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Article

Effects of gamma irradiation on shelf life and quality of Black Bengal goat meat

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Abstract: This study was undertaken to assess the effects of gamma irradiation (0, 1.5, 2, 4 kGy) on shelf life and meat quality of Black Bengal goat. About 3 kg of fresh Black Bengal goat meat samples were taken and divided into four groups like T_1 (non-irradiated, control), T_2 (irradiated, 1.5 KGy), T_3 (irradiated, 2.0 KGy) and T_4 (irradiated, 4.0 KGy). Irradiated and non-irradiated meat samples were stored at refrigeration temperature to elucidate the storage effect. One way ANOVA was performed to investigate the effects of gamma irradiation on different groups. Significant differences were found in color and overall acceptability compared to non-irradiated group and only overall acceptability significantly decreased with increasing storage. No significant differences were observed in flavor, tenderness and juiciness between non-irradiated and irradiated groups. Irradiation influenced color and overall acceptability of chevon. Dry matter content was found higher in 4 KGy irradiated group and increased gradually in day intervals. Cooking loss, free fatty acid, peroxide value and thiobarbituric acid-reactive substances indicated 1.5 KGy irradiation rated best. Microbial findings revealed that 2 KGy irradiated group is better due to safe level of microbial loads which increase shelf life of Black Bengal goat meat. Finally, it may be concluded that 1.5 and 2 KGy doses gamma irradiation in Bengal goat meat enhances sensory attributes, physico-chemical and microbial levels found satisfactory.

Keywords: chevon; cooking loss; free fatty acid; peroxide value; microbial loads

1. Introduction

Black Bengal goats (BBG) are dwarf breed and are known to be famous due to its adaptability, higher disease resistance, fertility, fecundity, early sexual maturity, larger litter size, delicacy of meat and superior skin quality (Husain *et al*., 1998). Total number of goat in Bangladesh is about 25.77 million (DLS, 2016). It represents 47.44% of the total livestock populations of Bangladesh (Salahuddin *et al*., 2017). BBG constitute nearly 90% of the total goat population of Bangladesh (Husain *et al*., 1998). Adult male goat weights about 25-30 kg whereas female 20-25 kg.

Meat is defined as the flesh of animals used as food. Goat meat (Chevon) is an important protein source throughout the world especially in developing countries (Biswas *et al*., 2007). The term ‘fresh meat’ includes meat from recently processed animals as well as vacuum packed meat or meat packed in controlled atmospheric gases, which has not undergone any treatment other than chilling to ensure preservation. Fresh meat is also highly perishable product due to its biological composition (Zhou *et al*., 2010). Chevon is also attractive to health conscious consumers due to its lower fat and higher unsaturated fatty acid levels compared to other traditional red meats (Lee *et al*., 2008). The diverse nutrient composition of meat makes it an ideal environment for the growth and propagation of meat spoilage micro-organisms and common food-borne pathogens. It is therefore essential that adequate preservation technologies are applied to maintain its safety and quality (Aymerich *et al*., 2008).

Radiation processing of meat is recognized as a safe and effective method among the existing technologies for meat preservation (Al-bachir, 2005). Radiation processing of fresh meat extends the shelf-life and protects the consumer against pathogenic bacteria (Al-bachir and Zeinou, 2009). Even though irradiation is a prospective technology, its application causes physico-chemical and biochemical changes which affect the nutritional value and sensory characteristics of irradiated food (Sohn *et al*., 2009). The advantages of irradiation in controlling microorganisms and improving the shelf-life of different kinds of red meat such as fresh beef (Chen *et al*., 2007), lamb meat (Kanatt *et al*., 2007) and camel meat (Al-bachir and Zeinou, 2009) are well known but there is only limited information in the literature on the effect of gamma irradiation on the quality and shelf-life of goat meat (Modi *et al*., 2008).

Knowledge on BBG meat preservation techniques as well as its safety and quality are of scarce in this country context. Published data on chemical composition, nutritional and sensory attributes of BBG meat is limited and little information is available in irradiated meat. Hence, this study was taken to investigate the effect of gamma irradiation on shelf-life, sensory attributes and physico-chemical properties of BBG meat.

2. Materials and Methods

2.1. Sample preparation and irradiation

About 3.0 kg of fresh BBG meat samples were taken and cleaned with fresh water. Then fat was trimmed off using sharp knife. The samples were divided into four groups and meat samples were packed in airtight zip locked bags, labeled with specific radiation dose before irradiation. Each group was exposed to the irradiation dose except control, 1.5, 2.0 and 4.0 KGy at Bangladesh Institute of Nuclear Agriculture. Meat sample was irradiated through Cobalt^{60} GC-5000 (BRIT, India) machine, whose central dose rate was 4.29 KGy/hr. Treatment group was irradiated with 1.5, 2.0 and 4.0 KGy for 22, 40 and 60 min, respectively. Then meat samples were transferred immediately to the Animal Science Laboratory and stored at -20^{0}C.

2.2. Sensory evaluation

Sensory evaluation was done by a trained 6-member panel. Panelists were selected among department staff and students and trained according to the American Meat Science Association guidelines (AMSA, 1995). The judges evaluated the samples according to Pena *et al*. (2009). Sensory qualities of the samples were evaluated after thawing of before cook and after cook. Each sample was evaluated by using a 9-point hedonic scale (9=like extremely, 1=dislike extremely). Sensory evaluation was accomplished at 0, 30 and 60 days at refrigerated storage condition.

2.3. Proximate composition analysis

Dry Matter, ether extract, crude protein and ash were analyzed according to (AOAC, 1995). These proximate components were determined in triplicate and the mean value was recorded.

2.4. Physico-chemical and biochemical parameters analysis

2.4.1. Cooking loss

About 5g samples weighed and wrapped in a heat-stable foil paper. Then meat sample kept in water bath at 80˚C for 30 min. Cooking loss was determined as described by (Sultana *et al*., 2008). Cooking loss was calculated using this equation:

Cooking loss (%) = $[(w_2 - w_3) / w_2] \times 100$

Where, w_2 = meat weight before cooking (g) and w_3 = meat weight after cooking (g).

2.4.2. pH

Meat pH value was measured using pH meter (Hanna, HI 9002) from raw meat sample.

2. 4.3. Free fatty acid (%)

The free fatty acid value was determined according to Rukunudin *et al*. (1998). About 5g of meat sample was dissolved in 30 mL chloroform using a homogenizer (IKA T25digital Ultra-Turrax, Germany) at 10,000 rpm for 1 minute. Then sample was filtered under vacuum using filter paper for removing meat particles. About 4-5 drops of 1%, ethanolic phenolphthalein indicator was added to the filtrate. Then solution was titrated with 0.01N ethanolic potassium hydroxide solution.

2.4.4. Peroxide value (meq/kg)
Peroxide value (PV) was determined according to Sallam *et al*. (2004). About 3g meat sample was weighed in a 250-mL glass stopper Erlenmeyer flask and heated in a water bath at 60˚C for 3 min to melt the fat. Then samples were agitated for 3 min with 30 mL acetic acid-chloroform solution (3:2 v/v) for dissolving the fat. The sample was filtered to remove meat particles. Saturated potassium iodide solution (0.5 ml) was added to the filtrate and continues with the addition of starch solution. The titration was allowed to run against a standard solution of sodium thiosulfate.

2.4.5. Thiobarbituric acids
Lipid oxidation was assessed in triplicate using the 2-thiobarbituric acid (TBA) method described by Schmedes *et al*. (1989). BBG meat samples (5 g) were blended with 25 mL of 20% trichloroacetic acid solution (200 g/L of tricholoroacetic acid in 135 mL/L phosphoric acid solution) in a homogenizer (IKA) for 30 sec. The homogenized sample was filtered with filter paper and 2 mL of the filtrate was added with 2 mL of 0.02 M aqueous TBA solution (3 g/L) in a test tube. The test tubes were incubated at 100^0C for 30 min and cooled with tap water. The absorbance was measured at 532 nm using a UV-VIS spectrophotometer (UV-1200, Shimadzu, Japan). The TBA value was expressed as mg malonaldehyde per kilogram of sample.

2.5. Microbial assessment
Total viable count (TVC), total coliform count (TCC) and total yeast-mould count (TYMC) were measured by using plate count agar (PCA), MacConkey agar (MCA) and potato dextrose agar (PDA), respectively. Each sample was debilitated into previously prepared normal saline and poured onto each plate and incubated at 37°C for overnight. Finally counts were presented as mean colony forming unit per gram (log CFU/g).

2.6. Statistical model and analysis
The proposed model for the planned experiment was a factorial experiment with two factors A (Treatments) and B (Days of intervals) is:

$y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + \varepsilon_{ijk}$ $i = 1,\ldots,a;\ j = 1,\ldots,b;\ k = 1,\ldots,n$

Where:

y_{ijk} = observation k in level i of factor A and level j of factor B

μ = the overall mean

A_i = the effect of level i of factor A

B_j = the effect of level j of factor B

Data were statistically analyzed using SAS Statistical Discovery Software, NC, USA. DMRT test was used to determine the significance of difference among treatments means.

3. Results and Discussion
3.1. Effect of different doses of irradiation on sensory attributes in BBG meat
3.1.1. Color
Effects of gamma irradiation on meat color are shown in Table 1. It showed that there no significant differences in color level between control and 1.5 KGy irradiated groups but significant changes existed among control, 2 KGy and 4 KGy groups. Higher color level observed in 2 KGy, 4 KGy irradiated groups at 0 day of storage. This color changes in irradiated fresh meat might be the susceptibility of myoglobin molecule, especially the iron, which alters the chemical environment as well as energy input (Brewer, 2004). The metmyoglobin-reducing capacity of fresh meat is essential for the meat to retain its capacity to bloom to a red color following its removal from vacuum packages (Li *et al*., 2012). Metmyoglobin is the pigment responsible for the characteristic brown color of meat as it deteriorates during refrigerated storage (Mancini and Hunt, 2005). In a review, Nam and Ahn (2002) suggested that the mechanism of color change in irradiated meat would be similar to that in non-irradiated meat. The results of this study are not similar with the findings of Yim *et al*. (2016) who found that the color of the irradiated meat was lower than those of the non-irradiated throughout the ageing period. Kundu *et al*. (2013) also noted that color of irradiated meat decreased with the advancement of storage periods.

Table 1. Sensory-attributes (mean ± SE) in irradiated Black Bengal goat meat.

Parameters	DI	Treatments				Mean ± SE	Level of significance		
		T_1	T_2	T_3	T_4		Treat.	DI	T*DI
	0	5.33 ± 0.33	5.33 ± 0.33	5.67 ± 0.33	6.00 ± 0.00	$5.58^{a} \pm 0.31$			
Colour	30	4.33 ± 0.33	5.33 ± 0.33	5.67 ± 0.33	5.33 ± 0.33	$5.17^{a} \pm 0.33$	0.0870	0.6580	0.4481
	60	5.00 ± 0.57	5.33 ± 0.33	5.33 ± 0.33	5.33 ± 0.33	$5.25^{a} \pm 0.38$			
	Mean	$4.88^{b} \pm 0.41$	$5.33^{ab} \pm 0.33$	$5.55^{a} \pm 0.33$	$5.55^{a} \pm 0.22$				
	0	5.66 ± 0.33	5.33 ± 0.33	5.66 ± 0.33	5.66 ± 0.33	$5.58^{a} \pm 0.33$			
Flavour	30	5.33 ± 0.33	5.66 ± 0.33	5.33 ± 0.33	5.66 ± 0.33	$5.50^{a} \pm 0.33$	0.5447	0.9396	0.8171
	60	5.66 ± 0.33	5.33 ± 0.33	5.00 ± 0.57	6.00 ± 0.57	$5.50^{a} \pm 0.60$			
	Mean	$5.55^{a} \pm 0.33$	$5.44^{a} \pm 0.33$	$5.33^{a} \pm 0.41$	$5.77^{a} \pm 0.41$				
	0	5.67 ± 0.33	5.67 ± 0.33	5.67 ± 0.33	6.00 ± 0.00	$5.75^{a} \pm 0.25$			
Tenderness	30	5.67 ± 0.33	5.00 ± 0.00	6.00 ± 0.57	6.00 ± 0.57	$5.66^{a} \pm 0.37$	0.5265	<.0001	0.6594
	60	5.67 ± 0.33	5.67 ± 0.33	5.33 ± 0.33	5.67 ± 0.33	$5.58^{a} \pm 0.33$			
	Mean	$5.66^{a} \pm 0.33$	$5.44^{a} \pm 0.22$	$5.66^{a} \pm 0.38$	$5.88^{a} \pm 0.26$				
	0	5.66 ± 0.33	6.67 ± 0.33	6.00 ± 0.57	5.66 ± 0.33	$6.00^{a} \pm 0.39$			
Juiciness	30	6.33 ± 0.33	5.33 ± 0.33	5.33 ± 0.33	5.33 ± 0.33	$5.58^{ab} \pm 0.33$	0.5950	<.0001	0.2206
	60	5.33 ± 0.33	5.33 ± 0.33	5.33 ± 0.33	5.33 ± 0.33	$5.33^{b} \pm 0.33$			
	Mean	$5.78^{a} \pm 0.33$	$5.78^{a} \pm 0.33$	$5.55^{a} \pm 0.41$	$5.44^{a} \pm 0.33$				
Overall acceptability	0	6.33 ± 0.33	6.67 ± 0.33	6.67 ± 0.33	6.66 ± 0.33	$5.50^{a} \pm 0.42$			
	30	5.33 ± 0.33	5.67 ± 0.33	6.33 ± 0.33	5.67 ± 0.33	$4.87^{b} \pm 0.36$	0.1768	0.0004	0.9380
	60	5.00 ± 0.57	5.33 ± 0.33	5.67 ± 0.33	5.67 ± 0.33	$4.33^{b} \pm 0.39$			
	Mean	$5.55^{b} \pm 0.41$	$5.89^{ab} \pm 0.33$	$6.22^{a} \pm 0.33$	$6.00^{ab} \pm 0.33$				

Mean in each row and column having different superscript varies significantly ($p < 0.05$).
T1, Control; T_2, 1.5 KGy irradiated; T_3, 2 KGy irradiated; T_4, 4 KGy irradiated.
DI, Days of Intervals; Treat, Treatment; T*DI, Interaction of Treatment and Days of Intervals.

3.1.2. Flavor

Effects of gamma irradiation on meat flavor are shown in Table 1. Results revealed that flavor non-significantly differed between the non-irradiated and irradiated groups but higher flavor score was found in 4 KGy irradiated group. Storage time had no significant (P>0.05) effects on flavor. This findings is supported by Al-Bachir *et al*. (2010) who noted that flavor of the chicken kabab product were not influenced by the irradiation treatment. Again, Modi *et al*. (2008) observed that flavor significantly decreased with advancement of storage which is contradicted with this study.

3.1.3. Tenderness and juiciness

Statistically no significant differences were found in tenderness and juiciness between non-irradiated and irradiated groups. There were also non-significant (P>0.05) changes of tenderness in day's interval but decreased trend observed in juiciness which is similar with (Badar, 2004). Again, this result was not supported by Ali and Zahran (2010) who reported that tenderness of chicken meat improved due to irradiation.

3.1.4. Overall acceptability

Effects of gamma irradiation on BBG meat overall acceptability are shown in Table 1. It revealed that significant differences existed in 2 KGy irradiated groups compare to control. Results also showed that overall acceptability was significantly differed in 30 and 60 days compared with 0 day of storage.

3.2. Effects of different doses of irradiation on proximate composition in goat meat

3.2.1. Dry matter (%)

Effects of gamma irradiation on dry matter (DM) in BBG goat meat are presented in Table 2. Results imply that significant difference existed in dry matter content among irradiated groups and 4 KGy irradiated group showed higher dry matter content than others. Non-significant differences present between control and T_4 groups. With the advancement of storage time dry matter increased gradually and higher dry matter was observed in 60 days of storage which is similar to Modi *et al*. (2008); Konieczny *et al*. (2007) who reported that dry matter content increased with storage time. The improvement of DM contents in meat probably due to reduction of metabolic activities.

3.2.2. Crude protein, ether extract and ash (%)

Crude protein, ether extract and ash percentages are shown in Table 2. Non-significant differences were found in crude protein, ether extract and ash between non-irradiated and irradiated groups. There were also no significant changes present among storage periods of these parameters. This may be due to the fact that the presence of the soluble solids in meat juice may exert a considerable effect in protecting the protein from radiation damage (Batzer *et al*., 1955). The present findings were supported by Al-Bachir *et al*. (2010) and Bakalivanova *et al*. (2009) who reported that no significant differences in the protein of meat were observed due to irradiation as well as increased in oxidation activity and lipid per oxidation both radiation treatment and storage time on meat and meat products. Again, Arannilewa *et al*. (2005) observed ash content of the meat decreased with frozen storage period.

Table 2. Proximate composition (mean ± SE) in irradiated Black Bengal goat meat.

Parameters	DI	Treatments				Mean ± SE	Level of significance		
		T_1	T_2	T_3	T_4		Treat.	DI	T*DI
DM (%)	0	29.39 ± 0.52	28.21 ± 0.64	28.16 ± 0.56	29.80 ± 0.62	28.89^b ± 0.59	0.0468	0.0022	0.8876
	30	29.61 ± 0.38	28.87 ± 0.86	28.93 ± 0.63	29.87 ± 0.59	29.32^b ± 0.62			
	60	30.32 ± 0.51	29.77 ± 0.69	30.75 ± 0.65	31.56 ± 0.31	30.60^a ± 0.54			
	Mean	29.77^{ab} ± 0.47	28.95^b ± 0.73	29.28^b ± 0.59	30.41^a ± 0.47				
CP (%)	0	22.04 ± 0.35	22.41 ± 0.50	23.07 ± 0.39	22.46 ± 0.75	22.49^a ± 0.50	0.6719	0.7522	0.5158
	30	22.45 ± 0.85	21.10 ± 0.59	22.45 ± 0.31	22.79 ± 0.35	22.20^a ± 0.53			
	60	22.37 ± 0.33	22.47 ± 0.32	22.10 ± 1.00	22.13 ± 0.60	22.26^a ± 0.57			
	Mean	22.29^a ± 0.45	21.99^a ± 0.47	22.54^a ± 0.57	22.46^a ± 0.57				
EE (%)	0	2.09 ± 0.60	2.39 ± 0.27	2.97 ± 0.58	2.80 ± 0.34	2.56^a ± 0.45	0.8120	0.5450	0.3497
	30	2.94 ± 0.34	2.53 ± 0.31	2.78 ± 0.38	3.33 ± 0.34	2.89^a ± 0.34			
	60	2.49 ± 0.58	3.27 ± 0.30	2.74 ± 0.29	2.15 ± 0.55	2.66^a ± 0.43			
	Mean	2.50^a ± 0.51	2.73^a ± 0.29	2.83^a ± 0.41	2.76^a ± 0.41				
Ash (%)	0	1.35 ± 0.10	1.36 ± 0.19	1.17 ± 0.09	1.21 ± 0.10	1.27^a± 0.12	0.1597	0.3555	0.9602
	30	1.44 ± 0.08	1.46 ± 0.21	1.32 ± 0.03	1.21 ± 0.03	1.36^a± 0.09			
	60	1.42 ± 0.12	1.48 ± 0.09	1.26 ± 0.06	1.40 ± 0.06	1.39^a± 0.08			
	Mean	1.40^a ± 0.10	1.43^a ± 0.16	1.25^a ± 0.06	1.27^a ± 0.06				

Mean in each row and column having different superscript varies significantly ($p < 0.05$).
T_1, Control; T_2, 1.5 KGy irradiated; T_3, 2 KGy irradiated; T_4, 4 KGy irradiated.
DI, Days of Intervals; Treat, Treatment; T*DI, Interaction of Treatment and Days of Intervals.
DM, Dry matter; CP, Crude protein; EE, Ether extract.

3.3. Effects of different doses of irradiation on physico-chemical and biochemical properties in BBG meat

3.3.1. Cooking loss

Table 3 showed that significant difference existed in cooking loss between non-irradiated and irradiated groups. Non-significant ($p>0.05$) changes observed in storage periods but higher cooking loss was found at 30 days at storage. Again, Yoon (2003) stated irradiation significantly increase cooking loss percentage in meat due to damage of muscle fibers and myofibrils as well as denaturation of muscle proteins.

3.3.2. pH

Effects of gamma irradiation on pH are shown in Table 3 and it showed that there was no significant difference present between non-irradiated and irradiated groups. With the increment of storage time pH had decreased but higher pH value was observed at 0 day of storage. The lack of change in pH reflects that there were not enough protein breakdowns during these storage times to elicit increased pH typical of meat storage for longer periods (Modi *et al*., 2008). The increase in fat values in irradiated samples and during storage caused a decrease in pH values (Morales-delanuez *et al*., 2009) which support this study finding. Similar results also found Aftab *et al*. (2015) who carried out a research on irradiated broiler chicken meat and found pH was slightly decreased as the dose increased in refrigerator storage condition.

3.3.3. Free fatty acid (%)

Table 3 revealed that non-significant difference existed in FFA (%) between control and T_2 groups as well as T_3 and T_4 groups. Irradiated group showed higher free fatty acid value compared to control group. An increasing trend of free fatty acid was observed with the advancement of storage periods**.** Lescano *et al*. (1991) found chicken half breasts packed in polystyrene trays and wrapped with PVC film that is irradiated at a dose of 4.5 KGy showed higher FFA content compared to non-irradiated control samples. Irradiation accelerates the lipid oxidation process which is highly significant in foods with a high content of fats and much unsaturated fatty acids in which numerous free radicals are formed due to this oxidation (O'Bryan *et al.*, 2008).

3.3.4. Peroxide value (%)

Statistically non-significant (p>0.05) differences observed in peroxide value among control, 1.5 and 2 KGy irradiated groups. 4 KGy irradiated group showed significantly higher peroxide value than control group. Peroxide value significantly increased with the increment of storage time and higher peroxide value was observed in 60 days of storage. The results of this study agrees with the findings of Al-Bachir and Zeinou (2009) who reported that an increase in oxidation activity and lipid peroxidation due to radiation treatment and storage time.

3.3.5. Thiobarbituric acid reactive substances (%)

Effects of gamma irradiation on thiobarbituric acid reactive substances are shown in Table 3 and it revealed that significant differences present between non-irradiated and irradiated groups. The TBARS increased with the increasing doses of irradiation. Higher TBARS was observed in 4 KGy irradiated group and these results agrees with findings of Kim *et al*. (2012). Lewis *et al*. (2002) stated that TBARS value of chicken breast fillets were greater than that of control samples over the storage due to subjection of 1 and 1.8 KGy and further it increased as storage time increased. The present findings not supported by Chun *et al*. (2010) findings who reported that no significant differences in TBARS values for both increasing irradiation doses and increasing storage period in chicken breasts.

Table 3. Physico-chemical and biochemical properties in irradiated Black Bengal goat meat.

Parameters	DI	Treatments				Mean ± SE	Level of significance		
		T_1	T_2	T_3	T_4		Treat.	DI	T*DI
pH	0	6.05 ± 0.16	6.17 ± 0.10	6.12 ± 0.17	5.88 ± 0.07	6.05^a± 0.12	0.7928	0.0007	0.6374
	30	5.83 ± 0.16	5.64 ± 0.17	5.69 ± 0.11	5.64 ± 0.07	5.70^b± 0.13			
	60	5.45 ± 0.23	5.73 ± 0.12	5.61 ± 0.14	5.67 ± 0.09	5.61^b± 0.14			
	Mean	5.78^a ± 0.18	5.85^a ± 0.13	5.81^a ± 0.14	5.73^a ± 0.07				
Cooking Loss (%)	0	21.16 ± 0.53	22.88 ± 0.22	22.99 ± 0.34	23.53 ± 0.37	22.64^a ± 0.36	<0.0001	0.2165	0.8708
	30	20.82 ± 0.51	22.70 ± 0.63	23.54 ± 0.50	24.06 ± 0.57	22.78^a ± 0.55			
	60	19.56 ± 0.33	22.48 ± 0.62	22.84 ± 0.63	23.35 ± 0.35	22.06^a ± 0.48			
	Mean	20.51^b ± 0.46	22.68^a ± 0.49	23.12^a ± 0.49	23.64^a ± 0.43				
FFA (%)	0	0.23 ± 0.03	0.32 ± 0.03	0.38 ± 0.01	0.45 ± 0.01	0.35^c ± 0.02	<.0001	<.0001	<.0001
	30	0.66 ± 0.02	0.71 ± 0.01	0.77 ± 0.01	0.63 ± 0.07	0.69^b ± 0.03			
	60	0.64 ± 0.06	0.60 ± 0.02	1.23 ± 0.08	1.40 ± 0.17	0.96^a ± 0.08			
	Mean	0.51^b ± 0.04	0.54^b ± 0.02	0.79^a ± 0.03	0.83^a ± 0.08				
PV (meq/kg)	0	1.03 ± 0.01	0.87 ± 0.01	0.88 ± 0.04	1.30 ± 0.05	1.02^c ± 0.03	<.0001	<.0001	<.0001
	30	0.82 ± 0.02	1.04 ± 0.02	1.23 ± 0.06	1.37 ± 0.03	1.12^b ± 0.04			
	60	1.22 ± 0.03	1.25 ± 0.05	0.99 ± 0.04	1.38 ± 0.03	1.21^a ± 0.04			
	Mean	1.02^b ± 0.02	1.05^b ± 0.03	1.04^b ± 0.05	1.35^a ± 0.04				
TBARS (mg-MDA/kg)	0	0.06 ± 0.01	0.15 ± 0.01	0.20 ± 0.01	0.23 ± 0.01	0.16^c ± 0.01	<.0001	<.0001	<.0001
	30	0.19 ± 0.01	0.31 ± 0.01	0.40 ± 0.01	0.55 ± 0.01	0.36^b ± 0.02			
	60	0.21 ± 0.01	0.46 ± 0.01	0.76 ± 0.03	0.58 ± 0.04	0.50^a ± 0.02			
	Mean	0.15^c ± 0.01	0.31^b ± 0.01	0.45^a ± 0.02	0.45^a ± 0.02				

Mean in each row and column having different superscript varies significantly (p<0.05).
T_1, Control; T_2, 1.5 KGy irradiated; T_3, 2 KGy irradiated; T_4, 4 KGy irradiated.
DI, Days of Intervals; Treat, Treatment; T*DI, Interaction of Treatment and Days of Intervals.
FFA, Free fatty acid; PV, Peroxide value; TBARS, Thiobarbituric acid reactive substances; DI, Days of Intervals.

3.4. Effects of different doses of irradiation on microbial loads in Black Bengal goat meat

3.4.1. Total viable counts (log CFU/g)

The total viable count of T_1, T_2, T_3 and T_4 type irradiated meats are shown in Table 4. Research findings showed that there was significant difference among the different meat samples. The highest total viable count was found in meat irradiated with 1.5 KGy and the lowest found in 4.0 KGy irradiated meat samples. TVC showed a decreasing trend with the increasing doses of irradiation and TVC increased gradually with the storage periods increased. Similar results also found by Ferawati *et al*. (2015) of total plate count showed that the microbial loads of the irradiated samples were lower than control and this finding confirms the reduction of the microbial count after irradiation of the fresh meat samples. Food spoilage microorganisms are generally susceptible to irradiation, 90% reduction of most vegetative cells can be accomplished with 1-1.5 KGy (Brewer, 2004).

Table 4. Effect of different doses of irradiation on microbial population in Black Bengal goat meat.

Parameters	DI	Treatments				Mean ± SE	Level of significance		
		T_1	T_2	T_3	T_4		Treat.	DI	T*DI
TVC (log CFU/g)	0	4.25 ± 0.10	3.72 ± 0.02	3.78 ± 0.09	3.64 ± 0.05	3.84^c ± 0.07	<.0001	<.0001	<.0001
	30	4.68 ± 0.01	3.81 ± 0.07	4.02 ± 0.01	4.03 ± 0.01	4.13^b ± 0.04			
	60	4.02 ± 0.01	5.63 ± 0.03	4.83 ± 0.08	4.57 ± 0.04	4.76^a ± 0.04			
	Mean	4.32^a ± 0.04	4.38^a ± 0.04	4.21^b ± 0.06	4.08^c ± 0.03				
TCC (log CFU/g)	0	1.22 ± 0.04	1.05 ± 0.02	0.94 ± 0.02	1.58 ± 0.03	1.20^a ± 0.04	0.0020	<.0001	<.0001
	30	1.12 ± 0.02	1.15 ± 0.01	0.90 ± 0.01	0.72 ± 0.02	0.97^b ± 0.02			
	60	1.06 ± 0.01	1.34 ± 0.02	1.38 ± 0.06	1.03 ± 0.03	1.20^a ± 0.03			
	Mean	1.13^{ab} ± 0.02	1.18^a ± 0.02	1.07^c ± 0.03	1.11^{bc} ± 0.04				
TYMC (log CFU/g)	0	1.57 ± 0.06	0.89 ± 0.01	0.78 ± 0.05	0.61 ± 0.04	0.96^b ± 0.04	<.0001	0.0008	0.4327
	30	1.75 ± 0.08	1.17 ± 0.31	0.78 ± 0.05	0.71 ± 0.02	1.10^b ± 0.11			
	60	1.74 ± 0.04	1.47 ± 0.09	1.13 ± 0.08	0.85 ± 0.05	1.30^a ± 0.05			
	Mean	1.68^a ± 0.06	1.17^b ±0.14	0.90^c ± 0.06	0.72^c ± 0.04				

Mean in each row and column having different superscript varies significantly ($p<0.05$).
T_1, Control; T_2, 1.5 KGy irradiated; T_3, 2 KGy irradiated and T_4, 4 KGy irradiated.
DI, Days of Intervals; Treat, Treatment and T*DI, Interaction of Treatment and Days of Intervals.
TVC, total viable count; TCC, total coliforms count and TYMC, total yeast and molds count.

3.4.2. Total coliform counts (log CFU/g)

The coliform bacterial count of T_1, T_2, T_3 and T_4 type irradiated meats are shown in Table 4 and which indicated that coliform bacterial count was very low in 2.0 KGy irradiated meat. Result showed that there was significant difference between control and irradiated meat samples. No significant changes observed in TCC between 0 day and 60 days storage periods but significantly differences were found at 30 day of storage group than others. The present study is in harmony with the findings (Inamura *et al*., 2012) reported that irradiated samples showed the decrease in microbiological counts of total coliforms and might be safe up to 8 months of storage after gamma irradiation. Mantilla *et al*. (2010) also tested the effect of irradiation with doses of 3 KGy and a modified atmosphere (80% CO2/20% N2) on the growth of coliforms only developed in samples packed in air and in the non-irradiated and non-modified atmosphere.

3.4.3. Total yeast and mold counts (log CFU/g)

Statistically significant differences observed in total yeast and mold counts (TYMC) between non-irradiated and irradiated groups (Table 4). Increased dose of irradiation decreased TYMC in meat samples. With the advancement of storage periods increased trend of TYMC had been observed and Badr (2004) reported that irradiation of rabbit meat significantly reduced the counts of yeasts and molds by 84 and 94%, respectively. Ahmed *et al*. (2009) also reported that 4 kGy was needed to control the fungal growth of sun-dried fish. It has been stated that yeasts and molds are sensitive to the irradiation process because of their large genomic structure (Fallah *et al*., 2010).

4. Conclusions

In conclusion, irradiation doses of both 1.5 and 2 KGy can be effective to control bacterial spoilage and pathogens in BBG meat, through its effectiveness in extending their refrigeration shelf-life without any significant effect on the chemical characteristics or sensory quality.

Conflict of interest

None to declare.

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