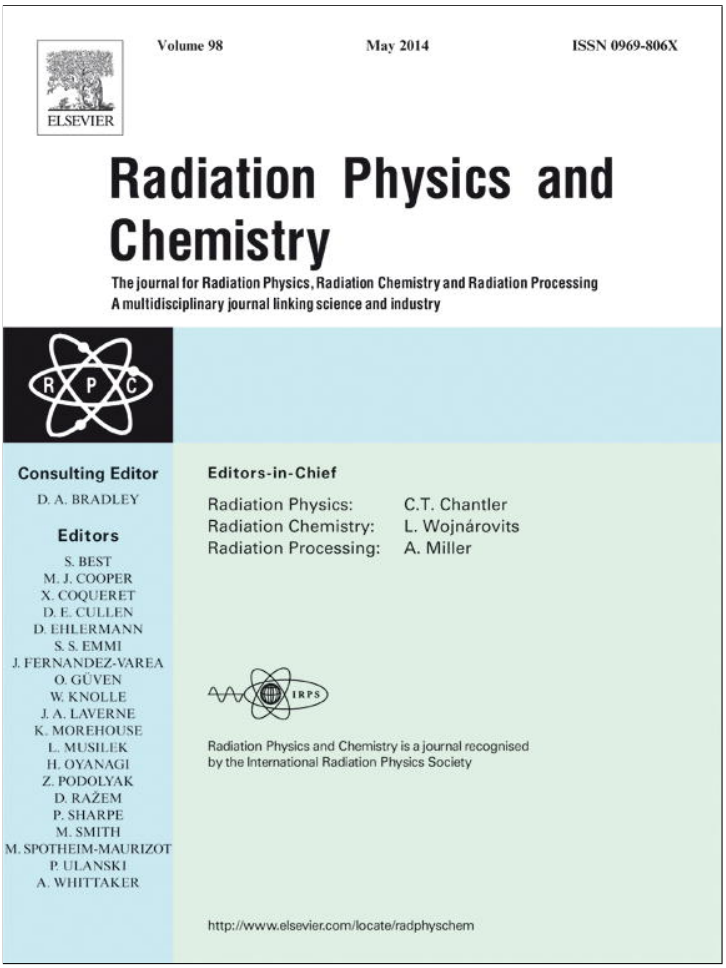

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Improvement of microbiological safety and sensorial quality of pork jerky by electron beam irradiation and by addition of onion peel extract and barbecue flavor

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HIGHLIGHTS

- Electron-beam (EB) was applied to pork jerky to improve safety.
- Onion peel extract (OP) was used synergistic effect on microbial reduction.
- Barbecue flavor (BF) was introduced to achieve consistency of flavor.
- EB with OP and BF improved safety without negative effects on quality of pork jerky.

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ABSTRACT

The combined effects of electron-beam (EB) irradiation and addition of onion peel (OP) extract and barbecue flavor (BF) on inactivation of foodborne pathogens and the quality of pork jerky was investigated. Prepared pork jerky samples were irradiated (0, 1, 2, and 4 kGy) and stored for 2 month at 25 °C. The D_{10} values of *Listeria monocytogenes*, *Escherichia coli*, and *Salmonella typhimurium* observed in the OP treated samples were 0.19, 0.18, and 0.19 kGy, whereas those in control were 0.25, 0.23, and 0.20 kGy, respectively. Irradiated samples with OP extract and BF had substantially lower total aerobic bacterial counts than the control had. Samples with added OP extract and BF had lower peroxide values than the control had. Sensory evaluation indicated that overall acceptability of treated samples was not changed up to 2 kGy. Therefore, EB irradiation, combined with OP extract and BF, has improved the microbiological safety with no negative effects on the quality of pork jerky.

1. Introduction

In recent years, consumer demand for microbiologically safe, stable, high quality meat products has increased. Therefore, researchers and the meat product industry have combined efforts to develop new technologies that can be used to maintain the safety, as well as improve the quality, of meat products (Artes et al., 2007).

Jerky is a popular meat product item in the world due to its stability and nutritional value (Allen et al., 2007). However, several outbreaks of foodborne disease have been attributed to consumption of both home-dried and commercial jerky due to contamination with *Staphylococcus aureus* and *Escherichia coli* O157:H7 (Nummer et al., 2004; Eidson et al., 2000). In addition, beef jerky recalls have been issued due to contamination with *Salmonella* spp. and *Listeria monocytogenes* (Porto-Fett et al., 2009).

Ionizing radiation is a well-known technology that improves microbiological safety and extends the shelf life of meat products (Mohamed et al., 2011). There are two common types of ionizing radiation: gamma ray and electron-beam (EB). EB irradiation is used to inactivate foodborne pathogens during storage and to guarantee the hygienic quality of foods (Sarrias et al., 2003). EB-irradiation use has advantages in industry due to the short processing time, low temperature rise, and consumer-friendliness, as it does not use radioisotopes (Hong et al., 2008). However, some problems in quality degradation exist in irradiated meat products.

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According to previous studies, irradiation generates free radicals that trigger quality problems in meat, including color changes, lipid oxidation development, and off-odor generation, and consumer may respond negatively to these quality aspects (Nam et al., 2006). Lipid oxidation of meat products is the most important factor for the decline in quality (Smith et al., 1960). To prevent oxidation, the use of antioxidants has been considered and, in some cases, applied to products (Kanatt et al., 1998). Natural antioxidants have been used to scavenge free radicals and to inhibit lipid oxidation due to their safety and wholesome quality (Murphy et al., 1998). Furthermore, the addition of certain flavors to food products may enhance their safety and maintain proper sensory quality following irradiation treatment (Kim et al., 2007). Kim et al. (2012) have reported that barbecue flavor (BF) has some antibacterial effects, as well as off-flavor masking effects, in jerky products irradiated for safety.

Onion (*Allium cepa*) is a versatile vegetable that is consumed fresh, as well as in the processed form. Onion is a major source of various biologically active phytomolecules (e.g., phenolic acids, flavonoids, cepaenes, thiosulfinates, and anthocyanins) (Singh et al., 2009). Onion peel (OP) contains over 20 times more flavonoids – especially quercetin – than the onion flesh. Although onion peels have high levels of flavonoids, they are usually discarded before onions are processed for human consumption (Park et al., 2007).

Our previous study (Kim et al., 2013) indicated that a combined treatment of EB irradiation and leek extract addition could eliminate all microorganisms present in pork jerky. However, improvement in sensory quality of the pork jerky was needed. Thus, the objective of the present study was to develop a treatment of pork jerky that resulted in a microbial safe product with proper sensory quality using EB irradiation and the addition of OP extract and BF.

2. Materials and methods

2.1. Sample preparation

Pork loins and OP were purchased from a local market in Daejeon, Korea. BF was purchased from Saerom B&F (Cheonan, Korea). BF was selected because of the consistency in flavor following irradiation (Kim et al., 2012).

OP was washed with tap water. OP extract was obtained by treating OP with 70% ethyl alcohol at room temperature for 72 h, followed by evaporation of the solvent. The extract was then lyophilized (TFD5505, Ilshin Lab Co. Ltd., Korea) to obtain a powder. Ethyl alcohol extracts have been shown to possess maximum antimicrobial activity, and the corresponding extraction procedure is the most effective amongst the different preparation methods for obtaining OP extract (Yun et al., 2011).

Pork loins were trimmed of all visible fat, and subsequently sliced to 0.7 cm thick pieces using a meat slicer (HFS 350G, Hankook Fugee Industries Co. Ltd., Seoul, Korea). The slices of pork were marinated at 4 °C for 12 h in a jerky curing solution (w/w) with the following composition: water (10%), soy sauce (10%), starch syrup (7%), sugar (5%), D-sorbitol (6%), ginger powder (0.1%), garlic powder (0.2%), onion powder (0.2%), potassium sorbate (0.1%), pepper (0.3%), OP extract (0.5%), and BF (0.5%).

Cured meat was sequentially dried using a convection oven (JSOF-150; JS Research Inc., Gongju, Korea) at 75, 65, and 55 °C for 150, 90, and 60 min, respectively. After cooling, the jerky samples were packaged under vacuum conditions.

After making pork jerky, the samples were cut into pieces of approximately 2 × 2 cm in size. The water activity (a_w) of each sample was then determined in triplicate using LabMASTER-a_w system (Nocasina AG, Lachen, Switzerland).

2.2. Inoculation test

2.2.1. Sterilization, inoculation of pathogens

For the inoculation test, samples were randomly selected and sterilized using EB irradiation (35 kGy at 2.5 MeV) with a linear electron beam RF accelerator (EB tech, Daejeon, Korea). *E. coli* (KCTC 1682), *L. monocytogenes* (KCTC 3569), and *Salmonella typhimurium* (KCTC 1925) were obtained from the Korean Collection for Type Culture (KCTC, Daejeon, Korea). *E. coli* and *L. monocytogenes* were cultivated in tryptic soy broth (Difco Laboratories, Detroit, MI, USA), and *S. typhimurium* was cultivated in nutrient broth (Difco Laboratories) at 37 °C for 48 h. The cultures were then centrifuged (3,000 × *g* for 10 min at 4 °C). The resulting pellet was washed twice with sterile saline solution (0.85%) and suspended in the same saline solution. The viable cell density was approximately 10^8 CFU/mL. The cut jerky samples (5 g, approximately 3.5 × 3.5 cm) were inoculated with 100 μL of this solution. Each sample was then resealed and shaken for homogenization.

2.2.2. EB irradiation

Each prepared sample was irradiated on both sides in a linear EB RF accelerator (Energy 2.5 MeV, beam power 40 kW, EB Tech., Daejeon, Korea). The beam current was 0–4.5 mA. Irradiation was performed with a conveyor velocity of 10 m/min and a dose rate of 1.1–4.4 kGy/s. Because the incident EB had a low penetration power, all the samples were sliced to a 0.7 cm thickness to enhance the effectiveness of irradiation. To confirm the target dose, alanine dosimeters, attached to the top and bottom surfaces of the sample packs, were read using a 104 Electron Paramagnetic Resonance unit (EMS-104; Bruker Instruments Inc., Bullerica, MA). The calculated maximum/minimum dose ratio was less than 1.004 for all samples. The doses employed in this study were 0, 0.5, 1, 1.5, 2, and 3 kGy. The experiment was replicated 4 times and 3 observations were made during each experiment. After irradiation, the samples were immediately stored under commercial storage conditions at 25 °C, until further analysis.

2.2.3. Microbial analysis

After irradiation, each sample (5 g) was cut into small pieces (approximately 0.5 × 0.5 cm) and homogenized for 2 min in a sterile Stomacher bag containing 45 mL of sterile saline solution using the Stomacher BagMixer® 400 (Interscience Co., St Nom, France). Then samples were serially diluted in sterile saline (0.85%) solution, and each diluent (0.1 mL) was spread on each bacterial media. Tryptic soy agar (Difco Laboratories) was used for *E. coli* and *L. monocytogenes*, and nutrient agar (Difco Laboratories) was used for *S. typhimurium*. Plates were incubated at 37 °C for 48 h, and microbial counts were expressed as colony forming units per gram (CFU/g). Radiation sensitivity of the pathogens was calculated as D_{10}, a value that represents the dose required to inactivate 90% of the microbial population.

2.3. Storage stability

2.3.1. EB irradiation

Each prepared sample (non-sterilized) was irradiated using the same conditions previously described above. The applied doses were 0, 1, 2, and 4 kGy. After irradiation the samples were immediately stored under commercial storage conditions at 25 °C during 2 months.

2.3.2. Microbial analysis

The sample (5 g) was aseptically homogenized for 2 min in a sterile Stomacher bag containing 45 mL of sterile saline solution using the Stomacher BagMixer® 400. Subsequently, the homogenized samples were serially diluted in sterile saline and plated by spreading 0.1 mL on a total plate count agar (Difco Laboratories) and eosin methylene blue agar (EMB; Difco) for total aerobic bacteria (TAB) counts and total coliform counts, respectively. Plates were then incubated at 37 °C for 48 h. For enumerating mold count, molds were plated onto YM agar (containing 10% citric acid, pH 3.6, Difco Laboratories), and the plates were incubated for 5 days at 25 °C. The number of colonies was counted and expressed as colony forming units per gram (CFU/g).

2.3.3. Physical characteristics

The color of the pork jerky sample surface was evaluated using a Color Difference Meter (Spectrophotometer CM-3500d, Konica Minolta Sensing, Inc., Osaka, Japan), and Hunter color values, $L*$ (lightness), $a*$ (redness), and $b*$ (yellowness) were determined. The instrument was calibrated to standard black and white plates before analysis. The Hunter values were monitored by a computerized system using spectra magic software (Konica Minolta Sensing, Inc., Japan). Measurements were performed in triplicate.

Shear force (kg) was determined using a Texture Analyzer (Model TA-XT 2i, Stable Micro system Ltd., Surrey, UK) with a Warner–Bratzler-blade attachment. Cross-sections (across to the fibers) as close as possible to $25 \times 230 \times 350$ mm were cut from each jerky treatment and samples were measured for shear force. The cross-sections of samples were placed at middle to the blade. Crosshead speed was 200 mm/min and full-scale load was 50 kg.

2.3.4. Peroxide value (POV)

Lipid extraction was performed according to Folch et al. (1957) extraction method. Each sample (10 g) was cut into small pieces (0.5×0.5 cm) and placed in a glass vial containing 50 mL of Folch solution (chloroform:methanol, 2:1). The pork jerky samples were stirred at room temperature for 24 h. Subsequently, the mixture was filtered using filter paper (Whatman No. 4, Whatman Ltd., Maidstone, England) and 15 mL NaCl (0.88%) was added. After vigorous shaking, a 10 mL sample was collected from the bottom layer and evaporated under a stream of nitrogen gas, leaving the extracted lipids for POV analysis. The lipid sample was treated with 35 mL of a solvent mixture (acetic acid:chloroform, 3:2) and shaken thoroughly, then 0.5 mL of saturated potassium iodide solution was added. The mixture was kept in the dark for 5 min; 75 mL of distilled water was added followed by vigorous mixing. Soluble starch solution in phosphate buffer (2.5 mL, 1% [w/v]) was used as an indicator. The peroxide value was determined by titrating the iodine liberated from potassium iodide using standardized 0.005 N sodium thiosulfate solutions. The POV was calculated by the following equation.

$$\mathrm{POV(meq/kg)} = \frac{(V_1 - V_0) \times F \times 0.01}{S} \times 1000$$

V_1: titration amount (mL) of 0.005 N $Na_2S_2O_3$ on the samples, V_0: titration amount (mL) of 0.005 N $Na_2S_2O_3$ on the blank, F: factor of 0.005 N $Na_2S_2O_3$ solution, S: sample weight (g).

2.3.5. Sensory evaluation

Sensory evaluation was performed by 10 panelists who had previous experience analyzing irradiation off-odor and pork jerky quality, while carrying out different studies related to food irradiation. Samples were assessed for their color, flavor, texture, juiciness, overall acceptability, and irradiation off-odor. A 7-point hedonic scale, where 7 indicates “extremely like” and 1 indicates “extremely dislike,” was employed for evaluating all the qualities, except off-odor. Off-odor was assessed as follows: 7, very strong; and 1, no off-odor. The samples were placed on transparent plastic dishes and labeled randomly with a 3-digit numerical code. All samples were provided to each of the panelists along with drinking water for rinsing their oral cavity following testing of each sample. This procedure of sensory evaluation was conducted in three independent experiments.

2.4. Statistical analyses

The experiment was conducted as three independent trials with three observations for each treatment combination in each trial. Data were analyzed using SAS software (Release 8.01, SAS Institute, Inc., Cary, NC, USA). Statistical analysis was performed by one-way analysis of variance (ANOVA). When significant differences were detected, the differences among the mean values were determined by the Duncan′s multiple comparison test at a confidence level of $p < 0.05$. Mean values and standard errors of the mean are reported.

3. Results and discussion

3.1. Water activity

When manufacturing intermediate moisture foods, such as jerky, it is necessary to control the a_w (Leistner, 1987). The a_w ranged from 0.761 to 0.770, but no significant difference in a_w was observed between the control and the samples treated with OP extract and BF (Table 1). However, the a_w of control samples decreased slightly due to irradiation. These results were similar to those previously reported by Kim et al. (2013). Yang and Lee (2002) reported that the a_w of commercial pork jerky available in Korea market was 0.743. Foods such as jerky must have a stable a_w to avoid changes in quality during storage (Yamaguchi et al., 1986).

3.2. Inoculation test

L. monocytogenes was initially loaded at 8.02 and 7.88 log CFU/g in control and sample with added OP extract and BF (Table 2). Irradiation of 1.5 kGy resulted in a ~6 decimal reduction in the number of *L. monocytogenes*. In addition, the jerky with OP extract and BF had a significantly lower *L. monocytogenes* population at each irradiation dose compared to control. Bacterial populations in the control and samples containing OP extract and BF were below the detection limit (10^1 CFU/g) following irradiation at 2 and 1.5 kGy, respectively.

The combination treatment of EB irradiation with OP extract and BF reduced the numbers of *E. coli* (Table 3). Irradiation of 2 and 1.5 kGy reduced the population of *E. coli* to an undetected level in control and treated samples, respectively. This result confirmed that OP extract and BF has a synergistic effect on the inhibition of survival of *E. coli* in jerky.

Table 1
Water activity (a_w) of pork jerky by electron beam irradiation and by addition of onion peel extract and barbecue flavor.

Irradiation dose (kGy)	Control	Sample*
0	0.767[a]	0.770
1	0.765[a]	0.766
2	0.761[b]	0.768
4	0.762[b]	0.763
SEM**	0.015	0.010

* Onion peel extract (0.5%)+barbecue flavor (0.5%).
** Standard errors of the mean ($n = 12$).
[a,b] Values with different letters within the same column differ significantly ($p < 0.05$).

Table 2
Inactivation of *Listeria monocytogenes* (log CFU/g) of pork jerky by electron beam irradiation and by addition of onion peel extract and barbecue flavor.

Irradiation dose (kGy)	Control	Sample*	SEM[1]
0	8.02^{ax}	7.88^{ay}	0.021
0.5	5.49^{bx}	5.13^{by}	0.026
1	3.00^{cx}	1.85^{cy}	0.015
1.5	1.46^{dx}	ND^{dy}	0.010
2	ND^{e2}	ND^{d}	–
3	ND^{e}	ND^{d}	–
SEM[3]	0.018	0.012	

Initial population: 10.48 ± 0.05 log CFU/mL.
[a–e]Values with different letters within the same column differ significantly ($p < 0.05$).
[x,y]Values with different letters within the same row differ significantly ($p < 0.05$).
* Onion peel extract (0.5%)+barbecue flavor (0.5%).
[1] Standard errors of the mean ($n=8$).
[2] Viable with no growth at a detection limit $< 10^1$ CFU/g.
[3] Standard errors of the mean ($n=24$).

Table 3
Inactivation of *Escherichia coli* (log CFU/g) of pork jerky by electron beam irradiation and by addition of onion peel extract and barbecue flavor.

Irradiation dose (kGy)	Control	Sample*	SEM[1]
0	8.49^{ax}	8.28^{ay}	0.007
0.5	5.99^{bx}	5.80^{by}	0.008
1	3.15^{cx}	2.67^{cy}	0.028
1.5	1.55^{dx}	ND^{dy}	0.021
2	ND^{e2}	ND^{d}	–
3	ND^{e}	ND^{d}	–
SEM[3]	0.014	0.016	

Initial population: 9.25 ± 0.01 log CFU/mL.
[a–e]Values with different letters within the same column differ significantly ($p < 0.05$).
[x,y]Values with different letters within the same row differ significantly ($p < 0.05$).
* Onion peel extract (0.5%)+barbecue flavor (0.5%).
[1] Standard errors of the mean ($n=8$).
[2] Viable with no growth at a detection limit $< 10^1$ CFU/g.
[3] Standard errors of the mean ($n=24$).

Table 4
Inactivation of *Salmonella typhimurium* (log CFU/g) of pork jerky by electron beam irradiation and by addition of onion peel extract and barbecue flavor.

Irradiation dose (kGy)	Control	Sample*	SEM[1]
0	7.77^{ax}	7.63^{ay}	0.037
0.5	5.75^{bx}	5.25^{by}	0.044
1	3.75^{cx}	2.07^{cy}	0.030
1.5	ND^{d2}	ND^{d}	–
2	ND^{d}	ND^{d}	–
3	ND^{d}	ND^{d}	–
SEM[3]	0.020	0.016	

Initial population: $8.53. \pm 0.05$ log CFU/mL.
[a–d]Values with different letters within the same column differ significantly ($p < 0.05$).
[x,y]Values with different letters within the same row differ significantly ($p < 0.05$).
* Onion peel extract (0.5%)+barbecue flavor (0.5%).
[1] Standard errors of the mean ($n=8$).
[2] Viable with no growth at a detection limit $< 10^1$ CFU/g.
[3] Standard errors of the mean ($n=24$).

Table 4 shows populations of *S. typhimurium* for in the combined-treated pork jerky. The initial population of *S. typhimurium* for non-treated pork jerky samples was 7.77 log CFU/g, however, with increasing irradiation doses, these populations significantly decreased in both treated and non-treated pork jerky samples.

Table 5
D_{10} value (kGy) and relative radiation sensitivity (RRS) for different pathogens inoculated in pork jerky containing onion peel extracts and barbecue flavor.

Pathogens	Treatment	D_{10} values (kGy)	RRS*
Escherichia coli	Control	0.25 ± 0.001**	1.000
	Sample***	0.19 ± 0.004	1.316
Listeria monocytogenes	Control	0.23 ± 0.001	1.000
	Sample	0.18 ± 0.001	1.278
Salmonella typhimurium	Control	0.20 ± 0.001	1.000
	Sample	0.19 ± 0.002	1.053

*** Onion peel extract (0.5%)+barbecue flavor (0.5%).
* Relative radiation sensitivity=D_{10} of control/D_{10} of the sample with added onion peel extract and barbecue flavor.
** Mean $\pm$ standard deviation ($n=4$).

Table 5 shows D_{10} values and relative radiation sensitivity (D_{10} of samples with OP extract/D_{10} of control; RRS), respectively. For all tested microorganisms, the combined treatment was more effective than the control in microbial inactivation. The D_{10} value for *L. monocytogenes* in the control was 0.23 kGy and 0.18 kGy in samples. Similarly, for *E. coli*, we obtained D_{10} values of 0.25 kGy and 0.19 kGy for the control and samples, respectively; and 0.20 kGy and 0.19 kGy, for *S. typhimurium,* respectively.

D_{10} values of bacteria in food are affected by a number of factors, including water activity, food composition, irradiation or storage temperature, and presence of oxygen (Mendoca, 2002). In addition, some of the constituents of complex food system, such as proteins, are thought to compete with cells for interactions with radiolytic free radicals, thereby reducing the net effect of radiation damage and making the organisms more radiation-resistant (Jo et al., 2004). Several studies have reported D_{10} values in various meat products. D_{10} values for *L. inocua, S. enteritidis*, and *S. typhimurium* in dry fermented sausages ranged from 0.41 to 0.54 kGy (Cabeza et al., 2009). Sommers et al. (2003) have reported that bologna inoculated with *L. monocytogenes* had a D_{10} value of 0.56 kGy after gamma irradiation.

RRS values are considered good indicators to compare the susceptibility of microorganisms to specific treatment methods (Lacroix et al., 2009). OP extract and BF treatment was the most effective in increasing RRS value (Table 4). The highest RRS was observed for *E. coli* in jerky treated with addition of OP extract and BF. Kang et al. (2012) reported that the highest value of RRS was observed for *L. monocytogenes* in pork jerky treated with leek extract.

Plant extracts usually contain multiple compounds with antimicrobial activity attributed to a number of phenolic compounds. Shan et al. (2007) suggested that phenolic compounds can degrade the cell wall, disrupt the cytoplasmic membrane, cause leakage of cellular components, change fatty acid and phospholipid constituents, influence synthesis of DNA and RNA, and destroy protein translocation. OP may possess antimicrobial and/or antifungal properties due to the presence of quercetin (Griffiths et al., 2002). Kim et al. (2011) have reported that OP extract, prepared using subcritical water extraction, exhibited a potent inhibitory effect on *Bacillus cereus*.

Smoke flavors such as barbecue flavor are considered to be Generally Regarded As Safe (GRAS), so they can be used in foods as an additional barrier to prevent microbial growth at levels which comply with good manufacturing practice (Holley and Patel, 2005). Vitt et al. (2001) reported that the antimicrobial activity of liquid smoke was caused by the presence of chemical compounds including phenols, carbonyls and organic acids. The higher inhibitory activity of some liquid smokes is believed to be due to the higher concentration of polar phenolic compounds present. Since they have higher water solubility, theses polar phenolics

Table 6
Total aerobic bacterial counts (log CFU/g) of pork jerky treated by electron beam irradiation and by addition of onion peel extract and barbecue flavor during storage for 2 months at 25 °C.

	Irradiation dose (kGy)	Storage period (months)			SEM[1]
		0	1	2	
Control	0	4.39^{ax}	4.43^{ax}	4.53^{ay}	0.018
	1	3.33^{bx}	3.35^{bx}	3.53^{by}	0.042
	2	1.83^{cx}	2.03^{cx}	2.43^{cy}	0.083
	4	ND[d2]	ND[d]	ND[d]	–
Sample*	0	4.22^{e}	4.24^{e}	4.32^{e}	0.043
	1	2.94^{fy}	2.96^{fy}	3.21^{fx}	0.034
	2	ND[d]	ND[d]	ND[d]	–
	4	ND[d]	ND[d]	ND[d]	–
	SEM[3]	0.053	0.033	0.024	

[a–f]Values with different letters within the same column differ significantly ($p < 0.05$).
[x,y]Values with different letters within the same row differ significantly ($p < 0.05$).
* Onion peel extract (0.5%)+barbecue flavor (0.5%).
[1] Standard errors of the mean ($n=12$).
[2] Viable colony was not detected at detection limit $< 10^1$ CFU/g.
[3] Standard errors of the mean ($n=32$).

have greater opportunity to contact and interact with target organisms and exert higher levels of destruction (Messina et al., 1988). The present results showed that a combination treatment of EB irradiation and OP extract and BF was found to be effective in sterilization of pork jerky.

3.3. Storage stability

3.3.1. Microbial analysis

The effect of combined treatment on total aerobic bacterial number (TAB) in pork jerky during a storage period is shown in Table 6. For non-irradiated pork jerky, viable counts were approximately 4.39, 4.43, and 4.53 log CFU/g for 0, 1, and 2-month storage period, respectively. EB irradiation significantly improved the safety of the jerky by reducing the TAB. Additionally, the combined treatment of EB irradiation and OP extract and BF improved the quality of microorganisms compared to control. The decrease in TAB was dose dependent in all pork jerky samples. TAB increased with storage period and there were significant differences between irradiation doses. No viable cells were observed in the 4 kGy-irradiated pork jerky. In addition, mold growth was detected only in non-irradiated control pork jerky at ~3.00 log CFU/g, at the 2-month storage time point (data not shown). Coliform bacteria were not detected in pork jerky in this study (data not shown).

Several studies have been conducted on the inactivation of pathogens in meat products by combined treatments. Giroux et al. (2001) have shown that synergistic effects were observed between irradiation and the presence of ascorbic acid for beef patties treated at doses of 2 and 3 kGy. Combined treatments of EB irradiation and addition of leek extract had an inhibitory effect on the growth of TAB in pork jerky (Kim et al., 2013). Radiation technology, such as EB and gamma ray, has positive effects in preventing decay by sterilizing the microorganisms and by improving the safety and shelf-stability of food products. Rose et al. (2005) indicated that flavonoid, phenolic and sulfur compounds are the main active antimicrobial agent. Preliminary data indicated that BF, at a concentration of 1000 ppm, resulted in a 0.5 log reduction of *S. typhimurium* (data not shown). However, very few studies have examined the mechanism of the antimicrobial activity of BF. The components responsible for this antimicrobial activity may be explained after further investigation. In the current study, EB irradiation was shown to be an effective method for microbial stability and the combination of OP extracts and BF were shown to have positive effects.

Table 7
Hunter color values of pork jerky treated by electron beam irradiation and by addition of onion peel extract and barbecue flavor during storage for 2 months at 25 °C.

Hunter	Treatment	Irradiation dose (kGy)	Storage period (months)			SEM[1]
			0	1	2	
*L**	Control	0	27.88^{a}	27.27^{ab}	27.99^{bcd}	1.820
		1	25.47^{bc}	29.18^{a}	26.94^{a}	1.134
		2	27.28^{ab}	28.86^{a}	28.15^{abc}	0.527
		4	25.04^{bc}	27.21^{ab}	28.03^{a}	1.415
	Sample*	0	25.23^{bc}	24.56^{bc}	25.34^{a}	0.716
		1	25.58^{dx}	23.41^{cx}	25.97^{cdy}	0.713
		2	23.73^{cd}	25.44^{bc}	25.76^{d}	1.206
		4	22.57^{dx}	26.23^{abcy}	25.05^{aby}	0.627
		SEM[2]	0.747	1.034	1.424	
*a**	Control	0	6.15^{abx}	5.98^{cdx}	9.68^{ay}	0.189
		1	6.50^{ab}	6.50^{abc}	6.18^{cy}	0.159
		2	6.15^{abx}	6.80^{ayx}	7.43^{bcy}	0.250
		4	7.29^{ay}	6.21^{bcdx}	6.93^{cy}	0.177
	Sample*	0	6.88^{abx}	5.81^{dez}	7.80^{by}	0.170
		1	6.94^{aby}	5.35^{ez}	6.33^{dx}	0.124
		2	7.00^{ab}	6.72^{ab}	7.67^{b}	0.544
		4	6.08^{bz}	6.72^{abx}	7.38^{bcy}	0.092
		SEM[2]	0.354	0.176	0.181	
*b**	Control	0	9.41^{c}	9.18^{ab}	10.63	1.550
		1	12.74^{aby}	10.81^{abyx}	8.96^{x}	0.861
		2	13.59^{ay}	11.74^{ayx}	10.28^{x}	0.539
		4	10.13^{c}	10.42^{ab}	11.53	1.273
	Sample*	0	10.91^{bcy}	8.48^{bcyx}	8.27^{x}	0.730
		1	9.21^{cy}	6.27^{cx}	9.50^{y}	0.426
		2	10.02^{c}	9.50^{ab}	9.85	1.034
		4	8.89^{c}	9.77^{ab}	8.83	0.895
		SEM[2]	0.794	0.823	1.247	

[a–d]Values with different letters within the same column differ significantly ($p < 0.05$).
[x,y,z]Values with different letters within the same row differ significantly ($p < 0.05$).
* Onion peel extract (0.5%)+barbecue flavor (0.5%).
[2] Standard errors of the mean ($n=32$).
[1] Standard errors of the mean ($n=12$).

3.3.2. Physical characteristics

Color changes in pork jerky during storage are shown in Table 5. Hunter color changes were not consistent. Sensory evaluation of color showed similar results (Table 7). Previous studies have found that irradiation reduced the redness of ground beef and pork jerky (Kim et al., 2013). However, the results of our study suggest that the combined effects of EB irradiation and addition of OP extract and BF cause negligible color changes.

Texture, including chewiness, is one of the most important sensory attributes of jerky-type foods and determines the uniqueness and market attractiveness of this type of products (Lee et al., 2004). In this study, the shear force of pork jerky ranged from 7.82 to 14.51 kg (Table 8). However, these changes did not show a constant trend and no significant difference with respect to the storage period or irradiation dose. Therefore, these shear force changes are unlikely to affect consumer preferences.

3.3.3. Peroxide value (POV)

Irradiation induces lipid oxidation by hydroxyl radicals generated by ionizing radiation in meat and meat products (McMillin, 1996), and this lipid oxidation adversely affects color, flavor, and texture of meat (Lee et al., 2012). Therefore, lipid oxidation is one of the major concerns in irradiated meat and meat products.

Table 8
Shear force (kg) of pork jerky treated by electron beam irradiation and by addition of onion peel extract and barbecue flavor during storage for 2 months at 25 °C.

	Irradiation dose (kGy)	Storage period (months)			SEM[1]
		0	1	2	
Control	0	9.24	8.85^{a}	9.79^{bac}	0.586
	1	10.08^{x}	9.49^{bax}	13.60^{dy}	0.768
	2	10.59	8.50^{a}	11.66^{dba}	1.074
	4	9.41	8.42^{a}	9.58^{a}	0.739
Sample*	0	9.33^{x}	10.75^{dbx}	14.51^{dy}	0.894
	1	8.87^{x}	11.23^{dy}	9.11^{acx}	0.587
	2	8.87	7.82^{a}	8.13^{c}	0.760
	4	10.12^{x}	9.19^{bax}	12.55^{aby}	0.368
	SEM[2]	0.662	0.543	0.975	

[a–d]Values with different letters within the same column differ significantly ($p < 0.05$).
[x,y]Values with different letters within the same row differ significantly ($p < 0.05$).
* Onion peel extract 0.5%+barbecue flavor 0.5%.
[1] Standard errors of the mean ($n=12$).
[2] Standard errors of the mean ($n=32$).

Table 9
Peroxide value (meq/kg) of pork jerky treated by electron beam irradiation and by addition of onion peel extract and barbecue flavor during storage for 2 months at 25 °C.

	Irradiation dose (kGy)	Storage period (months)			SEM[1]
		0	1	2	
Control	0	0.33^{a}	0.35^{b}	0.55^{cb}	0.163
	1	0.87^{d}	0.92^{c}	0.98^{ac}	0.244
	2	0.91^{d}	1.13^{a}	1.29^{a}	0.128
	4	1.02^{dx}	1.49^{dy}	1.75^{dz}	0.069
Sample*	0	0.42^{a}	0.43^{b}	0.49^{b}	0.148
	1	0.40^{a}	0.41^{b}	0.47^{b}	0.059
	2	0.42^{a}	0.43^{b}	0.45^{b}	0.057
	4	0.42^{a}	0.49^{b}	0.56^{ac}	0.100
	SEM[2]	0.121	0.068	0.188	

[a–d]Values with different letters within the same column differ significantly ($p < 0.05$).
[x,y,z]Values with different letters within the same row differ significantly ($p < 0.05$).
* Onion peel extract 0.5%+barbecue flavor 0.5%.
[1] Standard errors of the mean ($n=12$).
[2] Standard errors of the mean ($n=32$).

Table 10
Sensory evaluation of pork jerky treated by electron beam irradiation and by addition of onion peel extract and barbecue flavor.

	Dose (kGy)	Color	Flavor	Texture	Juiciness	Overall acceptability	Off-odor
Control	0	4.63^{ab}	4.83	4.80^{ca}	4.83^{ca}	4.87^{c}	2.27^{ca}
	1	4.77^{cab}	5.03	4.80^{ca}	4.70^{ca}	4.90^{c}	1.97^{a}
	2	5.00^{cab}	4.70	4.37^{ab}	4.43^{ca}	4.60^{ca}	2.50^{ca}
	4	4.47^{b}	4.53	4.37^{ab}	437^{ca}	4.23^{a}	2.53^{ca}
Sample*	0	5.00^{cab}	4.77	4.90^{ca}	5.03^{c}	4.83^{c}	2.20^{ca}
	1	4.87^{cab}	4.73	5.23^{c}	5.20^{c}	5.03^{c}	2.27^{ca}
	2	5.27^{ca}	4.50	4.50^{ab}	4.63^{ca}	4.53^{ca}	2.83^{c}
	4	5.43^{c}	4.30	4.07^{b}	4.17^{a}	4.23^{a}	2.70^{ca}
SEM**		0.299	0.306	0.306	0.355	0.242	0.313

[a–c]Values with different letters within the same column differ significantly ($p < 0.05$).
* Onion peel extract (0.5%)+barbecue flavor (0.5%).
** Standard errors of the mean ($n=32$).

Increasing the dose of EB irradiation was found to increase POV in control samples (Table 9). These results are consistent with a previous study (Kim et al., 2013). Quattara et al. (2002) showed that gamma irradiation increased lipid oxidation in ground beef. Lipid oxidation was attributed to the combination of free radicals and O_2 to form hydroperoxides (Javanmard et al., 2006).

However, the addition of OP extract and BF to pork jerky resulted in lower POV compared to pork jerky without added OP extract and BF. Lee et al. (2005) reported that rosemary extract inhibits lipid oxidation in hamburger steaks. A majority of flavonoids are found in dry onion peels, which are usually considered waste. Onion peels contain large amounts of quercetin, quercetin glycoside and their oxidative products, which are effective antioxidants against the lethal effects of oxidative stress (Prakash et al., 2007). Singh et al. (2009) reported that red OP could be used as a natural antioxidant in nutraceutical preparations. It is likely that the results of this study were primarily due to the OP extract, which has strong antioxidant activity.

3.3.4. Sensory evaluation

Our results indicate that color and off-odor changes were not consistent (Table 10). Flavor did not show any difference by EB irradiation and addition of OP extract and BF. Interestingly, the texture and juiciness of pork jerky with added OP extract and BF obtained higher scores in 1 kGy sample than controls. Overall acceptability was not changed up to 2 kGy.

Generally, most chemical changes such as off-flavor generation in meat are associated with free-radical reactions (Smith et al., 1960). Irradiation can initiate or promote lipid oxidation, resulting in undesirable off-odors and flavors. Several studies have reported that sensory qualities in jerky were reduced by irradiation (Oh et al., 2008; Kim et al., 2013). This observation is due to the formation of certain odor compounds by irradiation such as butane, propane, mercaptomethane, and dimethyl sulfide. The intensity of the irradiated odor dissipated a few days after irradiation treatment due to volatilization of such compounds (Chouliara et al., 2008).

The generation of off-flavor in irradiated meat and meat products could be reduced by various methods such as modified atmosphere packaging, low irradiation temperature, and addition of natural extracts (Brewer, 2009). Certain flavors and specific desirable flavor-notes in certain products survive at even higher irradiation doses. In our previous study, the addition of leek extract showed synergistic effect on improvement of microbial quality when EB irradiation was treated to pork jerky while sensory quality was deteriorated because of the leek extract (Kim et al., 2013). In another study, barbecue flavors did not change the flavor compounds or sensory characteristics by EB irradiation among five different flavors including green tea, lemon, barbecue, smoke, and sesame (Kim et al., 2012). In the present study, EB irradiation with OP extract and BF synergistically improved microbiological safety without significant change on sensory quality of pork jerky. Thus, combined treatment of EB irradiation and OP extract and BF can be applied to the production of pork jerky.

4. Conclusion

The present study indicated that combined treatment of low-dose EB irradiation and addition of OP extract and BF could synergistically reduce the risk of foodborne pathogens of pork jerky and improve the microbial quality with no adverse effects on the other quality factors. This method can be directly applied in industry.

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