Effect of Gamma-ray, Electron-beam, and X-ray Irradiation on Physicochemical and Microbial Properties of Pork Loin

Youn-Kyung Ham[1], Ko-Eun Hwang[1], Hyun-Wook Kim[2], Yoo-Sun Park[1], Dong-Hyun Kim[1], and Cheon-Jei Kim[1,*]

[1]Department of Food Science and Biotechnology of Animal Resources, Konkuk University, Seoul 143-701, Republic of Korea

[2]Meat Science and Muscle Biology Laboratory, Purdue University, West Lafayette, IN 47907, USA

[*]Corresponding author email: kimcj@konkuk.ac.kr

Abstract – The objective of this study was to evaluate the effects of irradiation sources and dose levels on physicochemical (pH, color, shear force, and TBARS values) and microbial properties of fresh pork loins. Pork loins were irradiated with gamma-ray, electron-beam, and X-ray at doses of 0 (Control), 2, 4, 6, 8, and 10 kGy, respectively. There was no significant tendency in pH values of irradiated pork loins according to irradiation sources or doses. The lightness of irradiated treatments was higher than non-irradiated control (*p*<0.05). The redness and yellowness of pork loins increased significantly as irradiation dose level increased up to 10 kGy (*p*<0.05). The shear force of samples was unaffected by irradiation (*p*>0.05). TBARS values of pork loins were increased significantly by e-beam irradiation above 6 kGy (*p*<0.05). These results indicates that X-ray irradiation may result in similar changes on the physicochemical and microbial properties of pork loin in comparison with gamma-ray and e-beam irradiation.

Key Words – irradiation, gamma-ray, e-beam, X-ray, pork loin.

I. INTRODUCTION

Fresh meat has been consumed as an important dietary source of protein and other nutrients, essential fatty acids, vitamins, and minerals that are not synthesized in our body system [1]. However, meat is perishable and susceptible to contamination of pathogens which could be a great threat to public health by causing foodborne illnesses. Therefore, officials and industry have been making efforts on improving shelf stability and controlling the pathogenic microorganisms to ensure the safety of meat.

Irradiation has been developed as a method to enhance microbial safety and extend shelf-life of meat and meat products [2]. After a wholesomeness of irradiation demonstrated by the Joint FAO/IAEA/WHO Expert Committee on Food Irradiation (JECFI) in 1981, it has been utilized for reduction of spoilage microorganisms and pathogens in meat processing industry [3].

Ionizing radiations permitted for food treatment are gamma-ray, electron-beam (e-beam), and X-ray. Although gamma-ray has excellent penetrating power so that capable of reducing foodborne generating microorganisms effectively [4], consumer would accept e-beam or X-ray more favorably because of the concern about radioactive sources (Cs^{137}or Co^{60}) of gamma-ray [5]. However, electron beam irradiation has limitation on penetration depth only up to 3.9 cm in water-equivalent food when one-side irradiated [6]. On the other hand, high energy X-ray is suitable for irradiation of thick materials due to its higher penetration power as much as gamma ray [7]. Nevertheless, there have been little to no comparative studies of all three ionizing sources in meat and meat product.

Therefore, the objective of this study was to evaluate effects of X-ray irradiation on the physicochemical and microbial properties of pork loin in comparison with gamma-ray and e-beam.

II. MATERIALS AND METHODS

2.1. Preparation of pork loin samples

Fresh pork loins (*longissimus dorsi*) were purchased from a local butcher shop at 48 hour post-mortem. After excessive subcutaneous fat and connective tissue were removed, pork loins were cut into approximately 2.5 cm thickness and vacuum packaged in nylon/PE pouch individually.

2.2. Irradiation procedure

Vacuum-packaged pork loins were irradiated at 0 (control), 2, 4, 6, 8, and 10 kGy by gamma ray, e-beam, and X-ray at room temperature. Gamma ray irradiation was conducted using ^{60}Co irradiator (point source AECL, IR-79, MDS Nordion International Co. Ltd., Canada) in the Advanced Radiation Technology Institute, Korea Atomic Energy Research Institute (Jeoung-Eup, Korea). E-beam and X-ray irradiation were performed using a LINAC Electron-Accelerator (10 MeV) and an X-ray linear accelerator (7.5 MeV) at the EB-tech Co. (Daejeon, Korea), respectively.

2.3. pH and color measurement

Five grams of pork loin were homogenized with 20 mL distilled water for 60 s using a homogenizer (Ultra-Turrax T25, Janke and Kunkel, Staufen, Germany). The pH of samples was determined with a pH meter (Model 340, Mettler-Toledo GmbH, Schwerzenbach, Switzerland). The color (CIE L*-, a*-, and b*-values) of irradiated pork loins was measured using colorimeter (Chroma meter, CR210, Minolta, Japan) calibrated with a standard plate (L*-value = +97.83; a*-value = -0.43; and b*-value = +1.98).

2.4. Warner-Bratzler Shear force

For the Warner-Bratzler shear force (WBSF) measurement, pork loins were cooked until the core temperature reached 75°C and cut into 1 cm diameter × 3 cm height parallel to the muscle fibers. The WBSF (kg) was measured usinga texture analyzer (TA-XT2i, Stable Micro Systems Ltd., Surrey, England) and cross head speed was 5 mm/sec.

2.5. Lipid oxidation

Lipid oxidation of irradiated pork loins was determined by measuring the TBARS according to the method described by Tarladgis *et al*. [8]. The absorbance of samples was measured at 538 nm against blank (5 mL distilled water mixed with 5 mL TBA reagent) using a UV/VIS spectro-photometer. TBARS values were expressed as mg malondialdehyde (MDA)/kg samples.

2.6. Total plate counts

For microbial analysis, total aerobic bacteria counts were determined by plating the diluted samples on to plate count agar. All plates were incubated at 37°C for 48 h.

2.7. Statistical analysis

The statistical analysis was conducted using PASW statistic 18 program (SPSS Inc., Chicago, IL, USA). An analysis of variance (ANOVA) was performed on the data and differences between treatment means were analyzed by Duncan's multiple range test with a significance level of 5% (p<0.05).

III. RESULTS AND DISCUSSION

The pH values of pork loins irradiated with gamma-ray, e-beam, and X-ray were not significantly different from those of non-irradiated control sample (p>0.05), except X-ray 10 kGy treatment (Table 1). As comparing pork loins irradiated at 10 kGy, X-ray irradiated samples showed higher pH values than the other treatments. However, there was no evident tendency in pH values depending on the irradiation sources within 10 kGy irradiation dose.

Table 1. Effects of ionizing source and irradiation dose on pH value of vacuum-packaged pork loin

Ionizing sources	Irradiation dose (kGy)					
	0	2	4	6	8	10
γ-ray	5.49±0.02^{ab}	5.44±0.03^{Bab}	5.40±0.06^{b}	5.52±0.05^{Aa}	5.54±0.02^{Aa}	5.50±0.20^{ABab}
e-beam	5.49±0.02^{abc}	5.53±0.12^{Aa}	5.42±0.09^{bc}	5.51±0.07^{Aab}	5.44±0.03^{Cabc}	5.40±0.02^{Bc}
X-ray	5.49±0.02^{b}	5.42±0.07^{Bb}	5.42±0.12^{b}	5.41±0.02^{Bb}	5.50±0.04^{Bb}	5.63±0.16^{Aa}

All values are the means±SD (n=10).
^{A,B}Mean values within a column follow by the different letter are significantly different (p<0.05).
$^{a-c}$Mean values within a row follow by the different letter are significantly different (p<0.05).

The instrumental color (CIE L*-, a*-, and b*-values) of the pork loins are shown in Table 2. Ionizing radiation increased lightness of pork loins compared to control regardless of ionizing sources (p<0.05). E-beam irradiation increased the lightness of samples in dose-dependent manner (p<0.05), whereas gamma- and X-ray did not result in evident tendency in the lightness of samples. As comparing samples with same absorbed dose of 4 kGy or more, gamma-ray irradiated treatments had the lowest lightness among the pork loins (p<0.05) except 10 kGy treatments. Similarly, the redness of pork loins increased dose dependently (p<0.05) by all irradiation sources. However, coherent changes on redness by ionizing sources did not observed in this study. Kwon *et al*. [9] reported that carbon monoxide was increased significantly after the irradiation and it may cause pink color in pork by binding to heme pigments. The yellowness of pork loins were increased as absorbed dose increased up to 10 kGy (p<0.05). When pork loins irradiated at same dose, gamma-ray irradiated treatments had lower yellowness compared to the other treatments.

Table 2. Effects of ionizing source and irradiation dose on color parameters of vacuum-packaged pork loin

Ionizing sources	Irradiation dose (kGy)					
	0	2	4	6	8	10
CIE L (lightness)*						
γ-ray	51.47± 1.01^{b}	54.70± 0.92^{Ba}	54.63± 1.01^{Ca}	54.35± 0.95^{Ca}	55.12± 1.08^{Ba}	54.50± 1.04^{Ba}
e-beam	51.47± 1.01^{d}	54.67± 0.95^{Bc}	55.64± 0.87^{Bb}	55.56± 0.97^{Bb}	58.19± 0.74^{Aa}	58.21± 0.83^{Aa}
X-ray	51.47± 1.01^{e}	57.34± 0.85^{Ac}	58.13± 0.94^{Abc}	59.86± 0.99^{Aa}	58.74± 1.02^{Ab}	54.82± 0.86^{Bd}
CIE a (redness)*						
γ-ray	6.70± 0.67^{d}	8.49± 0.63^{Bc}	9.76± 0.82^{Ab}	9.86± 0.49^{Bb}	11.67± 0.97^{Aa}	11.81± 0.87^{Ba}
e-beam	6.70± 0.67^{c}	9.29± 0.74^{Ab}	9.43± 0.79^{Ab}	10.60± 1.01^{Aa}	11.26± 1.00^{Aa}	11.05± 0.86^{Ca}
X-ray	6.70± 0.67^{d}	8.21± 0.69^{Bc}	8.26± 0.63^{Bc}	9.73± 0.96^{Bb}	9.86± 0.80^{Bb}	12.65± 0.76^{Aa}
CIE b (yellowness)*						
γ-ray	2.56± 0.67^{c}	3.65± 0.52^{Bb}	4.06± 0.88^{Bb}	4.10± 0.60^{Bb}	4.72± 0.61^{Ba}	4.77± 0.60^{Ba}
e-beam	2.56± 0.67^{c}	4.95± 0.64^{Ab}	4.47± 0.76^{ABb}	4.60± 0.87^{Bb}	5.82± 0.54^{Aa}	6.04± 0.95^{Aa}
X-ray	2.56± 0.67^{c}	4.86± 0.71^{Aab}	4.74± 0.81^{Ab}	5.20± 0.68^{Aab}	5.31± 0.86^{Aab}	5.47± 0.73^{Aa}

All values are the means±SD (n=20).
$^{A-C}$Mean values within a column follow by the different letter are significantly different (p<0.05).
$^{a-e}$Mean values within a row follow by the different letter are significantly different (p<0.05).

Table 3. Effects of ionizing source and irradiation dose on shear force (kg) of vacuum-packaged pork loin

Ionizing sources	Irradiation dose (kGy)					
	0	2	4	6	8	10
γ-ray	5.12± 0.60	4.81± 0.62	5.10± 0.79	4.87± 0.83	5.02± 0.85	4.82± 0.71
e-beam	5.12± 0.60	5.34± 0.95	5.28± 0.68	5.29± 0.83	5.31± 0.81	5.36± 0.90
X-ray	5.12± 0.60	5.09± 0.51	5.14± 0.80	4.95± 0.81	5.04± 0.83	5.19± 0.75

All values are the means±SD (n=18).

Ionizing sources nor irradiation doses within 10 kGy did not influenced significantly the shear force (p>0.05) of pork loins (Table 3).

Lipid oxidation of irradiated pork loins were determined by measuring TBARS values (Table 4). Pork loins irradiated by e-beam above 6 kGy had significantly higher TBARS values (*p<0.05*) followed by gamma-ray and X-ray irradiated ones. However, there was no consistent tendency in changes of TBARS values depending on the irradiation doses (*p<0.05*). Previous studies have been shown that hydroxyl radicals generated by irradiation may accelerate lipid oxidation of meat and meat products [4, 10].

Table 4. Effects of ionizing source and irradiation dose on 2-thiobarbituric acid reactive substances (TBARS) value (mg MDA/kg sample) of vacuum-packaged pork loin

Ionizing sources	Irradiation dose (kGy)					
	0	2	4	6	8	10
γ-ray	0.10± 0.03^{c}	0.12± 0.03^{ABbc}	0.11± 0.02^{ABbc}	0.14± 0.02^{ab}	0.16± 0.03^{Ba}	0.14± 0.01^{Bab}
e-beam	0.10± 0.03^{d}	0.15± 0.02^{Abc}	0.10± 0.06^{Bd}	0.11± 0.03^{cd}	0.20± 0.03^{Aa}	0.18± 0.04^{Aab}
X-ray	0.10± 0.03^{b}	0.14± 0.02^{Ba}	0.14± 0.02^{Aa}	0.13± 0.02^{a}	0.12± 0.01^{Cab}	0.13± 0.04^{Ba}

All values are the means±SD (n=8).
$^{A-C}$Mean values within a column follow by the different letter are significantly different (p<0.05).
$^{a-d}$Mean values within a row follow by the different letter are significantly different (p<0.05).

Total aerobic bacteria counts of irradiated pork loins are shown in Table 5. Microbial populations of pork loins were significantly reduced by irradiation compared to control (p<0.05). Although total aerobic bacteria was not eliminated in X-ray 4 kGy irradiated pork loins, treatments with gamma-ray and e-beam above 4 kGy and X-ray above 6 kGy irradiation showed total aerobic bacteria counts under detectable limit (<1.0 Log CFU g^{-1}).

Table 5. Effects of ionizing source and irradiation dose on total aerobic bacteria (Log $CFUg^{-1}$) of vacuum-packaged pork loin

Ionizing sources	Irradiation dose (kGy)					
	0	2	4	6	8	10
γ-ray	2.83± 0.84	2.15± 0.13	ND[1)]	ND	ND	ND
e-beam	2.83± 0.84[a]	1.83± 0.50[b]	ND	ND	ND	ND
X-ray	2.83± 0.84[a]	1.80± 0.48[b]	1.32± 0.22[b]	ND	ND	ND

All values are the means±SD (n=9).
[1)]ND: not detected (<1.0 Log $CFUg^{-1}$).
[a-b]Mean values within a row follow by the different letter are significantly different (p<0.05).

IV. CONCLUSION

Gamma-ray, e-beam, and X-ray irradiated pork loins showed increased redness in dose-dependent manner, without coherent tendency according to ionizing sources. Lipid oxidation of pork loins was considerably increased with e-beam irradiation above 6 kGy and other ionizing sources also caused higher lipid oxidation than non-irradiated control. As comparing with gamma-ray and e-beam, X-ray irradiation at 6 kGy or higher dose resulted in similar reduction effect on total aerobic bacteria of pork loins. From these results, X-ray irradiation is expected to have equivalent effect on physicochemical and microbial properties of pork loin as compared to gamma-ray and e-beam and further researches on the effects of X-ray in comparison with other ionizing sources will be needed for potential use of X-ray in meat industry.

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