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Review Article

Irradiation of meat with synthetic and natural antioxidant: A review on quality aspect of meat

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Abstract

Different types of research works have been carried out on irradiation to find out the shelf life, nutritive value, safety aspect of biochemical and microbial assessment. The available literatures regarding effect of irradiation with synthetic antioxidant betahydroxy anisole (BHA) and natural antioxidant black cumin seed extract marinated with beef and other meat are reviewed in this review.

History and development of irradiation

The first U.S. and British patents were issued for use of ionizing radiation to kill bacteria in foods in 1905. To establish the safety and effectiveness of the irradiation process, the U.S. Army began a series of experiments with fruits, vegetables, dairy products, fish and meats in the early 1950's. In 1970, the International Project in the Field of Food Irradiation (IFIP) was started worldwide with an objective to conduct research on health safety of irradiated foods. It conducted long-term animal feeding studies, short-term screening tests and study of chemical changes in irradiated food. This international project and different national programs were reviewed jointly by the Food and Agriculture Organization (FAO), International Atomic Energy Agency (IAEA), World Health Organization (WHO) expert committee and the group concluded of any food commodity with an average dose of 10 kGy poses no toxicological hazard and no specific nutritional or microbiological problems (Diehl, 2001). This was a major success in the use of irradiation in foods. After successful achievement of IFIP, the program was terminated but as IFIP had provided a platform of information exchange on food irradiation. Other platforms lead to establishment of International Consultants Group on Food Irradiation (ICGFI) in 1984.

In 1985, Canadian and U.S. food irradiation regulations were published, and the FDA approved irradiation of pork for control of *Trichinella spiralis*. The use of irradiation to delay maturation, inhibit growth and disinfect food including vegetables and spices was approved by FDA during 1986 (Molins, 2001). Later, another group of experts were appointed by WHO to re-evaluate the results of scientific studies carried out after 1980 along with the earlier studies (WHO, 1994). This expert group concluded that food irradiation is a thoroughly tested food technology. Safety studies of various foods have so far shown no deleterious effects (Diehl, 2001; Islam et al., 2021; Molins, 2001).

The important dates in history of food irradiation (Molins, 2001) is presented in the Tabl 1

Table 1. History of food irradiation

1895-96	Roentgen discovered X-rays. Becquerel discovered radioactivity.
1905	Patent granted to improve condition of food with irradiation.
1921	US patent for irradiation of pork for trichina.
1930	French patent for X-ray preservation of foods.
1943	Army sponsored feasibility study at MIT.
1958	The U.S. Food Additive Amendment to the Food Advisory Committee. Act classified food irradiation as an "additive."
1963-64	The U.S. Food and Drug Administration (FDA) approved irradiation of bacon, wheat, flour, and potatoes.
1978-90	The International Facility for Food Irradiation Technology (IFFIT) was founded under the sponsorship of FAO, IAEA, and The Netherlands; this group trained hundreds of scientists from developing countries in food irradiation and contributed in developing different applications of radiation process for foods.
1990	FDA approved the use of irradiation in poultry to control Salmonella.
1992	WHO appointed an Expert committee to re-evaluate the safety of irradiated foods on the request of Australia. The committee again concluded that irradiated foods are safe.
1997	FAO/IAEA/WHO study group formed to study high dose irradiation of foods. They declared that foods irradiated at any dose are safe, and there is no need to specify upper limit for irradiation in foods. FDA observed bacterial pathogenic reduction in meat by 4.5 kGy for fresh meat and 7 kGy for frozen meat.
1997	FDA approved the use of irradiation in red meat to inactivate pathogenic bacteria.
1998	European Union approved irradiation of spices, condiments, and herbs.
2000	FDA approved irradiation for control of Salmonella in shell eggs and seed decontamination for sprouting.

Effect of irradiation on sensory attributes of beef

Al-Perkhdri (2022) noted that there is a paucity of information and a scarcity of studies that have examined the effect of gamma rays on sensory characteristics of camel meat. However, many scientific works dealt with the study of the effect of gamma rays on the organoleptic characteristics of other types of meat. Most of the results of these studies indicated that there was no effect of radiation on the sensory attributes of the species of meat. Shehata (2005) obtained that the use of doses (1.5, 3 and 4.5 kGy) of gamma rays had little effect on the sensory attributes (appearance, smell and taste) of broiler meat. The results of sensory attributes also showed that radiotherapy improved the colour of Korean meat when compared with control samples (Sorman et al., 1987). The results of the sensory attributes indicated no significant differences in sausages prepared from radiation-treated lamb (Song et al., 2018). Swatland (2013) showed that the sensory attributes of broiler meat were not affected even when treated with a radiation dose of 6 kGy. Khan et al. (2017 found significant effect of gamma irradiation on sensory attributes in chevon.

Higher irradiation dose oxidizes myoglobin to metmyoglobin and irradiation at 9 kGy combined with aging can be used as an effective tool for improving the tenderness of Nellore beef but resulted in a discoloration of the beef observed by Lorena et al. (2020). Min et al. (2020) conducted an experiment to observe that up to 7 kGy irradiation could markedly promote the carbonylation of muscle protein. The tenderness of the muscle was increased by irradiation a dose-dependent manner. Calpains and structural proteins showed dose-dependent response to irradiation ($\leq$7 kGy). Arshad et al. (2020) reported that the sensory parameters were non-significantly differences with doses. Higher sensory score for appearance and texture was judged by the panelists to frozen duck meat (FDM) treated with 7 kGy radiation; however, higher score was attributed to FDM treated with 3 kGy radiation for flavour, taste, and overall acceptability. The results showed that irradiation had no effect on the sensory parameters of FDM. Al-Bachir and Othman (2013) reported that chicken sausages treated with different doses (0, 2, 4, and 6 kGy) had no effect on the sensory properties. Vickers and Wang (2002) showed that irradiation had no effect on the acceptability of ground beef patties, and the sensory scores ranged from 6.1 to 6.4 on a 9-point hedonic scale. Schilling et al. (2009) demonstrated that irradiation had no effect (p>0.05) on the consumer acceptability of ground beef patties, and Fregonesi et al. (2014) showed that the sensory quality of irradiated lamb meat was unaltered.

Mahajan et al. (2017) conducted an experiment on quality characteristics of functional spent hen meat nuggets incorporated with Amla (*Emblica officinalis*) fruit juice powder and they found that the hardness, chewiness and gumminess significantly decreased whereas springiness, resilience showed an increase with in treatments and control. The overall acceptability in treated products was higher than control. Sensory panelists awarded highest overall acceptability scores to 1.0% amla fruit juice powder. Haque et al. (2017) carried out a study on effect of gamma irradiation on shelf life and quality of beef where they found that the colour, flavour, tenderness, juiciness and overall acceptability at different treatments were 3.33 to 4.33, 4.33 to 3.44, 3.56 to 4.75, 3.89 to 4.22 and 3.56 to 4.17, respectively and days of interval were 4.67 to 3.254, 33 to 3.17, 4.75 to 3.08, 4.67 to 3.17 and 4.58 to 3.33, respectively in which all of sensory attributes were significantly (p<0.05) differed except flavour. Tareq et al. (2018) carried out a study on effect of clove powder and garlic paste on quality and safety of raw chicken meat at refrigerated storage where they observed that color score of 0.2% clove powder and odour score of 2% garlic paste were significantly higher (p<0.05) than other treated groups. They concluded that natural preservatives as 0.2% clove powder and 2% garlic paste were effective in increased shelf life of meat but their combination of 0.2% clove powder and 2% garlic paste could be utilized effectively as antioxidant and antimicrobial in preservation of raw chicken meat at refrigerated storage temperature (4°C±1°C).

Sadakuzzaman et al. (2021) carried out a study on combined effect of irradiation and butylated hydroxyanisole on shelf life and quality of beef at ambient temperature and found that color, flavor, tenderness, juiciness and overall acceptability were significantly differed (p<0.01) for days of intervals. Positive and significant interaction (p<0.01) between treatment and days of interval was found for color value (L*, a*, b*), drip loss, cooking loss, ERV, WHC except raw pH. Modi et al. (2008) carried out a study on changes in quality of minced meat from goat due to gamma irradiation and found that the sensory quality scores on a 9-point hedonic scale decreased from 7.5–8.3 to 7.1–7.9 during storage at 3°±1°C for 8 days and were marginally influenced by irradiation and 4-kGy dosage was appropriate for irradiation to maintain fresh meat quality under chilled condition.

Badr (2004) conducted an experiment on use of irradiation to control foodborne pathogens and extend the refrigerated market life of rabbit meat and found that on day 7 of refrigerated storage, non-irradiated samples were scored as poor samples and rejected due to the appearance of mold growth, slime formation and off-odours. Small spots of mold growth started to appear on the surface of samples and off-odours detected on day 13 and 22 at refrigerated storage for samples irradiated at 1.5 and 3 kGy, respectively. Therefore, concluded that on sensory evaluation, these doses could prolong the edible refrigerated storage life of rabbit meat to 12 and 21 days, respectively, compared to 6 days for non-irradiated controls. Arshad et al. (2019) conducted a study on the impact of gamma irradiation and turmeric powder (TP) on microbial quality (total aerobic bacteria and coliforms), physicochemical quality (pH, Hunter's parameter, oxidative and microbial stabilities, haem pigment), stability and antioxidant status of chicken meat. Only two doses (1 kGy and 2 kGy) of gamma irradiation alone and in combination with 3% TP along with the control (0 kGy) were applied. The aerobic and vacuum packaging was used for storage of chicken meat on the 0, 7th and 14th days at refrigeration temperature (4°C). They concluded that chicken meat treated with 2 kGy + TP was considered better for microbial and physicochemical quality and antioxidant activity as well as sensorial attributes of chicken meat.

Wafaa and Afaf (2016) conducted a study on the effect of gamma radiation and chilling on the hygienic quality of fresh beef, fatty acids content and survival of *Escherichia coli* as food poisoning microorganisms. Sensory examination revealed that there was no significant effect between gamma radiation at 3 kGy and non-irradiated groups in colour, odour and texture. Gamma radiation caused slight significant effect on the chemical analysis after irradiation. Yim et al. (2016) studied an experiment with increasing ageing temperature and ageing time, shear force values decreased. The colour of the irradiated meat was lower than those of the non-irradiated throughout the ageing period. As ageing time and temperature increased, the amounts of inosine monophosphate decreased and the hypoxanthine increased. Fadhel et al. (2016) carried out an experiment on sensory attributes of marinated pork loin meat treated or non irradiated at a dose of 1.5 kGy, was done by evaluating its colour, texture, odour, flavour and global appreciation, using a 9-points hedonic scale having the irradiation dose of 1.5 kGy was selected on the basis of shelf-life results. Results showed that gamma irradiation did not affect significantly (p>0.05) the colour, texture and the global appreciation of cooked pork loin meat. There was no significant difference (p>0.05) was observed between marinated meat and irradiated meat at 1.5 kGy showing a mean hedonic value of 7 “Like moderately” was evaluated for almost of all sensorial traits. Previous studies elucidated that an irradiation treatment of 3 kGy under vacuum did not significant ($p>0.05$) affect for the sensorial attributes of pork, beef and turkey meat (Kimet al., 2002).

Kanattet al. (2015) noted that radiation processing of meat samples resulted in some change in colour of meat. They found that irradiation leads to dose dependant tenderization of meat. Radiation processing of meat at a dose of 2.5 kGy improved its tender, texture and had acceptable flavour. The effects of gamma irradiation (0, 2, 4, and 6 kGy) on microbial, chemical, and sensory values of Jabaly Syrian goat meat during storage at 4 °C for 1, 3, 4, and 5 weeks. No significant differences were observed in sensory attributes (tenderness, flavour and taste) of irradiated and non-irradiated goat meat found by Al-Bachir and Zeinou (2014). The off-flavour intensity of patties was the only parameter where judges detected differences with increasing irradiation dose. The off-flavour intensity of patties made of irradiated and non-irradiated fresh (1 d) and 30 d stored trimmings. The other sensory attributes showed no significant changes due to irradiation treatment or storage time of trimmings and patties (Xavier et al., 2014). They found that the values, in a 0 to 10 continuous scale ranged as follows: flavour intensity (5 to 6), off flavour intensity (0.3 to 1.4), initial tenderness (4.2 to 5.9), final tenderness (4.7 to 5.8), initial juiciness (4.2 to 5.7), final juiciness (3.9 to 5.7). They observed that results judges from trained panelists and consumers indicated that there were no sensorial effects between patties produced from fresh 1 to 30 days stored irradiated trimmings at 2 or 5 kGy and concluded that it was possible to commercialize irradiated trimmings such to markets that require 30 days for transport and beef patties for up to a 180 day ($p<0.05$) taking into counting of sensorial findings.

Khare et al. (2016) carried out a study on utilization of carrageenan, citric acid and cinnamon oil as an edible coating of chicken fillets to prolong its shelf life under refrigeration conditions. They observed a significant difference for physicochemical parameters (pH, ERV, and drip loss) between storage periods in all the samples and between the control and treatments throughout the storage period but samples did not differ significantly for hunter colour scores. However, there was no significant difference among three methods of application throughout the storage period though dipping had a lower rate of increase. A progressive decline in mean sensory scores was recorded along with the increase in storage time. Sensory attributes like texture, flavour, colour and taste of irradiated and non-irradiated goat meat had no significant differences between irradiated and non-irradiated goat meat noted by Al-Bachir and Othman (2013). The effects of a low-dose (≤1 kGy), low-penetration electron beam on the sensory qualities of raw muscle pieces of beef and cooked ground beef patties were analyzed. The study of ground beef patties was evaluated by a trained panel for tenderness, juiciness, beef flavour, and aroma at 10, 20, and 30%, respectively levels of fat, containing 0 (control), 10, 20, 50 and 100% irradiated meat. They found redder colour in controls than irradiated muscles. Both control and treatments showed a gradual deterioration in colour over 14 days of aerobic storage at 4°C. The off-aroma intensity of both control and treatments increased with storage time, but by days of 14, the treated muscles showed significantly less off-aroma than the controls and lower microbial load.

Kundu et al. (2013) found that 1 kGy absorbed dose had minimal effects on the sensory attributes of intact beef muscle pieces. Irradiation did not significant ($p>0.05$) effect on any of the sensory attributes of the patties. Fallah et al. (2010) and Kim et al. (2012) observed the sensory attributes indicated that the rancid flavour of samples irradiated at 4 kGy was significantly ($p<0.05$) higher, but aroma and tastes sores were lower than those of the control at day 3 of storage. Irradiation of dry fermented sausages at 2 kGy was the best conditions to prolong the shelf life and decrease the rancid flavour without significant quality deterioration and irradiation had no significant effects ($p>0.05$) on the sensory attributes of raw and cooked camel meat. Henry et al. (2010) conducted an experiment to evaluate the irradiation process influence on the turkey meat preservation using two different dose rates (turkey meat cuts of frozen, frozen and irradiated at 1 kGy dose and 3 kGy dose). Beginning of the storage, the gamma radiation promote to reduce the sensory acceptance of the meat taste, especially when the sample was exposed to a dose of 3 kGy enhanced with the greatest lipid oxidation. Irradiated samples were kept within the pH range and characterized the consumption of meat for the maximum storage time did not show any change in the sensory attributes of flavour, colour and overall acceptability.

Park et al. (2010) studied on compared effects of gamma ray and electron beam irradiation on quality sensory attributes *viz.* tenderness and colour in beef sausage patties during storage for 10 days at 30 °C and beef sausage patties were vacuum-packaged irradiated by gamma ray and electron beam irradiation at 0, 5, 10, 15, and 20 kGy at room temperature. They found that the use of gamma ray irradiation up to 10 kGy on sausage patties were useful with no adverse effect on quality and sensory attributes such as colour, chewiness and taste. Al-Bachir et al. (2010) conducted a study on chicken kabab with 0, 2, 4 or 6 kGy doses of gamma irradiation on treated and control samples at refrigerated temperature (4°C) and the storage period of sensory attributes of chicken kabab was 0–5 months. They found that the nutritional components and sensory attributes namely taste, flavour, colour and texture of the chicken kabab were not influenced ($p>0.05$) by the irradiation doses. Islam et al. (2019) found significant effect of gamma irradiation on shelf life and quality of indigenous chicken meat. Lui et al. (2010) reported that the trained sensory panel scores showed the freeze meat significantly ($p<0.05$) less tender than the chilled meat. They noted that the sensory result was attributed to the loss of fluid during freezing resulting in less water available to hydrate the muscle fibers as a result, greater quantity of fibers per surface area seemed to be increased the toughness as perceived by the sensory panel. Sohn et al. (2009) revealed that the irradiation caused sensorial changed and affected on the physicochemical, biochemical and nutritional characteristics of irradiated food.

Ramamoorthi et al. (2009) carried out an experiment to evaluate the influence of irradiation dose on colour of co-modified atmosphere packaging packaged beef during storage. They found that the irradiated samples at <1.0 kGy were visually redder and had higher values than higher irradiation doses. Visual green colour of irradiated samples at the higher doses increased during the advancement of storage period. Sommers et al. (2004) showed that the sensory results, particularly aroma and overall acceptability scores indicated the significant advantages in using rosemary and citrus extracts in rancidity-susceptible meat products. Moreover, the use of irradiation in meat is restricted to raw and packaged poultry at 1.5 and 3 kGy respectively while maximum dose for fresh and frozen red meat are 4.5 and 7 kGy, respectively. Ahn and Nam (2004) reported that the redness of ground beef was significantly ($p<0.05$) decreased with increase of irradiation doses and the visible colour of beef changed from a bright red to a green or brown depending on the storage period of meat. They also noted that the addition of ascorbic acid prevented colour changes in irradiated beef and the effect of ascorbic acid was better as the storage period of meat as well as increase of irradiation doses.

Sommers et al. (2004) performed on evaluating of frozen ground beef patties (15% fat) of irradiated (1.35 and 3 kGy) and control and found that irradiation had no significant ($p>0.05$) impact on scoring of sensory attributes either at 1 day or after 6 months of storage period. Heliana et al .(2003) carried out an experiment on mechanically deboned frozen chicken meat (MDCM) with irradiation doses at 0.0, 3.0 and 4.0 kGy and storage temperature was 2±1 °C and kept at 4, 6, 10 and 12 days of interval. They found that the volatile compounds associated with the odour were produced due to expose of gamma rays. Al-Bachir et al. (2009) conducted an experiment with irradiation doses at 0, 1, 2, 3 and 4 kGy and found that the sensory attributes had no significant ($p>0.05$) effect between irradiated and non-irradiated samples for taste and flavour. Giroux et al. (2001) concluded that there was no significant ($p>0.05$) difference in odour and taste between irradiated (4 kGy) and non-irradiated ground beef patties during 7 days of storage at 4°C temperature. Ahn et al. (2000) found that a significant ($p<0.05$) odour was produced when irradiation treatment of pork meat packed under vacuum over 5 kGy doses. The intensity of irradiation odour was reduced during storage period having no negative effect on the acceptance of meat.

Effect of irradiation on instrumental colour values

Rodrigues et al. (2021) reported that the effect of storage time and radiation on sausage colour (L^* Brightness, a^* red-green and b^* yellow-blue) observed statistically did not reveal a significant ($p>0.05$) change in the luminosity (L^*) of the samples over time or among treatments and the application of 1.5, 3.0, or 4.5 kGy doses of gamma ray caused a reduction ($p<0.05$) in the red colour a^* intensity of the wieners. This difference was maintained until the 30th day of storage, the values of a^* among the treatments began to converge. It should be noted that the values of a^* for the irradiated samples differed (were lower) from those of the non-irradiated treatment. As for the parameter b^*, it was observed lower values than the other treatments. He showed that irradiation had a significant effect on reducing the red color (a^*) of the wieners. Nam and Ahn (2002) reported that the addition of citric or ascorbic acid did not affect the a^* values of irradiated meat but increased the L^* values, resulted in lighter overall colour impression to meat. Dimov and Popova (2022) conducted a study on a meta-analysis of the effect of gamma irradiation on chicken meat quality: Microbiology & colour and they showed that gamma rays also significantly diminished L^* ($p=0.013$), but increased a^* and b^* ($p<0.001$).

Arshad et al. (2020) observed that the values of L^*, a^*, and b^* exhibited significant differences with the doses. Higher value for L^* and a^* were observed in the 0 kGy treated frozen duck meat (FDM), whereas higher value for b^* was found in FDM treated with dose of 7 kGy ($p<0.05$). The statistical results showed that minimum values for L^* and a^* were observed in FDM treated with both 3 and 7 kGy, whereas the minimum value for b^* was found in 0 kGy treated FDM. The Hunter colour values decreased slightly as the dosage of the e-beam increased, except for the b^* value. Feng et al. (2017) showed that the L^* and b^* values of turkey breast meat decreased and increased, respectively, in a dose-dependent manner. Ham et al.(2017) speculated that the decrease in redness of irradiated beef patties and pork sausages might be related to the disintegration of the nitrosyl hemochrome. The irradiation produced free radicals, which altered the colour and enhanced the metmyoglobin content. The free radical generation could be more at higher doses. Yim et al.(2019) reported that with an increased aging period, a^* and b^* in irradiated samples at 2°C slightly increased, but irradiation caused negligible changes in meat colour.

Heat treatment of mustard seeds decreased the L^*, a^*, and b^* values of meatball samples ($p<0.01$). The addition of mustard seeds increased b^* value of meatball samples however it decreased a^* value of meatball samples ($p<0.01$). The yellowness values of the samples ranged from 9.73 to 19.31 at the end of the storage (Caglar et al., 2018). The lightness value of meatball samples increased during the storage time. Many studies showed that the increase in L^* during the storage of meatball products is related to metmyogobin (MMb) formation (Lopez et al., 2005). Also, MMb formation can be delayed and the L^* value can be decreased with the inclusion of antioxidants (Lopez et al., 2005). However, the addition of mustard in meatballs increased L^* value. This result can be explained by the mustard seeds colour and production methods of meatball. Colour formation and stability were important sensory properties of meat products and affect the acceptability of products by consumers (Zhang et al., 2007).

The colour values of beef with different irradiation doses and ageing temperature was shown in Hunter L^* and b^* values were in significantly different or inconsistent by irradiation and ageing temperature. Colour a^* values were decreased by irradiation but was not different or inconsistent by ageing temperature. The a^* values decreased by irradiation throughout the storage and the irradiated beef had lower a^* values than non-irradiated sample reported by Yim et al. (2015). According to the (Nam and Ahn, 2003) the degree of ageing was a critical factor on the redness of beef during the storage, but irradiation was the most critical factor on a^* value of irradiated beef. Irradiated beef reduced a^* values during storage (Nanke, 1998; Ahn and Nam, 2004) suggested that color changes of irradiated raw meat were dependent on species, irradiation dose, and packaging type.

Li et al. (2017) who reported that a^* and b^* values of pork increased between day 1 and 8 with ageing period. Especially, a^* values were highest for samples at 2° C after ageing for 8 d, regardless of irradiation. Kim et al. (2012) reported that storage at 4°C tended to decline the L^* of non-irradiated sausages, while a^* and b^* tended to increase. The changes of a^* in the irradiated sausages during ageing could be linked to the demolition of no-myoglobin by irradiation progression. Chouliara et al. (2008) reported a decrease in L^* values in chicken breast meat with storage time in samples containing 0.1 ml/100 g oregano oil.

Oguz et al. (2019) found that the effects of leaf on the colour of the extract when stored at 4°C for 15 days. Colour values of extracts has been quite effect ($p<0.01$) with addition leaf. The highest L^* value (76.50) was observed in the control group, while the lowest L^* value (65.59) was observed in rosemary-treated beef extract. During storage, L^* values decreased and the highest L^* values were observed on the 1st (76.44) and 3rd day (76.07) of storage, while the lowest L^* values were observed on the 15th day (73.97). Although fluctuations in a^* values were observed, the highest a^* value (1.29) was observed in BHA-treated extract, while the lowest a^* values (-2.25) were observed in laurel leaf treated sample groups. The highest a^* value was observed on the 1st day of storage while the lowest a^* value was seen on the 3rd, 7th and 15th days of storage. There were statistically significant differences between b^* values ($p<0.01$). The highest b^* values (14.51) were seen in the samples treated with laurel leaves, while the lowest b^* values (6.42) were observed in the BHA treated samples. There was a slight increase in b^* values during storage.

There was no statistically significant difference between b^* values on day 1st and day 3rd during storage, while the highest b^* value (11.19) was observed on 15 days of storage.

Cheng et al. (2017) observed the colour stability that was assessed by colour measurements changes in L^* and a^* of chilled ground beef kept refrigerated storage at 4° C was presented to compare with the control group, L^* values were higher and a^* values were lower in treated groups. In irradiated samples, L^* values decreased with increasing of the dose rate, while a^* values demonstrated a trend of rise first then fall with increasing of dose rates. The L^* values increased while a^* values showed a gradual decrease throughout 15 days of storage ($p<0.05$). The lightness and redness of 150 kGy/min treated groups had no significant difference with the non-irradiated samples through all storage periods.

The colour of meat is an important factor that directly affects consumers' choice for a product and is usually associated with the quality of meat, being regarded as early warning of meat spoilage (Smoragiewicz et al., 2000). The colour L^*-values were decreased but colour a^*-values were increased by irradiation. Even though a significant decrease or increase in yellowness (b^*-value) was found in all the irradiated turkey breast meat, the overall changes in yellowness were still minor. The most distinctive colour changes in muscle extracts were redness: the colour a^*-value of water-soluble muscle extract changed from positive to negative values by irradiation. Lightness and yellowness were also changed by irradiation: the lightness was gradually decreased while an increase was found in yellowness reported by Feng et al. (2017). Choi et al. (2015) found that the differences in lightness (L^*-value), redness (a^*-value), and yellowness (b^* value) of the heat-induced gel prepared with irradiated chicken salt soluble meat protein were significant ($p<0.05$). The L^*-value and b^* value of all irradiated treatment samples were higher than those of control, and among the irradiated treatments increased with increasing gamma irradiation levels. On the other hand, redness was highest in the unheated and heated control ($p<0.05$).

Xavier et al. (2014) showed that non-irradiated samples presented higher a^* and b^* values than the irradiated ones but there were no significant differences between the two doses 2 kGy and 5 kGy). Visual evaluation also suggested that irradiated samples were less red. Colour pigment behaviour on model systems, changing from oxymyoglobin to metmyoglobin at the surface could explain the lower a^* values on the exterior surface of irradiated beef. Obtained values of a^* and b^* were affected by the temperature of the samples at the moment of the irradiation process, and they were significantly lower in chilled samples than in the frozen ones. For non-irradiated samples, this difference was not significant. Storage time did not affect a^* and b^* values. The L^* was not affected by irradiation dose or temperature, but it did not decrease with storage time, being lower on samples stored for 30 days after irradiation. The same behaviour was observed for the saturation index, decreasing with storage. Irradiation dose did not significantly affect L^*, a^* and b^* values on beef patties ($p>0.05$). Montgomery et al. (2007) reported lower a^* and b^* values and higher L^* values on beef patties irradiated with 2 kGy compared with non-irradiated samples. All colour scores were significantly higher in patties made of trimmings aged for 30 days related to patties made with fresh (1 d) trimmings. Values of L^*, a^* and saturation indexes decreased significantly during the 180 days of storage while b^* values remained unchanged. Kim et al. (2018) worked with pre-rigor meat, showed that 5 kGy of electron beam (EB) and X-ray irradiation had no effect on the overall colour (CIE L^*, a^*, b^*) of beef (*Semi membranosus*) after 14 days of storage at 4°C, although a decrease in L^* and a^* values were detected at day 0 in irradiated samples when compared to non-irradiated samples. Kim et al. (2002) also did not observe a 3 kGy dose (EB) effect on beef (*L. dorsi*) L^* and b^* values after 7-days aging, but irradiated samples had lower a^* values than non-irradiated ones.

Fadhel et al. (2016) reported that the effects of marinating and irradiation on meat colour and showed that for all treatments, an increase of L^* value of meat during storage at 4°C was observed. Nevertheless, the treatment applied, L^* values for all treatments were > 50 (light level). For untreated meat, an increase of L^* value from 50.01 to 55.69 was observed during storage compared to values from 53.06 to 61.63 for marinated meat. This slight increase was explained by a pH decrease and the accumulation of metabolic by-products during postmortem glycolysis and meat ageing (Brewer, 2004). On the other hand, an irradiation treatment increased significantly the L^* value on day 0 which reached 55.87, 51.7 and 57.24 for a respective irradiation doses of 1, 1.5 and 3 kGy. When marinate was combined to irradiation treatment, no significant difference ($p>0.05$) of L^* value was observed between marinated and irradiated samples at almost all irradiation doses during the whole storage (28 days). Results obtained in this study showed that an irradiation treatment at 1 kGy reduced a^* value on day 0 which signify greening of meat. When the irradiation dose was increased a^* value increased for both marinated and non-marinated samples and it was dose-dependent. These results suggest that with a low irradiation dose, green pigments are formed. However, these 18 pigments are not enough stable by increasing the irradiation doses to 1.5 and 3 kGy, the green pigment was lost while the red pigment related to the heme pigment-CO ligand formation were formed and were more stable (Nam and Ahn, 2002). When marinate was applied without irradiation, the redness of meat decreased from 3.71 for untreated meat to 3.09 for marinated meat from day 0. From day 14, a^* values of marinated meat increased more than untreated meat and reached 5.78 on day 28 compared to 4.24 for untreated meat. When the addition of marinate was combined to irradiation treatment, a significant increase of a^* values ($p\leq0.05$) was observed showing at day 28 a respective a^* value of 6.66, 7.36 and 7.01 for marinated and irradiated meat at 1, 1.5 and 3 kGy, respectively compared to 3.99, 4.92 and 5.42 for non-marinated and irradiated meat treated with the same doses. As a consequence, the redness of marinated meat was more important than in non-marinated meat which could be related to the intrinsic colour of the marinated and its interaction with meat during storage. The increase of the redness by irradiation is not always perceived as detrimental, because it makes irradiated meat look fresher. Results of ΔE^* showed that regardless of the treatment used, the ΔE^* value increased during storage and became significant from day 14. When irradiation was applied alone, no significant difference of ΔE^* was observed ($p>0.05$) between untreated meat and almost of all samples treated at both doses during storage (28 days). It has been shown that combining marinating and irradiation increased the ΔE^* values more than in non-marinated and in irradiated samples at the same doses. In fact, for non-marinated samples, ΔE^* observed at day 28 was 5.67, 6.09, 6.33 and 5.67 for irradiated meat at doses of 0, 1, 1.5 and 3 kGy respectively. However, when marinate was applied, ΔE^* increased and reached 9.33, 7.97, 10.22 and 8.48, respectively treated meat at doses of 0, 1, 1.5 and 3 kGy on day 28. This is due especially to a^* values which were higher for marinated than non-marinated samples. Zhou et al.(2011) reported that irradiation treatment can alter meat colour because of the inherent susceptibility of the myoglobin molecule to energy input by irradiation and then can result in the formation of brown, green and bright red colours. Thus, meat colour can be a good indicator to determine the shelf life of meat products.

Millar et al. (2000) carried out a study on the effect of ionizing radiation on the colour of leg and breast of poultry meat. The L^* values of control and irradiated chicken, goose and turkey breast muscles changed a little during storage period of irradiation. The a^* values for un-irradiated goose breast were significantly higher than irradiated goose breast but declined to values similar to irradiated goose breast after 7 days of storage period. The b^* values for irradiated turkey breast were significantly higher than non-irradiated turkey breast at all times of post irradiation treatment. After 7 days of storage period a^* values of poultry breast were higher on the freshly cut surface due to irradiation in all species. The a^* values of leg of all species at 7 days of post irradiation was significantly higher in the irradiated treatment than the controls. The results for the turkey leg indicate that this effect may be mainly due to higher a^* values of the freshly cut surface.

Effect of irradiation on physicochemical attributes

Kim et al. (2012) observed the pH values of samples were ranged between 5.57- 5.68. There was no significant ($p>0.05$) changes, after the irradiation treatment. Irradiation had no effects on the pH of the fermented sausages. Al-Bachir and Othman (2013) reported that the chemical characteristics of chicken sausage as function of irradiation doses of 0, 2, 4 and 6 kGy showed the pH value was 5.57, 5.62, 5.68, and 5.66, respectively.

Pinto et al. (2005) found that the samples of non-irradiated chicken breast wrapped in air had a change in pH from 5.9 to 6.5 and the irradiated samples had pH ranging between 5.9 and 6.8, also informing that irradiation provided no changes in pH values compared with the control samples.

Kim et al. (2013) studied that the exudates amount increased due to freezing and with storage and most quality traits such as drip loss, cooking loss and moisture content were affected by storage condition ($p<0.05$). At freezing condition increased drip loss but decreased moisture content, cooking loss of meat ($p<0.05$). Therefore, removing meat exudates and avoiding freeze can slow down the quality deterioration of pork during cold storage.

Leygonie et al. (2012) observed loss of moisture due to cooking has been reported not to differ between fresh and frozen meat samples, as well as for samples frozen at different rates. During cooking, the melting of the fat and the denaturation of the proteins reported by causes the release of chemically bound water.

Anwar et al. (2012) obtained results that gamma irradiation had no effect on chemical composition and some physical properties of beef patties coated with glutenin protein. The pH values of all irradiated samples were slightly decreased with increasing irradiation doses. Water holding capacity (WHC) of beef patties coated and irradiated at different doses increased by increase doses whereas weight loss decreases by using edible coating and gamma irradiation. During cold storage, WHC and weight loss were increased by increasing the time of cold storage. The WHC was decrease by increasing time of cold storage.

Gamma radiation caused slightly significant effect on the chemical analysis after irradiation. There were no significant changes in pH values but slightly increased the amount of total volatile basic nitrogen (TVN), thiobarbituric acid reactive substances (TBARS) and peroxide value (POV). Fatty acids of irradiated chilled samples were slightly affected compared with control samples; the irradiated samples had higher saturated fatty acid content (C16:0, C18:0) and lower unsaturated fatty acid content (C18:1, C18:2) than the non-irradiated sample observed by Wafaa and Afaf(2016).

Rodrigues et al. (2019) carried out a study on combined effects of gamma irradiation and ageing on tenderness and quality of beef from Nellore cattle where they found that pH values was no significant effect ($p>0.05$) for gamma irradiation doses or during storage period factors (5.60±0.12) and was consistent with the mean values observed for beef. The WHC of meat was affected ($p<0.05$) only by the gamma irradiation doses. Overall, the radiation process reduced the filter paper pressure method (FPPM) from values of 0.30 in the non-irradiated samples to 0.25 in irradiated ones. This might be indicated a negative effect on proteolysis, which would reduce the degradation of cytoskeleton proteins and, consequently, the WHC. The irradiated samples, regardless of the dose applied, presented greater values (27.83%) of cooking loss than non-irradiated ones (25.17%) due to the effects of the free radicals generated by the radiolysis of the water molecule, as discussed for purge (drip loss).

Kanat et al. (2015) carried out an experiment on effect of radiation processing on meat tenderization and they mentioned that several factors influence the amount of drip loss such as pH of the meat, size of meat pieces and temperature of storage. Considerable variation was reported in the WHC of different meat species like chicken, lamb and buffalo. On radiation processing there was a dose dependent reduction in WHC in all the three meat systems. Maximum effect of irradiation on WHC was seen in case of chicken meat where the WHC of irradiated chicken (10 kGy) was more than 50% less compared to non-irradiated control samples. Irradiated (10 kGy) lamb meat had 40%WHC while in non-irradiated samples the WHC was higher (52.5%). In buffalo meat non irradiated samples had a WHC of 54%while in meat irradiated at 5 and 10 kGy it reduced to 45% and 36%, respectively. Cooking yield of chicken samples was higher compared to buffalo and lamb meat. With increasing irradiation dose cooking yield slowly decreased. Non-irradiated chicken meat had a cooking yield of 80.3% which reduced to 68.6% in irradiated (10 kGy) samples. In case of lamb and buffalo meat, irradiation (10 kGy) resulted in 24% and 20% reduction in cooking yield, respectively.

Al-Perkhdri (2022) mentioned no significant differences in the pH values among 3, 5 and 7 kg gamma ray treated camel meat samples and the control samples immediately after irradiation or two weeks after irradiation. Muhammad et al.(2019)also pointed out that the pH of beef fat was higher and that this rise was quite proportional to the increase in the radiation dose used (3-7 kg).

Ham et al. (2017) conducted an experiment on effects of irradiation source and dose level on quality characteristics of processed meat products where they showed the effect of irradiation source (gamma-ray, electron-beam, and X-ray) and dose levels on the physicochemical, organoleptic and microbial properties of cooked beef patties and pork sausages was studied during 10 days of storage at 30±1° C. The processed meat products were irradiated at 0, 2.5, 5, 7.5, and 10 kGy by three different irradiation sources. The cooked pH of beef patties was not significant ($p>0.05$) by both the irradiation source and the dose level whereas a significant interaction between those main effects on the pH value of cooked pork sausages was found. The pH value of cooked pork sausages irradiated with gamma-ray and e-beam decreased with increasing absorbed dose level. The pH difference in pork sausages irradiated within 0 and 10 kGy dose level was less than 0.1 units, which might be numerically slightly affect the quality of meat products.

Rima et al. (2019) carried out an experiment on effect of gamma irradiation on shelf life and quality of broiler meat where they found the range of different treatments of pH and cooking loss score was 6.15 to 5.99 and, 23.46 to 25.30%. The rage value of different days of interval for pH and cooking loss was 6.18 to 5.98 and 23.01 to 25.83%, respectively. The pH value was significantly ($p<0.05$) decreased with increasing irradiation doses and also decreased with storage period. Cooking loss was significantly ($p<0.05$) increased with higher irradiation doses and storage period. Yim et al. (2019) mentioned that an increased ageing time and temperature, cooking loss increased. In particular, the cooking loss of irradiated meat after ageing for 2 and 8 d at 2° C was lower than those aged at 10° C and 25° C ($p<0.05$). The cooking loss showed no differences among the irradiated and non-irradiated samples after ageing for 4 d.

Haque et al. (2017) mentioned that irradiation in beef raw pH was dose-dependent and decreased. The ultimate pH was also decreased throughout the storage period due to increased free fatty acids because of rancidity. Cooking loss in beef increased significantly ($p<0.05$) with irradiation doses. This was because of low pH in irradiated beef caused low WHC resulted in the high cooking loss in beef. Cooking losses also increased significantly with storage time.

Effect of irradiation on proximate components

Al-Bachir and Othman (2013) observed that the chemical characteristics of chicken sausage as function of irradiation doses. It can be seen that the proximate chemical contents were: crude fat (5.82%), crude protein (18.68%), ash (1.94%) and moisture (72.67%). The water activity value for chicken sausage was 0.92 at 24°C and the pH value was (5.57±0.05). Considering the nature of ingredients, chicken sausage is rich with nutritional constituents. In general, increase trend was observed in protein content with the higher irradiation doses. There was no significant ($p>0.05$) difference between the protein contents of the non-irradiated and irradiated samples.

The mean meatball characteristics were: moisture 58.31, protein 19.65, fat 18.24 and ash 2.71%, respectively. No significant ($p>0.05$) changes in the moisture, protein, fat and ash values of the meatballs were observed due to the irradiation process. Generally, the protein and lipid components are known to be declined when exposed to higher irradiation doses observed by Gecgel (2013). No significant differences in chemical compositions (moisture, crude protein, crude fat and ash) of various meat and meat products such as buffalo meat, lamb meat, camel meat, rabbit meat and raw meatballs were observed when processed with different doses of gamma irradiation (Badr, 2004; Rady et al., 2005; Yildirim et al., 2005; Kanatt et al., 2006; Al-Bachir and Zeinou, 2009).

Al-Perkhdri (2022) conducted an experiment on gamma rays impacts in qualitative traits of camel meat in different area – Iraq and found that humidity (75.41), crude protein (24.15) and crude fat (3.94) and the results also showed no effect of the radiation doses used in the synthesis of camel meat. Kadim and Purchas (2019) carried out a study on the effect of gamma rays on the composition of camel meat and found no significant differences in chemical composition like moisture, crude protein and crude fat and ash at buffalo meat treated with radiation doses of 2.5, 5 and 7.5 kGy of gamma radiation.

Anwar et al. (2012) observed that edible film glutenin protein contain nisin and non-irradiated keeping quality of beef patties and extend shelf life of beef patties to 18 days whereas edible coating contain nisin and irradiated at doses 3 and 5 kGy of beef patties keeping quality and extend shelf life of beef patties to 30 and 39 days, respectively. Arshad et al. (2020) worked on frozen duck meat and revealed that the percentages of crude fat, ash and crude protein as well as moisture were estimated as 6.01, 0.97, 19.43 and 73.58 %, respectively. Qiao et al. (2017) demonstrated that the moisture and fat content in duck meat was 73.29 % and 5.92 %, respectively. The protein and ash content were also similar to those reported by Michalczuk et al. (2016).

Gecgel (2013) conducted an experiment of meatball samples with different doses. The physicochemical results showed no significant differences in moisture, protein, fat and ash content of meatballs with irradiation doses. No gamma-ray effect recorded when used in doses up to 4.5 kg in the chemical composition and ingredients of cooked meat (Lavrova et al., 1975).

Rodrigues et al. (2019) showed that irradiation process did not affect ($p>0.05$) the solubility of meat proteins whereas Kanatt et al. (2015) observed the irradiation process significantly affect ($p<0.05$) the solubility of meat proteins. These authors observed an increase for total myofibrillar extractable protein from buffalo meat irradiated with 2.5 to 10 kGy. Lee et al. (2000) reported that myosin sub units were structurally modified, increasing its solubility when higher doses of irradiation were used. As per these authors, irradiation could affect the solubility of proteins through the formation of free radicals, generated due to the radiolysis of the water molecule, catalyzing reactions like deamination, decarboxylation, reduction of disulfide bonds, oxidation of sulfhydryl groups, hydrolysis of peptide bonds, and changes in the valence of the metal ions of enzymes. The changes in the proteins did not depend only on their structure and state, but also on the conditions of the radiation process, like dose and rate applied, temperature, and absence or presence of oxygen.

Conclusions

Based on the above reviews it is observed that there is a lack of comprehensive study on the effect of irradiation with BHA and Black cumin extract on the quality of beef at ambient temperature with different days of interval. More importantly, effect of irradiation with BHA and Black cumin extract on colour, flavour, juiciness, tenderness, overall acceptability, L^*, a^*, b^*, pH, DL, CL, ERV, WHC, DM, CP, EE are compiled as reported by different scientists and researchers. From the above reviews of literature, it is concluded that there is lack of research findings on the effect of irradiation on beef at different temperature in relation to the foregoing variables. So, this piece of research work was undertaken to fulfill the extant literature.

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