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Effect of radiation process on antinutrients, protein digestibility and sensory quality of pearl millet flour during processing and storage

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Abstract: Grains of Ashana and Dembi millet (*P. glaucum* L.) cultivars were used in this study to investigate the effect of radiation process on antinutrients, protein digestibility and sensory quality of the flour during processing and storage. Whole and dehulled flour of millet cultivars were stored for 30 and 60 days before and after radiation and/or cooking. Antinutrients (tannin and phytate) contents were assayed for all treatments. The results showed that the storage period had no effect on phytate and tannin contents. For both cultivars, dehulling of the grains reduced more than 50% of phytate and tannin. Moreover, cooking of the raw whole and dehulled flour significantly ($P \leq 0.05$) decreased tannin and phytate contents for both cultivars. Radiation process alone had no effect on tannin and phytate contents but when followed by cooking significantly ($P \leq 0.05$) reduced the level of such antinutrients for the whole and dehulled flour of both cultivars. Dehulling alone significantly ($P \leq 0.05$) increased the protein digestibility but decreased the quality attributes of both cultivars. Radiation alone for the whole or dehulled seeds had no effect on the protein digestibility but slightly improved the quality attributes of both cultivars. However, radiation followed by cooking significantly ($P \leq 0.05$) reduced the protein digestibility but improved the quality attributes of both cultivars.

Keywords: Radiation, millet, dehulling, antinutrients, protein digestibility, sensory characteristics

Introduction

Pearl millet is a multipurpose crop, which is grown for food, feed and forage. Like other cereal grains, the abundance of antinutrients such as phytic acid and tannins inhibits proteolytic and amylolytic enzymes, limits protein and starch digestibility and makes poor human bioavailability of proteins (Elhag *et al*., 2002). Pearl millet is a versatile foodstuff used mainly as cooked, whole, dehulled or ground flour dough or as a grain like rice. In Sudan, millet is a staple diet of the people in the Western region (Darfur) and is consumed as thick porridge (aseeda), a thin porridge (nasha), kisra (unleavened bread) from fermented or unfermented dough. Moreover, meals such as Jiria and Damierga are prepared from fermented dehulled pearl millet flour. Large variations in protein and mineral contents have been observed (AbdelRahaman *et al*., 2007). A protein content of 15.4%, 14.8% and 16.3% was reported by Klopfenstein *et al*. (1991) for gray, yellow and brown pearl millet, respectively. Local Sudanese cultivars investigated by Elyas *et al*. (2002) gave a range of 10.8-14.9% protein (Ali *et al*., 2003). Phytic acid content in pearl millet represents more than 70% of the total phosphorus of the grain (AbdelRahaman *et al*., 2007). A value of 990 mg/100 g phytic acid was reported by Khetarpaul and Chauhan (1990) while Kumar and Chauhan (1993) gave a value of 825.7 mg/100 g. Elhag *et al*. (2002) reported values of 943 and 1076 mg/100 g phytic acid for two Sudanese cultivars. AbdelRahaman *et al*. (2007) reported that millet contains some antinutrients (phytate and polyphenols) that affect nutrient absorption by the human body. The food industry has become increasingly interested in novel food processing technologies which promise to preserve and improve the quality of food without the use of heat or chemical additives while still retaining the food quality such as irradiation.

Food irradiation is already recognized as a technically feasible method for reducing post-harvest food losses, ensuring the hygienic quality of food and facilitating wider food trade (Jyoti *et al.*, 2009). Moreover, the safety of irradiated foods has been endorsed up to an overall average dose of 10 kGy. Ionizing radiation is an efficient technique used worldwide, to preserve food, extend its shelf life and control food borne pathogens. The chemical structure of irradiated food is less modified than heat-treated one and this technique avoids the use of potentially harmful chemicals (Siddhuraju *et al*., 2002). Radiation (2 kGy) alone was found to have a minor effect on antinutrients content of the whole and dehulled flour of millet cultivars. However, when combined with cooking significantly ($P \leq 0.05$) reduced antinutrients

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content of the flour (Mohamed *et al.*, 2010a). Moreover, it has been reported that radiation process had little or minor effect on the protein content of two millet cultivars (Mohamed *et al.*, 2010b). Millet flour had a severe problem during storage and was observed to produce off-flavor and bitter taste. In order to minimize nutritional losses occurring during storage of millet 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 as a preserving agent on the antinutritional factors, protein digestibility and sensory quality of raw and processed whole and dehulled millet flour.

Materials and Methods

Sample collection and preparation

Grains of Ashana and Dembi millet (*P. glaucum* L.) cultivars were collected from Nyala Agricultural Research Station, Southern Darfur State, Sudan. Collected seeds (4 kg) of each cultivar were either ground to pass a 0.4 mm screen or dehulled using mechanical dehuller and 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 uniformally 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) following the procedures described by Helinski *et al*. (2008) with a dose rate of ca. 2 Gy/min at 25^{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.

Processing and storage of the samples

Treated and untreated samples of whole and dehulled flour of each cultivar were divided into two portions. One portion was stored for 0, 30 or 60 days in polythene bags at room temperature (25^{o}C) and the other portion was cooked for 20 min in a water bath and then dried and ground to pass a 0.4 mm screen and then stored for 30 and 60 days.

Determination of Tannin content

Quantitative estimation of tannins was carried out using the modified vanillin-HCl method (Price *et al*., 1978). A 200 mg sample was extracted using 10 mL 1% (v/v) concentrated HCl in methanol for 20 min in capped rotating test tubes. Vanillin reagent (0.5%, 5 mL) was added to the extract (1 mL) and the absorbance of the colour developed after 20 min at 30 ^{o}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. Then tannin content (%) was calculated according to the equation:

$$\text{Catechin equivalent (CE)\%} = \frac{\text{C x volume extracted (10 mL)}}{\text{sample weight (g)}} \text{x100}$$

Where C, concentration obtained from the standard curve (mg/mL).

Determination of phytic acid content

Phytic acid content of the malt, treated and untreated sorghum flour was determined by the method described by Wheeler & Ferrel (1971) using 2.0 g of a 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 4:6 iron to phosphorus molar ratio.

Determination of in vitro protein digestibility (IVPD)

IVPD was carried out according to the method described by Monjula and John (1991) with a minor modification. A known weight of the sample containing 16 mg nitrogen was taken in triplicate and digested with 1 mg pepsin in 15 ml of 0.1 N HCl at 37^{o}C for 2 h. The reaction was stopped by the addition of 15 ml 10% trichloroacetic acid (TCA). The mixture was then filtered quantitatively, through Whatman No. 1 filter paper. The TCA soluble fraction was assayed for nitrogen using the micro-Kjeldahl method (AOAC, 1990). Digestibility was estimated by using the following equation:

$$\text{IVPD\%} = \frac{\text{N in supernatant - N in pepsin}}{\text{N in sample}} \text{x100}$$

Sensory evaluations

The sensory tests were conducted using conventional profiling by a trained panel. Ten judges were selected who had successfully passed standardized tests for olfactory and taste sensitivities as well as verbal abilities and creativity. The panellists were given a hedonic questionnaire to test color, flavor, bitterness and overall acceptability of coded samples of treated and/or processed samples. They were scored on a scale of 1–5 (1 = poor, 2 = fair, 3 = good, 4 = very good and 5 = excellent).

Statistical analysis

Each determination was carried out on three separate samples, on dry weight basis and each sample analysed in triplicate, the figures were then averaged. Data were assessed using ANOVA (Snedecor and Cochran, 1987). Mean comparisons for treatments were made using Duncan's multiple range tests. Significance was accepted at $P \leq 0.05$.

Results and Discussion

Effect of radiation process on antinutritional factors of raw and processed millet flour during storage

Table 1 summarizes the data for tannin content (mg/100 g) of whole and dehulled raw and processed flour during storage periods (0, 30 and 60 days) of two millet cultivars (Ashana and Dembi). Tannin content of whole raw flour was 0.38 and 0.34 mg/100 g while that of the dehulled raw flour was 0.20 and 0.17 mg/100 g for Ashana and Dembi, respectively. The results revealed that dehulling of the grains significantly ($P \leq 0.05$) reduced tannin content of both cultivars, which indicated that the seed coat contained an appreciable amount of tannin. As shown in Table 1, storage of treated and untreated whole and dehulled flour had slight effect on tannin content of both cultivars. Cooking of the whole raw flour significantly ($P \leq 0.05$) reduced tannin content to 0.29 and 0.30 mg/100 g for the cultivars, respectively. Further reduction in tannin content was observed when the dehulled raw flour was cooked and it was found to be 0.19 and 0.17 mg/100 g for the cultivars, respectively. The reduction in tannin after cooking may be due to heat treatment which inactivates tannin and reduces its ability to bind with proteins and enzymes to make insoluble complexes. El-Niely (2007) reported that radiation processing significantly ($P \leq 0.05$) reduced the levels of phytic acid and tannins of legumes and Toledo *et al*. (2007) observed a decrease in antinutritional factors after cooking of soybean grains. Similar observations were obtained by Elhag *et al*. (2002) when they studied the effect of dehulling on antinutritional factors of pearl millet cultivars. The results obtained for phytic acid content during treatments, cooking and storage of the whole and dehulled flour (Table 2) are similar to those obtained for tannin except that when the dehulled flour was cooked, phytate content significantly ($P \leq 0.05$) decreased while radiation process had no effect on phytate even after cooking. Phytate in cereals is one of major concern as it chelates mineral cations and interacts with proteins forming insoluble complexes which lead to reduced bio-availability of minerals and reduced digestibility of protein (Reyden and Selvendran, 1993). Sattar *et al*. (1990) reported that the extent of reduction in phytic acid increased linearly with increase in radiation dose. Treatment of soybean seeds with radiation (1.0 kGy) alone or in combination with soaking reduced the level of phytate compared to controls. Radiation (2 kGy) alone was found to have a minor effect on antinutrients content of the whole and dehulled flour of millet cultivars. However, when combined with cooking significantly ($P \leq 0.05$) reduced antinutrients content of the flour (Mohamed *et al*., 2010a). This reduction might be due to chemical degradation of phytate to the lower inositol phosphates and inositol by the action of free radicals produced by the radiation. Another possible mode of phytate loss during irradiation could have been through cleavage of the phytate ring itself (Sattar *et al*., 1990). In the present study, the ineffectiveness of the irradiation in combination with cooking on the reduction/cleavage of phytate might be governed by the medium radiation dose (2 kGy). The little reduction in tannin of studied flour might be due to the relative stability of phenolics in the samples for the applied radiation dose (2 kGy). The observations about phytic acid and tannin in the studied samples tend to suggest that radiation processing up to 2 kGy had little effects on their value and therefore to achieve greater reduction in these antinutrients, millet flour need to receive higher radiation dose up to 10 kGy.

Effect of radiation process on in vitro *protein digestibility of raw and processed millet flour during storage*

Table 3 shows the effect of radiation process of whole and dehulled raw and processed flour during storage periods (0, 30 and 60 days) on *in vitro* protein digestibility (IVPD) of Ashana and Dembi cultivars. The IVPD of the whole raw flour was 46.43 and 51.23% while that of the dehulled raw flour was 50.54 and 55.28% for Ashana and Dembi, respectively. The results revealed that dehulling of the grains significantly ($P \leq 0.05$) increased the IVPD of both cultivars due to a reducing level of antinutritional factors of the dehulled flour. The results obtained also indicated that the whole flour contained an appreciable amount

Table 1. Effect of radiation process on tannin content (mg/100g) of raw and processed whole and dehulled flour of pearl millet cultivars during storage

Cultivars						
Dembi			Ashana			Samples
Storage period (days)						
60	30	0	60	30	0	
Whole seeds flour						
0.35^{ab} (±0.02)	0.31^{ab} (±0.01)	0.34^{ab} (±0.05)	0.41^{b} (±0.01)	0.36^{b} (±0.03)	0.38^{a} (±0.05)	Untreated
0.29^{b} (±0.05)	0.31^{ab} (±0.10)	0.30^{b} (±0.08)	0.29^{de} (±0.02)	0.28^{cd} (±0.01)	0.29^{bc} (±0.03)	Cooked
0.40^{a} (±0.05)	0.36^{a} (±0.01)	0.37^{a} (±0.07)	0.46^{a} (±0.07)	0.43^{a} (±0.03)	0.34^{ab} (±0.06)	Irradiated
0.30^{b} (±0.05)	0.32^{ab} (±0.10)	0.35^{ab} (±0.03)	0.34^{c} (±0.05)	0.30^{cd} (±0.04)	0.27^{cd} (±0.06)	Irradiated/cooked
Dehulled seeds flour						
0.18^{c} (±0.06)	0.17^{cd} (±0.05)	0.17^{e} (±0.04)	0.20^{f} (±0.01)	0.23^{ef} (±0.02)	0.20^{e} (±0.01)	Untreated
0.20^{c} (±0.01)	0.19^{cd} (±0.09)	0.20^{de} (±0.11)	0.20^{f} (±0.03)	0.19^{ef} (±0.09)	0.19^{e} (±0.06)	Cooked
0.19^{c} (±0.05)	0.21^{c} (±0.12)	0.19^{de} (±0.02)	0.19^{f} (±0.05)	0.18^{f} (±0.03)	0.26^{cd} (±0.03)	Irradiated
0.21^{c} (±0.04)	0.13^{d} (±0.05)	0.28^{c} (±0.01)	0.18^{f} (±0.03)	0.14^{f} (±0.01)	0.24^{de} (±0.08)	Irradiated/cooked

Values are means (± SD) of triplicate samples. Means not sharing a common superscript letter in a column are significantly different at $P \le 0.05$ as assessed by Duncan's multiple range tests.

Table 2. Effect of radiation process on phytic acid content (mg/100g) of raw and processed whole and dehulled flour of pearl millet cultivars during storage

Cultivars						
Dembi			Ashana			Samples
Storage period (days)						
60	30	0	60	30	0	
Whole seeds flour						
724.95^{a} (±0.50)	723.53^{b} (±0.35)	722.31^{a} (±0.24)	769.56^{a} (±0.95)	768.92^{a} (±0.70)	768.21^{a} (±0.50)	Untreated
716.31^{e} (±0.30)	715.89^{e} (±0.10)	715.42^{b} (±0.21)	762.16^{d} (±0.88)	761.87^{d} (±0.11)	761.68^{b}(±0.75)	Cooked
724.41^{b} (±0.85)	724.59^{a} (±0.36)	722.35^{a} (±0.24)	768.82^{b} (±0.67)	768.53^{b} (±0.75)	768.14^{a} (±0.55)	Irradiated
716.90^{d} (±0.70)	717.28^{d} (±0.32)	715.20^{c} (±0.61)	759.84^{f} (±0.15)	757.85^{f} (±0.60)	761.61^{b} (±0.70)	Irradiated/cooked
Dehulled seeds flour						
285.89^{f} (±0.10)	283.87^{g} (±0.26)	284.69^{e} (±0.25)	303.13^{h} (±0.33)	302.52^{h} (±0.44)	302.79^{c} (±0.22)	Untreated
279.54^{h} (±0.65)	278.87^{i} (±0.71)	279.08^{d} (±0.23)	293.72^{j} (±0.15)	293.83^{j} (±0.22)	293.55^{e} (±0.31)	Cooked
285.79^{f} (±0.43)	285.72^{f} (±0.16)	284.66^{e} (±0.25)	303.91^{g} (±0.24)	303.32^{g} (±0.21)	302.70^{d} (±0.20)	Irradiated
276.81^{j} (±0.86)	275.55^{k} (±0.30)	279.13^{d} (±0.23)	293.87^{i} (±0.33)	293.67^{k} (±0.24)	293.40^{e} (±0.21)	Irradiated/cooked

Values are means (± SD) of triplicate samples. Means not sharing a common superscript letter in a column are significantly different at $P \le 0.05$ as assessed by Duncan's multiple range tests.

Table 3. Effect of radiation process on *in vitro* protein digestibility (%) of raw and processed whole and dehulled flour of millet cultivars during storage

Cultivars						
Dembi			Ashana			Samples
Storage period (days)						
60	30	0	60	30	0	
Whole seeds flour						
49.56^{g} (±0.30)	50.92^{e} (±0.15)	51.23^{b}(±0.23)	45.23^{f} (±0.18)	45.65^{e} (±0.47)	46.43^{b} (±1.07)	Untreated
36.65^{j} (±0.76)	37.21^{j} (±0.45)	37.68^{d}(±0.40)	35.39^{j} (±0.55)	35.40^{i} (±0.45)	36.35^{c} (±0.65)	Cooked
49.23^{h} (±0.10)	48.83^{g} (±0.08)	51.27^{b}(±0.23)	47.60^{e}(±0.98)	47.69^{d} (±0.59)	46.60^{b} (±1.07)	Irradiated
36.47^{j} (±0.22)	36.63^{j} (±0.18)	37.64^{d}(±0.40)	37.67^{i} (±0.33)	38.74^{g} (±0.27)	36.30^{c} (±0.65)	Irradiated/cooked
Dehulled seeds flour						
55.63^{c} (±0.49)	55.58^{b} (±0.20)	55.28^{a}(±0.15)	50.24^{c}(±0.43)	49.83^{c} (±0.30)	50.54^{a} (±0.80)	Untreated
49.23^{h} (±0.65)	51.36^{d} (±0.13)	50.33^{c}(±0.13)	43.37^{g}(±0.23)	45.37^{e} (±0.18)	46.33^{b} (±0.17)	Cooked
56.35^{b} (±0.88)	55.22^{c} (±0.28)	55.25^{a}(±0.15)	51.24^{b}(±0.14)	50.34^{b} (±0.27)	50.51^{a} (±0.80)	Irradiated
49.85^{f} (±0.45)	50.18^{f} (±0.05)	50.37^{c}(±0.13)	45.38^{f} (±0.20)	44.78^{f} (±0.10)	46.36^{b} (±0.17)	Irradiated/cooked

Values are means (± SD) of triplicate samples. Means not sharing a common superscript letter in a column are significantly different at $P \le 0.05$ as assessed by Duncan's multiple range tests.

of tannin and phytate which reduced the IVPD of both cultivars as reported by many researchers (Kumar and Chauhan, 1993; Elhag *et al*., 2002; ELyas *et al*., 2002). As shown in Table 3, storage of treated and untreated whole and dehulled flour had slight effect on IVPD of both cultivars. Cooking of the whole raw flour significantly ($P \le 0.05$) reduced the IVPD to 36.35 and 37.68% for the cultivars, respectively. Also cooking of the dehulled raw flour significantly ($P \le 0.05$) reduced the IVPD to 46.33 and 50.33% compared to uncooked flour of the dehulled flour for the cultivars, respectively. Radiation process alone resulted in insignificant change (fluctuated) in IVPD of the cultivars. However, when combined with cooking it resulted in a significant ($P \le 0.05$) reduction in the IVPD of both cultivars compared to the control sample. Evidence from *in vitro* studies indicates that digestion of native seed storage protein is limited because of the structure and conformation of the protein (Carbonaro *et al*., 2000). Also, *in vitro* studies have shown that phytate-protein complexes are insoluble and less subject to attack by proteolytic enzymes than the same protein alone (Ravindran *et al*., 1995) and subsequently affect the functional properties of the protein. Moreover, the partial removal of tannin and phytate probably created a large space within the matrix, which increased the susceptibility to enzymatic attack (Rehman and Shah, 2001) and consequently improve the digestibility of protein after radiation treatment. Higher protein digestibility after radiation treatment may be due to increased accessibility of the protein to enzymatic attack.

However, this effect could also be due to inactivation of proteinaceous antinutritional factors (Van der Poel, 1990). The *in vitro* apparent digestibility of protein data indicated a beneficial effect for radiation when the *in vitro* digestibility of the studied cereal seeds was considered. The apparent improvement in *in vitro* digestibility that being ensured through radiation treatment, may be attributed to appreciable effect of radiation treatment on the antinutritional factors present naturally in non-radiated flour which is more sensitive to enzyme action. It is well known that radiation could induce and (or) stimulate other factors. Molecular rearrangement and changes in peptide linkages between the amino groups of amino acids could affect the nutritive availability and the biological utilization of the irradiated proteins. Such changes could interfere with the protein digestibility and/or its biological value. Thus, protein digestibility may be decreased and/or increased without incurring amino acid destruction (El-Hakeim *et al*., 1991). Therefore, it could be concluded that the radiation process offers a good treatment for millet to reduce or eliminate their antinutritional factors with consequent increase in their digestibility and thereby increase utilization of their proteins.

Effect of radiation process on sensory quality of raw and processed millet flour during storage

Table 4 and 5 show the consumer panel data of whole and dehulled raw and processed flour during storage period (30 days) of two millet cultivars (Ashana and Dembi). The storage period of 60 days gave panel data similar to that of 30 days, therefore in Tables 4 and 5 we presented the data for 30 days only. The consumer panel data for the treated and untreated flour of Ashana cultivar (Table 4) indicated that significant ($P \leq 0.05$) differences in color, flavor, bitterness and overall acceptability were observed between the raw fresh whole flour and that stored for 30 days. However, for the raw dehulled flour no significant ($P \leq 0.05$) differences in color, flavor, bitterness or overall acceptability were observed between fresh dehulled flour and that stored for 30 days. Moreover, the whole raw flour was accepted by the panellists better than that of the dehulled one. Cooking of the whole raw flour significantly ($P \leq 0.05$) reduced the score obtained for the color, falvor and overall acceptability while cooking of the dehulled raw flour significantly ($P \leq 0.05$) improved the quality attributes. Radiation process of the whole and dehulled flour significantly ($P \leq 0.05$) improved the quality with respect to color and overall acceptability and to some extends the bitterness of the flour. When radiation process of whole flour combined with cooking, the score for all attributes decreased except that of bitterness while that of the dehulled flour all quality attributes were significantly ($P \leq 0.05$) improved. The results obtained for sensory characteristics of Dembi cultivar (Table 5) are similar to those reported for Ashana cultivar. The effect of gamma irradiation on the sensory characteristics of millet flour has not been reported previously. We

Table 4. Effect of radiation process on sensory characteristics of raw and processed whole and dehulled flour during storage of a millet cultivar (Ashana)

Overall acceptance		Bitterness		Flavor		Co lour		Samples
Storage period (days)								
30	0	30	0	30	0	30	0	
Whole seeds flour								
2.6^{d} (±1.06)	3.8^{ab}(±0.71)	2.5^{c} (±1.41)	3.3^{cd} (±1.16)	2.9^{b} (± 0.83)	3.9^{a} (± 0.83)	3.1^{b} (± 1.13)	4.0^{a} (± 0.76)	Untreated
4.3^{ab}(±1.04)	3.6^{bc} (±1.06)	4.0^{a} (±0.76)	4.3^{a} (±0.89)	3.4^{ab}(± 1.41)	3.1^{b} (± 1.25)	3.1^{b} (± 0.83)	3.1^{b} (±1.13)	Cooked
4.0^{ab}(±0.53)	4.2^{a} (±0.71)	4.1^{a} (±1.13)	3.4^{cd} (±1.06)	3.1^{ab}(± 0.83)	3.5^{a} (± 0.83)	4.5^{a} (±1.07)	4.5^{a} (± 0.76)	Irradiated
3.8^{b} (±0.46)	3.7^{ab}(±0.80)	2.9^{bc} (±1.46)	4.1^{ab}(±0.89)	3.3^{ab}(± 0.71)	3.7^{a} (± 1.25)	1.5^{d} (± 0.93)	3.5^{b} (±1.13)	Irradiated/cooked
Dehulled seeds flour								
3.6^{bc} (±1.19)	3.4^{bc} (±1.06)	2.8^{bc} (±1.28)	2.8^{de} (±1.04)	2.8^{bc}(± 0.89)	2.8^{b} (± 0.59)	1.9^{cd}(± 0.83)	2.4^{c} (±1.06)	Untreated
4.4^{a} (±0.74)	3.5^{bc} (±0.93)	4.1^{a} (±0.64)	3.3^{cd} (±0.46)	3.6^{a} (±1.41)	2.8^{b} (± 0.89)	3.7^{b} (±1.25)	3.6^{bc} (±1.06)	Cooked
3.9^{ab}(±0.64)	3.6^{bc} (±1.06)	2.4^{c} (±0.74)	2.9^{c} (±0.82)	2.9^{b} (± 0.83)	2.9^{b} (± 0.83)	1.6^{d} (± 0.92)	2.6^{c} (±1.06)	Irradiated
4.0^{ab}(±0.53)	3.9^{ab} (±0.93)	3.8^{ab}(±1.04)	3.7^{ab}(±0.52)	3.4^{ab}(±0.74)	3.8^{a} (± 1.16)	4.0^{a} (± 1.07)	4.0^{a} (±1.07)	Irradiated/cooked

Values are means (± SD) of triplicate samples. Means not sharing a common superscript letter in a column are significantly different at $P \leq 0.05$ as assessed by Duncan's multiple range tests.

Table 5. Effect of radiation process on sensory characteristics of raw and processed whole and dehulled flour during storage of a millet cultivar (Dembi)

Overall acceptance		Bitterness		Flavor		Co lour		Samples
Storage period (days)								
30	0	30	0	30	0	30	0	
Whole seeds flour								
3.4^{c} (±1.06)	3.1^{bc} (±0.83)	3.0^{c} (±1.20)	2.9^{bc} (±0.59)	2.6^{bc} (±0.52)	2.5^{d} (±0.53)	3.6^{ab} (±0.74)	4.5^{a} (±0.70)	Untreated
2.9^{d} (±0.99)	3.5^{ab} (±0.43)	2.9^{cd} (±1.13)	3.0^{ab} (±0.53)	2.8^{ab} (±0.89)	2.6^{cd}(±1.06)	1.9^{cd} (±0.83)	2.1^{e} (±0.83)	Cooked
3.6^{bc} (±0.92)	3.0^{c} (±0.83)	2.3^{d} (±1.04)	3.0^{ab} (±0.69)	2.4^{c} (±0.92)	2.5^{d} (±0.53)	3.5^{b} (±1.07)	3.5^{bc} (±1.07)	Irradiated
4.3^{a} (±1.04)	3.0^{c} (±0.76)	3.4^{ab}(±0.74)	3.0^{ab} (±0.53)	3.3^{ab} (±0.71)	2.6^{cd}(±1.06)	1.6^{cd} (0.92)	2.5^{de} (±0.53)	Irradiated/cooked
Dehulled seeds flour								
4.3^{a} (±0.71)	3.5^{ab}±1.07)	3.9^{ab} (±0.99)	3.5^{ab} (±1.07)	3.0^{ab} (±0.76)	2.5^{d} (±0.93)	4.0^{ab} (±0.93)	2.6^{de} (±1.30)	Untreated
4.3^{a} (±0.71)	3.5^{ab}(±0.93)	3.9^{ab} (±0.64)	3.6^{a} (±1.19)	3.4^{a} (±0.52)	3.0^{bc}(±1.20)	1.4^{de} (±0.74)	4.0^{ab} (±0.51)	Cooked
3.9^{ab}(±0.99)	3.7^{a} (±0.07)	3.3^{bc} (±1.04)	3.4^{ab} (±1.09)	3.0^{ab} (±0.76)	3.5^{ab}(±0.33)	4.1^{ab} (±1.13)	2.9^{cd} (±1.10)	Irradiated
4.1^{ab} (±0.99)	3.5^{ab} (±0.93)	4.0^{a} (±0.76)	3.5^{ab} (±0.19)	3.4^{a} (±0.74)	3.8^{a} (±0.20)	1.0^{e} (±0.00)	3.2^{cd} (±1.31)	Irradiated/cooked

Values are means (± SD) of triplicate samples. Means not sharing a common superscript letter in a column are significantly different at $P \leq 0.05$ as assessed by Duncan's multiple range tests.

found that the 2 kGy dose caused noticeable changes in these characteristics especially the bitterness attribute which affect the quality of the flour during storage.

Conclusion

The observations about phytic acid and tannin in the studied samples tend to suggest that radiation processing up to 2 kGy had little effects on their value and had no effects on the protein digestibility and sensory characteristics of the flour whether whole or dehulled. Therefore, radiation can be applied to alleviate the severe problem of off-flavor and bitter taste production during storage. Moreover, radiation process when compared to chemicals or heat treatment emerges as an attractive and healthy alternative.

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