Effect of gamma irradiation on beef quality

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Beef *longissimus dorsi* steaks were treated with 10, 25, and 50-kGy gamma irradiation and weekly examined during refrigeration storage at 5°C to evaluate the changes in their organoleptic, bacteriological, chemical and nutritional quality characteristics as well as deterioration criteria. The signs of spoilage became apparent after 17 days of refrigeration storage in control untreated samples compared with 52 days for 10 kGy treated samples; however, samples treated with 25 or 50 kGy remained without signs of spoilage until the end of storage period (4 months). A characteristic burnt flavor was distinguished in irradiated beef samples, which was intensified with high irradiation dose, but decreased during storage. High doses of irradiation especially 50 kGy resulted in a brownish color of meat surface. Moreover, gamma irradiation resulted in high thiobarbituric acid values after treatments and during storage due to lipid oxidation. Thiamin content of beef was severely reduced and the reduction was dependant on the irradiation dose. Riboflavin was also affected by irradiation, but it was much stable than thiamin. The proximate chemical composition of beef was slightly affected by irradiation.

Consumers require high quality and safe meat that has fresh appearance, natural flavor and taste. Therefore, there is an interest by industry for new non-thermal technologies, which can inactivate both pathogenic and spoilage causing microorganisms while keeping the meat quality.

Food irradiation is a physical process involves direct exposure to ionizing radiations (Urbain, 1986). Irradiation of meat can provide several benefits: it improves the safety of fresh meats by reducing and/or eliminating food borne pathogens, and extends the shelf life of meat during refrigeration storage or produce shelf stable products without deterioration of its nutritive and sensory qualities (Thayer, 1993 and Fu *et al.*, 1995a).

The joint FAO/IAEA/WHO Expert Committee (1981) reported that irradiation of any food commodity with up to 10-KGy presents no toxicological hazards. It introduces no nutritional or microbiological problems. They added that further studies on high doses are required. Currently more than 26 countries used food irradiation on a commercial scale (Stevenson, 1994). With the exception of irradiation of spices and dried vegetables, which is widespread, other applications of this technology remain marginal. Therefore, the present study was conducted to evaluate the changes in different meat quality characteristics (sensory, chemically and bacteriologically) due to use of different doses of gamma radiation.

Material and Methods

Samples. Eighty beef *L. dorsi* muscle samples at the 11-13th rib were collected as soon as possible after slaughter, and then rapidly transported to the laboratory in polyethylene bags surrounded by ice in order to minimize the chemical changes. In the laboratory, the external fascia and visible fat were removed, then each muscle sample was cut into steaks of about 100 g weights and ~3 cm thickness. The samples were packed in polyethylene bags of about 0.03 mm thickness and about 20 cm long x 15 cm wide. The polyethylene bags containing steaks were heat sealed, and then frozen at -40°C for 24 h before the different treatments.

Irradiation process and storage. Packed frozen beef steaks were transported to the National Center for Radiation Research and Technology (NCRRT) at Nasr city, Cairo, where the radiation treatments were applied using the Egypt Mega Unit "J-6500 Co^{60}". The J-6500 machine is designed to irradiate the samples in boxes of 38.1 to 48.2 cm width, 91.4 cm height and 40.6 to 58.4 cm length. The dose rate being 1.50 kGy /h in the center of the irradiation box. The used irradiation doses in this study were 10, 25 and 50-kGy . Irradiated and non-irradiated packed steaks were stored in the refrigerator at 5°C and samples were weekly subjected for the following analysis:

Laboratory analysis.

Organoleptic evaluation. Irradiation flavor scores were recorded using 5-point hedonic scale described by (Sudarmadji and Urbain, 1972) with 1 indicates no irradiation flavor and 5 very strong irradiation flavor. The texture, color and off-odor scores were recorded using 5-point hedonic scale described by (Abu-Tarboush *et al.*, 1997) where 1 and 5 indicate unacceptable and acceptable score respectively.

Bacteriological examination. Sample homogenate was prepared by homogenizing ten grams in 90 ml of 0.1% peptone water for 1.5 min. using lab blender and appropriate decimal dilutions were prepared in peptone water (APHA , 1992). Microbial populations were estimated as follows: colony forming units of aerobic mesophiles at 35°C (Swanson *et al.*, 1992), anaerobic count (Lake *et al.*, 1992), mesophilic aerobic sporeformers (Stevenson and Segner, 1992), Pseudomonas count (Kielwein, 1969), psychrotropic bacteria at 7°C (Cousin *et al.*, 1992) and lipolytic bacteria (Smith and Hass, 1992).

Chemical analysis. Both irradiated and non-irradiated beef samples were analyzed for its proximate chemical analysis according to (Ronald and Ronald, 1991). Thiamin and riboflavin content according to (Chase *et al.*, 1993). Moreover, deterioration criteria (pH value, thiobarbituric acid value and total volatile bases nitrogen) were assessed according to (FAO 1986).

Results and discussion

The data illustrated in Fig. (1A) and Table (1) clearly declared that irradiation developed a characteristic burnet flavor. The intensity of such flavor increased as the irradiation dose increased, with 25 and 50-kGy resulted in very strong irradiation flavor. However, the irradiation flavor scores were decreased during refrigeration storage at 5°C. In this regard, Ahn *et al.* (2001) attributed the reduction in the intensity of the irradiation flavor scores to the volatization of the sulfur-containing compounds, responsible for most of the irradiation off-flavor, during aerobic storage. Irradiation flavor of foods are owing to the generation of volatile compounds from lipids and protein precursors produced by the radiolysis of water (Simic, 1983). Development of irradiation flavor in meat can be attributed to the oxidation of polyunsaturated fatty acids (Giroux and Lacroix, 1998), and/or the destruction of the antioxidants in muscle by the free radicals generated by irradiation (Thayer *et al.* 1993 and Lakritz *et al.*, 1995).

Irradiation resulted in dose dependent decrease in the color scores of beef with samples treated with 10-kGy remained acceptable throughout 45 days of storage at 5°C. Moreover, irradiation at 25 and 50 kGy resulted in a more decrease in color scores, with the color scores remained within the organoleptically acceptable limit for 4 months of refrigeration storage in samples irradiated with 25 kGy (Fig. 1B, Table 1).

The bright red color of non-irradiated meat had been turned brown color especially in samples irradiated at 50 kGy, which generally lower its acceptability. Kamarei *et al.*, (1979) reported the generation of free radicals during food processing and storage and upon irradiation the free binding site of myoglobin reacts with such free radicals to form the brown colored metmyoglobin (Giroux *et al.*, 2001). In this respect, consumers consider the visual appearance to be one of the major parameters to judge the quality and acceptability of meat (Demos *et al.*, 1996 and Zhao *et al.*, 1996).

The texture of control non-irradiated or 10 kGy irradiated meat decreased during storage until reached the unacceptable limit at 17th and 52nd days of refrigeration storage respectively, whereas the texture of irradiated. All the investigated bacterial groups were lower than the detectable level of standard plating techniques (2 Log CFU/g) at the first day of treatment with 10-kGy gamma irradiation. During storage at 5°C, the investigated bacterial groups remained under the countable level until the 24th day of storage, and tend to increase by the 32nd day of storage and finally reached ~6 Log CFU/g by the 52nd day with the samples became slimy, off-color and had a sour and putrid odor (Fig. 2b). On the other hand, all the examined bacterial groups of beefsteaks treated with 25 or 50-KGy remained under the detectable level throughout the storage period with acceptable organoleptic parameters.

The obtained results revealed that beef samples treated with 10 kGy had unacceptable organoleptic criteria while the bacterial counts still lower than the level recommended by (Ehioba *et al.*, 1987). This may be due to the action of proteolytic enzymes, which usually survive exposure of up to 10 kGy (Taub *et al.*, 1979).

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Gamma irradiation even at low or medium doses can effectively kill both food-borne pathogens and spoilage bacteria that ultimately increase wholesomeness and shelf life of the meat. The effectiveness of gamma irradiation depends on various factors such as the microorganisms itself, type of food, irradiation dose, irradiation temperature, presence of oxygen and water content (Thayer, 1995; Thayer and Boyd, 1995 and Thayer *et al.*, 1995b), with the initial contamination of meat is the determining factor in shelf-life extension produced by gamma irradiation (Dogbevi *et al.*, 1999).

The obtained results indicated that irradiation slightly decreased both moisture and protein content of beef and refrigeration storage induced an additional decrease in moisture content in both irradiated and non-irradiated samples. Moreover, the decrease in moisture content was dose related and 50 kGy induced the most pronounced change (Fig. 3A, B). The reduction in moisture may be due to improvement of permeability of cells with consequent increase in the fluid exudation (Urbain, 1978) and the decrease in protein may be due to the increase in drip which contain variable amounts of nitrogenious compounds, as well as the breakdown of nitrogenious compounds to form volatile nitrogen (Hafiz, 1973). On the other hand, irradiation slightly increased the ether extractable fat except with 50-kGy treatment (Fig. 3C). These results are constant with the records Mahmoud *et al.*, (1989). Irradiation had no effect on ash content of beef (Fig. 3d). These results were in agreement with Shams El-Din (1984) and Mahmoud *et al.* (1989).

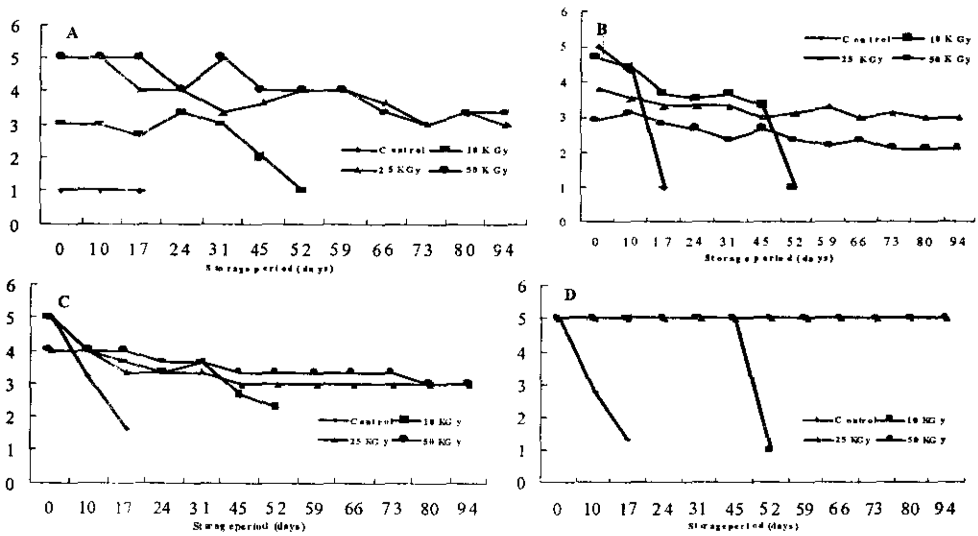

Fig. (1): Effect of gamma irradiation on the organoleptic quality of beef during refrigerated storage. A) Irradiation flavor, B) Color, C) Texture and D) spoilage odor.

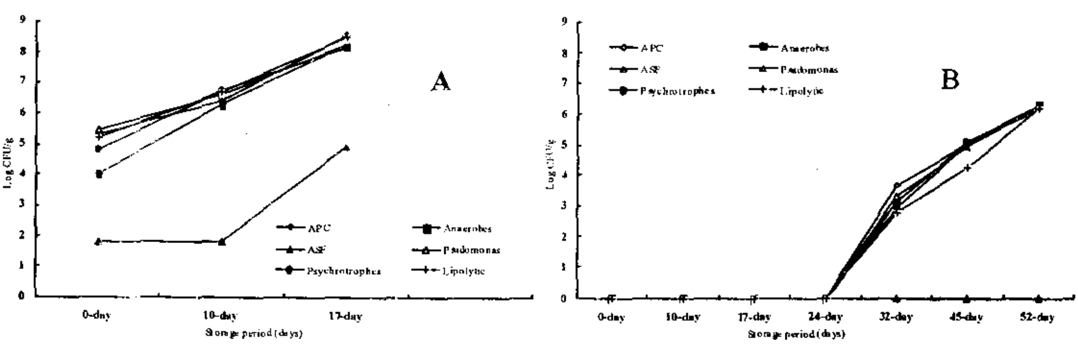

Fig. (2): Bacterial counts (Log CFU/g) of beef *L. dorsi* muscle during storage at 5°C. A, control and B, 10 KGy treated.

Table (1): Organoleptic criteria of gamma irradiated beef during storage at 5°C.

Storage (days)	Spoilage off-odor				Irradiation flavor				Color				Texture			
	Control	10KG	25KG	50KG	Control	10KG	25KG	50KG	Control	10KG	25KG	50KG	Control	10KG	25KG	50KG
0	5	5	5	5	1	3	5	5	5	4.7	3.8	2.9	5	4.3	4	3.9
10	2.75	5	5	5	1	3	5	5	4.3	4.4	3.5	3.1	3.25	3.66	4	4
17	1.33	5	5	5	1	2.66	4	5	1	3.66	3.33	2.8	1.66	3.33	3.33	4
24	*	5	5	5	*	3.33	4	4	*	3.5	3.33	2.66	*	3.66	3.33	3.66
31	*	5	5	5	*	3	3.33	5	*	3.66	3.33	2.33	*	3.33	3.33	3.66
45	*	5	5	5	*	2	3.66	4	*	3.33	3	2.66	*	2.66	3	3.33
52	*	1	5	5	*	1	4	4	*	1	3.1	2.33	*	2.3	3	3.33
59	*	*	5	5	*	*	4	4	*	*	3.3	2.18	*	*	3	3.33
66	*	*	5	5	*	*	3.66	3.33	*	*	3	2.33	*	*	3	3.33
73	*	*	5	5	*	*	3	3	*	*	3.1	2.1	*	*	3	3.33
80	*	*	5	5	*	*	3.33	3.33	*	*	3	2.1	*	*	3	3
94	*	*	5	5	*	*	3	3.33	*	*	3	2.1	*	*	3	3

Table (2): Bacterial populations (Log CFU/g) of control and 10Kgy treated samples during storage at 5°C.

Microorganisms	Control			10 kGy						
	0-day	10-day	17-day	0-day	10-day	17-day	24-day	32-day	45-day	52-day
APC	5.33	6.43	8.5	<2	<2	<2	<2	3.64	5.02	6.12
Staph	3.97	4.56	7.28	<2	<2	<2	<2	<2	3.84	6.05
S.aureus	2.8	3.36	4.82	<2	<2	<2	<2	<2	<2	<2
Anaerobes	4.05	6.3	8.23	<2	<2	<2	<2	3.1	5.1	6.26
Aerobic spore former	1.8	1.8	4.9	<2	<2	<2	<2	<2	<2	<2
Psudomonas	5.44	6.62	8.26	<2	<2	<2	<2	3.25	4.9	6.19
Psychrotrophes	4.82	6.75	8.14	<2	<2	<2	<2	2.9	5.02	6.09
Lipolytic	5.23	6.7	8.47	<2	<2	<2	<2	2.75	4.24	6.13

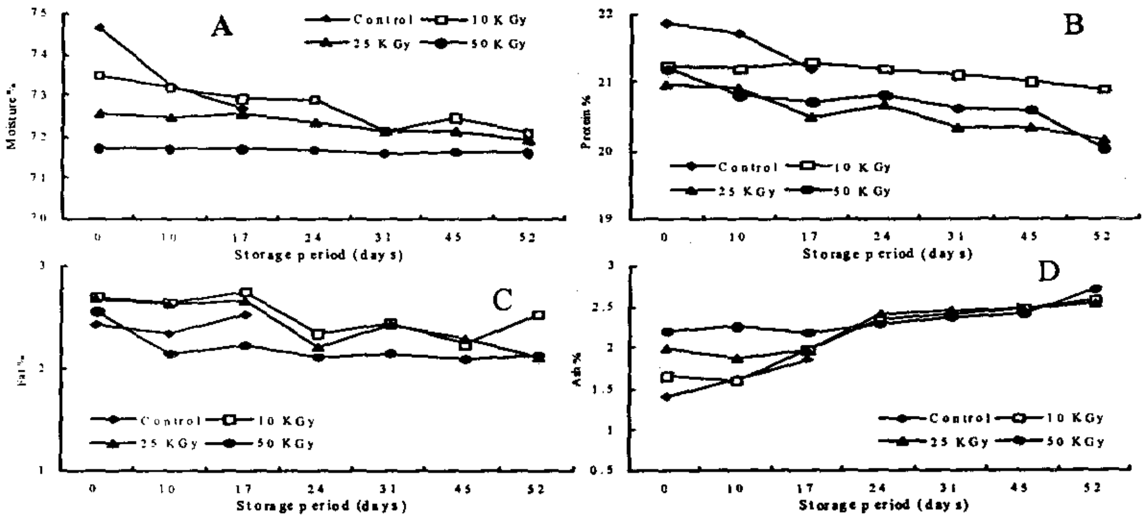

Fig. (3): Effect of gamma irradiation on the proximate chemical analysis of beef during storage at 5°C. A, moisture; B, protein; C, fat; and D, ash.

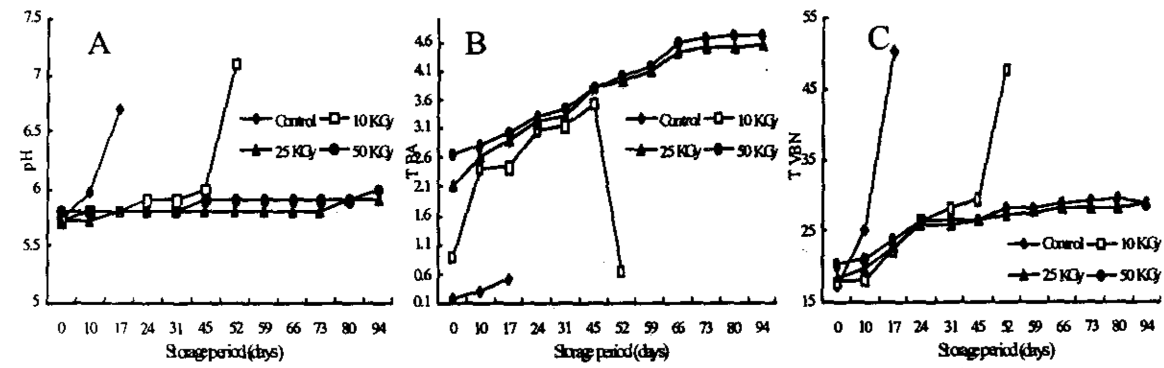

Fig. (4): Effect of gamma irradiation on the deterioration criteria of beef during storage at 5°C. A, pH; B, Thiobarbituric acid value; C, Total volatile base nitrogen

Table (3): Proximate chemical analysis of gamma irradiated beef during storage at 5°C.

Storage (days)	Moisture %				Protein %				Fat %				Ash %			
	Cont.	10KGy	25KGy	50KGy	Cont.	10KGy	25KGy	50KG	Cont.	10KG	25KG	50KG	Cont.	10KG	25KG	50KG
0	74.65	73.48	72.56	71.71	21.86	21.25	20.96	21.2	2.42	2.7	2.68	2.56	1.4	1.65	1.99	2.2
10	73.22	73.21	72.5	71.71	21.71	21.21	20.9	20.8	2.34	2.65	2.63	2.15	1.6	1.59	1.87	2.25
17	72.67	72.93	72.57	71.71	21.19	21.31	20.5	20.7	2.54	2.75	2.66	2.23	1.86	1.97	1.98	2.19
24	*	72.9	72.34	71.69	*	21.19	20.65	20.81	*	2.34	2.22	2.12	*	2.35	2.4	2.28
31	*	72.16	72.15	71.6	*	21.1	20.33	20.62	*	2.45	2.43	2.15	*	2.4	2.45	2.38
45	*	72.45	72.12	71.65	*	21	20.35	20.59	*	2.24	2.29	2.09	*	2.47	2.47	2.42
52	*	72.1	71.92	71.64	*	20.89	20.16	20.03	*	2.54	2.12	2.13	*	2.58	2.53	2.71

*Samples spoiled

Table (4): Deterioration criteria of gamma irradiated beef during storage at 5°C.

Storage (days)	TBA values (mg/kg)				TVB-N values (mg/100g)				pH values			
	Control	10 kGy	25 kGy	50 kGy	Control	10 kGy	25 kGy	50 kGy	Control	10 kGy	25 kGy	50 kGy
0	0.19	0.89	2.12	2.65	17.36	17.9	18.48	20.3	5.7	5.7	5.7	5.8
10	0.28	2.4	2.63	2.8	25.2	18.2	19.6	21	5.97	5.8	5.7	5.8
17	0.51	2.42	2.9	3.02	50.2	22.4	22.8	23.8	6.7	5.8	5.8	5.8
24	*	3.07	3.23	3.3	*	26.6	25.8	26.3	*	5.9	5.8	5.8
31	*	3.12	3.29	3.43	*	28	25.8	26.6	*	5.9	5.8	5.8
45	*	3.5	3.8	3.8	*	29.4	26.6	26.6	*	6	5.8	5.9
52	*	0.64	3.91	4.02	*	47.6	27.2	28	*	7.1	5.8	5.9
59	*	*	4.1	4.19	*	*	27.6	28	*	*	5.8	5.9
66	*	*	4.4	4.6	*	*	28	28.6	*	*	5.8	5.9
73	*	*	4.5	4.66	*	*	28	29.2	*	*	5.8	5.9
80	*	*	4.52	4.7	*	*	28	29.4	*	*	5.9	5.9
94	*	*	4.53	4.7	*	*	28.8	28.8	*	*	5.9	6

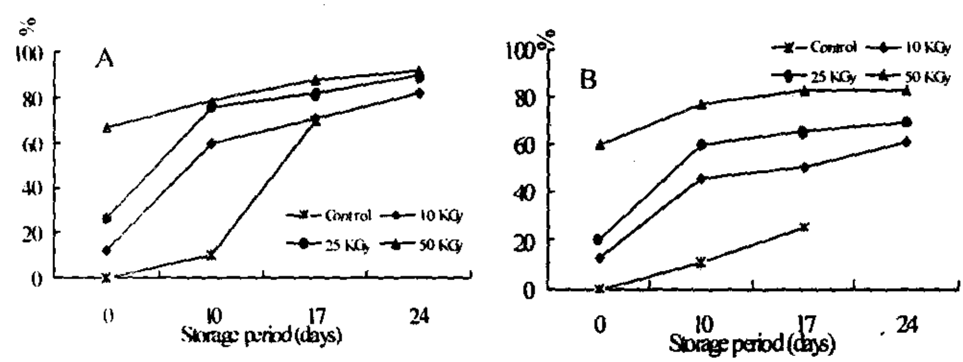

Fig. (5): Percentage loss of vitamin in gamma irradiate beef *L. dorsi* muscle during storage at 5°C. A, thiamin; B, riboflavin.

Table (5): Losses of thiamin and riboflavin of gamma irradiated beef during storage at 5°C.

Storage (days)	Percentage of losses							
	Thiamin				Riboflavin			
	Control	10 kGy	25 kGy	50 kGy	Control	10 kGy	25 kGy	50 kGy
0	0	12	26.4	67.5	0	12.76	26.3	59.6
10	9.8	60.3	76.2	78.5	10.72	46.24	60.19	76.77
17	70.2	71.3	81.8	88.6	25.26	50.53	65.07	82.77
24	*	82.6	90.1	92.4	*	60.9	69.4	82.83

*Samples spoiled

The data illustrated in Fig. (4A) showed that irradiation at 10, 25 or 50 kGy did not cause significant changes in pH values; however, there was a slight increase in pH values during refrigeration storage. The pH values of control and 10 kGy treated samples reached 6.7 and 7.1 after 17 and 52 days of storage; respectively with apparent signs of spoilage. While the pH values of samples treated with 25 and 50 kGy remained within the acceptable values until the end of storage period. Lebepe *et al.*, (1990) and Fox *et al.*, (1995) reported that irradiation did not induce significant change in pH of beef, lamb, pork, and turkey after treatment with irradiation doses up to 9.4. It is evident from Fig. (4B) that high dose of gamma irradiation caused a pronounced increase in TBA-values, which was dose dependant. Moreover, TBA value was also increased during refrigeration storage at 5°C. Generally, irradiation increased TBA-values in meat, which may be explained by the fact that autoxidation of fat is accelerated when oxygen is present during or after irradiation as a result of initiation of lipid oxidation (Nawar, 1985). There was a decline in TBA-value of beef irradiated at 10 KGy by the end of storage period, which might be due to breakdown of hydroperoxides and formation of secondary products of lipid oxidation, which do not react with the TBA reagent, or the reaction of malonaldehyde with protein (Melton, 1983). Fig. (4C) showed that irradiation cause slight increase in TVB-N as compared with the non-irradiated samples. This slight increase may be due to formation of protein degradation products as carbonyl groups, ammonia, hydrogen peroxide and organic peroxide (Delincee, 1982). By 17th day, the TVB-N of unirradiated samples reached 50.2 mg/100g with apparent signs of spoilage, while in beef irradiated with 10 kGy, it reached 47.6 mg/100g by the 52nd day. In samples irradiated at 25 and 50 kGy, the TVB-N remained within acceptable limit (30 mg/100g) for up to 4 months of refrigerated storage at 5°C. Paul *et al.*, (1990) reported that TVB-N values increased in unirradiated lamb meat chunks and meat mince to 35 mg/100g within 2 weeks corresponding to poor scores for sensory evaluation. Moreover, after 4 weeks, the values were as high as 60 mg/100g compared to 35 mg/100g for samples irradiated at 1.0 kGy, while no increase was detected in TVB-N values for samples irradiated at 2.5 kGy. It has been well established that meat is a significant source of thiamin and it is the most sensitive vitamin to irradiation (Diehl, 1995). Thiamin losses were 12.8, 26.4 and 67.5% of non-irradiated samples after treatments with 10, 25, and 50 kGy respectively, compared to 12.76, 26.3 and 59.6 % for riboflavin. Storage at 5°C resulted in much more loss of both vitamins in both irradiated and non-irradiated meat, and the loss of riboflavin was lower than that of thiamin (Fig. 5). Al-Kahtani *et al.,* (1996) and Giroux and Lacroix (1998) found that riboflavin is relatively stable to irradiation. However, Ziporin *et al.,* (1957) found that irradiation of beef samples containing 1.86 μg riboflavin/g at 28 and 56 kGy resulted in retention of about 1.76 and 1.79 μg/g of riboflavin after treatment respectively. The loss of thiamin as a result of irradiation may be attributed to oxidative damage, destruction of its pyrimidin ring, and loss of the amino group (Giroux and Lacroix, 1998).

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