds (4 kg) of each cultivar were ground to pass a 0.4 mm screen. All chemicals used for the experiments were of reagent grade.

Irradiation procedure The flour with a moisture content of 5.45 % was spread uniformly and stored in polythene bags of mass of 100 gm, Gamma radiation process was conducted at Kaila irradiation processing unit, Sudanese Atomic Energy Corporation (SAEC). The flour was exposed to gamma rays generated by a cobalt-60 source (Gammacell 220, MDS Nordion, Ottawa, Canada). The flour was irradiated at 0, 5, 10 and 15 kGy following the procedures described by Helinski et al. (2008) with a dose rate of ca. 3.2 kGy/h at 24 ± 1 °C and normal relative humidity. Double side irradiation (exposure to both sides) was performed for uniform dose delivery. A dosimetry system was used to measure the dose received by the batch based on the Gafchromic HD-

810 film (International Specialty Products, NJ, USA; FAO/IAEA/USDA 2003). Three dosimeters were included with each batch of flour and read after irradiation with a Radiachromics reader (Far West Technology Inc., CA, USA). All experiments were repeated 3 times and 3 replicates of each flour type were irradiated.

Processing and storage of the samples Treated and untreated samples of the whole flour of each cultivar were either fermented till the pH of the dough reached 4.50 or cooked for 20 min in a water bath and then dried and ground to pass a 0.4 mm screen for further analysis.

Tannin determination Quantitative determination of tannins was carried out using the modified vanillin-HCl method according to Price and Butler (1978). A 200 mg sample was extracted with 10 ml 1 % (v/v) conc. HCl in methanol for 20 min in capped rotating test tubes. Vanillin reagent (0.5 %, 5 ml) was added to extract (1 ml) and the absorbance of the colour developed after 20 min at 30 °C was read at 500 nm. A standard curve was prepared expressing the results as catechin equivalents, i.e. amount of catechin (mg/ml) which gives a colour intensity equivalent to that given by tannins after correcting for blank.

Phytic acid determination Phytic acid content was determined by the method described by Wheeler and Ferrel (1971) using 2.0 g dried sample. A standard curve was prepared expressing the results as $\text{Fe}(\text{NO}_3)_3$ equivalent. Phytate phosphorus was calculated from the standard curve assuming a 4:6 iron to phosphorus molar ratio.

Total minerals determination Minerals were extracted from the samples by the dry ashing method described by Chapman and Pratt (1982). About 2.0 g of sample was acid-digested with diacid mixture ($\text{HNO}_3:\text{HClO}_4$, 5:1, v/v) in a digestion chamber. The digested samples were dissolved in double-distilled water and filtered (Whatman No. 42). The filtrate was made to 50 mL with double-distilled water and was used for determination of total calcium, phosphorus and iron. Calcium was determined by a titration method. Iron was determined by atomic absorption spectrophotometer (Perkin-Elmer 2380). Phosphorus was determined spectrophotometrically using molybdovanadate method.

HCl extractability of minerals (in vitro bioavailability) Minerals in the samples were extracted by the method described by Chauhan and Mahjan (1988). About 1.0 g of the sample was shaken with 10 mL of 0.03 M HCl for 3 h at 37 °C and then filtered. The clear extract obtained was oven-dried at 100 °C and then acid-digested. The amount of extractable minerals was determined by the methods

described above. HCl extractability (%) was determined as follows:

$$\text{Mineral extractability (\%)} = \frac{\text{Mineral extractable in 0 : 0.3N HCl (mg/100g)}}{\text{Total minerals (mg/100g)}} \times 100$$

Statistical analysis Each determination was carried out on three separate samples and analysed in triplicate on dry weight basis; the figures were then averaged. Data were assessed by the analysis of variance (Snedecor and Cochran 1987). Comparisons of means for treatments were made using Duncan's multiple range tests. Significance was accepted at $P \geq 0.05$.

Results and discussion

Effect of radiation process on tannin and phytate of raw and processed sorghum flour The effect of gamma irradiation and/or traditional processing on tannin content of sorghum cultivars are shown in Table 1. Radiation of raw flour at 5 KGy resulted in a significantly ($P \leq 0.05$) decreased tannin content by 7.0, 8.4 and 11.3 % for Dabar, Wad Ahmed and Karamaka, respectively. While irradiation at 10 KGy significantly ($P \leq 0.05$) decreased tannin content by 27.6, 20.9 and 22.7 % for the cultivars, respectively and at 15 KGy was 29, 21, and

23.2 %, for the cultivars, respectively. The results are in agreement with those reported by 108 Brigide and Canniatti-Brazaca (2006) who observed that tannin content was inversely correlated with the applied irradiation doses. Also Osman et al. (2012) reported that application of gamma irradiation up to 1.0 kGy significantly ($P \leq 0.05$) reduced tannin content of faba bean. Fermentation of raw flour significantly ($P \leq 0.05$) decreased tannin content by 34.4, 33.6 and 39.6 % for Dabar, Wad Ahmed and Karamaka, respectively. The results obtained agree with the findings of Idris et al. (2005), who found that fermentation caused reduction in tannin content of Tabat and Wad Ahmed cultivars by 35.1 and 38.1 %, respectively. Osman (2004) reported that fermentation markedly reduced tannin content of three sorghum cultivars namely Hamra, Shahla and Baidha by 31, 15 and 35 %, respectively. The reduction in tannin content due to fermentation is likely to be due to biochemical activity of fermenting organisms. Cooking of raw flour significantly ($P \leq 0.05$) decreased tannin content by 49.1 %, 56.1 % and 60.8 % for the cultivars, respectively. Idris et al. (2005) reported that cooking treatment markedly reduced tannin content of sorghum cultivars Tabat and Wad

Table 1 Tannin content (%) of sorghum cultivars as affected by irradiation followed by processing

Radiation dose (KGy)	Treatment	Sorghum cultivars		
		Dabar	Wad Ahmed	Karamaka
0	Raw	0.100±0.002 ^a	1.400±0.190 ^a	2.900±0.234 ^a
	Fermented	0.066±0.009 ^e	0.930±0.205 ^e	1.752±0.072 ^e
	Cooked	0.039±0.005 ⁱ	0.615±0.014 ⁱ	1.137±0.004 ⁱ
	Fermented cooked	0.034±0.006 ^k	0.379±0.035 ^m	0.586±0.023 ^m
5	Raw	0.093±0.018 ^b	1.282±0.051 ^b	2.572±0.223 ^b
	Fermented	0.062±0.013 ^f	0.866±0.023 ^f	1.657±0.016 ^f
	Cooked	0.036±0.004 ^j	0.559±0.019 ^j	1.050±0.024 ^j
	Fermented cooked	0.030±0.001 ^m	0.339±0.008 ⁿ	0.528±0.003 ⁿ
10	Raw	0.072±0.021 ^c	1.109±0.052 ^c	2.242±0.101 ^c
	Fermented	0.042±0.011 ^h	0.754±0.153 ^g	1.352±0.291 ^h
	Cooked	0.031±0.006 ^l	0.492±0.028 ^k	0.913±0.050 ^k
	Fermented cooked	0.027±0.002 ^o	0.299±0.025 ^o	0.465±0.015 ^o
15	Raw	0.071±0.006 ^d	1.106±0.115 ^d	2.227±0.024 ^d
	Fermented	0.050±0.003 ^g	0.722±0.071 ^h	1.358±0.022 ^g
	Cooked	0.027±0.001 ⁿ	0.464±0.017 ^l	0.840±0.005 ^l
	Fermented cooked	0.026±0.002 ^p	0.284±0.053 ^p	0.444±0.015 ^p

Values are means ± SD ($n=3$)
Means not sharing a common superscript(s) in a column are significantly different at $p \leq 0.05$

Ahmed by 55.2 and 48.6 %, respectively. Cooking of fermented dough significantly ($P \leq 0.05$) reduced tannin content by 66, 72.9 and 79.8 % for the cultivars, respectively. AbdelHaleem et al. (2008) reported that combination of fermentation and cooking of sorghum improved the nutritional quality and drastically reduced the tannin content to safe levels than any other processing methods. Further Idris et al. (2007) reported that fermentation and cooking greatly improved the extractability of Ca, P and Fe. As shown in Table 1 irradiation at 5, 10 and 15 KGy followed by fermentation and/or cooking significantly ($P \leq 0.05$) decreased tannin content of the three cultivars compared to raw flour. The highest reduction percent in tannin content was observed at 15KGy for cooked fermented flour as 74.33, 79.7 and 84.69 % for Dabar, Wad Ahmed and Karamaka, respectively. These results indicated that tannin content was reduced by irradiation followed by processing more than irradiation or processing alone. The effect of gamma radiation on phytate content of Dabar, Wad Ahmed and Karamaka are shown in Table 2. Irradiation of raw flour at 5KGy resulted in a reduction of phytate content by 13.69, 11.89 and 13.09 % for the cultivars Dabar, Wad Ahmed and Karamaka, respectively and that at 10 KGy significantly ($P \leq 0.05$) reduced phytate content by 17.6, 17.62 and 16.69 % for the cultivars, respectively. The highest reduction level of phytate was obtained at 15 KGy as 19.1, 17.8 and 20.09 % for the cultivars, respectively. The results clearly showed that irradiation alone had an effect on phytate content which was increased with increasing dose of radiation. Osman et al. (2012) reported that phytic acid and tannin contents of broad bean were significantly ($P \leq 0.05$) reduced as a result of radiation. El-Niely (2007) stated that radiation significantly ($P \leq$

0.05) decreased the level of phytic acid of legumes. The reduction in phytic acid during radiation process is likely to be due to chemical degradation of phytate to the lower inositol phosphates and inositol by the action of free radicals produced by radiation or might be due to cleavage of the phytate ring itself (Siddhuraju et al. 2002). Fermentation of raw flour significantly ($P \leq 0.05$) reduced phytate content of Dabar, Wad Ahmed and Karamaka cultivars by 57.0, 51.4 and 52.5 %, respectively. Similar results were reported by Osman (2004) who reported that phytic acid contents of three sorghum varieties namely Hamra, Shahla and Baidha were markedly reduced as a result of fermentation. Both cereal and microbial phytases can contribute to a reduction in phytate during the fermentation process. Cooking of raw flour significantly ($P \leq 0.05$) decreased phytate content for the cultivars by 16.1, 21.0 and 20 %, respectively. Idris et al. (2005) reported that cooking significantly ($P \leq 0.05$) reduced phytate content of two sorghum cultivars. The low reduction in phytate level caused by cooking may be due to limited activation of phytase enzyme during cooking before it is denatured by heat, or partially due to formation of insoluble complexes between phytate and other compounds such as phytate-protein and phytate-protein-mineral complexes. Cooking of fermented dough of raw flour significantly decrease phytate content for the three cultivars by 41.5, 37.7 and 41 %, respectively. The results are similar to those reported by Idris et al. (2005) and AbdelHaleem et al. (2008). Processing of irradiated flour significantly ($P \leq 0.05$) reduced phytate content when compared to raw flour. Duodu et al. (1999) reported that cooking did not decrease phytic acid in sorghum porridge, but cooking and irradiation caused a significant decrease

Table 2 Phytate content (mg/100 g) of sorghum cultivars as affected by irradiation followed by processing

Radiation dose (KGy)	Treatment	Sorghum cultivars		
		Dabar	Wad Ahmed	Karamaka
0	Raw	266.00±0.45 ^a	268.00±1.50 ^a	272.00±0.16 ^a
	Fermented	114.38±0.42 ^m	130.20±0.12 ^m	129.20±1.98 ^m
	Cooked	223.44±1.02 ^c	211.72±0.18 ^c	217.61±0.23 ^d
	Fermented cooked	155.61±1.00 ⁱ	166.96±0.05 ⁱ	160.48±0.11 ^h
5	Raw	229.56±1.61 ^b	236.11±1.92 ^b	236.37±2.13 ^b
	Fermented	99.17±1.04 ⁿ	113.58±0.12 ⁿ	112.53±0.11 ⁿ
	Cooked	196.85±0.10 ^f	185.89±3.16 ^f	191.92±0.21 ^f
	Fermented cooked	136.00±1.98 ^j	147.34±0.99 ^j	138.98±0.13 ⁱ
10	Raw	219.18±0.17 ^d	220.76±0.11 ^c	226.58±0.05 ^c
	Fermented	97.68±0.87 ^o	110.19±0.02 ^o	132.30±1.95 ^k
	Cooked	191.49±0.12 ^g	179.54±0.10 ^g	109.69±0.11 ^o
	Fermented cooked	133.98±0.11 ^k	141.37±2.01 ^k	136.41±0.84 ^j
15	Raw	215.19±0.18 ^e	220.28±0.06 ^d	217.33 ±0.04 ^c
	Fermented	92.53±0.19 ^p	105.76±0.12 ^p	104.40±0.12 ^p
	Cooked	181.21±0.01 ^h	171.71±0.10 ^h	176.91±1.56 ^g
	Fermented cooked	126.51±0.11 ^l	135.24±0.29 ^l	131.11±0.92 ^l

Values are means ± SD ($n=3$)

Means not sharing a common superscript(s) in a column are significantly different at $p \leq 0.05$

Table 3 Total (mg/100 g) and extractable (%) Ca, P and Fe of sorghum cultivar (Dabar) as affected by irradiation followed by processing

Radiation dose (KGy)	Treatment	Minerals					
		Ca		P		Fe	
		Total (mg/100 g)	Extractable (%)	Total (mg/100 g)	Extractable (%)	Total (mg/100 g)	Extractable (%)
0	Raw	14.2±1.03 ^c	35.0±0.12 ^k	340.0±0.01 ^k	43.5±0.01 ^m	3.5±0.03 ^{ef}	5.1±0.06 ^d
	Fermented	15.4±2.06 ^a	76.7±0.65 ^f	351.0±0.98 ^g	56.0±0.41 ⁱ	3.7±0.01 ^d	21.5±0.11 ^c
	Cooked	14.3±0.11 ^{bc}	37.5±0.19 ^j	339.2±0.01 ^l	41.7±0.83 ⁿ	4.0±0.01 ^{ab}	4.9±0.11 ^d
	Fermented cooked	14.3±0.11 ^{bc}	81.7±0.49 ^c	340.0±0.19 ^k	53.5±0.71 ^j	3.0±1.03 ^g	21.2±0.12 ^c
5	Raw	14.2±0.52 ^c	39.1±0.64 ⁱ	339.0±0.03 ^l	45.7±0.02 ^l	3.5±1.04 ^{ef}	5.1±2.17 ^d
	Fermented	15.0±0.23 ^a	78.0±0.02 ^e	361.0±0.82 ^f	68.6±0.24 ^f	3.7±0.09 ^d	22.0±0.02 ^b
	Cooked	14.1±0.12 ^c	34.9±0.09 ^k	344.0±0.72 ^j	43.9±0.02 ^m	3.0±0.13 ^g	5.0±0.82 ^d
	Fermented cooked	14.1±0.54 ^c	80.5±0.65 ^d	362.0±0.32 ^e	75.0±0.02 ^e	3.9±0.76 ^{ab}	22.1±0.76 ^{ab}
10	Raw	13.9±0.79 ^{cd}	35.0±1.18 ^k	346.0±0.67 ⁱ	61.7±0.05 ^g	3.6±0.81 ^e	5.1±0.02 ^d
	Fermented	14.8±0.21 ^b	86.0±0.13 ^b	375.5±0.12 ^a	81.5±0.02 ^c	4.0±0.97 ^a	22.0±0.09 ^b
	Cooked	13.7±0.23 ^d	63.7±0.08 ^h	335.5±0.53 ^m	57.1±0.02 ^h	3.0±0.76 ^g	4.9±0.72 ^d
	Fermented cooked	14.4±0.72 ^{bc}	90.7±0.43 ^a	373.0±0.96 ^b	82.6±0.02 ^b	3.8±0.54 ^{cd}	22.0±0.05 ^b
15	Raw	14.1±1.05 ^c	35.0±0.52 ^k	347.4±1.13 ^h	52.1±0.16 ^k	3.5±0.85 ^{ef}	5.0±0.98 ^d
	Fermented	15.2±0.01 ^a	85.5±0.86 ^b	365.4±0.95 ^d	78.5±0.02 ^d	3.9±0.23 ^{ab}	22.7±0.08 ^a
	Cooked	13.9±0.65 ^{cd}	67.8±0.09 ^g	344.0±0.23 ^j	53.3±0.02 ^j	3.5±0.76 ^f	5.1±0.12 ^d
	Fermented cooked	14.0±0.06 ^{cd}	91.2±0.78 ^a	369.3±0.23 ^c	83.7±0.88 ^a	3.9±0.21 ^{bc}	22.5±0.53 ^a

Values are means ± SD (*n*=3)Means not sharing a common superscript(s) in a column are significantly different at *p*≤0.05**Table 4** Total (mg/100 g) and extractable (%) Ca, P and Fe of sorghum cultivar (WadAhmed) as affected by irradiation followed by processing

Radiation dose (KGy)	Treatment	Minerals					
		Ca		P		Fe	
		Total (mg/100 g)	Extractable (%)	Total (mg/100 g)	Extractable (%)	Total (mg/100 g)	Extractable (%)
0	Raw	15.3±0.12 ^{ef}	32.0±0.65 ^k	330.0±0.43 ^l	44.3±1.76 ^j	3.3±0.21 ^{bcd}	6.0±0.01 ^f
	Fermented	20.4±3.42 ^c	73.3±0.43 ^d	355.0±1.64 ^c	60.7±0.52 ^c	3.4±1.07 ^b	20.1±1.54 ^c
	Cooked	14.9±0.16 ^f	38.9±0.16 ⁱ	328.0±2.06 ^m	43.1±1.71 ^k	3.8±0.37 ^a	5.9±0.59 ^e
	Fermented cooked	17.1±0.43 ^d	71.1±1.98 ^e	333.0±0.18 ^j	57.2±2.04 ^f	3.4±0.11 ^{bc}	20.0±0.72 ^d
5	Raw	15.6±0.02 ^e	36.7±0.20 ^j	330.0±0.74 ^l	45.7±1.63 ⁱ	3.3±0.23 ^{bcd}	16.0±0.94 ^f
	Fermented	20.5±0.29 ^{bc}	70.0±0.98 ^f	343.0±0.76 ^e	66.6±0.0 ^d	3.1±0.32 ^{efg}	22.1±0.98 ^c
	Cooked	15.3±0.43 ^{ef}	25.0±0.34 ^l	331.0±0.31 ^k	48.3±0.90 ^h	3.0±0.98 ^{gh}	15.9±0.65 ^f
	Fermented cooked	17.0±0.22 ^d	68.0±0.76 ^g	341.0±0.54 ^f	67.6±0.65 ^d	3.4±0.43 ^{bc}	22.9±0.12 ^b
10	Raw	15.2±0.73 ^{ef}	50.0±0.07 ^h	337.0±1.02 ^h	46.4±0.04 ⁱ	3.3±0.13 ^{cde}	6.8±0.19 ^e
	Fermented	21.0±0.12 ^b	101.0±0.87 ^a	355.0±0.65 ^c	74.7±0.16 ^c	3.2±0.35 ^{ef}	22.2±0.45 ^c
	Cooked	14.9±0.08 ^f	38.8±0.07 ⁱ	327.5±0.24 ^a	51.0±0.36 ^g	3.2±0.68 ^{efg}	6.0±0.76 ^f
	Fermented cooked	16.6±0.05 ^d	75.0±0.87 ^c	344.0±0.75 ^d	73.9±0.45 ^c	3.2±0.97 ^{def}	22.6±0.43 ^b
15	Raw	15.2±0.83 ^{ef}	50.0±0.71 ^h	338.6±0.09	46.9±0.27 ⁱ	3.3±0.67 ^{bcd}	15.9±0.23 ^f
	Fermented	27.0±1.93 ^a	92.6±0.70 ^b	356.0±0.87 ^b	76.7±0.98 ^b	3.0±0.87 ^h	23.7±0.23 ^a
	Cooked	13.8±0.86 ^g	36.7±0.63 ^j	335.0±1.83 ⁱ	48.1±0.34 ^h	3.1±0.43 ^{fgh}	6.1±0.18 ^f
	Fermented cooked	20.6±0.63 ^{bc}	75.0±0.06 ^c	360.0±0.76 ^a	83.4±0.31 ^a	3.0±0.32 ^{gh}	22.8±0.43 ^b

Values are means ± SD (*n*=3)Means not sharing a common superscript(s) in a column are significantly different at *p*≤0.05

Table 5 Total (mg/100 g) and extractable (%) Ca, P and Fe of sorghum cultivar (Karamaka) as affected by irradiation followed by processing

Radiation dose (KGy)	Treatment	Minerals					
		Ca		P		Fe	
		Total (mg/100 g)	Extractable (%)	Total (mg/100 g)	Extractable (%)	Total (mg/100 g)	Extractable (%)
0	Raw	14.7±0.02 ^{de}	30.0±0.09 ^k	333.0±0.01 ^k	45.2±0.45 ^l	4.4±0.03 ^a	4.6±0.08 ^g
	Fermented	17.2±0.13 ^b	66.0±0.71 ^f	340.0±2.08 ^f	58.4±0.86 ^f	4.5±1.09 ^a	33.2±1.03 ^d
	Cooked	14.6±1.95 ^{de}	30.0±0.14 ^k	329.0±0.00 ^m	42.8±0.78 ⁿ	4.4±0.01 ^a	4.7±0.17 ^g
	Fermented cooked	14.9±0.09 ^d	57.9±0.06 ^g	335.2±0.07 ⁱ	49.7±0.13 ⁱ	4.4±0.34 ^a	32.9±0.91 ^e
5	Raw	14.6±1.65 ^{de}	31.1±1.12 ^j	330.0±0.09 ^l	45.5±0.60 ^l	4.4±0.94 ^a	4.0±0.76 ⁱ
	Fermented	16.9±0.09 ^b	75.0±0.18 ^d	341.0±0.75 ^e	60.0±0.09 ^e	4.5±0.05 ^a	33.9±0.51 ^{bc}
	Cooked	14.7±0.25 ^{de}	37.5±0.45 ^h	329.0±0.96 ^m	43.9±0.23 ^m	4.4±0.85 ^a	4.3±0.75 ^h
	Fermented cooked	15.1±0.75 ^d	70.0±0.95 ^e	336.0±0.64 ^h	52.7±0.76 ^h	4.4±0.75 ^a	33.8±0.76 ^c
10	Raw	14.4±0.51 ^c	31.0±0.96 ^j	334.0±2.23 ^j	46.2±0.01 ^k	4.4±0.93 ^a	4.6±0.16 ^g
	Fermented	18.2±0.87 ^a	90.0±0.64 ^c	342.0±0.08 ^d	69.5±0.98 ^c	4.5±0.54 ^a	34.1±0.01 ^b
	Cooked	14.8±0.96 ^{de}	35.1±0.98 ⁱ	329.0±0.53 ^m	58.8±0.76 ^f	4.4±0.63 ^a	5.0±0.18 ^f
	Fermented cooked	15.8±0.13 ^c	94.0±0.07 ^a	344.0±0.79 ^c	63.3±0.43 ^d	4.4±0.01 ^a	34.0±0.97 ^b
15	Raw	14.9±0.06 ^d	30.0±0.87 ^k	337.0±0.06 ^g	46.7±0.28 ^j	4.5±0.45 ^a	4.7±0.76 ^g
	Fermented	18.0±0.36 ^a	89.7±0.91 ^c	352.0±0.78 ^a	72.2±0.01 ^a	4.5±0.81 ^a	34.3±0.43 ^a
	Cooked	13.8±0.97 ^g	30.2±1.22 ^k	336.0±0.71 ^h	57.5±0.12 ^g	4.4±0.36 ^a	4.9±0.01 ^f
	Fermented cooked	15.1±0.64 ^d	92.6±0.53 ^b	351.0±0.01 ^b	71.7±0.96 ^b	4.4±0.42 ^a	34.1±1.01 ^a

Values are means ± SD ($n=3$)

Means not sharing a common superscript(s) in a column are significantly different at $p \leq 0.05$

(40 %). Higher reduction in phytate content was observed at 15 KGy of fermented dough as 65.2, 60.5 and 61.6 % for the three cultivars, respectively.

Effect of radiation process on total and extractable Ca, P and Fe of raw and processed sorghum flour Table 3 shows the content and HCl extractability of Ca, P and Fe of sorghum cultivar Dabar flour as affected by radiation and/or traditional processings. For the raw flour, Ca content was found to be 14.2 mg/100 g and out of this amount about 35.0 % was extractable; P was 340 mg/100 g with extractability of 43.5 % and Fe was 3.5 mg/100 g and out of this amount about 5.1 % was extractable. Radiation of raw flour had no effect on total and extractable Ca and Fe. However, at 10 kGy it increased both total and extractable P. Mohamed et al. (2010) reported that radiation of millet flour significantly decreased the antinutritional factors and increased the extractability of minerals. Fermentation of raw flour significantly ($P \leq 0.05$) increased Ca, P and Fe extractability but had no effect on total Ca, P and Fe. It has been reported that fermentation significantly reduced the level of antinutrients with a concomitant increase in minerals extractability of millet cultivars (AbdelRahaman et al. 2005). Cooking of raw flour slightly increased the extractable Ca and decreased extractable P and Fe but had no effect on total Ca, P and Fe. Cooking of fermented dough significantly ($P \leq 0.05$) increased the extractable Ca, P and Fe and did not change the

level of total minerals. Irradiation of raw flour at 5KGy followed by cooking gave varying changes in total and extractable minerals for Dabar cultivars but there is a significant ($P \leq 0.05$) increase in total P as well as in extractable Ca and Fe but significant ($P \leq 0.05$) decrease in total Fe. Cooking of irradiated fermented dough caused further improvement in total and extractable minerals. Moreover, as the level of radiation increased, the degree of improvement in minerals extractability was significantly ($P \leq 0.05$) increased. Processing of irradiated flour significantly ($P \leq 0.05$) increased the extractable Ca, P and Fe with an increase in radiation dose but had no significant ($P \leq 0.05$) effect on total minerals. Generally the increase in extractable minerals during traditional processing before and after radiation could be attributed to the reduction in the level of antinutrients as a result of such treatments. The trend of the results obtained for the cultivars WadAhmed (Table 4) and Karamaka (Table 5) regarding the effect of radiation process followed by fermentation and/or cooking were more or less similar to those reported for the cultivar Dabar.

Conclusion

The observations about antinutritional factors and minerals content and extractability in the studied samples suggest that

radiation processing up to 15 kGy had little effects on their value and had no effects on minerals quality of the flour by improving the extractability or bioavailability of such minerals. Therefore, radiation can be applied to alleviate the severe problem of antinutrients and off-flavor of flour during storage. Moreover, radiation process when compared with chemicals or heat treatment emerges as an attractive and healthy alternative.

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