Meat Research
Vol 5, Issue 3: 1-6, Article 118, June 2025
ISSN: 2790-1971
https://doi.org/10.55002/mr.5.3.118 http://www.bmsa.info/meatresearch

[1]Department of Animal Science, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh;
[2]Department of Animal products and By-products Technology, Faculty of Animal Science and Veterinary Medicine, Patuakhali Science and Technology University, Babugonj, Barishal-8210, Bangladesh;
[3]Department of Poultry Science, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh;
[4]Department of Wildlife and Ecotourism Management, University of Ibadan, Oyo State, Nigeria;

***Corresponding Author:**
MA Hashem
E-mail: hashem_as@bau.edu.bd

Keywords:
Irradiation
BHA
Freezing temperature
Biochemical
Microbial

Article Info:
Received: May 07, 2025
Accepted: June 13, 2025
Published online: June 30, 2025

Research Article

Evaluating gamma irradiation and butylated hydroxyanisole (BHA) as preservation strategies for frozen beef

M Sadakuzzaman[1], MM Rahman[1], MAZ Rion[1], MH Rahman[2], MS Ali[3], ES Apata[4], MA Hashem[1]*

Abstract

This study examined the effects of butylated hydroxyanisole (BHA), a synthetic antioxidant, in conjunction with gamma irradiation on the biochemical characteristics and microbiological population of beef during frozen storage at various time intervals. BHA (0.01%) was applied to fresh boneless beef samples, and a ^{60}Co source was used to expose them to varying doses of gamma radiation (0, 3, 5, and 7 kGy). At intervals of 0, 15, 30, and 120 days, treated samples were kept at -20°C and examined for lipid oxidation markers such as free fatty acid (FFA), peroxide value (POV), and thiobarbituric acid reactive substances (TBARS). Additionally, microbiological parameters such as total coliform count (TCC), total viable count (TVC), total yeast and mold count (TYMC), Salmonella spp., and Staphylococcus spp. were measured. FFA and TBARS were substantially higher ($p<0.01$) in all trial groups than in the control, while POV was lower in all but T1 treatment groups. These oxidative markers also dramatically increased with the storage period. Microbial studies found that although TVC, TYMC, and Salmonella spp. increased in irradiated groups, they remained within acceptable ranges. Staphylococcus spp. levels considerably decreased ($p<0.01$) with increasing irradiation doses. Interaction effects between irradiation dosage and storage period were substantial ($p<0.01$) for most biochemical and microbiological parameters. The research indicates that irradiation along with BHA can enhance beef's microbial safety and oxidative stability during frozen storage if proper dosage levels and storage conditions are carefully maintained.

Introduction

Beef, obtained from cattle carcasses, is an essential red meat that significantly contributes to a balanced diet by providing higher levels of protein, vitamins, and minerals compared to plant-based foods (Sayeed et al., 2023; Azad et al., 2022). Despite its nutritional benefits, beef is highly susceptible to spoilage caused by microbial growth, enzymatic reactions, and oxidative processes, which collectively reduce its shelf life and negatively impact consumer acceptance (Chakrabartty et el., 2024; Dave & Ghaly, 2011). To mitigate these issues, irradiation has been widely explored as an effective preservation method to reduce microbial populations and extend shelf life (Rima et al., 2019; Sadakuzzaman et al., 2021). For example, applying 2 kGy irradiation to Black Bengal goat meat effectively maintained microbial safety (Ruman Khan et al., 2017). However, biochemical markers of spoilage, such as free fatty acids (FFA), peroxide value (POV), and thiobarbituric acid reactive substances (TBARS), tend to increase with higher irradiation doses and prolonged storage durations (Rima et al., 2019; Yim et al., 2019). Similarly, frozen duck meat exposed to 7 kGy irradiation exhibited elevated TBARS, POV, and total volatile basic nitrogen (TVBN) values compared to non-irradiated controls (Zhang et al., 2016). While irradiation effectively inhibits microbial growth, microbial counts—including total coliform count (TCC), total yeast and mold count (TYMC), and total viable count (TVC)—can increase during extended storage, underscoring the necessity for preservation strategies that balance microbial suppression with oxidative stability (Rima et al., 2019). In this regard, combining irradiation with synthetic antioxidants such as butylated hydroxyanisole (BHA) presents a promising approach by slowing lipid oxidation and maintaining freshness without compromising sensory or nutritional quality (Islam et a., 2025; Sadakuzzaman et al., 2024; Liu et al., 2015).

Natural antioxidants have also demonstrated potential in meat preservation. Moringa oleifera leaf extract, for instance, has been shown to preserve the quality of beef meatballs comparably to BHA, with a 0.3% concentration providing optimal microbial stability and sensory acceptability (Islam et al., 2018). These findings suggest that both synthetic and plant-based antioxidants, particularly when used in combination with irradiation, offer effective preservation solutions. Understanding species-specific meat quality characteristics is crucial for developing tailored preservation methods.

Comparative research between Black Bengal goats and Indigenous sheep revealed that sheep meat exhibited greater tenderness and lipid oxidation, while goat meat was preferred for its distinctive flavor and higher acceptability (Akter et at., 2022; Murshed et al., 2014). Moreover, studies on organic sheep production practices highlight feeding, healthcare, and housing systems that influence meat quality and may limit the use of synthetic additives (Sarker et al., 2017).

Advances in technology have introduced non-destructive analytical tools such as Near-Infrared Spectroscopy (NIRS) coupled with Artificial Intelligence (AI) to enhance meat quality assessment. Machine learning algorithms—including Support Vector Machines (SVM), logistic regression, and neural networks—have achieved classification accuracies exceeding 84% in distinguishing cooked broiler and duck meat (Bristy et al., 2025). These techniques facilitate rapid authentication and fraud detection in the meat industry. Additionally, predictive models using filter paper wetness methods have successfully estimated drip loss and water-holding capacity, establishing essential benchmarks for broiler meat quality classification (Sarkar et al., 2024). The rigor state of meat also significantly affects quality attributes; post-rigor aging for 24 hours has been shown to improve tenderness, flavor, and color in broiler meat (Khatun et al., 2025). Food safety concerns related to antibiotic residues in meat have been rigorously investigated. One study reported that residues of tetracycline, ciprofloxacin, and enrofloxacin in various beef tissues remained below international maximum residue limits; however, it emphasized the importance of stringent veterinary drug administration and regulatory oversight to safeguard public health (Kamal et al., 2025).

The objective of this study was to investigate the effect of gamma irradiation combined with butylated hydroxyanisole on the biochemical properties and microbial population of beef stored at freezing temperatures over different time intervals

Materials and Methods

Sample Collection and Treatment

Approximately 3 kg of fresh boneless beef was collected from indigenous cattle at a local market. The beef was marinated with 0.01% butylated hydroxyanisole (BHA) and divided into 500 g portions. Each portion was sealed in a zip-lock bag with three replications per treatment group. The samples were divided into four groups: control (no irradiation) and three treatment groups subjected to 3, 5, and 7 kGy gamma irradiation, respectively. Irradiation was carried out using a 60Co gamma chamber (Model GC-5000, Activity: 10,473 Ci) at the Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, at room temperature (15–20°C). The exposure times for 3, 5, and 7 kGy doses were 54:04, 1:30:06, and 2:06:08, respectively. All irradiated and control samples were stored at –20°C and analyzed at 0, 15, 30, and 120 days of storage.

Chemicals and Reagents

Chemicals used in the study included BHA, peptone, potato dextrose agar, MacConkey agar, chloroform, sulphuric acid, sodium hydroxide, copper sulphate, starch solution, phenolphthalein, and various buffer solutions. All chemicals were of analytical grade and used as per standard protocols.

Apparatus and Equipment

A range of instruments was used, including a muffle furnace, Minolta colorimeter, refrigerator, Hanna pH meter, microscope, Kjeldahl and Soxhlet apparatus, digital shaking bath, incubator, oven, homogenizer, centrifuge, spectrophotometer, magnetic stirrer, micro-grinder, meat grinder, microwave oven with grill, digestion system, precision balances, water pump, and general laboratory tools. Equipment was thoroughly cleaned, autoclaved, and dried prior to use.

Irradiation Procedure

Post-marination, the beef samples were assigned to four irradiation treatments (0, 3, 5, and 7 kGy). Irradiation was conducted using a cobalt-60 gamma irradiator (GC-5000) at BINA. Each dose group received its corresponding radiation exposure and was then immediately frozen at –20°C for subsequent biochemical and microbiological evaluation.

Biochemical Analysis

Lipid oxidation and fat degradation were measured using three markers: peroxide value (POV), free fatty acid (FFA), and thiobarbituric acid reactive substances (TBARS). POV was determined following the method of Sallam et al. (2004) using the formula: POV (meq/kg) = (S × N) / W × 1000, where S is the titration volume in ml, N is the normality of sodium thiosulfate (0.01N), and W is the sample weight in grams. FFA content was calculated based on Rukunudin et al. (1998) as: FFA (%) = titrate (ml) × KOH normality × 28.2 / sample weight (g). TBARS was assessed following Schmedes and Holmer (1989), and results were expressed in mg malonaldehyde per kg of sample.

Microbiological Analysis

Microbial counts were conducted according to Ikhlas et al. (2012). Total coliform count (TCC) was enumerated on MacConkey agar incubated at 35°C for 24–48 hours. Total viable count (TVC) was assessed using plate count agar (PCA) under similar conditions. Total yeast and mold count (TYMC) was determined using potato dextrose agar incubated at 25°C for 48–72 hours. Salmonella spp. were detected on XLD agar based on colony morphology (black-centered colonies), while Staphylococcus spp. were identified using Mannitol Salt Agar (MSA). All counts were calculated as colony-forming units per gram (CFU/g).

Statistical Analysis

The data were analyzed using a 4×4 factorial design in a completely randomized design (CRD). Statistical analysis was performed using SAS software. Differences among treatment means were tested using Duncan's Multiple Range Test (DMRT), with significance considered at the 1% level ($p < 0.01$).

Results and Discussion

Effect on biochemical properties

The impact of BHA on the biochemical properties of frozen beef such as POV, FFA and TBARS value is presented in Table 1. The average values of FFA, POV and TBARS were found 0.19, 2.33, 0.23; 0.21, 2.36, 0.27; 0.21, 2.29, 0.31 and 0.24, 2.29, 0.27, respectively in T_0, T_1, T_2 and T_3 treatment groups. The FFA and TBARS had significant ($p<0.01$) impact on four groups of treatment but POV showed insignificant ($p>0.05$) effect. Average values of FFA, POV, and TBARS were 0.12, 1.26, 0.11; 0.31, 1.78, 0.38; 0.34, 2.56, 0.46; and 0.08, 3.67, 0.11, respectively, over storage time. These numbers showed a substantial ($p<0.01$) effect for intervals of 0, 30, 60, and 120 days. Treatment and interval days had a significant ($p<0.01$) impact on the interaction for FFA, POV, and TBARS levels. (Gecgel, 2013) showed that radiation significantly ($p<0.05$) affected FFA values. Arshad et al. (2020) found that when irradiation doses rose, the FFA% of frozen duck flesh dropped, but the current study did not support their findings. (Quattara et al., 2002) discovered the POV value was raised in beef with the increasing of irradiation doses which contrast with our results. According to the current investigation, POV was improved during the term of storage in comparison to the group under control, which was supported by the findings of (Biplob et al., 2024; Shohiduzjaman et al., 2024; Javanmard et al., 2006). Increased TBA level in cooked or processed beef with a 4.5 kGy gamma radiation exposure was reported by some sources (Rady et al., 2002). This outcome was identical with the findings of present study. The findings of other researchers about TBARS levels in various meats and meat-based products have increased due to exposure to radiation doses and storage periods (Masum et al., 2025; Arshad et al., 2020; Badr, 2004; Kanatt et al., 2006; Chen et al., 2007).

Table 1. Effect on biochemical properties of beef

Parameters	Storage time(days)	Dose (kGy) T_0	T_1	T_2	T_3	Mean	Level of significance Treat.	DI	T*DI
FFA (%)	**0**	0.11±0.00	0.11±0.00	0.11±0.00	0.15±0.01	0.12^{b}±0.00	p<0.01	p<0.01	p<0.01
	30	0.22±0.03	0.28±0.03	0.35±0.04	0.37±0.03	0.31^{a}±0.03			
	60	0.36±0.04	0.33±0.06	0.32±0.01	0.37±0.03	0.34^{a}±0.03			
	120	0.07±0.01	0.13±0.01	0.07±0.01	0.07±0.01	0.08^{b}±0.01			
	Mean	0.19^{b}±0.02	0.21^{ab}±0.02	0.21^{ab}±0.0	0.24^{a}±0.02				
POV (meq/kg)	**0**	1.16±0.10	1.30±0.05	1.29±0.04	1.29±0.09	1.26^{d}±0.06	p>0.34	p<0.01	p0<.01
	30	1.75±0.04	1.70±0.02	1.81±0.03	1.87±0.01	1.78^{c}±0.02			
	60	2.40±0.05	2.66±0.02	2.53±0.02	2.64±0.02	2.56^{b}±0.03			
	120	4.02±0.10	3.78±0.05	3.55±0.05	3.35±0.11	3.67^{a}±0.07			
	Mean	2.33^{a}±0.07	2.36^{a}±0.03	2.29^{a}±0.03	2.29^{a}±0.06				
TBARS (mg-MA/kg)	**0**	0.09±0.00	0.13±0.02	0.12±0.00	0.12±0.00	0.11^{c}±0.00	p<0.01	p<0.01	p<0.01
	30	0.32±0.01	0.37±0.04	0.43±0.02	0.42±0.00	0.38^{b}±0.02			
	60	0.36±0.04	0.46±0.00	0.57±0.01	0.45±0.00	0.46^{a}±0.01			
	120	0.11±0.00	0.10±0.00	0.11±0.00	0.11±0.00	0.11^{c}±0.00			
	Mean	0.23^{c}±0.01	0.27^{b}±0.01	0.31^{a}±0.00	0.27^{b}±0.00				

Variations in superscripts across treatment groups and interval days are statistically significant ($p<0.05$). T_0 is the group under control, T_1 is a 3 kGy gamma ray, T_2 is a 5 kGy gamma ray, and T_3 is a 7 kGy gamma ray. DI stands for Days of Interval, Treat for Treatment, and T*DI for Treatment-Interaction with Days of Interval.

The current study supports the findings of past investigations. They found that storage duration and radiation dosages increased oxidation activity and lipid peroxidation (Bachir and Zeinou, 2009; Bakalivanova et al., 2009). The highest TBARS levels measured in 60 days of interval. (Zhang et al., 2016) noted that when irradiation dosages increased, so did lipid oxidation. The rise in TBARS levels might be driven by lipid oxidation. The breakdown of peroxides and interaction with nucleophilic molecules, as well as carbonyl synthesis and irradiation, produced hydroxyl radicals, which accelerated lipid oxidation (Aubourg et al., 2004). (Park et al., 2010) and (Hocaoglu et al., 2012) discovered that the higher the irradiation dosages, the higher the TBARS readings in beef sausages.

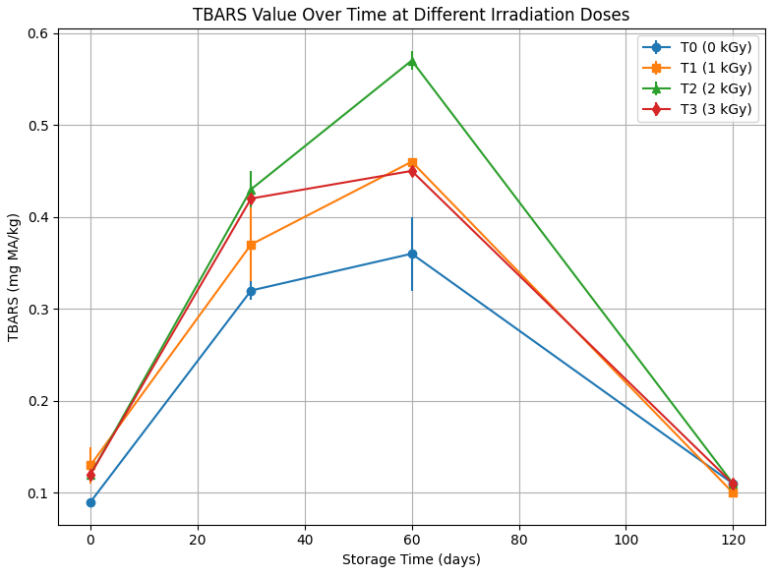

Figure 1. Effect of storage time and irradiation dose on TBARS values in meat samples. Error bars represent standard deviation. Significant differences observed among treatments ($p<0.01$).

Effect on microbial population

Total *Salmonella* species, TVC, TYMC, and total *Staphylococcus* species counts are presented in Table 2.

Table 2. Effect on microbial population of beef

Parameters	Storage time (days)	Dose (kGy)				Mean	Level of significance		
		T_0	T_1	T_2	T_3		Treat.	DI	T*DI
TCC (logCFU/g)	**0**	1.61±0.05	1.65±0.03	1.63±0.02	1.70±0.09	1.64^{a}±0.8			
	30	1.53±0.03	1.47±0.08	1.47±0.04	1.48±0.07	1.49^{b}±0.03			
	60	1.46±0.06	1.50±0.07	1.44±0.06	1.45±0.10	1.46^{b}±0.05	p>0.89	p<0.01	p>0.95
	120	1.22±0.05	1.25±0.09	1.33±0.08	1.35±0.05	1.28^{c}±0.07			
	Mean	1.46^{a}±0.04	1.47^{a}±0.06	1.46^{a}±0.05	1.49^{a}±0.07				
TVC (logCFU/g)	**0**	3.05±0.07	3.30±0.07	3.15±0.16	3.56±0.06	3.35^{a}±0.08			
	30	2.46±0.13	2.69±0.05	2.75±0.11	2.76±0.16	2.66^{b}±0.09			
	60	1.87±0.03	1.99±0.03	2.10±0.07	2.28±0.09	2.06^{c}±0.02	p<0.01	p<0.01	p>0.21
	120	1.88±0.04	1.81±0.06	1.87±0.02	1.84±0.05	1.85^{d}±0.04			
	Mean	2.31^{c}±0.06	2.45^{bc}±0.05	2.55^{ab}±0.09	2.61^{a}±0.08				
TYMC (logCFU/g)	**0**	2.01±0.10	2.40±0.10	2.32±0.08	2.41±0.04	2.28^{a}±0.06			
	30	1.86±0.08	1.81±0.03	1.80±0.01	2.29±0.33	1.94^{b}±0.08			
	60	1.71±0.04	1.77±0.05	1.69±0.12	1.67±0.09	1.71^{c}±0.07	p<0.01	p<0.01	p>0.14
	120	1.42±0.09	1.64±0.04	1.68±0.02	1.70±0.02	1.61^{c}±0.03			
	Mean	1.75^{b}±0.07	1.91^{ab}±0.05	1.87^{ab}±0.10	2.02^{a}±0.12				
Salmonella (logCFU/g)	**0**	3.37±0.14	3.51±0.19	3.67±0.27	3.67±0.23	3.56^{c}±0.20			
	30	3.53±0.06	4.03±0.03	0.00±0.00	4.10±0.05	2.91^{bc}±0.30			
	60	3.47±0.05	3.87±0.05	3.69±0.05	4.17±0.05	3.80^{b}±0.05	p<0.01	p<0.01	p<0.01
	120	4.60±0.00	4.22±0.20	4.43±0.00	3.54±0.00	4.19^{a}±0.00			
	Mean	3.74^{b}±0.06	3.90^{a}±0.12	2.94^{a}±0.08	3.87^{a}±0.08				
Staphylococcus (logCFU/g)	**0**	3.67±0.17	3.67±0.12	3.53±0.18	3.58±0.23	3.61^{a}±0.17			
	30	4.47±0.05	3.65±0.00	3.60±0.05	3.80±0.07	3.88^{a}±0.22			
	60	3.94±0.02	4.00±0.05	3.87±0.00	3.60±0.00	3.83^{a}±0.00	p<0.01	p<0.01	p<0.01
	120	4.74±0.00	3.58±0.14	3.65±0.00	3.69±0.00	3.91^{a}±0.30			
	Mean	4.20^{a}±0.06	3.73^{b}±0.07	3.66^{b}±0.05	3.66^{b}±0.07				

Significant differences (p<0.05) exist in the superscripts of various treatment groups and interval days. T0 stands for the control group, T1 for a 3 kGy gamma ray, T2 for a 5 kGy gamma ray, and T3 for a 7 kGy gamma ray. T*DI = Interaction of Treatment and Days of Interval, DI = Days of Interval, and Treat = Treatment

The study found average values of TCC, TVC, TYMC, Salmonella spp., and total Staphylococcus spp. in various groups of treatment, with log CFU/g values ranging from 1.46 to 3.66. Staphylococcus species, TVC, TYMC, and Salmonella species all exhibited substantial (p<0.01) variations between different treatments and different storage durations, although TCC did not. Only *Salmonella spp.* and *Staphylococcus spp*. demonstrated significant treatment-time interaction. Compared to the control group, the levels of *Staphylococcus* and TYMC in the various groups given treatment were substantially reduced (p<0.05). *Staphylococcus* considerably (p<0.01) decreased and *Salmonella* insignificantly (p>0.05) increased as beef was exposed to increasing radiation levels. (Haque et al., 2017) proved similar results. *Salmonella spp.* dramatically reduced (p<0.01) and *Staphylococcus spp.* displayed significantly decreased (p<0.01) with increasing radiation dosages. (Ham et al., 2017) revealed that the entire aerobic bacteria from cooked beef patties was totally eradicated by electron beam irradiation levels of 2.5, 5, 7.5, and 10 kGy. It was found that as the irradiation dose increased in beef, there was a decreasing trend in TCC, TVC, and TYMC levels. TCC, TVC, and TYMC values in our study increased in groups receiving treatment because of higher irradiation dosages, but decreased throughout storage times (Islam et al., 2022; Haque et al., 2017).

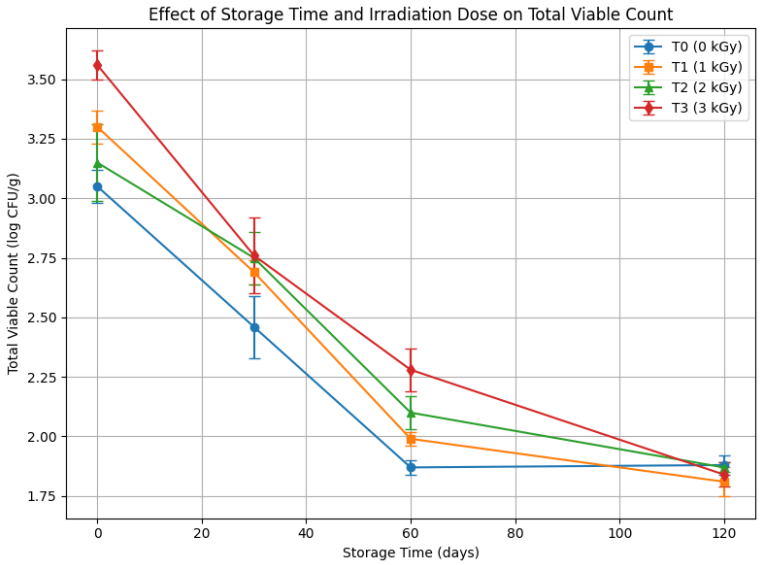

Figure 2. Total Viable Count (TVC) changes over storage time for different irradiation doses. Error bars represent standard deviation. Significant effects of dose and storage time observed (p<0.01).

Conclusion

BHA treatment combined with freezing influenced beef quality by accelerating lipid oxidation, as seen through increased FFA and TBARS and reduced POV over time. While microbial counts like TCC, TVC, and TYMC rose initially in irradiated samples, they declined with extended storage and stayed within safe limits. Staphylococcus spp. significantly decreased with higher irradiation, whereas Salmonella spp. showed a slight upward trend. The interaction between dose and storage time had a notable impact on most quality indicators. Overall, effective dose and storage control are essential to balance oxidative stability and microbial safety in treated beef.

References

Akter R, Hossain MA, Khan M, Rahman MM, MAK Azad, Hashem MA. 2022. Formulation of value added chicken meatballs by addition of Centella leaf (Centella asiatica) extracts. Meat Research. 2 (2), Article No. 18. DOI: https://doi.org/10.55002/mr.2.2.18

Al-Bachir M, Zeinou R. 2009. Effect of gamma irradiation on microbial load and quality characteristics of minced camel meat. Meat Science, 82: 119–124. DOI: https://doi.org/10.1016/j.meatsci.2008.12.012

Ana BA, Marcondes VS, Suzana CSL. 2018. Lipid oxidation in meat mechanisms and protective factors. Food Science and Technology, 38: 1–5. DOI: https://doi.org/10.1590/fst.32518

Arshad MS, Kwon J, Ahmad RS, Ameer K, Ahmad S, Jo Y. 2020. Influence of E-beam irradiation on microbiological and physicochemical properties and fatty acid profile of frozen duck meat. Food Science and Nutrition, 8: 1020–1029. DOI: https://doi.org/10.1002/fsn3.1386

Aubourg SP, Perez-Alonso F, Gallardo JM. 2004. Studies on rancidity inhibition in frozen horse mackerel (Trachurus trachurus) by citric and ascorbic acids. European Journal of Lipid Science and Technology, 106(4): 232–240. DOI: https://doi.org/10.1002/ejlt.200400937

Azad MAK, Rahman MM, Hashem MA. 2022. Meat microbiota: A conceptual review. Meat Research, 2(3). DOI: https://doi.org/10.55002/mr.2.3.20

Badr HM. 2004. Use of irradiation on control food borne pathogens and extent the refrigerated market life of rabbit meat. Meat Science, 67: 541–548. DOI: https://doi.org/10.1016/j.meatsci.2003.11.018

Bakalivanova T, Grigorova S, Kaloyanov N. 2009. Effect of irradiation and packaging on lipid fraction of Bulgarian salami during storage. Radiation Physics and Chemistry, 78: 273–276. DOI: https://doi.org/10.1016/j.radphyschem.2008.12.005

Biplob MAKA, Hossan MI, Khatun H, Rahman MM. 2024. Quality assessment of chicken meatball with different types of antioxidants in short-term preservation. Meat Research, 4: 6. Article No. 106. https://doi.org/10.55002/mr.4.6.106

Bristy KK, Ghosh D, Hashem MA. 2025. NIRS and machine learning algorithms as a non-invasive technique to discriminate and classify cooked broiler and duck meat. Applied Food Research. DOI: https://doi.org/10.1016/j.afres.2025.100984

Bristy KK, Ghosh D, Hashem MA. NIRS and machine learning algorithms as a non-invasive technique to discriminate and classify cooked broiler and duck meat. Applied Food Research. 2025 May 20:100984. https://doi.org/10.1016/j.afres.2025.100984

Cardoso GP, Andrade MPD, Rodrigues LM, Massingue AA, Fontes PR, Ramos ALS, Ramos EM. 2019. Retail display of beef steaks coated with monolayer and bilayer chitosan-gelatin composites. Meat Science, 152: 20–30. DOI: https://doi.org/10.1016/j.meatsci.2019.02.009

Chakrabartty S, Akter S, Murshed HM, Rahman MM, Azad MAK. 2024. Effects of ageing on longissimus thoracis et lumborum (LTL) muscle of local beef. Meat Research, 4: 1, Article No. 83.

Chen YJ, Zhou GH, Zhu XD, Xu XL, Tang XY, Gao F. 2007. Effect of low dose gamma irradiation on beef quality and fatty acid composition of beef intramuscular lipid. Meat Science, 75: 423–431. DOI: https://doi.org/10.1016/j.meatsci.2006.08.014

Dave D, Ghaly AE. 2011. Meat Spoilage Mechanisms and Preservation Techniques: A Critical Review. American Journal of Agricultural and Biological Sciences, 6(4): 486–510. DOI: https://doi.org/10.3844/ajabssp.2011.486.510

Gecgel U. 2013. Changes in some physicochemical properties and fatty acid composition of irradiated meatballs during storage. Journal of Food Science and Technology, 50(3): 505–513. DOI: https://doi.org/10.1007/s13197-011-0375-3

Ham YK, Kim HW, Hwang KE, Song DH, Kim YJ, Choi YS, Kim CJ. 2017. Effects of irradiation source and dose level on quality characteristics of processed meat products. Radiation Physics and Chemistry, 130: 259–264. DOI: https://doi.org/10.1016/j.radphyschem.2016.09.010

Haque MA, Hashem MA, Hossain MM, Rima FJ, Hossain A. 2017. Effect of gamma irradiation on shelf life and quality of beef. Journal of Meat Science and Technology, 5(2): 20–28.

Hashem MA, Begum M, Hasan MM, Al Noman MA, Islam S, Ali MS. 2022. Effect of sodium alginate on the quality of chicken sausages. Meat Research, 2(3): 20. DOI: https://doi.org/10.55002/mr.2.4.31

Hashem MA, Jun KY, Lee E, Lim S, Choo HY, Kwon Y. 2008. A rapid and sensitive screening system for human type I collagen with the aim of discovering potent anti-aging or anti-fibrotic compounds. Molecules and Cells, 26(6): 625–630. DOI: https://doi.org/10.1016/S1016-8478(23)14047-7

Hocaoglu A, Demirci AS, Gumus T, Demirci M. 2012. Effects of gamma irradiation on chemical, microbial quality and shelf life of shrimp. Radiation Physics and Chemistry, 81(12): 1923–1929. DOI: https://doi.org/10.1016/j.radphyschem.2012.07.017

Ikhlas B, Huda N, Ismail N. 2012. Effect of cosmos caudatus, polygonum minus and Bht on physical properties, oxidative process, and microbiological growth of quail meatball during refrigeration storages. Journal of Food Processing and Preservation, 36(1): 55–66. DOI: https://doi.org/10.1111/j.1745-4549.2011.00552.x

Islam MR, Hasan, Masum MMR, Khan M, Rahman MM. 2025. Effect of organic acid and natural antioxidant on the quality and shelf life of raw chicken meat at refrigerated storage. Meat Research 5 (1), Article No. 111. https://doi.org/10.55002/mr.5.1.111

Islam MA, Hossain MA, Sadakuzzaman M, Khan M, Rahman MM, Hashem MA. 2022. Effect of gamma irradiation on the shelf life and quality of mutton. Turkish Journal of Agriculture-Food Science and Technology, 10 (2): 117-124.

Islam F, Hossain MA, Rahman MF, Hashem MA, Rahman M, Azad MA. 2018. Effect of synthetic or herbal preservatives on the quality of beef meatballs at different shelf-life periods. SAARC Journal of Agriculture, 16(1): 23–34. DOI: https://doi.org/10.3329/sja.v16i1.37420

Javanmard M, Rokni N, Bokaie S, Shahhosseini G. 2006. Effect of gamma irradiation and frozen storage on microbial, chemical and sensory quality of chicken meat in Iran. Food Control, 17: 469–473. DOI: https://doi.org/10.1016/j.foodcont.2005.02.008

Kamal MT, Deen RA, Ahmed B, Hashem MA. 2025. Assessment of antibiotic residues in beef cattle slaughtered in Bangladesh: Implications for food safety and public health. Meat Research, 5(2). DOI: https://doi.org/10.55002/mr.5.2.114

Kanatt SR, Chander R, Sharma A. 2006. Effect of radiation processing of lamb meat on its lipids. Food Chemistry, 97(1): 80–86. DOI: https://doi.org/10.1016/j.foodchem.2005.03.024

Khan SH, Salahuddin M, Habib MR, Billah MM, Miah MAH, Akhter S, Hashem MA. 2017. Effects of gamma irradiation on shelf life and quality of Black Bengal goat meat. Asian-Australasian Journal of Food Safety and Security, 1(1): 65–73. DOI: https://doi.org/10.3329/aajfss.v1i1.55763

Khatun R, Akter I, Deen RA, Ghosh D, Hashem MA. 2025. Are there any differences on sensory and physicochemical attributes of pre-and post-rigor broiler meat? Meat Research, 5(1). DOI: https://doi.org/10.55002/mr.5.1.112

Liu F, Xu Q, Ni Y, Dai R. 2015. Effects of natural antioxidants on colour stability, lipid oxidation and metmyoglobin reducing activity in raw beef patties. Acta Scientiarum Polonorum Technologia Alimentaria, 14(1): 37–44. DOI: https://doi.org/10.17306/j.afs.2015.1.4

Mahto R, Ghosh S, Das MK, Das M. 2015. Effect of gamma irradiation and frozen storage on the quality of fresh water prawn (Macrobrachium rosenbergii) and tiger prawn (Penaeus monodon). Food Science and Technology, 61(2): 573–582. DOI: https://doi.org/10.1016/j.lwt.2014.12.028

Masum MMR, Mahmud S, Liza FA, Islam MR, Azad MAK, Rahman MM. 2025. Effect of natural and synthetic antioxidant on the quality of broiler meat during refrigeration. Meat Research 5 (1), Article No. 110. https://doi.org/10.55002/mr.5.1.110

Murshed HM, Sarker MA, Rahman SM, Hashem MA. 2014. Comparison of carcass and meat quality of Black Bengal goat and Indigenous sheep of Bangladesh. Journal of Meat Science and Technology, 2(3): 63–67.

Rahman MI, Kabir MH, Hossain MA, Milon M, Hossain MM, Hashem MA. 2017. Effect of kalogira (Nigella sativa) and BHA (beta hydroxyl anisole) on quality control and shelf-life of beef meatballs. International Journal of Natural and Social Sciences, 4(1): 85–94.

Rima FJ, Sadakuzzaman M, Hossain MA, Ali MS, Hashem MA. 2019. Effect of gamma irradiation on shelf life and quality of broiler meat. SAARC Journal of Agriculture, 17(1): 149–159. DOI: https://doi.org/10.3329/sja.v17i1.42768

Sadakuzzaman M, Rahman MM, Hashem MA, Ali MS, Alam AN. 2024. Synergistic effects of gamma irradiation and butylated hydroxyanisole on the sensory, physicochemical, and microbiological quality of beef. Applied Food Research, 4(2): 100547. DOI: https://doi.org/10.1016/j.afres.2024.100547

Sadakuzzaman M, Hossain MA, Rahman MM, Azad MAK, Hossain MM, Ali MS, Hashem MA. 2021. Combined effect of irradiation and butylated hydroxyanisole on shelf life and quality of beef at ambient temperature. Meat Research, 1(1). DOI: https://doi.org/10.55002/mr.1.1.3

Sarkar RR, Jahan I, Sarker T, Deen RA, Ghosh D, Akther S, Hashem MA. Drip loss assessment by standard bag and filter paper wetness method and their relationships with broiler chicken meat quality classification. Meat Research. 2024 Aug 31;4(4). https://doi.org/10.55002/mr.4.4.100

Sarker AK, Amin MR, Hossain MA, Ali MS, Hashem MA. 2017. Present status of organic sheep production in Ramgoti Upazila of Lakshmipur district. Journal of Environmental Science and Natural Resources, 10(2): 95–103. DOI: https://doi.org/10.3329/jesnr.v10i2.39018

Sarker T, Deen RA, Ghosh D, Mia N, Rahman MM, Hashem MA. 2024. AI driven approach and NIRS: A review on meat quality and safety. Meat Research, 4(6). DOI: https://doi.org/10.55002/mr.4.6.105

Schmedes A, Homer G. 1989. A new thiobarbituric acid (TBA) method for determining free malondialdehyde (MDA) and hydroperoxides selectively as a measure of lipid peroxidation. Journal of American Oil Chemistry Society, 66: 813–817. DOI: https://doi.org/10.1007/BF026536

Shohiduzjaman M, Biplob MAKA, Hashem MA, Rahman MM. 2024. Effects of natural and synthetic antioxidant on the quality of beef in short-term preservation. Meat Research, 4: 6. Article No. 107. https://doi.org/10.55002/mr.4.6.107

Yim D, Jo C, Mahabbat A, Park J, Lee S, Nam K. 2019. Combined effect of aging and irradiation on physiological quality of pork shoulder. Food Science of Animal Resources, 39(3): 510–519. DOI: https://doi.org/10.5851/kosfa.2019.e46

Zhang HF, Wang W, Zhang SF, Wang HY, Ye QF. 2016. Influence of 10-MeV E-beam irradiation and vacuum packaging on the shelf-life of grass carp surimi. Food and Bioprocess Technology, 9(5): 830–838. DOI: https://doi.org/10.1007/s11947-016-1675-4