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RESEARCH ARTICLE

THE IMPACT OF RADIATION PROCESS FOLLOWED BY TRADITIONAL TREATMENTS ON NUTRITIONAL QUALITY OF LOW TANNIN SORGHUM CULTIVAR

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Abstract
The present work describes radiation-induced effects on nutritional quality of raw and processed flour of low tannin sorghum cultivar (Dabar). The flour of the cultivar was radiated using gamma irradiation at doses of 5, 10 and 15 kGy and thereafter the radiated flour was fermented and/or cooked. Radiation of raw flour decreased the level of antinutreints with a concomitant increase in protein digestibility and minerals extractability. Moreover, it increased the level of some amino acids and decreased others. Among amino acids the most limiting ones are lysine, methionine plus cysteine and threonine. Fermentation and/or cooking of radiated and non-radiated flour improved the protein digestibility and minerals extractability as well as the level of some amino acids. Despite a significant ($P \leq 0.05$) reduction in antinutreints when radiated and non-radiated flour was cooked, the level of protein digestibility and minerals extractability was fluctuated. Most of the amino acids were slightly stable against all treatments except lysine and threonine which were significantly affected. Phenylalanine plus tyrosine was significantly ($P \leq 0.05$) increased after radiation and even after processing of raw and radiated flour.

Keywords: *Sorghum; amino acids; radiation process; fermentation; cooking*

Introduction

Irradiation has been proposed for disinfestation, inhibition of sprouting, destruction of parasites in meat and fish, to delay maturation of fruit and pasteurization and sterilization. In some applications it could replace or supplement chemical preservatives; in other cases it may have unique advantages whether dry or frozen foods (Sendra *et al.*, 1996).

Sorghum (*Sorghum bicolor* L. Monech) is one of the major food crops of the semiarid regions of Africa and Asia. Sudanese people consumed sorghum as fermented flat bread (Kisra), thick porridge (Aceda), thin fermented gruel (Nasha), boiled grains (Balella) and beverages (Abreh and Hulumur) as a source of protein and mierals (Abdelseed *et al.*, 2011). 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 growth (Mbarki *et al.*, 2008 and Bhavsar *et al.*, 2007). There are also many reports supporting the use of gamma irradiation as a fungicidal agent (Aziz *et al.*, 2007).

However, the viability and sometimes the developmental process of the seedling or the plant have 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 sterilizations. Seeds of different plants that are consumed as food have varying nutrient values which are dependent on the basic constituents of

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seed proteins. The amino group ($–NH_2$) is the most radiosensitive portion of the amino acids (Siddhuraju *et al.*, 2002). Extensive research showed that the macronutrients (carbohydrates, proteins and lipids) content are relatively stable against irradiation dose sup to10 kGy (WHO, 1999).

However, Lee *et al.* (2005) reported that gamma irradiation affects proteins by causing conformational changes, oxidation of amino acids, rupturing of covalent bonds and formation of protein free radicals. Also, chemical changes in the proteins caused by gamma irradiation include fragmentation, cross-linking, aggregation and oxidation by oxygen radicals that are generated in the radiolysis of water. Gamma irradiation has a slight effect on the amino acid profile at recommended doses to foods (WHO, 1999).

This effect could be related to the structure of each amino acid, simple amino acids increased upon irradiation, such as glycine, which undergo reductive deamination and decarboxylation (Erkanand, 2007). In addition, aliphatic amino acids with increasing chain length provide additional C–H bonds for interaction with OH radicals which reduces the extent of oxidative deamination (Erkanand, 2007). Wang and vonSonntage (1991) reported that sulphur-containing as well as aromatic amino acids are, in general, the most sensitive to irradiation, while simple amino acids could be formed by destruction of other amino acids. Pearl millet flour had a severe problem during storage and it was observed to produces off-flavour and bitter taste. In order to minimize losses occurring during storage, the radiation process emerges as an attractive and healthy alternative when compared to chemical conventional treatments (Mohamed *et al.*, 2010a).

The literature has many reports demonstrating that thermal processing methods improve the nutritional quality of foods. However, there is a scarcity of information relating to the effects of processing with ionizing energy. Therefore, the present work was carried out to investigate the effects of radiation process followed by traditional treatments on nutritional quality of raw and processed sorghum cultivar flour.

Materials and methods

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

The seeds with a moisture content of 5.45% were 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 ^{o}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.

Radiated and non-radiated flour of the cultivar was naturally fermented till the pH of the dough reached 4.50 and thereafter cooked for 20 min in a water bath and then dried and ground to pass a 0.4 mm screen for further analysis.

Quantitative determination of tannins was carried out using the modified vanillin - HCl method according to Price *et al.* (1978) using 200 mg sample. A standard curve was prepared expressing the results as catechin equivalents, i.e amount of catechin (mg per ml) which gives a colour intensity equivalent to that given by tannins after correcting for blank.

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 $Fe(NO_3)_3$ equivalent. Phytate phosphorus was calculated from the standard curve assuming a 4:6 iron to phosphorus molar ratio.

In vitro protein digestibility was carried out according to the method of Maliwal (1983) in the manner described by Monjula and John (1991). Digestibility was calculated using the following equation:

$$\text{Protein Digestibility (\%)} = \frac{\text{N in supernatant} - \text{N in pepsin}}{\text{N in sample}} \cdot 100$$

For total content, minerals were extracted from the samples by the dry ashing method described by Chapman and Pratt (1982).

Minerals were determined using atomic absorption spectrophotometer (Perkin-Elmer 2380). Na and K contents were determined using flame photometer (corning 400).

For extractability, minerals in the samples were extracted by the method described by Chauhan and Mahjan (1988) using 1.0 g of the sample. HCl extractability (%) was determined as follows:

$$\text{Mineral extractability (\%)} = \frac{\text{Mineral extractable in 0.03 M HCl (mg/100g)}}{\text{Total minerals (mg/100g)}} \cdot 100$$

The amino acids composition of the samples was measured on hydrolysates using amino acids analyzer (Sykam-S7130, Tokyo, Japan) based on high performance liquid chromatography technique. Sample hydrolysates were prepared following the method of Moore and Stain (1963). About 200 mg of the sample was taken in a hydrolysis tube. Then 5 ml of 6 N HCl was added to the sample and the tube tightly closed and incubated at 110 ^{o}C for 24 h. After incubation, the solution was filtered and 200 ml of the filtrate was evaporated to dryness at 140^{o}C for 1 h. The hydrolysates after dryness were diluted with 1.0 ml of 0.12 N citrate buffer (pH 2.2). Aliquot of 150 µl of the sample hydrolysates was injected in an action separation column at 130 ^{o}C.

Ninhydrin solution and an eluent buffer (solvent A, pH 3.45 and solvent B, pH 10.85) were delivered simultaneously into a high temperature reactor coil (16 m length) at a flow rate of 0.7 ml/min. The buffer⁄ninhydrin mixture was heated in the reactor at 130 ^{o}C for 2 min to accelerate chemical reaction of amino acids with ninhydrin.

The products of the reaction mixture were detected at wavelengths of 570 and 440 nm on a dual channel photometer. The amino acids composition was calculated from the areas of standards obtained from the integrator and expressed as gm/100 gm protein.

The essential amino acid (EAA) score was determined by applying the formula:

$$\text{AS score \%} = \frac{\text{gm of EAA in 100 gm test protein}}{\text{gm of EAA in 100 gm FAO/WHO reference pattern}} \cdot 100$$

Each determination was carried out on three separate samples and analysed in duplicate 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

The effect of gamma irradiation and/or traditional processing on tannin and phytate contents and *in vitro* protein digestibility of sorghum cultivar (Dabar) are shown in Table 1.

Table 1. *Tannin (%), Phytate (mg/100g) contents and in vitro protein digestibility (IVPD) of sorghum cultivar Dabar as affected by irradiation followed by processing*

Radiation dose (KGy)	Treatment	Parameter		
		Tannin	**Phytate**	**IVPD**
0	Raw	0.100 (±0.02)[a]	266.0(±0.45)[a]	70.10(±0.01)[h]
	Fermented	0.066(±1.98)[e]	114.38(±0.42)[m]	70.80(±0.07)[g]
	Cooked	0.039 (±0.05)[i]	223.44(±1.02)[c]	73.10(±0.02)[f]
	Fermented/cooked	0.034(±1.65)[k]	155.61(±1.00)[i]	74.06(±0.11)[e]
5	Raw	0.093 (±1.84)[b]	229.56(±1.61)[b]	74.59(±0.02)[d]
	Fermented	0.0616(±0.01)[f]	99.168(±1.04)[n]	77.34(±1.9)[c]
	Cooked	0.0362 (±1.14)[j]	196.85(±0.10)[f]	80.08(±0.01)[b]
	Fermented/cooked	0.0305(±0.01)[m]	136.00(±1.98)[j]	81.11(±1.93)[a]
10	Raw	0.0724(±0.21)[c]	219.18(±0.17)[d]	56.08(±1.29)[p]
	Fermented	0.0421(±0.11)[h]	97.68(±0.87)[o]	57.38(±0.87)[o]
	Cooked	0.0309 (±0.06)[l]	191.49(±0.12)[g]	57.88(±2.63)[n]
	Fermented/cooked	0.0268 (±1.92)[o]	133.98(±0.11)[k]	58.25(±0.00)[m]
15	Raw	0.0710(±0.28)[d]	215.19(±0.18)[e]	59.94(±1.26)[l]
	Fermented	0.0505(±0.03)[g]	92.53(±0.19)[p]	60.64(±0.01)[k]
	Cooked	0.0272 (±0.01)[n]	181.21(±0.01)[h]	62.17(±0.01)[j]
	Fermented/cooked	0.0257(±1.96)[p]	126.51(±0.11)[l]	62.53(±0.01)[i]

Values are means of three replicates ± SD. Means not sharing a common superscript(s) in a column are significantly different at p ≤ 0.05 as assessed by Duncan's Multiple Range Test.

Ten cultivars of sorghum were investigated for tannin content; Dabar was found to contain least amount (0.10%) of tannin and accordingly designated as low tannin cultivar. Tannin content of raw flour significantly ($P \leq 0.05$) reduced after radiation and the level of reduction increased with increase in radiation dose as reported by Mohamed *et al.* (2010a) for millet cultivars.

Traditional processing (fermentation and/or cooking) of raw flour significantly ($P \leq 0.05$) decreased the level of tannin which agree with that reported by Idris *et al.* (2005), who stated that combination of fermentation and cooking of sorghum improved the nutritional quality and drastically reduced tannin content to safe levels than any other processing methods. Also Osman (2004) reported that fermentation markedly reduced tannin content of three sorghum cultivars by 31, 15 and 35%.

The reduction in tannin content due to fermentation is likely to be due to biochemical activity of fermenting organisms (Eltayeb *et al.*, 2007). However, when traditional treatments applied in combination with radiation process further reduction in tannin content was observed with a minimum value of 0.025% when fermented and cooked seeds were radiated at a dose of 15 KGy. The results are in agreement with those reported by Brigide and Canniatti-Brazaca (2006) who observed that tannin content was inversely correlated with the applied irradiation doses. Radiation of raw flour significantly ($P \leq 0.05$) reduced the level of phytate and the rate of reduction increased with increase in radiation dose as reported by Mohamed *et al.* (2010a) for millet cultivars.

Traditional processing (fermentation and/or cooking) significantly ($P \leq 0.05$) decreased the level of phytate as reported by Idris *et al.* (2005), who found that combination of cooking and fermentation of sorghum significantly ($P \leq 0.05$) reduced the level of phytate. Also Osman (2004) reported that fermentation markedly and significantly ($P \leq 0.05$) reduced phytate content of sorghum cultivars. The reduction in phytate content due to fermentation is likely due to biochemical activity of fermenting organisms which release the enzyme phytase which hydrolyzed phytate. However, when traditional treatments applied in combination with radiation process further reduction was observed with a minimum value of 92.53 mg/100gm when fermented seeds were radiated at a dose of 15 KGy. Osman *et al*. (2012) reported that phytic acid and tannin contents of broad bean were significantly (P ≤ 0.05) reduced as a result of radiation. El-Niely (2007) stated that radiation after processing significantly (P ≤ 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). Both cereal and microbial phytases can contribute to a reduction in phytate during fermentation process (Eltayeb *et al*., 2007).

Duodu *et al*. (1999) reported that cooking did not decrease phytic acid in sorghum porridge, but cooking and irradiation caused a significant decrease (40%). The effect of gamma irradiation on *in vitro* protein digestibility (IVPD) of Dabar cultivar is shown in Table 1. Radiation of raw flour was found to be effective in improving the protein digestibility at low dose of 5 KGy but as the level of radiation increased the protein digestibility significantly (P ≤ 0.05) decreased. Traditional processing (fermentation and/or cooking) of raw flour significantly (P ≤ 0.05) increased the level of protein digestibility as reported by AbdElhaleem *et al.* (2008). When traditional treatments applied in combination with radiation process further improvement in IVPD was observed with a maximum value of 81% when fermented and cooked flour was radiated at a dose of 5 KGy but at high doses the protein digestibility was significantly (P ≤ 0.05) decreased for all treatments.

The results obtained agrees with results obtained by El-Niely (1996) who studied the influence of irradiation on *in vitro* protein digestibility of broad beans irradiated at 2.5, 5, 10 and 20 KGy, he observed that the *in vitro* protein digestibility improved by 4.5, 10, 16 and 20%, respectively. The improvement in IVPD at 5 KGy is likely to be due to reduction in antinutreints during traditional treatment as reported by Babiker and ElTinay (1993). The reduction in IVPD may be due to disulphide formation resulting in disulphide cross-linked protein oligomers and polymers. These polymers form a coat reducing the accessibility of the protein bodies to enzymatic attack (Duodu *et al*., 2003).

Table 2 *Total (mg/100gm) and extractable (%) Sodium (Na), Potassium (K) and Magnesium (Mg) of Dabar cultivar as affected by gamma irradiation followed by processing*

Radiation dose (KGy)	Treatment	Minerals					
		Na		K		Mg	
		Total	extractable	Total	extractable	Total	extractable
0	Raw	23.00^{d}(±1.24)	64.5^{l}(±1.95)	440.0^{c}(±1.98)	54.5^{h}(±0.00)	48.20^{g}(±1.96)	54.31^{j}(±0.09)
	Fermented	25.50^{bc}(±1.07)	75.6^{f}(±1.95)	480.3^{a}(±1.96)	78.0^{d}(±0.76)	56.0^{b}(±0.11)	69.20^{f}(±0.87)
	Cooked	22.82^{d}(±1.06)	61.6^{m}(±1.95)	423.6^{ef}(±0.75)	47.9^{j}(±0.41)	47.20^{h}(±0.23)	53.92^{j}(±0.67)
	Fermented /cooked	22.96^{d}(±1.86)	67.3^{k}(±0.85)	449.4^{b}(±1.03)	67.5^{e}(±0.43)	52.01^{e}(±0.01)	66.51^{g}(±0.16)
5	Raw	22.89^{d}(±0.02)	62.1^{m}(±0.28)	440.0^{c}(±0.21)	51.2^{i}(±0.27)	48.02^{g}(±0.65)	56.74^{i}(±1.06)
	Fermented	26.33^{a}(±0.24)	76.3^{e}(±0.87)	483.6^{a}(±1.98)	77.4^{d}(±0.97)	58.00^{a}(±0.27)	78.63^{c}(±0.03)
	Cooked	23.00^{d}(±0.76)	57.1^{n}(±0.13)	417.0^{g}(±0.45)	45.0^{k}(±0.73)	42.11^{j}(±0.02)	53.91^{jk}(±0.09)
	Fermented /cooked	22.80^{d}(±0.34)	66.9^{k}(±0.56)	428.0^{e}(±0.78)	79.5^{c}(±0.54)	54.12^{c}(±1.01)	75.00^{e}(±0.64)
10	Raw	22.80^{d}(±2.02)	71.6^{i}(±1.69)	439.5^{c}(±0.55)	58.5^{f}(±0.01)	48.33^{g}(±0.72)	61.71^{h}(±1.36)
	Fermented	25.65^{b}(±0.45)	85.7^{a}(±0.64)	479.7^{a}(±0.35)	80.0^{c}(±0.78)	56.00^{b}(±0.76)	81.50^{b}(±0.85)
	Cooked	22.10^{f}(±0.35)	68.8^{j}(±0.32)	440.0^{c}(±0.02)	55.5^{gh}(±0.83)	44.11^{i}(±0.32)	57.12^{i}(±0.21)
	Fermented /cooked	22.90^{d}(±0.89)	77.1^{d}(±0.75)	420.0^{fg}(±0.05)	83.3^{b}(±0.05)	53.00^{d}(±0.21)	82.60^{a}(±0.97)
15	Raw	22.71^{de}(±0.05)	72.3^{h}(±6.56)	438.8^{c}(±0.44)	58.4^{f}(±0.48)	49.02^{f}(±0.87)	62.13^{h}(±0.49)
	Fermented	25.30^{c}(±1.98)	83.6^{b}(±0.36)	481.1^{a}(±0.89)	77.3^{d}(±0.12)	56.00^{b}(±0.01)	78.51^{c}(±0.65)
	Cooked	21.9^{f}(±0.35)	74.1^{g}(±0.08)	409.0^{h}(±0.76)	56.0^{g}(±0.34)	48.00^{g}(±0.11)	53.30^{k}(±0.14)
	Fermented /cooked	22.47^{e}(±0.19)	78.0^{c}(±0.67)	433.0^{d}(±0.23)	85.0^{a}(±0.65)	54.00^{c}(±0.65)	77.51^{d}(±0.87)

Values are means of three replicates (± SD). Means not sharing a common superscript(s) in a column are significantly different at p ≤ 0.05 as assessed by Duncan's Multiple Range Test.

Table 2 shows the content and HCl extractability of some major minerals (Na, K and Mg) of sorghum cultivar (Dabar) as affected by radiation and/or traditional processing. For the raw flour, Na content was found to be 23.00 mg/100g and out of this amount about 64.5% was found to be extractable; K was 440 mg/100g with extractability of 54.50% and Mg was 48.2 mg/100g and out of this amount about 54.31% was extractable.

Variations in extractability between Na, K and Mg is likely to be due to the binding ability of such minerals with antinutreints which are observed to form complexes with minerals and reduced their extractability as reported by Idris *et al.* (2005). Radiation of raw flour had no significant (P ≤ 0.05) effect on total and extractable Na, K and Mg with few exceptions. Fermentation of the raw flour significantly (P ≤ 0.05) increased both total and extractable Na, K and Mg. Cooking of raw flour slightly decreased both total and extractable minerals.

Cooking of raw fermented dough alleviates the effect of cooking and significantly (P ≤ 0.05) increased both total and extractable minerals. Fermentation of radiated flour significantly (P ≤ 0.05) increased both total and extractable minerals. Irradiation of the flour at all levels followed by cooking gave varying changes in total and extractable minerals for the cultivar but there is a significant (P ≤ 0.05) decrease in total as well as in extractable Na, K and Mg compared to raw samples.

Cooking of irradiated fermented dough caused significant (P ≤ 0.05) improvement in extractable minerals. Moreover, as the level of radiation increased the degree of improvement in minerals extractability was significant (P ≤ 0.05).

Processing of irradiated flour significantly (P ≤ 0.05) increased the extractable Na, K and Mg with increase in radiation dose but had no significant (P ≤ 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 (Idris *et al.*, 2007; Mohamed Nour *et al.*, 2010).

Table 3 *Total (mg/100gm) and extractable (%) trace minerals of Dabar cultivar as affected by gamma irradiation followed by processing.*

Radiation dose (KGy)	Treatment	Minerals							
		Zn		Cu		Mn		Co	
		Total	extractable	Total	extractable	Total	extractable	Total	extractable
0	Raw	2.61^{a}(±0.18)	45.08^{j}(±0.02)	0.37^{a}(±0.01)	30.16^{o}(±0.65)	3.30^{a}(±0.05)	47.72^{k}(±0.76)	0.15^{a}(±1.93)	61.25^{g}(±0.64)
	Fermented	2.65^{a}(±0.02)	63.19^{f}(±0.04)	0.39^{a}(±1.97)	62.20^{g}(±0.71)	3.39^{a} (±0.05)	61.84^{f}(±0.18)	0.20^{a} (±0.0)	80.29^{d}(±0.74)
	Cooked	2.61^{a}(±1.28)	44.84^{j}(±0.49)	0.32^{a} (±2.05)	29.53^{p}(±0.32)	3.35^{a} (±1.76)	42.20^{m}(±0.45)	0.14^{a}(±0.25)	61.20^{g}(±0.41)
	Fermented /cooked	2.63^{a}(±2.97)	60.94^{g}(±0.37)	0.38^{a}(±0.12)	59.77^{h}(±0.97)	3.36^{a} (±0.11)	61.22^{g}(±0.01)	0.15^{a}(±0.23)	88.57^{b} (±0.12)
5	Raw	2.61^{a}(±0.011)	44.9^{j}(±0.67)	0.36^{a}(±1.25)	38.3^{l}(±0.53)	3.29^{a} (±0.04)	48.2^{j}(±0.03	0.15^{a}(±0.06)	65.40^{gh}(±1.44)
	Fermented	2.64^{a}(±0.02)	65.0^{e}(±0.13)	0.40^{a}(±0.98)	66.7^{e}(±0.02)	3.36^{a}(±0.87)	62.2^{e}(±0.76)	0.16^{a}(±0.67)	79.70^{d}(±0.64)
	Cooked	2.57^{a}(±0.02)	47.7^{i}(±0.07)	0.38^{a}(±0.34)	33.1^{n}(±0.04)	3.29^{a} (±0.23)	42.4^{m}(±0.24)	0.14^{a}(±0.34)	58.40^{h}(±0.52)
	Fermented /cooked	2.59^{a}(±0.92)	60.3^{g}(±0.43)	0.37^{a}(±0.05)	63.3^{f}(±0.90)	3.39^{a} (±0872	61.2^{g}(±0.97)	0.16^{a}(±0.82)	78.60^{d}(±0.65)
10	Raw	2.62^{a}(±0.01)	57.0^{h}(±0.98)	0.37^{a}(±0.05)	38.8^{k}(±0.03)	3.24^{a} (±0.07)	51.4^{h}(±1.32)	0.16^{a}(±0.06)	75.40^{e}(±0.01)
	Fermented	2.64^{a}(±1.92)	87.3^{a}(±0.45)	0.39^{a}(±0.09)	71.4^{c}(±0.09)	3.35^{a} (±0.72)	73.8^{c}(±0.98)	0.20^{a}(±0.82)	89.30^{ab}(±0.76)
	Cooked	2.63^{a}(±0.92)	55.6^{h}(±0.96)	0.38^{a}(±0.34)	37.7^{m}(±0.76)	3.28^{a} (±0.52)	49.3^{i}(±0.23)	0.17^{a}(±0.23)	65.60^{f}(±0.48)
	Fermented /cooked	2.63^{a}(±0.42)	71.5^{d}(±0.65)	0.39^{a}(±0.12)	69.4^{d}(±0.98)	3.39^{a} (±0.12)	70.5^{d}(±0.45)	0.15^{a}(±0.24)	84.90^{c}(±1.82)
15	Raw	2.60^{a}(±0.07)	61.5^{g}(±0.01)	0.36^{a}(±0.12)	41.3^{j}(±0.26)	3.28^{a} (±0.02	51.1^{h}(±0.13)	0.14^{a}(±0.71)	78.40^{d}(±0.03
	Fermented	2.65^{a}(±0.54)	84.9^{b}(±0.76)	0.38^{a}(±0.87)	74.1^{a}(±0.76)	3.34^{a} (±0.02)	77.3^{b}(±0.98)	0.17^{a}(±0.12)	91.00^{a}(±1.02)
	Cooked	2.61^{a}(±0.87)	60.4^{g}(±0.07)	0.33^{a}(±0.98)	45.7^{i}(±0.54)	3.28^{a} (±0.92)	46.8^{l}(±0.04)	0.15^{a}(±0.05)	67.30^{f}(±0.98)
	Fermented /cooked	2.61^{a}(±0.98)	73.5^{c}(±0.82)	0.39^{a}(±0.54)	72.2^{b}(±0.43)	3.30^{a} (±0.12)	78.2^{a}(±0.13)	0.16^{a}(±0.18)	85.57^{c}(±0.72)

Values are means of three replicates (± SD). Means not sharing a common superscript(s) in a column are significantly different at p ≤ 0.05 as assessed by Duncan's Multiple Range Test.

Table 3 shows the content and HCl extractability of some trace minerals (Zn, Cu, Mn and Co) of sorghum cultivar (Dabar) as affected by radiation and/or traditional processing.

The raw flour of the cultivar contained 2.61, 0.37, 3.30 and 0.15 mg/100g of Zn, Cu, Mn and Co, respectively and out of this amount about 45.05, 30.16, 47.72 and 61.25 were found to be extractable for the minerals, respectively.

Variations in extractability between trace minerals is likely to be due to the binding ability of such minerals with antinutreints which are observed to form complexes with minerals and reduced their extractability as reported by Idris *et al.* (2005). Radiation of raw flour had no significant ($P \leq 0.05$) effect on total minerals but significantly ($P \leq 0.05$) increased the extractability of such minerals. Fermentation of the raw flour significantly ($P \leq 0.05$) increased both total and extractable trace minerals.

Cooking of raw flour had no effect on total and extractable minerals. Cooking of fermented dough alleviates the effect of cooking and significantly ($P \leq 0.05$) increased the extractability of trace minerals but did not affect total minerals. Irradiation at all levels followed by fermentation of raw flour gave varying changes in total and extractable minerals for the cultivar but generally there is a significant ($P \leq 0.05$) increase in total as well as in extractable minerals compared to raw flour. However, cooking of irradiated flour had no great effect on total and extractable trace minerals.

Table 4 *Amino acids composition (mg/100gm protein) and score (AAS) of Dabar cultivar as affected by gamma radiation followed by traditional treatments.*

Radiation dose (KGy)	Treatment	Amino acids													
		Isoleucine		Leucine		Lysine		Methionine + Cysteine		Phenyl alanine + Tyrosine		Threonine		Valine	
		Total	AAS	Total	AAS	Total	AAS	Total	AAS	Total	AAS	Total	AAS	Total	AAS
0	Raw	3.95^{b}	141.07	11.30^{j}	171.20	1.65^{b}	28.45	1.75^{c}	70.08	7.77^{n}	123.20	2.04^{d}	60.00	4.03^{i}	115.20
	Fermented	3.45^{f}	123.00	11.67^{i}	176.76	1.71^{a}	29.55	1.59^{j}	63.80	7.39^{p}	117.30	2.13^{b}	62.50	4.55^{b}	130.00
	Cooked	3.63^{c}	129.60	11.76^{h}	178.21	0.89^{j}	15.34	1.88^{a}	75.12	7.94^{k}	126.10	1.62^{i}	47.60	4.79^{a}	136.70
	Fermented /cooked	3.05^{n}	108.90	13.00^{c}	196.91	0.98^{i}	16.90	1.66^{g}	66.52	8.34^{f}	132.40	1.38^{m}	40.60	4.21^{h}	120.20
5	Raw	3.04^{o}	108.60	11.79^{g}	178.90	1.19^{f}	20.52	1.78^{b}	71.24	8.12^{g}	128.90	2.16^{a}	63.41	3.99^{k}	114.00
	Fermented	3.32^{i}	119.00	12.10^{e}	183.40	1.64^{c}	28.32	1.72^{e}	68.60	7.73^{o}	122.70	2.09^{c}	61.50	3.87^{m}	110.70
	Cooked	3.47^{e}	123.80	9.27^{m}	140.30	0.67^{l}	11.6	1.49^{l}	59.70	7.84^{m}	124.60	1.62^{h}	47.80	4.54^{c}	129.80
	Fermented /cooked	3.08^{m}	110.10	8.13^{o}	123.20	0.79^{k}	13.62	1.64^{h}	65.70	8.42^{e}	133.70	1.40^{l}	41.10	4.24^{f}	121.20
10	Raw	3.10^{l}	110.80	11.98^{f}	181.50	1.14^{g}	19.71	1.60^{i}	64.00	7.95^{j}	126.20	1.08^{o}	31.60	4.01^{j}	114.70
	Fermented	3.61^{d}	128.90	13.49^{b}	204.30	1.63^{d}	28.11	1.69^{f}	67.80	7.87^{l}	125.00	2.02^{e}	59.40	4.55^{b}	130.00
	Cooked	3.40^{h}	121.50	9.41^{l}	142.50	0.66^{m}	11.31	1.38^{m}	55.40	8.09^{h}	128.40	1.48^{k}	43.60	4.42^{e}	126.20
	Fermented /cooked	3.12^{k}	111.30	8.37^{n}	126.80	0.62^{o}	10.71	1.73^{d}	69.00	8.61^{c}	136.70	1.57^{j}	46.30	4.24^{g}	121.10
15	Raw	3.26^{j}	116.30	12.52^{d}	189.70	1.01^{h}	17.41	1.29^{n}	51.60	7.98^{i}	126.60	1.02^{p}	30.00	4.01^{j}	114.60
	Fermented	4.61^{a}	164.70	14.00^{a}	212.20	1.52^{e}	26.24	1.27^{p}	50.90	8.51^{d}	135.00	1.99^{f}	58.60	3.92^{l}	112.00
	Cooked	3.42^{g}	122.10	9.70^{k}	147.00	0.64^{n}	11.0	1.28^{o}	51.20	8.87^{a}	140.80	1.73^{g}	50.90	4.50^{d}	128.50
	Fermented /cooked	2.62^{p}	93.70	7.16^{p}	108.40	0.54^{p}	9.33	1.51^{k}	60.40	8.67^{b}	137.60	1.36^{n}	49.90	3.51^{n}	100.30

Values are means of duplicate samples. Means not sharing a common superscript(s) in column are significantly different at $p \leq 0.05$ as assessed by Duncan's Multiple Range Test.

Cooking of irradiated/fermented dough caused a significant ($P \leq 0.05$) improvement in extractable minerals but did not affect total minerals. The results obtained showed that as the level of radiation increased the degree of improvement in minerals extractability was significant ($P \leq 0.05$). Processing of irradiated flour significantly ($P \leq 0.05$) increased the extractable trace minerals with increase in radiation dose but had no significant ($P \leq 0.05$) effect on total trace 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.

Tables 4 show the effect of radiation process on amino acids composition of raw and treated flour of Dabar cultivar. Radiation of raw flour of Dabar cultivar at 5KGy increased leucine from 11.3 to 11.792, methionine plus cysteine from 1.752 to 1.781, phenylalanine plus tyrosine from 7.76 to 8.119 and threonine from 2.039 to 2.156 gm/100gm protein with a concomitant increase in amino acid scores. Isoleucine, lysine and valine of the cultivar were decreased. Radiation of raw flour of the cultivar at 10 KGy resulted in a significant ($P \leq 0.05$) increase in phenylalanine plus tyrosine, while other amino acids were decreased except leucine which was increased. Irradiation of raw flour at 15 KGy significantly ($P \leq 0.05$) increased leucine, phenylalanine plus tyrosine for the cultivar while the other amino acids were decreased as a result of radiation. Joseph *et al.* (2005) reported that with the exception of tyrosine the amino acids in cowpea (acidic, basic, polar and non polar amino acids) were decreased significantly with increase in gamma radiation compared to their respective controls. Hooshmand and Klopfenstein (1995) reported that lysine content decreased by 7 and 13% respectively, when maize and wheat flours were irradiated at 7.5 KGy. The observed increase in some free amino acid content due to exposure to ionizing radiation is in agreement with the findings reported by Satter *et al.* (1990), who documented increases in essential and nonessential amino acids of soybean when irradiated at a dose level of 10 kGy.

The precise effect of ionising radiation on free amino acid content depends on various factors, such as sensitivity of the exposed system, the type of particular functional tissue and even other conditions, such as aqueous soaking after irradiation, as has been indicated in the works of Siddhuraju *et al.* (2002). Wang and vonSonntage (1991) reported that sulphur-containing as well as aromatic amino acids are, in general, the most sensitive to irradiation, while simple amino acids could be formed by destruction of other amino acids.

Bhat *et al.* (2008) reported that irradiation is an efficient process in maintaining the nutritional potential of Mucuna pruriens seeds. Fermentation of raw flour of Dabar culivar increased the level of leucine, lysine, threonine and valine (Table 4). It has been reported that fermentation of Sicklepod leaves significantly ($P \leq 0.05$) increased alanine, valine, cystine, isoleucine, leucine and ammonia contents while aspartic, threonine, serine, glutamic, tyrosine, histidine, lysine and arginine contents were significantly ($P \leq 0.05$) decreased (Osman *et al.*, 2010).

Radiation at 5 KGy followed by fermentation significantly ($P \leq 0.05$) increased leucine and threonine of the cultivar (Table 4) while that at 10KGy significantly ($P \leq 0.05$) increased leucine, phenylalanine plus tyrosine and valine and that at 15KGy significantly ($P \leq 0.05$) increased isoleucine, leucine and phenylalanine plus tyrosine. Cooking of raw flour of the cultivar increased the level of leucine, methionine plus cysteine, phenylalanine plus tyrosine and valine. Fageer *et al.* (2004) observed that cooking of corn in water increased lysine, valine, leucine and phenylalanine while threonine, methionine and isoleucine were decreased. Radiation at 5KGy followed by cooking significantly ($P \leq 0.05$) increased phenylalanine plus tyrosine and valine of the cultivar while that at 10 KGy significantly ($P \leq 0.05$) increased phenylalanine plus tyrosine and valine and that at 15 KGy significantly ($P \leq 0.05$) increased phenylalanine plus tyrosine and valine for Dabar cultivar. Cooking of fermented dough of the cultivar increased the level of leucine, phenylalanine plus tyrosine and valine. Osman *et al.* (2010) reported that cooking of the fermented Sicklepod leaves significantly ($P \leq 0.05$) decreased aspartic, threonine, serine, glutamic acid, glycine, tyrosine, phenylalanine and arginine contents. Radiation at 5KGy followed by cooking of fermented dough significantly ($P \le 0.05$) increased phenylalanine plus tyrosine and valine while that at 10 KGy significantly ($P \le 0.05$) increased phenylalanine plus tyrosine and valine and that at 15KGy significantly ($P \le 0.05$) increased phenylalanine plus tyrosine for the sorghum cultivars.

The results obtained showed that the effect of radiation alone on amino acids composition was minor as both fermentation and cooking had negative effect on some amino acids. Moreover, radiation process is an ideal method in preserving material as reported for millet flour (Mohamed *et al.*, 2010b).

Conclusions

The observations about nutritional quality in the studied samples tend to suggest that radiation processing up to 15 kGy had little effects on their value and had slight effects on the amino acids of the flour whether raw or processed. Therefore, radiation can be applied to alleviate the severe problem of antinutreints. Moreover, when accompanied by traditional processing an improvement in protein and minerals availability was observed.

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