Applied Tropical Agriculture
Volume 21, No. 3, 151-157, 2016.
© A publication of the School of Agriculture and Agricultural Technology, The Federal University of Technology, Akure, Nigeria.

Physicochemical Properties and Fatty Acid Profile of Gamma-irradiated Sorrel Seed (*Hibiscus sabdariffa*) Flour and Oil

Sanni, T.A.[1]*, Alabi, O.O.[1] and Ogundele, J.O.[2]

[1]Department of Food Science and Technology, Federal University of Oye, Oye-Ekiti, Ekiti state, Nigeria
[2] Department of Industrial Chemistry, Federal University of Oye, Oye-Ekiti, Ekiti state, Nigeria
*Corresponding author: toibudeen.sanni@fuoye.edu.ng

ABSTRACT

This work evaluated the quality of sorrel seeds as function of irradiation doses (0, 2.5, 5, 10, and 20kGy, respectively) so as to determine dose level causing minimal undesirable changes to sorrel seed. Physicochemical properties (proximate, color, peroxide value, free fatty acid value, saponification value and fatty acids), and functional properties (Water and oil holding capacity, foaming capacity, emulsification and protein solubility) of the oil were determined using standard analytical methods. The results showed that irradiation decreased crude protein and crude lipids significantly, while the ash content and the crude fiber remained unaffected. Significant changes in peroxide values, saponification and free fatty acids were observed after irradiation. Gas chromatography (GC) results revealed a clear trend toward an increase in the amount of saturated fatty acids with increasing irradiation dose and a decrease in the amount of polyunsaturated fatty acids in the triacylglycerol composition of the irradiated samples compared to the unirradiated sample. An inducement of trans-fatty acids at 20kGy was also observed. The functional properties showed fluctuation with increasing dose of irradiation.

Key words: Fatty acids, Irradiation, Peroxides, Trans fatty acid

INTRODUCTION

In developing countries, there is an urgent need for new plant foods to meet the nutritional requirements of ever-increasing populations. Large segments of the populations from these countries suffer from malnutrition (Akubor *et al*., 2004). In Nigeria for example, popular legumes, such as cowpea, beans and groundnut, are widely consumed to complement the low protein contents of cereals (rice, maize), and tubers (cassava and yam); as animal proteins such as meat, milk and eggs are expensive and relatively difficult to acquire. Therefore, other rich protein sources need to be identified.

There are quite a lot of underutilized plant crops that have been put to use in recent time (Sridhar and Bhat, 2007). Many of them have been considered for usage because of their high protein content which readily serves as substitute for the expensive animal protein. Among these underutilized seeds are Sorrel (*Hibiscus sabdariffa*, Linn.) seeds. According to Al-Wandawi *et al*., 1984 and Balami, 1998, Sorrel seeds are valuable food source, when its protein, calories, fiber and micronutrients contents are put into consideration. It is an excellent source of culinary oil (Omobuwajo *et al*., 2000).

Actually, Sorrel crop has attracted great interest because of the high antioxidant properties that is contained in the calyxes, which has been thoroughly evaluated (Tee *et al*., 2002; Tsai *et al*., 2002; Tsai and Huang, 2004; Tseng *et al*., 1997; Prenesti *et al*., 2007). The large-scale production of calyx is expected to lead to large quantity of seeds as by-product. Most of these seeds are used to be discarded as waste in the time pass, until recently when attention is being shifted to the possible utilization of food by-products, waste and underutilized agricultural product (Glew *et al*., 1997; Arinathan *et al*., 2003; Sridhar and Bhat, 2007; Vadivel and Janardhanan, 2004).

Food irradiation has been adjudged as a reliable and safe method for preservation of food, improve hygienic and nutritional value of foods (Diehl, 2002; Gampbell*et al*. 1983; Al-Kaisey *et al*. 2002). Furthermore, regulatory body such as the Joint Food and Agriculture organization, World Health Organisation and International Atomic Energy Agency (FAO/WHO/IAEA)Study Group on High Dose Irradiation had considered the wholesomeness of food irradiated with doses above 10kGy, the current limit in the Codex General Standard for Irradiated Foods (CODEX STAN 106-1983), and had confimed that food irradiated to any dose appropriate to achieve the technological objective was both safe and nutritionally adequate. To the best of our knowledge, information on the effect of gamma irradiation on grain beyond 10kGy are limited and the chemical analysis of sorrel seeds at 20kGy showed effect of cis-trans isomerization of the unsaturated fatty acids which is reported in this study. Being underutilized seeds, not much work has been done on the preservation of the seeds industrial use. Irradiation as a method of preservation and decontamination looks attractive for quarantine purpose in international trade, as chemical methods in being widely discouraged because of its effect on ozone layer (Aziz *et al*., 2006). The objectives of this study, therefore, were to investigate the impact of gamma irradiation on the physicochemical properties of the seed flour, its oil, and the fatty acids profile, respectively.

MATERIALS AND METHODS

Materials

Dried Sorrel seeds (*Hibiscus sabdariffa*) from a single lot, weighing 50kg, were obtained from a local market in Kano, Kano State, Nigeria. The seeds were sorted to remove physically damaged and immature seeds, dirt, stones, and pebbles. The seeds were then kept in airtight polyethylene bag, and stored in a dry and cool environment until ready for use. All the chemicals and reagents used in the study were of analytical grade.

Irradiation and Packaging

The moisture content of the seeds was pre-determined. The cleaned seeds were packaged in 500g portions, in 8cm by 12cm size of 140µm thick polyethylene bags and heat sealed, then placed in a Multipurpose gamma irradiator with a Cobalt^{60} source (Model GS 1000, Category 4, Panorama Wet Storage Source, Siemen, Germany) at the Gamma irradiation Facility, Nuclear Technology Center, Sheda, Abuja, Nigeria. The raw grains were treated with gamma rays at doses of 0, 2.5, 5.0, 10.0 and 20.0kGy with an overall uncertainty of ± 4%. The pouches of the samples were rotated 180^{o} half way during radiation process, to ensure even distribution of radiation absorption. The absorbed dose was measured by employing Alanine/ E-scan. The packaged seeds were stored in cool and dried place until used.

Determination of proximate composition of sorrel seed

The recommended methods of AOAC, (2010) were adopted for proximate analysis, which was carried out to determine moisture, crude protein, ash, crude fat and crude fibre.

Color measurement: The color of sorrel flour was measured in the L* a* b* mode of CIE (angle 10°, illuminant D65) using a Hunter Lab (DP 9000, Hunter Associates Laboratory, Reston, VA, USA). L*, a*, b* indicated lightness, redness/greenness, and yellowness/blueness, respectively.

Determination of physical properties of sorrel seed oil: Peroxide value, Iodine value, and Saponification value of sorrel oil, extracted using soxhlet method, were determined according to standard analytical methods (AOAC, 2010).

Fatty acid determination of Sorrel Seeds Oil: Fatty acids of sorrel seeds treated with gamma irradiation were determined using gas chromatographic analysis as described by Mexis, and Kontominas, (2009).

Determination of Functional properties: The functional properties of sorrel seed flour: water absorption capacity, oil absorption capacity, emulsifying properties, and foaming properties, respectively were determined according to the standard methods described by Kaptso *et al*. (2007).

Statistical Analysis: All analyses were replicated (n>3). Data were statistically evaluated by one-way analysis of variance (ANOVA) using the SPSS 15.0 statistical software program. Significant differences between mean values were determined by the Duncan's multiple range test procedure at the 5% significance level (p<0.05).

RESULTS AND DISCUSSION

Effect of gamma irradiation on the proximate composition of sorrel seed

The effect of irradiation on the proximate chemical composition of sorrel seed is presented in Table 1. Irradiation significantly decreased the protein content of the seed from 31.94% in non-irradiated seed to 27.38, 25.92, 26.48, 27.55, and 30.63% in 2.5kGy, 5kGy, 7.5kGy, 15kGy, and 20kGy, γ- irradiated seed respectively. The data obtained were similar to that reported by Mohammed *et al*. (2012). Nzikou *et al*. (2011) reported that sorrel seed contained 27.78% protein. The difference could be due to varietal differences and condition of maturity at the time of harvest. Sridhar and Bhat (2007), also, reported a significant decrease in the protein content of γ-irradiated lotus bean seeds. However, other studies have also suggested that irradiation could bring about modification in the protein content of irradiated samples. A significant dose-dependent decrease ($p<0.05$) in crude lipid was recorded at all doses compared with the control. The decrease in lipid content upon irradiation of sorrel seeds was also reported by Bhat and Sridhar (2008). It decreased from 26.43% in non-irradiated seed to 23.70% in sample irradiated at 20kGy.Irradiation had no significant effect on the crude fibre and ash content of the seed. There was no significant difference between crude ash and crude fibre of sorrel seed irradiated at different kGy, respectively. High ash content in sorrel seeds indicated that it could contain high mineral constituents.

Colour of irradiated sorrel seed

The changes in colour as affected by γ-irradiation are presented in Table 3. There was no significant difference in the colour intensity index (L^*) and (b^*) of sorrel seed. The (a^*) values decreased with increase in irradiation doses. This observation contradicted the report of Mexis *et al*., 2009, that there is a breakdown of glycosidic and peptidic linkages during irradiation, which brings about maillard reaction, and results in darkening of seed colour.

Physical properties of the Oil

There was no significant difference in the peroxide value (PV) of gamma irradiated and non-gamma irradiated sorrel oil as shown in Table 2. The PV value (1.38meq of O_2/kg of oil) obtained in this study was lower than that reported by Nyam *et al*. (2009) for seed oil. The data obtained is in general agreement with that of Al- Bachir, (2004), who reported that there was no significant differences in the peroxide value of both γ-irradiated and non-irradiated walnut at doses up to 2kGy, but contradicted the report of Mexis and Kontominas, (2009), who reported that irradiation increased the PV value of cashew nut from 0.48 in non- irradiated cashew to 2.65meqO_2/kg up to doses of 7kGy. The PV value (1.38meqO_2/kg of oil) obtained in this study was lower than that reported by Nyam *et al*. (2009). Lipid oxidation resulted in the formation of hydroperoxides, which are unstable and decomposes to form secondary compounds such as aldehydes, ketones, alcohol, and hydrocarbons.

The saponification value of both gamma irradiated and non-gamma irradiated oil showed no difference significantly. A constant value of 173.41mgKOHg^{-1} was recorded up till 20kGy dose level, which was in agreement with the values obtained for linseed oil (190.86mgKOHg^{-1}), sunflower (188.98mgKOHg^{-1}) and soybeans (179.45mgKOHg^{-1}) as reported by Nehdi (2011). The free fatty acid of the non-irradiated and gamma-irradiated oil ranges between 1.39 mg KOHg^{-1} and 2.92 mg KOHg^{-1} which were lower than 6.50 mg KOHg^{-1} reported for sorrel seed oil by Nyam *et al*. (2009). This variation could be as a result of differences in variety, or the duration of storage before analysis.

Table 1: Proximate composition of γ-irradiated sorrel seed (on dry weight basis) (n=3, mean ± SD)

	Dose (kGy)						
Component (%)	0	2.5	5	7.5	10	15	20
Crude protein	31.94 ± 0.04^e	27.38 ± 0.37^c	25.92 ± 0.02^a	26.48 ± 0.35^b	26.34 ± 0.04^b	27.55 ± 0.05^c	30.63 ± 0.04^d
Crude lipid	26.43 ± 0.4^c	24.58 ± 0.52^b	22.78 ± 0.25^a	22.58 ± 0.52^a	23.00 ± 0.5^a	23.41 ± 0.35^a	23.70 ± 1.35^a
Crude fibre	11.51 ± 0.14^a	11.50 ± 0.14^a	11.46 ± 0.04^a	11.67 ± 0.16^a	11.41 ± 0.07^a	11.43 ± 0.07^a	11.47 ± 0.05^a
Total ash	6.49 ± 0.02^a	6.44 ± 0.03^a	6.42 ± 0.02^a	6.35 ± 0.11^a	6.43 ± 0.11^a	6.44 ± 0.06^a	6.39 ± 0.06^a
Carbohydrate	23.66 ± 0.13^a	29.56 ± 0.13^b	33.92 ± 0.02^d	32.40 ± 0.23^c	33.21 ± 0.06^d	32.32 ± 0.21^c	29.39 ± 0.05^b

Values followed by the same letter along the same row are not significantly different. ($P<0.05$)

Table 2: Effect of γ-irradiation on physical properties of sorrel seed oil

	Dose (kGy)						
Component	0	2.5	5	7.5	10	15	20
Peroxide value (meqO_2/ kg oil)	1.38 ± 0.02^a	6.67 ± 0.12^b	6.89 ± 0.45^b	7.77 ± 0.06^c	8.24 ± 0.10^c	8.56 ± 0.11^c	9.45 ± 0.41^d
Saponification value (mgKOHg^{-1})	173.41 ± 0.78^a	201.56 ± 1.57^d	191.52 ± 1.76^d	178.40 ± 2.10^b	177.99 ± 1.24^b	$2.06.48\pm4.52^e$	202.13 ± 2.18^d
Free fatty acid value (mgKOHg^{-1})	1.39 ± 0.13^a	2.24 ± 0.12^b	2.54 ± 0.02^c	2.55 ± 0.00^c	2.71 ± 0.09^d	2.82 ± 0.06^e	2.92 ± 0.03^e

Values with different superscript in the same column are significantly different. ($P<0.05$)

The values obtained in this study was similar to that reported for irradiated Almond nut oil (1.14mgKOHg^{-1}) after storage for a period of 12months by Al-Bachir, (2004), and that of Bhatti *et al.* (2010) who found 1.12mgKOHg^{-1} in peanuts oil. Free fatty acid is an index of oil quality, used to determine its edibility and suitability for use in industry. Bhatti *et al*., (2013) reported that irradiation increased the acidity of oil.

Table 3: Colour changes of irradiated sorrel seeds (*Hibiscus sabdariffa* L.)

	Irradiation dose (kGy)						
	0	2.5 k Gy	5 k Gy	7.5 k Gy	10 k Gy	15 k Gy	20 k Gy
Lightness (L*)	63.97±0.05[a]	64.69±0.12[b]	63.99±0.13[a]	64.20±0.18[a]	64.04±0.31[ab]	64.37±0.04[b]	63.96±0.22[a]
Redness (a*)	29.08±0.01[b]	17.72±0.03[a]	17.41±0.01[a]	17.32±0.05[a]	17.06±0.03[a]	17.56±0.03[a]	17.73±0.07[a]
Yellowness b*)	36.86±0.21[b]	35.48±0.25[a]	35.46±0.17[a]	35.40±0.07[a]	35.85±0.15[a]	36.70±0.06[b]	35.19±0.09[a]
Hue	51.72±0.12[a]	63.46±0.15[b]	63.59±0.05[b]	63.93±0.12[b]	63.40±0.13[b]	64.44±0.16[c]	63.20±0.21[b]
Chroma	46.95±0.02[c]	39.60±0.2[a]	39.15±0.0[a]	39.41±0.17[a]	39.48±0.02[a]	39.48±0.13[a]	40.05±0.05[b]

Values represent means ±SD of triplicate determination.

Table 4: Fatty acid composition of flours of Sorrel seeds treated with γ-irradiation

	Dose(kGy)				
Fatty Acids	**0**	**2.5**	**5**	**10**	**20**
Saturated fatty acids					
Lauric acid (C12:0)	-	-	-	-	1.06±1.06
Myristic acid (14.0)	0.20±0.02[b]	0.22±0.01[b]	0.21±0.02[b]	0.24±0.02[b]	3.05±0.12[a]
Pentadecanoic acid (C15.0)	-	-	-	-	0.28±0.00
Palmitic acid (C16.0)	17.11±0.11[b]	16.79±0.01[b]	16.06±0.32[b]	16.72±0.01[b]	19.82±0.24[a]
Hepatadeconoic acid (17.0)	0.13±0.01[b]	-	0.05±0.07[c]	-	0.42±0.04[a]
Stearic acid (18.0)	5.41±0.13[b]	4.97±0.06[b]	4.91±0.11[b]	4.97±0.14[b]	8.43±0.56[a]
Arachidic acid (C20.0)	0.73±0.01[a]	0.79±0.02[a]	0.77±0.03[a]	0.74±0.02[a]	0.34±0.03[b]
Behenic acid (C22:0)	0.27±0.01[a]	0.34±0.00[a]	0.32±0.02[a]	0.57±0.21[a]	0.34±0.16[a]
Lignoceric acid (C24:0)	0.37±0.03[b]	0.38±0.01[b]	0.39±0.01[b]	0.53±0.01[a]	0.04±0.05[c]
Polyunsaturated fatty acids					
Myristoleic acid (C14:1)	-	-	-	-	0.08±0.03
Pentadeconoic acid (C15:1)	-	-	-	-	-
Palmitoleic C16:1 trans	-	-	-	-	0.52±0.01
Palmitoleic C16:1	0.32±0.01[b]	0.34±0.02[b]	0.33±0.02[b]	0.37±0.00[b]	4.60±0.16[a]
Heptadecanoate C17:1	0.15±0.01[a]	-	0.06[b]	-	0.17±0.01[a]
Oleic acid (C18:1)cis	31.16±0.16[a]	32.32±0.56[a]	30.41±0.58[b]	30.41±0.24[b]	24.76±1.16[c]
Oleic acid (C18:1)trans	-	-	-	-	1.07±0.08
Linoleic acid (C18:2)cis	41.28±0.48[b]	41.08±0.29[b]	40.92±0.16[b]	42.74±0.31[a]	11.17±0.22[c]
Linoleic acid (C18:2) trans	-	-	-	-	0.12±0.06
Linolenic acid (C18:3)	0.26±0.00[b]	0.26±0.05[b]	0.30±0.01[b]	0.34±0.01[b]	1.08±0.09[a]
Eicosadienoic acid (C20:1)	-	-	-	-	1.26±0.02
Total trans	-	-	-	-	1.71
Total saturated	24.33	23.11	22.68	23.77	33.28
Total monounsaturated	31.49	32.66	30.74	30.78	30.62
Total polyunsaturated	41.54	41.32	41.22	43.08	14.55
Total Unsaturated	73.03	74.00	71.96	73.86	45.17
Total unsaturated/Total saturated	3.01	3.20	3.17	3.11	1.36

Values followed by the same letter along the same row are not significantly different. (P<0.05)

Functional properties of sorrel seed flour

The effect of γ-irradiation on the water absorption capacity (WAC) and oil absorption capacity (OAC) of sorrel seeds flour is presented in Figure 1. The WAC of the sorrel seed flour significantly increased from 3.43g/100g in the non-gamma irradiated flour to 3.75g/100g in flour with doses up to 15kGy. Decrements in the WAC (3.57 g/100g and 3.68 g/100g) were observed at 5kGy and 20kGy, respectively. Bhat *et al.* (2007) also observed the same trend with Mucuna seed flour, while Abu *et al.* (2005) did not find any appreciable increase in WAC of irradiated Cowpea flour at 50kGy. The increase in WAC might be attributed to the depolymerisation of starch into short chain dextrin with a higher affinity for water (Whistler and Daniel, 1985). Bhat *et al.*(2007) reported that high WAC of flours is advantageous in the preparation of pastries such as bread and sausages, to maintain freshness and for easy handling.

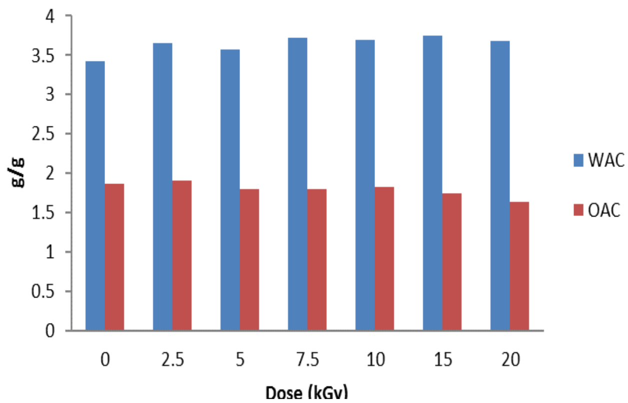

Figure 1: Water and oil absorption capacity for irradiated sorrel seeds

Oil Absorption Capacity significantly decreased from 1.87g/100g in untreated flour to 1.9g/100g, and then to 1.63g/100g in flour treated with 2.5kGy and 20kGy flour, respectively which might be due to denaturation of the seed protein during irradiation, which in turns destroyed the hydrophobic domain of the seed and reduced fat binding. The values obtained in this study may be attributed to the high fat content of the sorrel seed. Kinsella, (1976) explained that the mechanism of oil absorption involves the physical entrapment of oil by food component and the affinity of non-polar protein side chain for lipids. Mwangwela *et al.*, (2007) did not observed any significant changes in OAC of cowpea flour micronized at temperatures of 130 and 170^{o}C, respectively.

The Foaming properties of sorrel seed flour is presented in Figure 2. Foaming stability decreased as the irradiation doses increased. It increased from 57.66 % in non-irradiated flour to 37.50 % in flour irradiated at 20kGy, while foaming capacity was not significantly affected up to doses of 10kGy. Foaming capacity was significantly increased to 47.00 % and 48.10 % in 20 and 15kGy flour, respectively. This might be as a result of differences in the protein solubility and chemical composition. Bhat and Sridhar (2008) also observed increase in foam stability of mucuna seeds even at 30kGy, while Pednekar *et al*, (2010) reported no significant difference in the foaming capacity of irradiated soybean up to 30kGy. Irradiated sorrel flour could find application in pastry and baking industry.

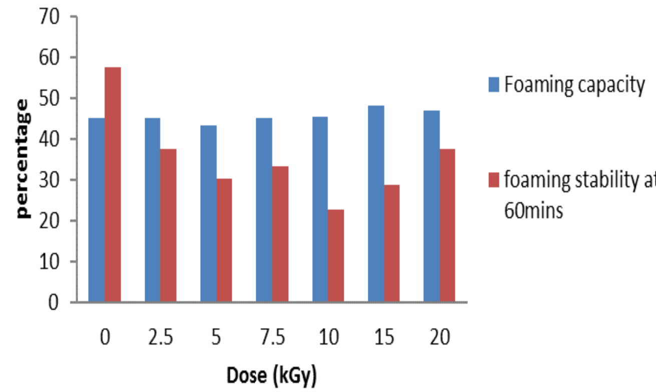

Figure 2: Foaming properties of irradiated sorrel seeds

Emulsion capacity (EC) and emulsion stability (ES) of irradiated sorrel seed flour are presented in Figure 3. Emulsifying properties increased as the doses increased which made it important in the preparation of milk-like beverages and meat analogues as reported by Fasasi *et al.*, (2007).

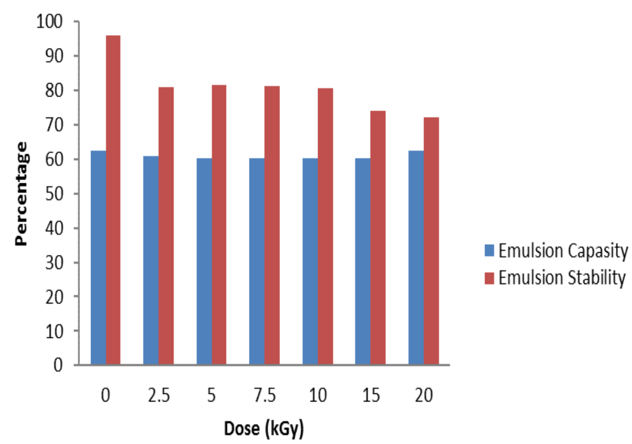

Figure 3: Emulsion properties of irradiated sorrel seeds

Fatty acids profile

The main monounsaturated fatty acids (MUFA) present in the non-irradiated sorrel seed was Oleic (31.17%) with traces of palmitoleic acid (Table 4). The major polyunsaturated fatty acid (PUFA) present was linoleic acid (41.28%) with a small amount of linolenic acid (0.26%). The major saturated fatty acids present were palmitic acid (17.11%) and stearic acid (5.41%), small quantities of myristic (0.20%), behenic (0.27%), lignoceric acid (0.37%) and arachidic acid (0.73%) were detected. In irradiated sorrel seeds oil, PUFA were relatively stable to irradiation up to the dose of 10kGy, but their concentration decreased from 41.54% at 0kGy to 14.55% at 20kGy.

Monounsaturated was also stable to irradiation up to 10 kGy dose, while a decrease was observed at 20kGy. Oleic acid content decreased from 31. 17% in untreated to 24.76% at 20kGy. A relative increase was observed for saturated fatty acid (SFA) rising from 24.23% in untreated to 33.28% in oil irradiated at 20kGy.It is apparent that the higher the unsaturation of fatty acids, the higher the oxidation, which made the rate of oxidation approximately 1:10:100:200 for stearic, oleic, linoleic and linolenic acids, respectively in this study. Thus, the increase in SFA concentration at 20kGy might be explained by the oxidation of PUFA and MUFA, respectively. The saturated fatty acids, stearic acid increased from 5.41% in untreated to (8.43%) at 20kGy while palmitic acid increased from 17.11% to 19.32%, myristic also increased from 0.20% to 3.05%. Lauric and pentadecanoic acids were detected at values 1.06 and 0.28%, respectively only at 20kGy. The high level of unsaturated fatty acids in sorrel seeds is beneficial for human consumption.

The trans-fatty acid detected in irradiated sample was at the level of 20kGy. *Trans* Fatty acids occur due to changes in molecular structure of fatty acid, breakdown of double bonds forming free radicals and trans-fatty acids. Trans-Fatty acids are found in numerous foods (Yilmaz and Gecget, 2007). Similar to saturated fatty acids, trans-fatty acids, also increase low density lipoprotein (LDL) cholesterol and lower high density lipoprotein (HDL) cholesterol.

CONCLUSION

It could be concluded that gamma irradiation of sorrel seed had no significant adverse effect on the nutritional constituents of the seed, its oil fatty acid profile, and the physical properties, and also, on the functional properties on its flour which made it suitable for use both domestically and industrially. The study also established in many ways that treatment up to 10 kGy would be preferable for the seeds preservation than the higher dose of 20 kGy.

REFERENCES

Abu, J.O., Muller, K., Duodu, K.G. and Minnaar, A. 2005. Functional properties of cowpea (Vignaunguiculata L. Walp) flours and pastes as affected by γ-irradiation. *Food Chemistry* 93**,** 103–111

Ahmed, A.W.K. and Hudson, B.J.F. (1979). The fatty acid composition of *Hibiscus sabdariffa* seed oil. *Journal of Science of Food and Agriculture* 33, 1305-1309.

Akubor P.I. and Badifu G.I.O. (2004). Chemical composition, functional properties and baking potential of African breadfruit kernel and wheat flour blends. *International Journal of Food Science and Technology*, 39, 223-229.

Al-Bachir, M. 2004. Effect of gamma irradiation on fungal load, chemical and sensory characteristics of walnuts (*Juglans regia L.*). *Journal of Stored Products Resources* 40, 355–362.

Al-Bachir. M/ 2014. Physicochemical properties of oil extracts from gamma irradiated almond (*Prunus amygdalus L.*) *Innovative Romanian Food Biotechnology*, 14, 37-45

Nzikou, G. Bouanga-Kalou, L. Matos, F.B. Ganongo-Po, P.S. Mboungou-Mboussi, F.E. Moutoula, E. Panyoo-Akdowa, T.H. Silou and S. Desobry. (2011). Characteristics and Nutritional Evaluation of seed oil from Roselle (*Hibiscus sabdariffa L.*) in Congo-Brazzaville. *Current Research Journal of Biological Sciences* 3(2): 141-146

Al-Kaisey, M.T., Mohammed, M.A., Alwan, A. Mohammed, M.H. (2002). The effect of gamma irradiation on the viscosity of two barley cultivars for broiler chicks. *Radiation and Physics Chemistry* 63, 295–297.

Al-Wandawi, H., Al-Shaikhaly, K., and Abdu-Rahman, M. (1984). Roselle seeds: a new source of protein. *Journal of Agricultural and Food Chemistry* 32, 510–512.

AOAC (2010) Official Methods of Analysis, 19th Ed. Association of Official Analytical Chemists, Washington DC.

Arinathan, V., Mohan, V. R., and De Britto, A.J. (2003). Chemical composition of certain tribal pulses in south India. *International Journal of Food Sciences and Nutrition* 54, 209–217

Aziz, N.H., Souzan, R.M. and Azza, A.S. (2006) Effect of γ-irradiation on the occurrence of pathogenic microorganism and nutritive valve of four principal creal grains. *Applied Radiation Isotopes* 64, 1555-1562

Balami, Y.A. (1998). The effect of processing conditions packaging and storage on selected quality attributes of ''MungzaNtusa''. M.Sc. Thesis, University of Ibadan, Ibadan, Nigeria.

Bhat, R. Sridhar, K.R. (2008). Nutritional quality evaluation of electron beam-irradiated lotus (Nelumbo nucifera) seeds. *Food Chemistry* 107, 174–184

Bhat, R., and Sridhar, K.R. (2007). Effect of electron beam irradiation on the quality characteristics of an underutilized economically valued tropical legume Mucunapruriens L. DC. *Electronic Journal of Environmental, Agricultural and Food Chemistry* 7(12), 2578-2581

Bhatti I.J., Ashraf S., Shahid M., Rafiqueasi M. and Mehboob S. (2010). Quality index of oils extracted from γ-irradiated peanuts (*Arachishypogaea L.*) of the golden and bari varieties. *Applied Radiation and Isotopes* 68, 2197-2207

Bhatti I.A., Iqbal1 M., Anwar F., Shahid S.A., Shahid M. (2013). Quality characteristics and microbiological safety evaluation of oils extracted from gamma irradiated almond (*Prunus dulcis Mill.*) seeds, *Grasas y aceites* 64 (1), 68-76.

Diehl, J.F., (2002). Food irradiation-past, present and future. Radiation Physics Chemistry. 63, 211–215

Fasasi, O.S. Eleyinmi, A.F. and Oyarekua, M.A. (2007). Effect of some traditional processing operations on the functional properties of African breadfruit seed (*Treculia africana*) flour. *LWT- Food Science and Technology* 40**,** 513–519

Gampbell, G.L., Classen, H.I., Reichert, R.D. and Gampbell, I.D. (1983). Improvement of the nutritive value of rye for broiler chickens by gamma irradiation- induced viscosity reduction. *Poultry Science* 24, 205–211.

Glew, R. H., VanderJagt, D.J., Lockett, C.,Grivetti, L. E.,Smith, G.C., Pastuszyn, A. andMillson, M. (1997). Amino acid, fatty acid, and mineral composition of 24 indigenous plants of Burkina Faso. *Journal of Food Composition and Analysis*10, 205–217

Kinsella J.E. (1976). Functional properties of proteins in foods: a survey. *Critical Reviews Food Science and Nutrition*, **1**(3), 219-280.

Mexis S.F., Kontominas M.G. (2009). Effect of gamma-irradiation on the physicochemical and sensory properties of cashew nuts (*Anacardium occidentale L.*), *LWT - Food Science and Technology* 42, 1501–1507.

Shaheen M.A, El-Nakhlawy F.S and Al-Shareef A.R. (2012). Roselle (*Hibiscus sabdariffa* L.) seeds as unconventional nutritional source. *African Journal of Biotechnology* 11(41), 9821-9824

Mwangwela, A.M., Waniska, R.D., and Minnaar, A. (2007). Effect of micronisation temperature (130 and 170°C) on functional properties of cowpea flour. *Food Chemistry* 104(2), 650–657.

Nehdi I. (2011). Characteristics, chemical composition and utilisation of *Albizia julibrissin* seed oil. *Industrial Crops and Products* 33, 30-34

Nyam K.L., Tan, C.P., Lai, O.M. Long, K.and Che Man Y.B. (2009). Physicochemical properties and bioactive compounds of selected seed oils. *LWT-Food Science and Technology* 42, 1396-1403

Omobuwajo, T.O., Sanni, L.A., Balami, Y.A., (2000). Physical properties of sorrel (*Hibiscus sabdariffa*) seeds. *Journal of Food Engineering* 45 (1), 37–41.

Pednekar, M., Das, A.K., Rajalakshmi, V. and Sharma A. (2010). Radiation Processing and functional properties of soybean (Glycine max). *Radiation Physics and Chemistry* 79, 490–494

Prenesti, E., Berto, S., Daniele, P.G., Toso, S., (2007). Antioxidant power quantification of decoction and cold infusions of *Hibiscus sabdariffa* flowers. *Food Chemistry* 100 (2), 433-438.

Sridhar, K. R., & Bhat, R. (2007). Agro botanical, nutritional and bioactive potential of unconventional legume – Mucuna. Livestock Research for Rural Development, 19, 1–36.

Tee, P., Yusof, S. and Mohamed, S., (2002). Antioxidative properties of Roselle (*Hibiscus sabdariffa*) L. in linoleic acid model system. *Nutrition and Food Science* 32 (1), 17–20.

Tsai, P.J, Mcintosh, J., Pearce, P., Camden, B. and Jordan, B.R. (2002). Anthocyanin and antioxidant capacity in Roselle (Hibiscus sabdariffa L.) extract. *Food Research International* 35(4), 351– 356.

Tsai, P.-J., Huang, H.-P., (2004). Effect of polymerization on the antioxidant capacity of anthocyanins in Roselle. *Food Research International* 37 (4), 313–318.

Tseng, T.H., Kao, E.-S., Chu, C.-Y., Chou, F.-P., Lin Wu, H.W, and Wang, C.J. (1997). Protective effects of dried flower extracts of *Hibiscus sabdariffa* L. against oxidative stress in rat primary hepatocytes. *Food and Chemical Toxicology* 35, 1159–1164.

Vadivel, V. and Janardhanan, K. (2004). The nutritional and antinutritional attributes of sword bean [*Canavalia gladiata* (Jacq) DC.]: An underutilized tribal pulse from south India. *International Journal of Food Science and Technology* 39, 917–926

Whistler, R. L., and Daniel, J. R. (1985). In O. R. Fennema (Ed.), Food Chemistry (2nd ed., pp. 69–125). New York: Marcel Dekker.

Yilmaz, I., and Gecget, U. (2007). Effects of gamma irradiation on trans-fatty acid composition in ground beef. *Food Control* 18, 635–638.

*****